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Pilot Acceptance of Personal, Wearable Fatigue Monitoring Technology: An Application of the Extended Technology Acceptance Model

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PILOT ACCEPTANCE OF PERSONAL, WEARABLE FATIGUE MONITORING TECHNOLOGY: AN APPLICATION OF THE EXTENDED TECHNOLOGY ACCEPTANCE MODEL

By

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ABSTRACT

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The research problem of pilot fatigue has been referenced as a causal factor for aircraft accidents in many United States National Transportation and Safety Board (NTSB) accident reports; however, the United States Code of Federal Regulations 14 CFR Part 117, Flight and Duty Limitations and Rest Requirements for Flight Crew Members, does not provide a tangible means of measuring fatigue for aircraft crew members. This problem is relevant to the airline industry and the travelling public because pilot fatigue is preventable as a causal factor in aviation accidents, and pilots need an accurate way to measure it.

Adoption of a technology-based solution has been recommended by the NTSB. The purpose of this study was to determine the factors that affect United States certified airline transport pilots' behavioral intention to use personal, wearable fatigue monitoring technology (FMT), such as a Fitbit or Apple Watch, to assess their personal fatigue levels. FMT could potentially be used to help meet pilots' legal requirement to be aware of their personal fatigue levels, per 14 CFR Part 117. The theoretical framework for this study is the Extended Technology Acceptance Model, and the research question is: *What factors affect pilots' behavioral intention to use personal, wearable fatigue monitoring*

technology, and to what degree? There were ten hypotheses tested that corresponded to different relationships in the model.

The data for this study was collected using an online survey distributed to certified airline transport pilots in the United States, in which the survey questions corresponded to observed variables pertaining to each of the eight factor constructs in the model. The data was analyzed using confirmatory factor analysis (CFA) and structural equation modeling (SEM) techniques to test the hypotheses. The results of the study contributed to the theoretical body of knowledge by demonstrating that a modified version of the Extended Technology Acceptance Model was applicable to U.S. airline transport pilot behavioral intention to use FMT. Six of the ten original hypotheses were supported, and four were not supported.

It was determined that the primary factors that positively affect a pilot's behavioral intention to use FMT are perceived usefulness and perceived ease of use. Perceived usefulness is positively affected by the external factors of job relevance, results demonstrability, and perceived image or social status, which act as secondary factors positively influencing behavioral intention to use FMT. A tertiary factor influencing behavioral intention to use FMT is subjective norms, which positively influence perceived image, thus positively affecting perceived usefulness and intention to use FMT. Output quality, subjective norms, and perceived ease of use were determined to not have a statistically significant effect on pilots' perceived usefulness of FMT, and subjective norms were determined not to have a statistically significant effect on pilots' behavioral intention to use FMT.

The practical significance of this study is that pilots find FMT devices most useful when it is applicable to their jobs, provides tangible results, and increases their social status perception. It is beneficial if others around them think they should use FMT, and that if they use FMT, their social status perception increases. Practical solutions to increase the likelihood of pilot FMT device usage should include wearable device applications that provide features that directly apply to the pilot profession, report data in ways that make sense to pilots, and also make the pilot look and feel stylish. Nearly 87 percent of pilots already wear a watch while flying, and over 40 percent of pilots already wear some form of FMT for personal use, so the challenge going forward is to make the right improvements to the devices to increase usage. Such improvements may include new aviation-themed applications that appeal to pilots and provide results that can help them make more informed decisions, while simultaneously improving the aesthetic to drive an increase in social pressures to wear the FMT devices regularly.

DEDICATION

This dedication is to my husband and friends serving as professional pilots around the globe. I see that you are being pushed to your limits everyday, and I pursued this degree to hopefully make things better for you. I see that you are tired, and I know that you deserve better. May this research be one more step in the right direction for better working conditions, quality of life, and safer skies.

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CHAPTER I

INTRODUCTION

Pilot fatigue has been a researched topic in aviation for many years, often as a response to an aircraft accident or incident where pilot fatigue is cited as a causal factor. By understanding the circumstances leading up to an accident or incident, similar scenarios can ideally be prevented in the future. The most recent instance of fatigue being listed as a causal factor in United States commercial aviation history involving passenger transportation was Colgan Flight 3407, which crashed just outside of Buffalo, New York, in 2009, killing all 49 souls on board and one on the ground (National Transportation and Safety Board, 2015). The errors made by the crew were largely attributed to pilot fatigue (NTSB, 2015).

The United States National Transportation and Safety Board (NTSB) first cited fatigue as a primary causal factor of an aviation accident in 1993 after the crash of American International Airways, doing business as Connie Kalitta Services (now Kalitta Air), Flight 808, when the McDonnell Douglas DC-8 crashed into terrain short of a runway in Cuba, seriously injuring the three crew members on board and destroying the aircraft (1993). In the Kalitta Flight 808 accident report, the NTSB specifically referred to the impaired judgment, decision-making, and flying abilities of the crew due to fatigue. The report further cited the inadequacy of flight and duty time regulations applied to 14 CFR Part 121 operations, which extended the duty times of the crew members (NTSB, 1993).

In the commercial cargo sector of the United States airline industry, a recent example of fatigue being cited as a causal factor was in 2013 when United Parcel Service

(UPS) Flight 1354 crashed on approach into Birmingham, Alabama, killing the two crew members on board (NTSB, 2014). In its accident report, the NTSB stated that the first officer did not make effective use of her allocated rest period, the captain was fatigued due to circadian factors, and neither of the pilots called in fatigued to UPS flight operations (2014).

In 1999, American Airlines Flight 1420 crashed upon landing in Little Rock, Arkansas, killing 11 of the 145 souls on board, including the captain. The McDonnell-Douglas MD-82 crew overran the runway, striking several obstacles during severe weather conditions, and after the investigation was completed, the NTSB cited the flight crew's "impaired performance resulting from fatigue" as one of the contributing factors to the accident (1999).

Crew or operator fatigue is not unique to the airline industry. In 2014, a Chicago Transit Authority train collided with a post at O'Hare Station, causing the train to derail and ascend up a pedestrian escalator at the end of the track. The root cause cited by the NTSB was fatigue due to rotating shift work, circadian factors, and acute sleep loss from poor off-duty rest time management. Though no one was on the escalator, 33 passengers and the train operator were injured and hospitalized (NTSB, 2015).

In 2014, the Federal Aviation Administration (FAA) amended 14 CFR Part 117, which regulates flight duty limitations and rest requirements for flight crew members, and provides requirements for 14 CFR Part 121 operators to implement a fatigue risk management system and training program to increase fatigue awareness (FAA, 2015); however, there is still the potential for pilots to operate an aircraft without meeting minimum rest requirements, and it is possible for individuals to personally require higher than the federally regulated minimum rest times in order to consider themselves not fatigued, which can be further complicated depending on medical conditions or medications consumed (NTSB, 2016). Simply because a company has allocated an employee enough time off to obtain eight hours of rest does not mean that eight hours will be spent sleeping.

As indicated per the UPS Flight 1354 accident report, the “first officer’s use of her off-duty time indicated she was likely experiencing fatigue, primarily due to improper off-duty time management” (NTSB, 2014, p. xii). The accident report also mentions “even though the first officer was aware that she was very tired, she did not call in and report that she was fatigued, contrary to the UPS fatigue policy” (NTSB, 2014, p. xii). In alignment with 14 CFR Part 117 requirements, the NTSB recommended both fatigue counseling for pilots to increase their awareness, as well as airline guidance for managing fatigue and fostering an environment where pilots feel comfortable calling in fatigued (NTSB, 2014).

The underlying human factors issue is how to mitigate vehicle operator fatigue when rules are not complied with; any solution must overcome the complexities of human habits and behavior. The NTSB demanded a comprehensive approach comprised of “research, education and training, technologies, treatment of sleep disorders, hours-of-service regulations, and on- and off- duty scheduling policies and practices” (2016). The NTSB has issued more than 200 fatigue-related safety recommendations across airline, highway, and rail industries focused on research, education, training, medical treatments, regulations, and schedule requirements. Several key recommendations can be summarized as follows (NTSB, 2016):

1. Vehicle operators need to be better educated about medical conditions and drugs that can impact the quality and duration of sleep, as well as their on-duty performance.
2. Interstate commercial vehicle carriers should equip their vehicles with electronic logging devices to collect data on driver service hours to monitor service hour requirement compliance.
3. In-vehicle technologies reduce the occurrence of fatigue-related incidents and should be implemented to improve safety.
4. Fatigue risk management programs need to be implemented to address operational issues concerning scheduling, attendance, education, medical screening and treatment, personal awareness and responsibility, task loads, rest environments, and commuting.

The FAA has implemented regulations that require the use of fatigue risk management systems and training programs, as well as outline crew member rest rules, per 14 CFR Part 117. Rest rules are provided for various airline operation scenarios, such as the following (FAA, 2015):

> *117.25 (e)* No certificate holder may schedule and no flightcrew member may accept an assignment for any reserve or flight duty period unless the flightcrew member is given a rest period of at least 10 consecutive hours immediately before beginning the reserve or flight duty period measured from the time the flightcrew member is released from duty. The 10-hour rest period must provide the flightcrew member with a minimum of 8 uninterrupted hours of sleep opportunity.

There have been, however, few technology applications implemented in the airline industry, either as part of the aircraft systems, or worn by the pilots, to monitor fatigue or minimize the occurrence of fatigue-related incidents and accidents. Conversely, the commercial truck driving industry in the United States and Canada has taken an innovative approach to using technology to help solve the problem of vehicle operator fatigue, particularly regarding the usage and acceptance of fatigue monitoring technology (FMT) to help increase vehicle operator fatigue awareness, such as lane tracking software, ocular and facial parameter measurement technology, and wrist actigraphy devices (Alsamman & Ratecki, 2011; Dinges et al., 2005). This research is discussed in-depth as part of the Chapter 2 literature review, and serves as a basis for similar research to be conducted in the commercial airline industry.

One option to help pilots better understand their current fatigue levels is to use a device commonly used in popular culture to monitor human sleep patterns, such as the Fitbit. The Fitbit is an ideal platform due to its relative accessibility to the public and established history of use, with 93 million devices sold and the world's largest database of validated health data, including nine billion nights of sleep data (Fitbit Health Solutions, 2019). Fitbit has also been demonstrated as having technical validity in measuring physical activity parameters when compared to clinical devices such as an ActiGraph, especially when used over an extended period of seven days or more (Brewer, Swanson, & Ortiz, 2017). There are other similar wearable sleep tracking platforms available to the general public, including the Apple Watch and the Samsung Gear watch, for which sleep tracking applications were reviewed by Ong & Gillespie (2016). This research is focused generically on personal, wearable technology, not a specific brand or platform. The purpose of using a fitness tracker is to increase fatigue awareness, not to make clinical recommendations regarding sleep habits or recommend a specific brand of sleep tracker.

Personal, wearable fatigue monitoring devices are readily available for purchase by consumers, and are regularly used to monitor sleep patterns by more than 23 million people worldwide in 2016 (Statista, 2017). One of the challenges in adopting this type of technology for use in the airline industry will be pilot acceptance. Understandably, feedback regarding the adoption of similar technology in the commercial truck driving industry was, while the devices worked, the drivers did not like to be monitored (Dinges et al., 2005). From those drivers' perspectives, it causes liability concerns for the operator, because the device may indicate an unacceptable fatigue level for driving when they do not personally feel too fatigued to operate a truck.

It is reasonable to presume aircraft pilots would share a similar sentiment regarding operating an aircraft because they too are liable for the safety of the vehicle operation and would also likely not want to be held accountable to the results presented by the technology. For this reason, FMT is being proposed by the researcher for personal awareness in accordance with 14 CFR Part 117, and not for accountability with employers, unions, regulatory agencies, or the NTSB. The purpose of this research is to measure the perceived usefulness and ease of use of personal, wearable FMT according to airline transport pilots in accordance with the Extended Technology Acceptance Model (TAM), such that aircraft pilots could be better enabled to be personally accountable for and comply with 14 CFR Part 117 fatigue awareness requirements. Developed by Venkatesh and Davis (2000), the Extended TAM is used to explain behavioral usage intentions and perceived usefulness of a particular type of technology in terms of cognitive instrumental processes and social influence. The Extended TAM is explained more in-depth in the Chapter 2 literature review.

Statement of the Problem

Pilot fatigue has been referenced as a causal factor in multiple aviation accidents; to mitigate the risk of pilots operating an aircraft while fatigued, the United States FAA published 14 CFR Part 117, Flight and Duty Limitations and Rest Requirements for Flight Crew Members. The FAA (2015) provides 14 CFR Part 117 with multiple sections, including the following definitions:

Section 117.1: Applicability to flight crew members conducting passenger operations under 14 CFR Part 121

Section 117.5: Fitness for duty, requiring pilots report for flight duty rested and prepared to perform said duties, and prohibiting operators from requiring pilots to operate an aircraft if they deem him or herself to be fatigued

Section 117.7: Fatigue risk management system, requiring operators to have a fatigue risk management system in place, including a fatigue risk management policy education and awareness training program, fatigue reporting system, a system for monitoring flight crew member fatigue, incident reporting process, and performance evaluations

Section 117.9: Fatigue education and awareness training program, requiring operators to have such a program approved by the Federal Aviation Administration, and provide the training to its employees, which covers fatigue awareness, effects on pilots, and countermeasures

The FAA's regulatory scheme provides a definition of fatigue and imposes a requirement upon operators to train pilots on the effects of fatigue and how to avoid it. It does not, however, provide a means for pilots to measure their personal fatigue levels. There are devices readily available in the marketplace that measure sleep patterns quantitatively and then qualitatively assess how well an individual has slept, which can be useful as a tool for pilots interested in having the technology to help them measure their personal fatigue levels. It should be noted that there are a multitude of factors that are associated with pilot fatigue, including circadian rhythm and time since last restorative sleep, both of which are further discussed in the literature review. Research needs to be conducted to better understand the factors that influence a pilot's behavioral intent to use FMT to measure their personal fatigue levels as a means of meeting 14 CFR Part 117 requirements to increase their personal fatigue awareness. In accordance with the Extended TAM, the factors to be evaluated in this research are behavioral intention to use, perceived usefulness, perceived ease of use, subjective norms, perceived image, job relevance, output quality, and results demonstrability (Venkatesh & Davis, 2000). In this study, each of these factors was assessed using survey data based on questions adapted from the standard Extended TAM questionnaire (Venkatesh & Davis, 2000).

Purpose Statement

The purpose of this research was to examine the extent of the factors that affect a pilot's behavioral intention to use FMT in accordance with the Extended Technology Acceptance Model. The factors explored in this study, pertaining to their influence on a pilot's behavioral intent to use FMT, per the Extended Technology Acceptance Model, were subjective norms, perceived image, job relevance, output quality, results demonstrability, perceived ease of use, and perceived usefulness. Once the effects of these factors on the pilot's behavioral acceptance are understood, steps can be taken to increase the usability of FMT devices, in terms of ease of use and perceived usefulness, subjective norms, perceived image, job relevance, output quality, and result demonstrability to thereby increase a pilot's intention to use FMT for the purposes of monitoring their personal fatigue levels. The research was conducted within the United States certified airline transport pilot population, with a special interest in those conducting passenger transportation in accordance with 14 CFR Parts 121 and 135. An online survey was distributed to the U.S. certified airline transport pilot population using a variety of methods to collect data in accordance with the Extended Technology Acceptance Model questionnaire, and the data was subsequently analyzed using structural equation modeling (SEM) to validate the model.

Significance of the Study

The theoretical significance of this study is a contribution to the body of knowledge by using the Extended Technology Acceptance Model (TAM) to determine the factors that affect a pilot's behavioral intention to use personal, wearable fatigue monitoring devices. There are studies substantiating the reliability and accuracy of various FMT devices to monitor personal fatigue levels, such as the *Effects of sleep/wake history and circadian phase on proposed pilot fatigue safety performance indicators* published in the Journal of Sleep Research (Gander, 2015), which established the validity of the Phillips ActiWatch technology in measuring pilot fatigue levels, as well as the *Validity of Fitbit's active minutes as compared with a research-grade accelerometer and self-reported measures* published in the BMJ Journal of Open Sport & Exercise Medicine

(Brewer, Swanson, & Ortiz, 2017), which established the technical validity of the Fitbit when compared to a research-grade ActiGraph with regards to measuring physical activity parameters over an extended period greater than seven days.

These studies included one by Rahman et al. (2017) who studied perceived usefulness, perceived ease of use, and behavioral intent from the Extended TAM to the use of FMT by automobile operators, as well as a structural investigation by Lunney et al. (2016) who studied the acceptance and perceived fitness outcomes using wearable fitness technology by consumers in terms of perceived usefulness, ease of use, and subjective norms. There were, however, no studies found indicating the extended TAM has been used to assess pilots' behavioral intention to use wearable FMT for measuring their personal fatigue levels prior to flight. This provides a theoretical gap to be filled through the proposed study, as pilots are a unique subset of the population with distinct characteristics.

Pilots serve in a profession that presents a high degree of technical difficulty requiring significant training, certifications, and experience. They represent a limited subset of the population, where only 158,000 people operate as United States certified airline transport pilots (FAA, 2016), as compared to the 227.5 million people operating as licensed drivers in the United States (Statista, 2019). If it is assumed that all U.S. certified airline transport pilots also are licensed drivers, they only represent approximately .07 percent of that population, and that limited population was responsible for transporting 850 million passengers domestically within the United States in 2018 (United States Department of Transportation, 2018).

Pilots are a unique population in that they are highly trained professionals representing an extremely limited subset of the United States population that is responsible for transporting hundreds of millions of people each year. Understanding how to influence the behavior of airline transport pilots can have an exponential effect on the safety of the flying public. There was an additional exploratory, open-ended question at the end of the survey for pilots to provide free-form commentary on any additional factors that may affect their behavioral intention to use FMT, which are not a part of those assessed in accordance with the standard Extended TAM. Using qualitative assessment techniques, factors can potentially be extracted to enhance the theoretical model in future research.

In addition to validating the Extended TAM as applied to United States certified airline transport pilots and their behavioral intention to use FMT, this study also contributes information regarding the airline transport pilot demographics as they pertain to pilot acceptance of FMT. Demographics being researched in this study include pilot age, gender, length of experience as a pilot, type of airline transport pilot, whether the pilot regularly wears a wristwatch or FMT device already for personal use, and geographic region within the United States with which the pilot identifies as home. This study fills a gap in the literature by connecting the research demonstrating FMT as being reliable and accurate with the pilot community's behavioral intention to use it.

The practical significance of this study is understanding the factors that contribute to a pilots' acceptance of using FMT to monitor their fatigue levels prior to flight. The use of FMT should enable pilots to better control and mitigate their levels of fatigue, resulting in potentially safer operations. By surveying pilots regarding their acceptance of and behavioral intent to use wearable FMT, there is potential to influence their behavior in such a way that it increases their likelihood to use a device that is inexpensive and quick to implement across the industry to enhance their ability to mitigate their personal fatigue levels. The benefits of this research would transcend multiple parties, including pilots by providing a tangible means of increasing their fatigue awareness, 14 CFR Part 121 operators and Federal Aviation Regulators by knowing pilots are better equipped to meet the requirements of increasing their fatigue awareness, and the flying public by feeling safer knowing pilots have the ability to better understand when they are not fit for flight duty due to their fatigue levels exceeding their personal limitations.

Research Question and Hypothesis

The research question to be addressed with this research is, *what factors affect pilots' behavioral intention to use personal, wearable fatigue monitoring technology, and to what degree?*

The proposed application of the Extended TAM with directional hypotheses is shown as a path diagram in Figure 1. Each of the hypotheses was tested through a review of literature, and the factor structure of the proposed model was tested through SEM using data collected through a survey based on the Extended TAM questionnaire. The hypotheses for this study represent the directional effects in the model, as depicted in the path diagram:

H_1. *Subjective norms have a significant, positive effect on a pilot's perceived image of FMT.*

H_2. *Subjective norms have a significant, positive effect on a pilot's perceived usefulness of FMT.*

H_3. *Perceived image has a significant, positive effect on a pilot's perceived usefulness of FMT.*

H_4. *Job relevance has a significant, positive effect on a pilot's perceived usefulness of FMT.*

H_5. *Output quality has a significant, positive effect on a pilot's perceived usefulness.*

H_6. *Results demonstrability has a significant, positive effect on a pilot's perceived usefulness of FMT.*

H_7. *Perceived ease of use has a significant, positive effect on a pilot's perceived usefulness of FMT.*

H_8. *Subjective norms have a significant, positive effect on a pilot's intention to use FMT.*

H_9. *Perceived usefulness has a significant, positive effect on a pilot's intention to use FMT.*

H_{10}. *Perceived ease of use has a significant, positive effect on a pilot's intention to use FMT.*

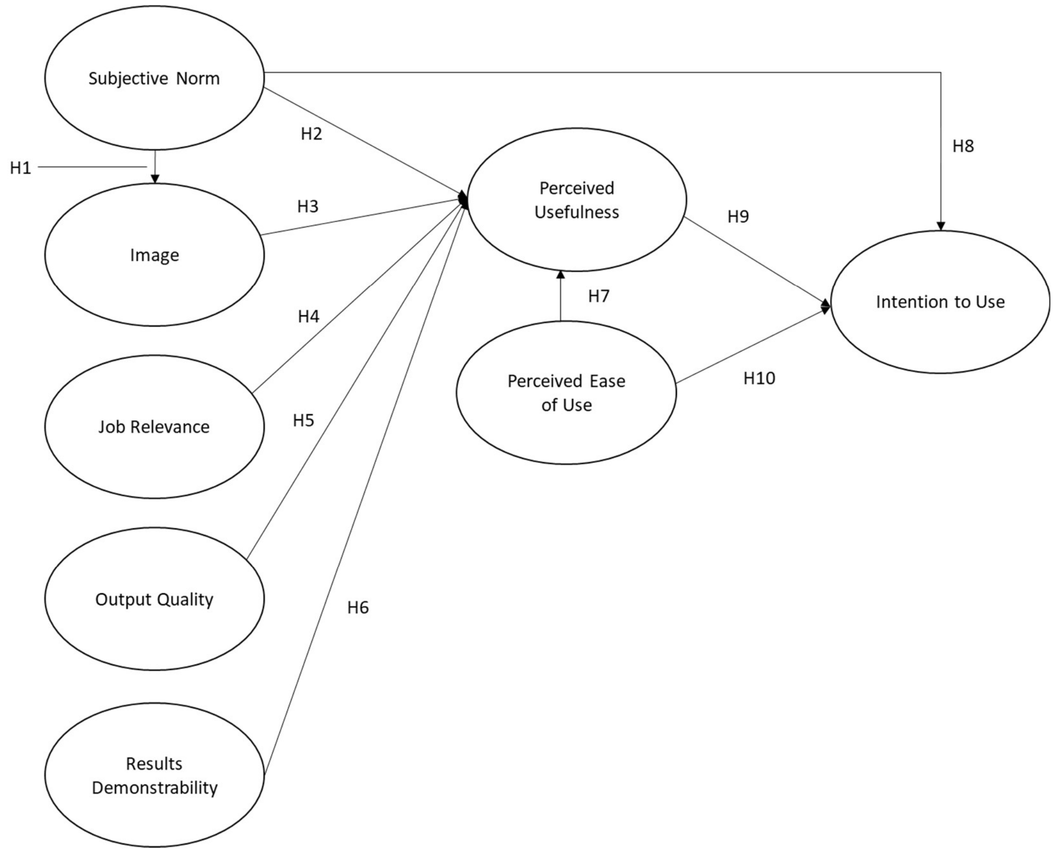

Figure 1. Proposed path diagram developed for testing using confirmatory factor analysis and structural equation modeling in this study. Adapted from "A theoretical extension of the technology acceptance model: Four longitudinal field studies," by Venkatesh & Davis, 2000, Management Science, Copyright 2000.

Delimitations

There are several delimitations for this study. The first is the scope selection of United States certified airline transport pilots, to drive alignment with 14 CFR Part 117 application and wording. This delimitation affects the generalizability by being pertinent to pilots flying for a U.S. airline in passenger transport operations but can be applied to cargo and general aviation pilots within the United States who hold the same certificate type, since this study is based on individual pilot behavior, and many pilots have and continue to work across the different commercial aviation sectors within the United States. The survey questionnaire contained a section to record pilot demographic information, including type of commercial aviation operation (airline, cargo, or general aviation) with which they have spent the most time serving.

The second delimitation is the selection of specific outreach methods for survey distribution, which for this study included networking through social media. To ensure a diverse demographic was reached, and to minimize the effects of location bias, a demographic question was included to determine if generalizability needed to be limited to a certain geographic region.

A third delimitation is three factors from the established extended TAM published by Venkatesh and Davis (2000) are not included as part of this study; voluntariness, experience, and actual device use are not included, since the technology has not yet been implemented at the airlines for measuring aircraft pilot fatigue levels, and so they cannot be measured in accordance with the intent of the original extended TAM. The rationale for these delimitations is explained further in Chapter 2 Literature Review.

Limitations and Assumptions

The primary limitation of this study was the often-low response rates to surveys; however, the minimum sample size for this study was achieved, the details of which are included in the Chapter 4 pilot study results. All survey responses were voluntary and anonymous, and as such, were subject to errors, bias, and duplicate responses. To minimize bias, consistency in messaging was used across social media posts using a message approved by the Embry-Riddle Aeronautical University Institutional Review Board, shown in Appendix D. The survey was distributed to multiple large Facebook groups, such as *Female Aviators Sticking Together (FAST), Flights Above the Pacific Northwest, Flights Above the Mountain Southwest, and Professional Jet Pilots*. This provided an opportunity to any qualified member of those groups to participate in the survey and also share the survey with others they may know to help the researcher achieve a greater representation of the population.

The survey was also shared across Facebook and Instagram to the researcher's personal network. It is a similar process to what would be completed in-person by handing out business cards to pilots at an aviation conference or posting an ad for the survey in an aviation magazine, but with the ability to reach a greater quantity of potential respondents in a shorter time period and at a lower cost through remote access to the target population (Baltar & Brunet, 2012). Very few of the respondents were personal acquaintances or friends of the researcher; the vast majority of respondents were members of the large pilot social media groups on Facebook with no prior connection with the researcher. Regarding respondents who did know the researcher, those individuals were still verified as eligible based on their qualifications of being a United States certified airline transport pilot. It is worth noting that the validity of the final questionnaire and full SEM was limited to the interpretation of the pilot study results.

While the Extended TAM does not provide actionable guidance for technology implementation within a given environment, it is known to be highly valid in predicting acceptance of technology based on perceived usefulness and perceived ease of use, as the latent variables. Another limitation of the TAM relevant to the research question of the current study is that the TAM model is not context or technology-specific (Venkatesh & Bala, 2008); therefore, the results of the study did not offer an explanation as to why participants perceive the usefulness and ease of use of FMT technology the way they do, as rated in the survey. Instead, the Extended TAM offered a framework that enabled the operationalization of conceptual variables that are determinants of technology acceptance, in this case, FMT.

Summary

In Chapter 1, the problem statement, significance, and purpose of the proposed study were discussed; additionally, the research questions, proposed model, limitations, and delimitations of the proposed study were also presented. Fatigue is known as both a causal and contributing factor in aviation accidents and incidents in the United States, as cited in various NTSB reports. While 14 CFR Part 117 and its contained sections were published to provide guidance regarding the minimum rest time air carriers must provide to their crew members, pilots' awareness of their personal fatigue levels, and operators' requirements to provide training on the definition of fatigue and how to counteract it, the regulations do not provide an established method for measuring pilot fatigue levels. What pilots do in their rest periods is variable, and the amount of rest required varies by individual.

A review of the literature suggested there are multiple types of reliable FMT that can be worn by individuals to help assess their sleep performance and personal fatigue levels (Ong & Gillespie, 2016); these devices are presented in the Chapter 2 literature review. Theoretically, these devices can be worn by aircraft pilots to help mitigate the likelihood of operating an aircraft while fatigued by increasing the awareness of their personal fatigue levels to comply with 14 CFR Part 117 requirements. Many of these devices are readily available to pilots, such as the Fitbit or various applications on the Apple Watch, but it is unknown what factors most significantly affect a pilot's behavioral intent to utilize this technology, in accordance with the Extended Technology Acceptance Model, and to what degree.

The next chapter includes a detailed literature review supporting the documented influence of fatigue on the occurrence of aviation accidents in the United States, the variety of wearable fatigue monitoring devices available and their performance, and various accepted measures of fatigue in the airline industry. The theoretical framework of the Extended TAM will also be explained regarding its use in this study. Data for this study was collected using a survey questionnaire distributed to the United States airline pilot population. SEM was used to analyze the data and validate the proposed model.

Definitions of Terms

Fatigue	A physiological state of reduced mental or physical performance capability resulting from lack of sleep or increased physical activity that can reduce a flight crew member's alertness and ability to safely operate an aircraft or perform safety-related duties (Federal Aviation Administration, 2015).
Image	The degree to which the use of an innovation is perceived to enhance one's status in one's social system (Venkatesh & Davis, 2000, p. 4).
Job Relevance	An individual's perception regarding the degree to which the target system is applicable to his or her job (Venkatesh & Davis, 2000, p. 5).

Output Quality	The degree to which a system performs its intended tasks (Venkatesh & Davis, 2000, p. 5).
Perceived Ease of Use	The extent to which a person believes that using the system will be free of effort (Venkatesh & Davis, 2000, p. 2).
Perceived Usefulness	The extent to which a person believes that using the system will enhance his or her job performance (Venkatesh & Davis, 2000, p. 2).
Polysomnography	A test used to diagnose sleep disorders; polysomnography records your brain waves, the oxygen level in your blood, heart rate, and breathing, as well as eye and leg movements during the study, also known as a sleep study (Mayo Clinic, 2018). In general, this is the "gold standard" for measuring sleep in clinical research studies.
Result Demonstrability	The tangibility of the results of using the innovation (Venkatesh & Davis, 2000, p. 6).
Subjective Norm	A person's perception that most people who are important to him think he should or should not perform the behavior in question (Venkatesh & Davis, 2000, p. 2).

List of Acronyms

ATP	Airline Transport Pilot
CFA	Confirmatory Factor Analysis
FAA	Federal Aviation Administration
FMT	Fatigue Monitoring Technology
FRMS	Fatigue Risk Management System
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFALPA	International Federation of Airline Pilots Associations
NTSB	National Transportation and Safety Board
PVT	Psychomotor Vigilance Task
SEM	Structural Equation Model (or Modeling)
SPI	Safety Performance Indicator
TAM	Technology Acceptance Model
TPB	Theory of Planned Behavior
UTAUT	Unified Theory of Acceptance and Use of Technology

CHAPTER II

REVIEW OF THE RELEVANT LITERATURE

The NTSB has documented many occurrences of fatigue as a causal factor for aviation accidents and incidents in recent United States history, and only minimal regulatory changes have been made to mitigate the occurrences. There are established technology devices and measurement scales for measuring fatigue in the industry, many of which are readily available to pilots; that being stated, pilots have the freedom to choose whether they would utilize this technology to monitor their personal fatigue levels. A literature review was conducted to understand how behavioral intent to use various forms of technology was measured using the Extended Technology Acceptance Model (TAM) in several different applications. This not only demonstrated how the Extended TAM could be used, but also that the Extended TAM has not been previously used to measure the behavioral intent of airline pilots to use personal, wearable FMT, demonstrating a literature gap.

Fatigue-Related Aviation Accidents

There is an extensive history of aviation accidents attributed to crewmember fatigue, as cited in government aviation accident reports. Between the years 2001 and 2012, of the 182 major NTSB investigations, 20 percent listed human fatigue as a probable cause, finding, or contributing factor (NTSB, 2016). Pilot fatigue was first cited as a primary causal factor of an aviation accident by the NTSB in 1993 after the crash of Connie Kalitta Services Flight 808, when the McDonnell Douglas DC-8 crashed into terrain short of a runway in Cuba, seriously injuring the three crew members onboard and destroying the aircraft (1993). The NTSB specifically referred to the impaired judgement, decision-making, and flying abilities of the crew due to fatigue, and further cited inadequacy of flight and duty time regulations applied to 14 CFR Part 121 operations, which extended the duty times of the crew members (1993). Six years later, in 1999, American Airlines Flight 1420, a McDonnell-Douglas MD-82, crashed on approach to landing in Little Rock, Arkansas, killing 11 of the 145 souls on board, including the captain. The crew overran the runway, striking multiple obstacles during severe weather conditions. Upon completion of the accident investigation, the NTSB (1999) also cited the flight crew's "impaired performance resulting from fatigue" as one of the contributing factors to the accident.

In 2009, Colgan Flight 3407, a Bombardier -8 Q400 doing business as Continental Airlines, crashed on approach to landing in Buffalo, New York. Crew member fatigue was cited as a causal factor, and the NTSB looked extensively into the fatigue risk management system in place at Colgan, which at the time did not provide any information to its pilots regarding prevention of fatigue (NTSB, 2011). In fact, the Colgan management team indicated the document they were developing to inform pilots about the dangers of and prevention techniques for pilot fatigue was not released because it would require changing crewmember duty times and report periods as a direct countermeasure, which for this particular regional airline was not a feasible operational option (NTSB, 2011).

In the cargo segment of the United States commercial airline industry, fatigue was cited as a causal factor in 2013 when United Parcel Service (UPS) Flight 1354 crashed on approach to landing into Birmingham, Alabama, killing the two crew members onboard (NTSB, 2014). In the accident report, the NTSB (2014) explained how the first officer did not make effective use of her allocated off-duty rest period, the captain was fatigued due to circadian factors; neither of the pilots called in fatigued to UPS flight operations. This problem is not isolated to the airline industry. In 2014, a Chicago Transit Authority locomotive collided with a post at Chicago O'Hare Station, causing the train to derail and ascend up a pedestrian escalator at the end of the track, with the root cause cited by the NTSB being fatigue due to rotating shift work, circadian factors, and acute sleep loss from poor off-duty rest time management; though no one was on the escalator, 33 passengers and the train operator were injured and hospitalized (NTSB, 2015).

Fatigue has been cited as a causal factor in many aviation accidents, and there are many reasons why a pilot would be fatigued while operating an aircraft, including poor time management, illness, stress, high workload, and circadian rhythm disruption. The circadian biological clock is the body's natural timing for sleepiness and alertness and is "measured by the distinct rise and fall of body temperature, plasma levels of certain hormones, and other biological conditions" (National Sleep Foundation, 2017, p. 1). For pilots, their natural circadian rhythm can be disrupted as a result of flying at night, alternating between standard and red-eye schedules, or rapidly crossing multiple time zones, often referred to as "jet lag" (National Sleep Foundation, 2017). Since there are so many reasons why pilots operate aircraft while fatigued, it is important to develop acceptable methods to help them objectively monitor their fatigue levels using technology in accordance with the technology acceptance model.

Fatigue Monitoring Technology Methods and Devices

Successful fatigue management based on non-intrusive monitoring systems have also been applied in other industries. For example, Ali, Sarkar, Kumar, and Cabibihan

(2012) developed an algorithm to monitor fatigue in commercial truck drivers based on ocular parameters and head positioning of the vehicle operator. The research team at the National University of Singapore developed the algorithm to measure vehicle operator fatigue levels using Seeing Machines Facelab 5 software that uses a camera to track and measure variations in ocular, facital, and head positions (Ali, Sarkar, Kumar, & Cabibihan, 2012). It measured the percentage of eyelid closure (PERCLOS), an established lab measure of fatigue, as well as operator blink rates. The software was able to determine and filter out regular blinks based on the observed blink rates. In addition to the PERCLOS and blink rate measurements, the software also recorded head movements with respect to a head reference frame, which was the newly proposed method of measuring fatigue in their study.

Results of the National University of Singapore study indicated the head position variance tracking was accurate at a statistically significant level when held to the lab standard of the PERCLOS and blink rate measurements. Their study demonstrated there are established means of measuring human fatigue levels, but these require cameras, special software, and lab analysis, all of which are not practical in the commercial airline environment. Airline pilots would have to either subject themselves to a lab test prior to every flight or have live video monitoring approved in the flight deck, both of which have some method of instantly analyzing the data for pilot use. This type of technology is also expensive to qualify and implement.

Alsamman and Ratecki (2011) used infrared cameras to capture ocular data designed for commercial truck driving command center employees, not unlike air traffic controllers in the airline industry. An infrared light-emitting diode (LED) system was developed to quickly identify the eye pupils and subsequently measure PERCLOS of the operator to quantify the level of fatigue. The benefit to using this infrared technology was it required very little computing power and did not interfere with the operator's standard work duties, often in a low-light environment. The methods were determined to be successful at detecting the onset of operator fatigue; however, the algorithms required inputs from cameras (Alsamman & Ratecki, 2011).

Unfortunately, in the airline industry, cockpit video cameras have been prohibited by commercial pilot unions, citing video as an invasion of privacy that would likely be misinterpreted or misused (Huey, 2004). There are additional technical reasons that may make this technology difficult to use in a flight deck environment that differ from an automobile operation, such as head, eye, and body movements required to read materials, perform crew resource management activities, and operate different flight controls that would be a challenge to program using fatigue monitoring software. It is also for this reason that a personal, wearable device readily available for purchase by pilots is the subject of the proposed study, in lieu of a more sophisticated technology option that would be implemented in the flight deck. Not only is video prohibited by the FAA as previously mentioned, but such sophisticated technology would be expensive to qualify and implement across a fleet of aircraft. In terms of value engineering, it is worth determining if a simple and cost-effective solution, such as personal, wearable technology could help mitigate pilot fatigue in the airline industry.

Dinges, Maislin, Brewster, Krueger, and Carrol (2005) evaluated the use of four different FMT devices on commercial truck driver alertness levels, amount of time spent sleeping, and personal reactions of the drivers. It was hypothesized that device usage would not only increase driver alertness while operating commercial trucks, but also directly correspond to an increase in driver sleep time. The four devices studied were the Walter Reed Army Institute of Research (WRAIR) Sleep watch to record driver sleep patterns, as well as a CoPilot optical device to measure driver percentage of eyelid closure rates (PERCLOS), a SafeTrac lane tracking system to assess and track driver position on the road, and the Howard Power Center Steering system, used to alleviate manual truck driver inputs with the use of on-board hydraulics equipment.

Upon completion of their study on commercial truck drivers in both the United States and Canada, Dinges et al. (2005) were able to demonstrate that while the various fatigue monitoring devices tested increased driver alertness, they failed to support their hypothesis that the devices would increase driver sleep time on work nights (Dinges et al., 2005). In other words, even though driver alertness increased during operations, the drivers were not motivated to change their sleep habits during allocated rest hours to further minimize their fatigue levels. Dinges et al. (2005) also collected driver feedback regarding the FMT devices, and found the study participants favored the SafeTrac lane tracking device, since it monitored the vehicle to infer information about driver fatigue, as opposed to the other devices that measured physical parameters of the driver to directly measure their fatigue.

In a study by Gander, Mulrine, van den Berg, Smith, Signal, Wu, and Belenky (2015) in the Journal of Sleep Research, the research team utilized the Actiwatch AW-64 for subject sleep monitoring. The AW-64 device is typically worn on the wrist and is the size of a normal wristwatch. The AW-64 monitors sleep and wake time with a sensitive accelerometer. It has light measurement sensors and records data with event markers.

The Actiwatch also records when it is not being worn. This type of wrist-worn sleep versus wake monitoring technology is also known in the literature as wrist actigraphy (Gander et al., 2015; Signal, Gale, & Gander, 2005). The AW-64 uses an application called Actiware software. It is a Windows-based application which can export sleep versus wake, illuminance, and activity data from any Actiwatch model, as well as analyze and present its information graphically with event markers.

Brewer, Swanson, and Ortiz (2017) conducted a study published in the BMJ Journal for Open Sport and Exercise Medicine assessing the validity of the technology used in personal Fitbit devices against the clinically proven technology used in the research-grade ActiGraph GT3X+ accelerometer. In the study, 53 individuals wore a Fitbit and ActiGraph for seven days, and data were analyzed using correlation coefficients and t-tests to determine the extent of agreement between the devices (Brewer, et al., 2017). Results of the study indicated the devices were comparable with regards to measuring physical activity when used over a seven-day period, and the data produced by the Fitbit was consistent with that produced by the ActiGraph over the same seven-day period (Brewer et al., 2017). There were some inconsistencies in the 1-day timeframe, so it would be recommended that pilots use the device consistently to ensure the highest technical validity with regards to their fatigue awareness.

Many studies have been conducted comparing wrist actigraphics with polysomnography (Kosmadopoulos et al., 2014; Kripke et al., 2010; Rupp & Balkin, 2011; Sargent, Halson, & Roach, 2014; Signal et al., 2005). The universal cautionary finding of these studies is that wrist actigraphics perform well compared with polysomnography to identify sleep, but not the type of sleep or the onset of sleep. These studies found wrist actigraphy measurements were not good for identifying wake unless the thresholds for wake activity are correctly defined in the software settings. Setting activity threshold levels for the accelerometer requires some experience with wrist actigraphics, understanding of the managing software, and perhaps an individual's calibration of the thresholds with polysomnography (Sargent, Lastella, Halson, & Roach, 2016; Signal et al., 2005). Rupp and Balkin (2011) conducted a study comparing the Motionlogger Watch (Ambulatory Monitoring, Ardsley, NY) to the Actiwatch. The Motionlogger used sleep/wake Action-W Version 2, software, and the Actiwatch used Actiware Version 3.4. The study showed that Motionlogger had a slightly better correlation to polysomnography in detecting sleep than the Actiwatch but no advantage in detecting sleep/wake transitions.

Ong and Gillespie (2016) reviewed variations of mobile phone-based sleep tracking applications. There are over 50 different sleep applications available for mobile phones equipped with accelerometers. The mobile phone platform actigraphy limitations are like the wrist actigraphy limitations in that both platforms are sensitive to sleep time, but do not perform well when determining the type of sleep a person is experiencing (Ong & Gillespie, 2016). Based on reviews of mobile phone applications in Google Play and the Apple Store, John Corpuz published a list of the most frequently used mobile applications for sleep monitoring in 2017, which are shown below in Table 1 (Corpuz, 2017). FitBit devices are used as frequently as Apple and Android devices but offer the advantage of measuring battery life in terms of days, as opposed to hours, like mobile phones or Apple or Android smart watches (Simon, 2018). These smart devices are getting more intelligent with each release; for example, the Apple Watch comes with a built-in EKG monitor, and the next Fitbit release will incorporate a sleep apnea alert.

Table 1

Types of FMT Devices

Application	Device	Description
Sleep Cycle	iPhone	Uses accelerometer to record sleep habits, wakes user at optimal time based on software calculation.
Pillow	Apple Watch	Uses Apple Watch sensors to track sleep duration and quality, uses smart alarm feature to wake user at optimal time.
Sleep Better	Android Devices, iPhone, Apple Watch	Uses device accelerometer to record sleep quantity and quality, uses smart alarm feature to wake user at optimal time.
Sleep As Android	Android Devices	Uses device accelerometer to record sleep quantity and quality, uses smart alarm feature to wake user at optimal time. Uses CAPTCHA wakeup tests to help ensure user has actually ended sleep cycle.
Sleep Tracker by Prime Nap	Android Devices	Uses device accelerometer to record sleep quantity and quality, uses smart alarm feature to wake user at optimal time. Tracks activities throughout day and projects how those may affect sleep quantity and quality.

Adapted from “Best Sleep Apps,” by John Corpuz, 2017, *Tom’s Guide for reviewing technology.*

Fatigue Measures and Risk Management Systems

Prior to discussing the TAM in conjunction with theoretical significance of this study, it is important to understand the foundations for measuring fatigue and development of risk management systems the airline industry. As aforementioned, pilot fatigue has been cited as a causal factor in numerous aviation accidents and has thus been a topic of interest in aviation human factors with respect to fatigue measurement and risk mitigation strategies. In fact, the International Civil Aviation Organization (ICAO) has issued regulatory approval for the use of fatigue risk management systems (FRMS) as a means of mitigating higher fatigue levels in pilots (ICAO, 2011).

An FRMS is a form of a safety management system, modeled after a four-step process loop. First, one must monitor pilot fatigue levels; second, one must identify when said levels could represent a safety hazard; third, one must assess the associated safety risks; fourth, if deemed necessary, one must implement mitigation strategies to lower the risks (Gander et al., 2015). This four-step process depicted below in Figure 2 is iteratively applied to continuously mitigate the risks of pilots operating an aircraft while fatigued.

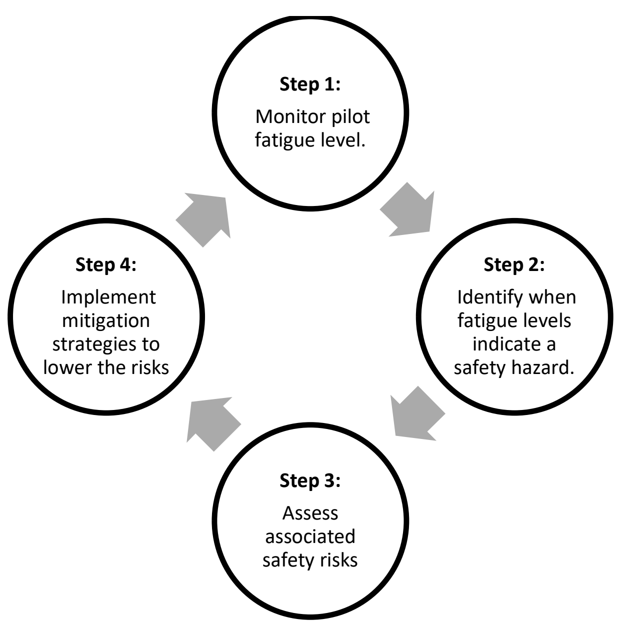

Figure 2. Visual depiction of 4-step fatigue risk management cycle. Adapted from "Effects of sleep/wale history and circadian phase on proposed pilot fatigue safety performance indicators," Gander, P. H., Mulrine, H. M., van den Berg, M. J., Smith, A. A. T., Signal, T. L., Wu, L. J., and Belenky, G., 2015, *Journal of Sleep Research*, Copyright 2015.

To execute Step One, "monitor pilot fatigue levels," it must first be understood what the appropriate measure of fatigue levels in pilots is. ICAO, International Air Transport Association (IATA), and International Federation of Airline Pilots Associations (IFALPA) (2011) have set standards that require fatigue measures to have been scientifically validated, not impede the pilot's ability to perform his or her duties, and to have a history of use in the airline industry. As part of the study conducted by Gander et al. (2015), the Karolinska Sleepiness Scale (KSS), Samn-Perelli Crew Status Check, and psychomotor vigilance task (PVT) performance were proposed as measures for aircraft pilot fatigue.

The KSS is a self-assessment of fatigue, accepted by ICAO, IATA, and IFALPA, where the individual evaluates his or her sleepiness on a 9-point scale, where 1 indicates extremely alert, and 9 indicates extremely sleepy to the point where the individual is actively fighting sleep. The Samn-Perelli Crew Status Check is another self-assessment of fatigue accepted by ICAO, IATA, and IFALPA, where the individual ranks his or her fatigue level on a 7-point scale, where 1 indicates fully alert and awake, and 7 indicates completely exhausted and unable to function effectively. The PVT is a tool used to measure an individual's alertness by measuring how he or she reacts to stimuli after completing a brief three to five-minute test. These measures of fatigue are also referred to as safety performance indicators (SPI), and have been tested in multiple laboratory studies (ICAO, 2011). In the study performed by Gander et al (2015), the research team evaluated the three methods with comparable variations in sleep-wake history and circadian phase, to determine if any particular measure was superior to the others using data taken from four field studies by different airlines spanning three continents, 237 pilots, 730 flights, and 13 city pairs using wrist actigraphy and logbooks before, during, and after trips.

Results of the study by Gander et al. (2015) indicated that obtaining more sleep in the 24 hours preceding a flight is an effective fatigue risk mitigation strategy. There was no significant relationship found between napping immediately prior to a flight and mitigating fatigue (Gander et al., 2015). In other words, although it is important to obtain a full rest period of sleep in the 24 hours prior to flight, it does not need to be immediately preceding the pilot report time. Interesting takeaways from the studies indicated that throughout the duration of the waking day, while sleepiness and fatigue levels continuously increase, PVT performance improves until its evening peak (Gander et al., 2015). The study also measured fatigue levels at the top of descent, where it was observed that higher fatigue and sleepiness measurements were a function of longer time awake and less total in-flight sleep, but not associated with the total flight duration. Correspondingly, PVT performance improved with total flight duration, but was not significantly correlated to time awake or total in-flight sleep at the top of descent (Gander et al., 2015).

Overall, it was determined that the three SPIs were effective measures of pilot fatigue levels. More importantly, for the purpose of this research, it is important to document the type of devices used to measure the fatigue levels. First, the sleep monitoring was completed using wrist actigraphy, in the form of the Actiwatch AW-64 or Spectrum and the Philips Respironics/Mini Mitter (Gander et al., 2015). Next, the fatigue and sleepiness SPIs were measured at specified points by recording their measures in a logbook, 1 through 9 for KSS, and 1 through 7 for Samn-Perelli Crew Status Check (Gander et al, 2015). Finally, the PVT SPI test was completed on company-issued smartphones prior to and during flight (Gander et al, 2015).

There are many technology devices available that are accepted as reliable means of tracking sleep performance, in terms of both quantity and quality. Having this information available real-time to pilots would theoretically increase his or her personal awareness of his or her fatigue level, thus better equipping him or her to make the decision to operate an aircraft, or to actively seek opportunities for sleep during designated rest periods. While this technology is readily available, it is important to understand the acceptance-readiness of the pilots prior to implementing a policy that requires them to use FMT as a requirement for their job, as there may be other subjective factors that influence their intent to use the technology and need to be mitigated.

Theoretical Framework

The Extended Technology Acceptance Model (TAM) is being proposed as the foundational framework for the current study, as a commonly used theory for explaining the determining factors in technology adoption and use.

Technology Acceptance Model. The Extended TAM is an expanded iteration of the original TAM. During the 1970s, due to an increase in issues related to the adoption of systems in organizations, predicting technology acceptance or rejection became the focus within the information systems community, and the original TAM was developed as part of a doctoral work by Fred Davis, at the Massachusetts Institute of Technology (MIT), to address technology acceptance research needs (Chuttur, 2009). The original TAM was derived from the Theory of Reasoned Action (TRA) by Fishbein and Ajzen

(1975), which offered a way to model and predict human behavior in the adoption and use of new technology. The proposed theory explained an information system user's actual behavior in adopting a technology to be motivation-driven, which has shown to be directly impacted by the features and the capabilities of that technology. The basic conceptual model behind TAM demonstrates the prediction of actual use of technology in a form of relationships between *stimulus-organism-response*, as shown below in Figure 3 (Chuttur, 2009).

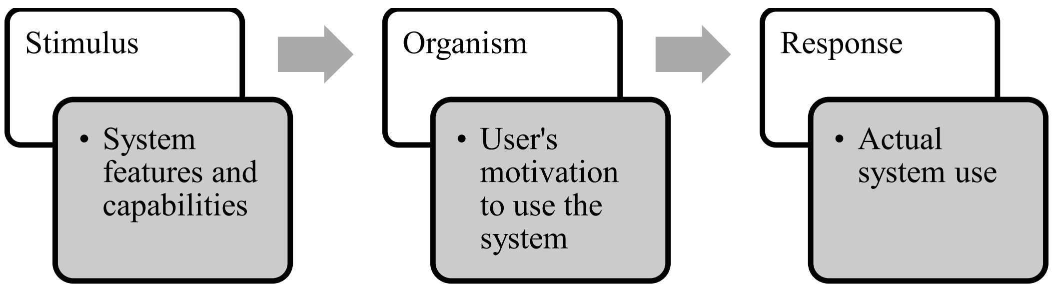

Figure 3. Conceptual model showing the *stimulus-organism-response* relationship in technology acceptance. Adapted from "Stimulus-Organism-Response Relationship," by M. Y. Chuttur, 2009, Sprouts: Working Papers on Information Systems, Copyright 2009 by Indiana University.

Since the 1980s, the TAM has undergone several iterations to include new variables and relationships. An early validation of the TAM required Davis to define, operationalize, and test perceived usefulness and ease of use, as factors that determine user attitude and intention toward using a given technology. *Perceived usefulness* was defined as, "the extent to which a person believes that using the system will enhance his or her job performance," and *perceived ease of use* was defined as, "the extent to which a person believes that using the system will be free of effort" (Venkatesh & Davis, 2000, p. 2). The conceptual variables were then operationalized through a revised 10-item psychometric scale measures for each variable. The reliability and validity of the TAM were demonstrated by the results of a study on 112 International Business Machines (IBM) employees, where perceived usefulness, perceived ease of use, and attitudes toward using the two new technologies were measured using a seven-point Likert rating scale. The actual use of the technologies was also measured and recorded, and it was found to be highly correlated with perceived usefulness and perceived ease of use.

Once these statistical relationships were observed, Davis continued exploring and refining TAM based on additional findings. In 1993, Davis revised his original prediction to demonstrate direct influence of perceived usefulness on actual use of technology and direct influence of technology characteristics on user attitudes. After further investigation, Davis introduced the construct of behavioral intention, or user intention to use the technology, and eliminated user attitude from the original TAM because a direct statistical relationship of both perceived usefulness and perceived ease of use on intention to use the technology was observed. In the earlier model, this relationship was shown to be indirect, through the construct of user attitudes toward the technology (Venkatesh & Davis, 2000). The attitude toward using technology is now represented through the various external factors in the Extended TAM.

Extended Technology Acceptance Model.

In 2000, Fred Davis partnered with Viswanth Venkatesh to develop a theoretical extension of the technology acceptance model using four empirically tested, longitudinal field studies; this became known as the "TAM2" or "Extended TAM," hereon referred to as the "Extended TAM." In the original TAM, behavioral intention to use a new system was a function of user perceived usefulness and perceived ease of use. This is still the case in the Extended TAM, but on the input side of the model, what was originally labeled as “external factors” are now additional constructs covering social influence processes and cognitive instrumental processes that act as influencing factors for perceived usefulness.

The external factors classified as social influence processes are *subjective norms, voluntariness, and image*, which account for the effects of those opinions that matter greatly to the technology user (Davis & Venkatesh, 2000). These factors are consistent with the Theory of Reasoned Action (Fishbein & Ajzen, 1975) and the Theory of Planned Behavior (Ajzen, 1991), that explain if one or more important individuals think the user should take an action, the user is more likely to take the action, even if they wouldn’t normally, because people inherently care about how they are perceived by others. The external factors classified as cognitive instrumental processes are *perceived ease of use, job relevance, output quality, and results demonstrability*, derived from work motivation theory (Vroom, 1964), action theory from social psychology (Fishbein & Ajzen, 1975), and task-contingent decision making from behavioral decision theory (Beach & Mitchell, 1978; Davis & Venkatesh, 2000). The Extended TAM theoretical framework model is shown below in Figure 4. Each of the model constructs has corresponding standard questions to be used in a survey instrument, published by Venkatesh and Davis (2000).

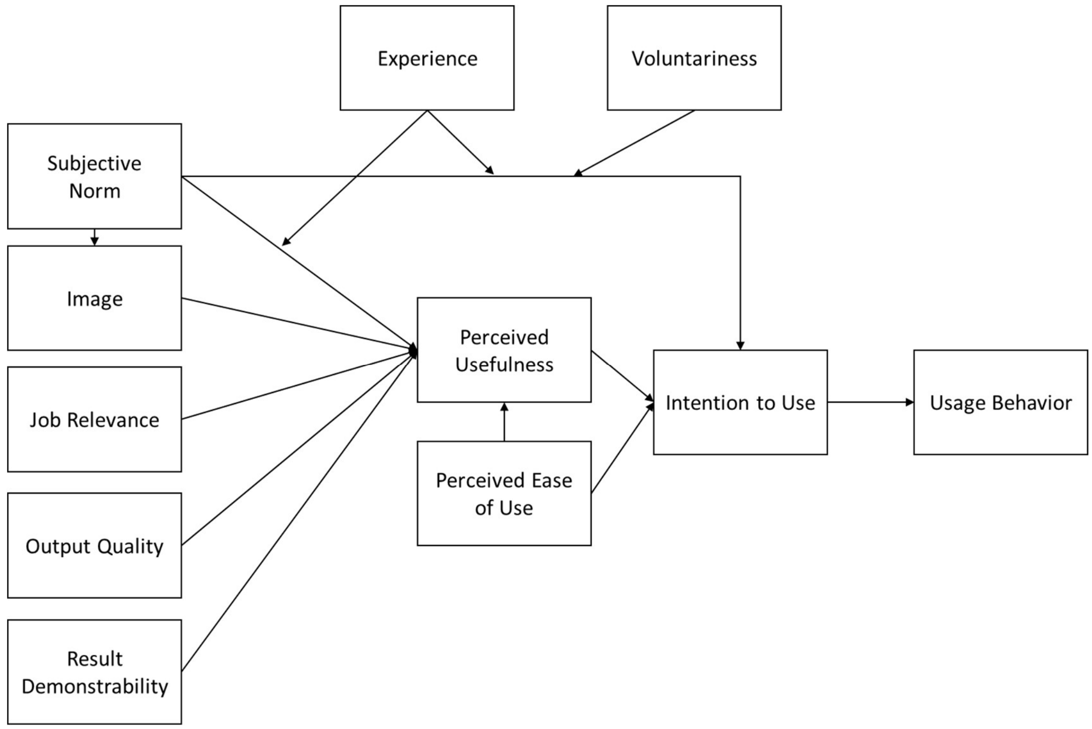

Figure 4. Final released version of the extended Technology Acceptance Model. Adapted from "A theoretical extension of the technology acceptance model: Four longitudinal field studies," by Venkatesh & Davis, 2000, Management Science, Copyright 2000.

In general, the model on technology acceptance by Venkatesh and Davis (2000) explains how users are motivated based on how well an object helps a user achieve their goals, and how well an object performs in accordance with its intended use. Both the social influence processes and cognitive instrumental processes were used in this study to assess factors that influence a pilot's perceived usefulness and ease of use in regard to FMT. The external latent variable constructs used in this study are consistent with the Extended TAM: *Subjective norms, perceived image, job relevance, output quality, and result demonstrability*.

Extended Technology Acceptance Model Exceptions.

The Extended TAM variables of *actual use*, *experience,* and *voluntariness* were not directly measured in this study. The latent variable of *actual usage* of FMT was not modeled or measured as part of this study, as it was not an experimental design, but could be pursued as part of a follow-on study. The moderating variable of *experience* was not measured because it requires a series of longitudinal studies to be completed based on actual system use, as Venkatesh & Davis (2000) concluded the effects of subjective norms on perceived usefulness and intention to use change as users gain experience with the system. Since this was an initial study regarding pilot acceptance of FMT, not including actual usage data, the effect of experience with the system over time could not be measured. This presents another opportunity for future research to collect actual use data over time through a series of longitudinal studies measuring actual usage to observe and measure a potential change in behavior as technology advances and user experience with the technology increases.

Voluntariness was not directly measured as part of this study. Voluntariness was a moderating variable in the Extended TAM, defined as "the extent to which potential adopters perceive the adoption decision to be non-mandatory" (Venkatesh & Davis, 2000). This meant that user intentions change based on whether the use of new technology is mandatory or voluntary. In a mandatory scenario, subjective norms become a compliance-driven factor, where the "important individuals" are those who can drive potential punitive actions if the technology is not used. This is different than a voluntary scenario where the opinions of important individuals influencing their intention to use the technology and is more comparable to peer pressure or recommendations (Venkatesh & Davis, 2000). Venkatesh and Davis (2000) posed three hypotheses regarding voluntariness:

Hypothesis 1a. Subjective norms will have a positive direct effect on intention to use when the system use is perceived to be mandatory.

Hypothesis 1b. Subjective norms will have no significant direct effect on intention to use when system use is perceived to be voluntary.

Hypothesis 1c. Voluntariness will moderate the effect of subjective norms on intention to use.

This study was set up to assess general pilot acceptance of FMT, and the scenario was not specific to the voluntary or mandatory nature of the FMT use by pilots. The model for this study, however, did hypothesize that subjective norms would have a positive effect on behavioral intention to use FMT, which corresponds to the mandatory usage context in the Extended TAM, when considering voluntariness as a moderating variable. The researcher originally assumed implementation of FMT would need to be driven through policy change by regulators or companies in order to be successful, though implementation context was not specified as voluntary or mandatory in the questionnaire.

In future research, a way to assess the influence of voluntariness would be to complete the study in two groups, where one scenario provided to respondents specifies a mandatory implementation of the technology, and the other scenario specifies a voluntary implementation of the technology (Hartwick & Barki, 1994; Venkatesh & Davis, 2000). Being that this study was preliminary in nature to determine a path forward for future research, it was intentionally determined to delimit the scenarios to assess general pilot acceptance of FMT. The results of the data collected as part of this study actually supported *Hypothesis 1b* by Venkatesh and Davis (2000), the implications of which are discussed in Chapter 5 of this dissertation.

Extended Technology Acceptance Model Applications

There is no shortage of studies that have used the Extended TAM to evaluate users' intentions to accept and use a new type of technology. Many studies use the original TAM, which includes the user's attitude toward using the technology, in alignment with the TPB framework, and then add custom external factors, or subsequently refer to their model as the "Extended TAM," though the true theoretical Extended TAM framework was not used. For the purposes of this literature review, when the referenced sources use external factors not from the standard Extended TAM, the corresponding factor that is most applicable is also indicated. It was the intent of Davis and Venkatesh (2000) to have factors in their model that transcended different technology types and industries; however, it is often decided by researchers to modify the names of the factors, add new factors, or change the corresponding questions in the survey to best fit their needs. In most cases, however, the custom factors can be tied back philosophically to one of the external factors indicated by Davis and Venkatesh in their Extended TAM standard model, which is why it was selected as the framework for this research.

TAM-based studies, extended or not, range back to when electronic mail was introduced in the office place all the way up through the last five years studying the acceptance and adoption of mainstream, modern technology applications such as wearable technology, information sharing, virtual reality, mobile social network games, tablet usage, wiki technology, car navigation systems, and mobile applications such as

Facebook, Instagram, and Snapchat. A practical implementation of the proposed study would be a mainstream, modern, wearable device such as a Fitbit, Apple Watch, Samsung Galaxy Gear, or other wrist actigraphy device in an application where the device is used to monitor a health and fitness parameter – fatigue – in the airline industry. As such, scholarly studies have been included in this upcoming section which demonstrated usage of the Technology Acceptance Model or Extended TAM, sometimes in combination with the Theory of Planned Behavior, to study new uses of modern technology, use of existing modern technology to measure health and fitness parameters including fatigue, use of wearable technology in various applications, and use of wearable technology to measure fatigue in environments aside from aviation. No studies, however, were able to be located that specifically study the use of modern, wearable technology to measure fatigue in the airline industry through use of the Technology Acceptance Model or Extended TAM, thus demonstrating a theoretical knowledge gap in scholarly literature.

Altanopoulou and Tselios (2017) published a study where they investigated undergraduate students' intention to use wiki technology using the Extended TAM, taking into consideration external factors of social norms and facilitating conditions. Wikis are used to emphasize collaborative writing, open culture, learning, and information sharing, and previous studies regarding wiki adoption indicated trust and social norms were contributing influencing factors to user acceptance (Altanopoulou & Tselios, 2017). Their study revealed social norms had a significantly positive effect on perceived usefulness and behavioral intention to use the wiki. This is an important finding for the proposed study because there is potential the sleep-pattern information would be shared with either the pilot's company or union, and all of the pilots would be participating and contributing to the data collection, so understanding the influence of social or subjective norms is of utmost importance.

Park, Kim, and Ohm (2014) published the results of a study where they used the Extended TAM to evaluate drivers' intention to use car navigation systems. Results indicated the service and display quality components were the most statistically significant contributors to a driver's behavioral intent to use their car's navigation system (Park, et al, 2014). These items correspond to the original external factor of output quality in the Venkatesh and Davis (2000) Extended TAM. Additional significant contributing factors were perceived usefulness and perceived locational accuracy, which corresponds to the original external factor of result demonstrability in the original Extended TAM. This is a relevant study because it was conducted on vehicle operators using technology to increase driver and vehicular safety. It can be expected pilots using wearable technology to measure fatigue would also consider display or output quality to be influential in a decision to use wearable technology to monitor their personal fatigue levels, especially considering the amount of effort put into user-centered design of flight deck technology to ensure pilots' needs for output quality are met.

Ducey (2016) published his study regarding the application of the Extended TAM to evaluate physicians' behavioral intent to use tablets in the health care industry. The study supported a hypothesis from the original Extended TAM, that subjective norms are positively related to a user's behavioral intent to use a specific technology, as well as perceived usefulness of using the specific technology. Ducey's (2016) model also supported a hypothesis for the external factor of reliability affecting both perceived ease of use and perceived usefulness, which in terms of the original Extended TAM, corresponds to both output quality and results demonstrability. It is reasonable to expect that pilots using wearable technology to monitor their personal fatigue levels, like physicians using tablets to monitor patient health parameters, would find both output quality and results demonstrability to be influencing factors to their behavioral intent to use the technology. If the user does not find the results accurate or reliable, he or she will hypothetically be less likely to use the device.

Wang, Amadou, and Ropp (2016) applied the Extended TAM to aviation by measuring aviation students' perceptions toward augmented reality maintenance training instruction. This group used a simplified version of the Extended TAM proposed by Masrom (2007), that excluded external factors and actual use, but did still measure the core factors of perceived usefulness and perceived ease of use. The results of their study supported the applicability of the TAM to aviation students' acceptance of augmented reality technology applications in the aviation maintenance classroom, in terms of perceived usefulness and perceived ease of use but was limited in that it did not test or demonstrate the applicability of external factors. The simplified Extended TAM, which is nearly identical to Fred Davis' original Technology Acceptance Model from 1989, is shown below in Figure 5. This is still a relevant example because perceived ease of use and perceived usefulness are both included in the proposed model being for this study for pilot acceptance of wearable technology for measuring personal fatigue levels. Additional rigor is added in the proposed model by including the external factors presented in Venkatesh and Davis' final Extended TAM (2000).

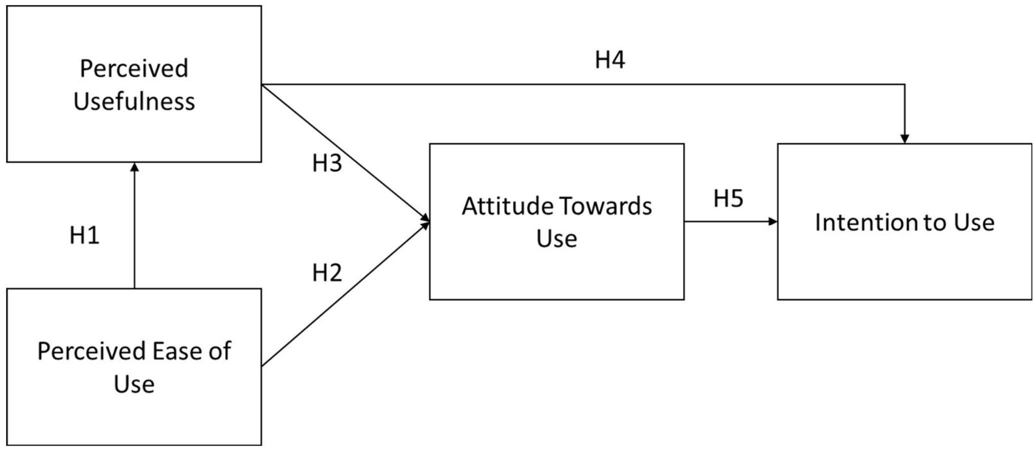

Figure 5. Hypothesis diagram based on the Simplified Extended TAM. Adapted from "Technology acceptance model and e-learning," by Masrom, 2007, Technology, Copyright 2007.

Rahman, Lesch, Horrey, and Starderman (2017) published a study in the Accident Analysis & Prevention Journal assessing the utility of the Technology Acceptance Model, Theory of Planned Behavior, and Unified Theory of Acceptance and Use of Technology (UTAUT) for advanced driver assistance systems. In their study, participants interacted with a fatigue monitoring system or an adaptive cruise control system, combined with a lane-keeping system, and then participated in a survey measuring factors in the TAM, TPB, and UTAUT frameworks. Fatigue monitoring was based on established measures of driver fatigue that measured driver alertness as a function of driver behavior. A front camera on the vehicle detected lane position and used a series of algorithms to measure the driver's ability to maintain lane position and calculate driver alertness. Depending on the various alertness level thresholds, the program sounded audible warnings to increase driver alertness. This is similar technology to that demonstrated in a study by Dinges et al. (2005) but improved based on the use of modern technology released in the last ten years.

Rahman et al. (2017) studied perceived usefulness, perceived ease of use, and behavioral intent from the Extended TAM to the use of FMT by automobile operators. From the Theory of Planned Behavior, the research team used the external factors of subjective norms and behavioral control, corresponding to ease of use in the Extended TAM, as well as attitude toward using the technology, corresponding to perceived image in the Extended TAM. They also considered behavioral intent, which is consistent with the standard Extended TAM. From the UTAUT, they studied performance expectancy, corresponding to result demonstrability and output quality in the Extended TAM, as well as effort expectancy, corresponding to ease of use in the Extended TAM, social influence, corresponding to subjective norms and perceived image in the Extended TAM, and behavioral intent, consistent with the Extended TAM. They were able to successfully demonstrate perceived usefulness, perceived ease of use, subjective norms, perceived image, results demonstrability, and output quality were all significant influences on drivers' behavioral intention to use the FMT in the vehicle (Rahman et al., 2017). Though they did not use wearable technology, their ideas are still relevant in users accepting the use of technology to provide input on personal fatigue levels of vehicle operators. It is realistic pilots would have similar requirements and feedback regarding wearable FMT.

The use of modern technology is actively being pursued as a means of mitigating risks for aviation incidents and accidents, such as fatigue, poor situational awareness, or controlled flight into terrain. Richardson (2017) published a study using the Technology Acceptance Model to evaluate pilot acceptance of Automatic Ground Collision Avoidance System (AGCAS) as his doctoral dissertation subject through Embry-Riddle

Aeronautical University, using archival survey data collected from United States Air Force F-16 operators in 2014 in a previous study, by correlating their survey questions to the acceptance-based factors of the standard TAM. In Richardson's study, as well as previous acceptance studies for AGCAS, one of the primary objectives was to provide evidentiary support for the budgetary expenditure of incorporating new technology into next generation military fighter aircraft. His study explored latent variables of AGCAS perceived usefulness, AGCAS perceived ease of use, and AGCAS usage behavior, like those factors used in the standard Technology Acceptance Model. Upon completion of confirmatory factor analysis in conjunction with SEM, his results indicated the Technology Acceptance Model was a valid representation of pilot behavioral acceptance of AGCAS onboard military fighter aircraft (Richardson, 2017).

In the study, which is the subject of this dissertation, pilots' acceptance of personal wearable fatigue monitoring devices was evaluated, which included devices such as the Fitbit, Apple Watch, or Samsung Gear, colloquially referred to as "smart watches." It is relevant to consider any previous Technology Acceptance Model based studies completed on "smart watches," since many of the contributing factors to user acceptance would likely be in alignment with pilots asked to evaluate their behavioral intention to use a "smart watch" to monitor their personal fatigue levels. Kim and Shin (2015) published a study regarding user acceptance of smart watches in accordance with the technology acceptance model framework to determine psychological determinates of smart watch adoption. Kim and Shin (2015) integrated data collected from 342 survey respondents regarding external factors of affective quality, relative advantage, mobility, availability, and subcultural appeal into the original TAM constructs of perceived usefulness and perceived ease of use.

Kim and Shin (2015) analyzed the survey response data using SEM. They determined affective quality and relative advantage, corresponding to the external factors of output quality and job relevance in the original Extended TAM, were statistically significant contributors to perceived usefulness of smart watches. They also determined mobility and availability were statistically significant contributors to perceived ease of use. Finally, the subcultural appeal, corresponding to the external factors of subjective norm and perceived image in the original Extended TAM, as well as cost of the smart watches, were statistically significant contributors of users' behavioral intention to use the device (Kim & Shin, 2015). While subjective norms are included in the proposed study for this dissertation, the cost of the device is not included as part of the proposed model because it is expected the fatigue monitoring device would be provided to the pilots at no cost, following the precedent of the electronic flight bags used by a variety of regional and mainline commercial air carriers in the United States.

A structural investigation on the acceptance and perceived fitness outcomes using wearable fitness technology by commercial consumers was completed by Lunney, Cunningham, and Eastin (2016). This is a relevant study to consider, since the wearable fitness technologies (WFT) they studied were the same as those proposed as FMT in this study, such as the Fitbit One and Fitbit Flex (Lunney et al., 2016). Lunney et al. (2016), collected data from survey respondents regarding perceived usefulness and perceived ease of use, as well as external factors of subjective norms and attitude toward using

WFT. The hypothesized model proposed by Lunney et al. (2016) is shown below in Figure 6.

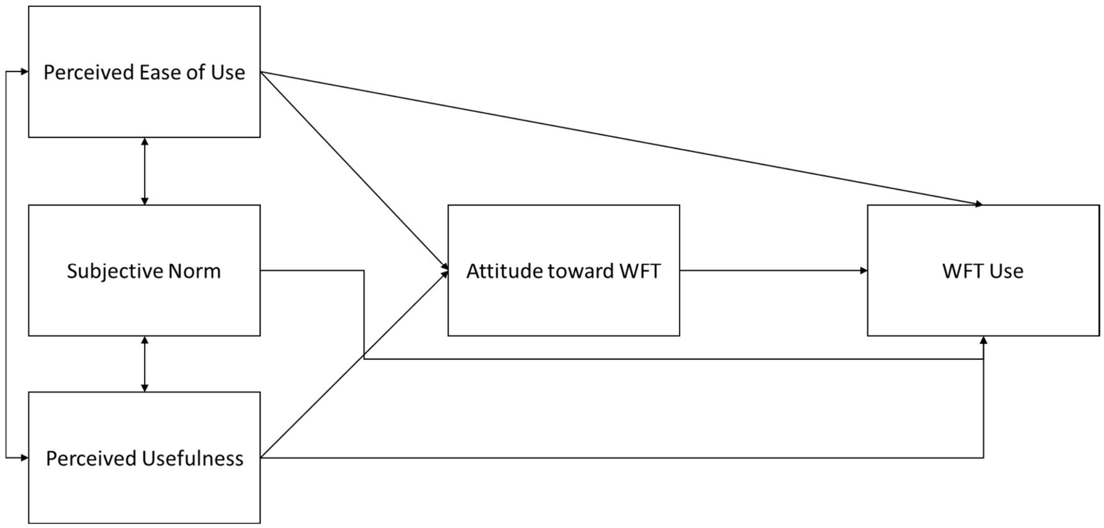

Figure 6. Hypothesis diagram proposed in study on acceptance of wearable fitness technology by commercial consumers. Adapted from "Wearable fitness technology: A structural investigation into acceptance and perceived fitness outcomes," by Lunney, Cunningham, & Eastin, 2016, Computers in Human Behavior, Copyright 2016.

Lunney et al. (2016) analyzed their survey data using SEM to validate the application of the Extended TAM to WFT devices. Their study further postulates the inclusion of subjective norms in this study of pilot acceptance of wearable FMT, since the inherent nature of wearing the proposed devices is within a social environment where subjective norms are naturally present (Lunney et al., 2016). The researchers noted a limitation in their study that data accuracy of the device was not modeled or considered but would likely have been a contributing factor toward user acceptance (Lunney et al., 2016). Had data accuracy been considered, it would have corresponded to the external factors of results demonstrability and output quality in the Extended TAM, which are both included as part of this proposed research.

Chuah, Rauschnabel, Krey, Nguyen, Ramayah, and Lade (2016) published a study where they validated their application of the Extended TAM to wearable technology, specifically “smart watches,” such as the Apple Watch, in general applications (not particularly geared toward fitness tracking, sleep monitoring, or other intentional uses of “smart watches”). This is a relevant study, as the Apple Watch is also included as part of this proposed study, but exclusively for fatigue monitoring. Chuah et al. (2016) concluded visibility and perceived usefulness as contributing factors to technology acceptance. In their study, visibility was defined “a person's belief of the extent to which smartwatches are noticed by other people,” corresponding to the factor of perceived image in the conventional Extended TAM. The team was able to show a statistically significant relationship between visibility and behavioral intent to use smart watches in their model using the SEM technique. Results of the SEM analysis completed by Chuah et al. (2016) are shown below in Figure 7.

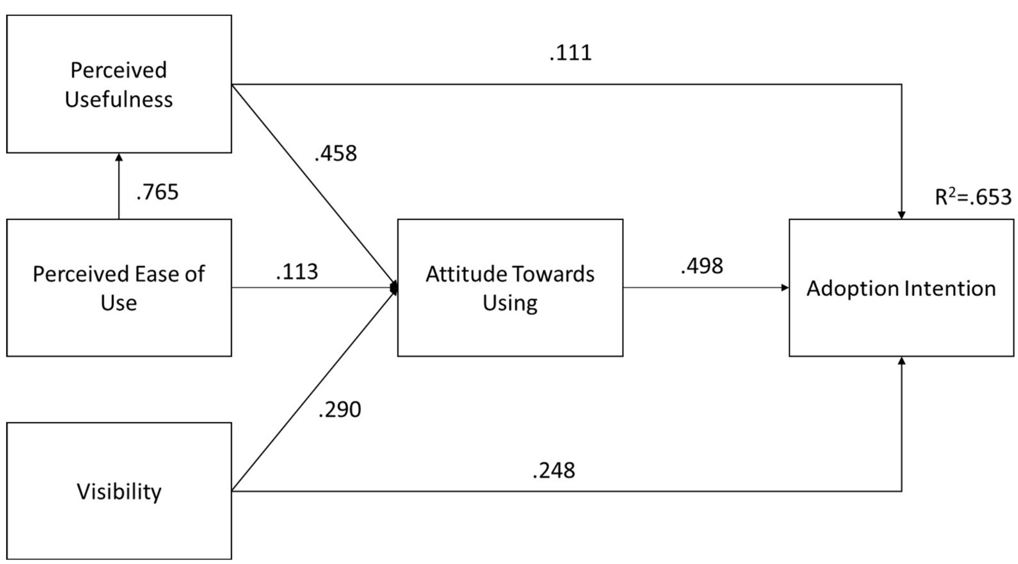

Figure 7. SEM results from TAM-based study of general consumer acceptance of smart watches for the use of monitoring fitness parameters. Adapted from “Wearable technologies: The role of usefulness and visibility in smartwatch adoption,” by Chuah,

Rauschnabel, Krey, Nguyen, Ramayah, & Lade, 2016, Computers in Human Behavior, Copyright 2016.

The Extended TAM was also applied to using wearable technology devices as next-generation tools for health communication (Park, Kim, & Kwon, 2016). Their study was completed in the broader context of wearable computing devices such as watches, glasses, or clothing for health parameters such as heart rate, calorie burn, sleep quality, and intensity of physical activities in the healthcare industry (Park et al., 2016). Their study envelopes the technology and purpose proposed in this study, being a watch for the purposes of monitoring sleep patterns, making it relevant support for the proposed research. Their research team advocated the use of wearable technology for these applications because they can be "remotely and constantly monitored, stored, and analyzed without boundaries" (Park et al., 2016, p. 2), a justification that can simultaneously be applied to pilots in the commercial airline industry. Using SEM to analyze data collected from 877 respondents, they were able to validate a model indicating statistically significant relationships between perceived usefulness, perceived ease of use, device interactivity level, innovativeness, and cost with behavioral intent to use the wearable technology for measuring and monitoring health parameters (Park, et al, 2016).

Gaps in the Literature

After a thorough literature review, it was well established that pilot fatigue is a problem in the United States commercial airline industry, having been cited in the NTSB reports for multiple aircraft accidents. Extensive research has also been completed regarding the causes for pilot fatigue, both physiological and psychological. To address vehicle operator fatigue, experimental research has been completed to develop and assess various types of FMT, including those that monitor the operator and the vehicle. Regulatory agencies have also recommended the use of FMT and fatigue awareness as part of commercial airline fatigue risk management systems.

A wrist actigraph is being proposed as the preferred device type for this study, based on its low implementation cost and immediate availability to pilots. Wrist actigraph devices have been researched extensively to demonstrate their reliability and accuracy across many industries, including with airline pilots. Where the literature falls short is the human factors research associated with understanding what it would take to make usage of this type of technology commonplace in the airline industry. There was no evidence of the Extended TAM, or other similar frameworks such as the Theory of Planned Behavior, being used to assess the factors that influence a pilot's behavioral intent to use personal, wearable technology to monitor their individual fatigue levels with the intent of understanding their readiness to operate an aircraft.

There are many examples of the Extended TAM being used in various industries, including education, health care, automotive manufacturing, and even aviation to monitor user acceptance of wearable technology as a function of behavioral intent through a series of latent factors, such as perceived image, subjective norms, results demonstrability, output quality, perceived ease of use, and perceived usefulness. The Extended TAM has not, however, been used to specifically evaluate pilot acceptance of personal, wearable FMT. The research being proposed as part of this study is the culmination of previous research explaining the need to use FMT, the established accuracy and reliability of available technology, and many successful examples of the Extended TAM framework being used for similar technology evaluations to assess which factors affect a pilot's behavioral intention to use wearable FMT – specifically wrist actigraphy – to mitigate their individual likelihood of operating an aircraft while fatigued.

Research framework and hypotheses. The hypotheses for this study are derived from the hypotheses developed by Venkatesh and Davis's (2000) final version of the Extended TAM. Each of the factors corresponded to a latent variable in the model to be tested using confirmatory factor analysis and SEM. The corresponding structural model representing the Extended TAM proposed for this study is shown below in Figure 8, where H_1 through H_{10} in the diagram correspond to the hypotheses listed in Chapter 1.

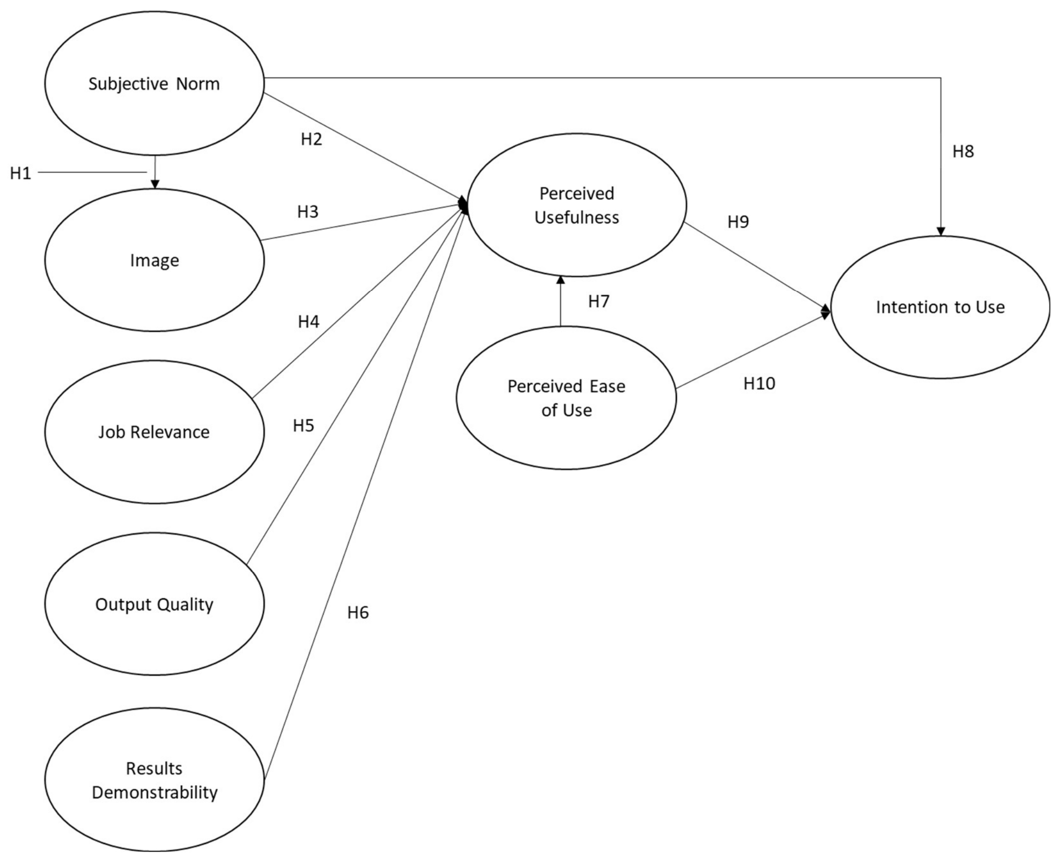

Figure 8. Proposed model developed for testing using confirmatory factor analysis and SEM in this study. Adapted from "A theoretical extension of the technology acceptance model: Four longitudinal field studies," by Venkatesh & Davis, 2000, Management Science, Copyright 2000.

The exogenous variables are identical between the final Extended TAM released by Venkatesh and Davis (2000) and the proposed model to be tested through this study, except for experience and voluntariness not being included in the proposed model for the study. Subjective norms, image, job relevance, output quality, and result demonstrability have evidence of use in scholarly literature presented by various authors regarding the use of new, modern technology, including Altanopoulou and Tselios (2017), Ducey (2016), Park et al. (2014), and Rahman et al. (2017), Richardson (2015), Kim and Shin (2015), Lunney et al. (2016), and Park et al. (2016), as aforementioned in the *Extended TAM Applications* section of the literature review. While no studies were located using the Extended TAM to measure pilots' behavioral intention to use FMT, indicating a gap in the literature, qualitative feedback from studies conducted using FMT with commercial truck drivers indicated drivers preferred devices that monitored the vehicle versus the operator, indicating they did not trust the output of the device to indicate their fatigue levels accurately (Dinges et al., 2005). The lack of trust the drivers displayed in the FMT substantiates the inclusions of output quality and result demonstrability in the proposed model for this study.

Voluntariness was not included in the model because the purpose of this study was to evaluate general pilot acceptance of FMT. Currently, using FMT is entirely voluntary to the pilot population, and has not been implemented through policy. According to Venkatesh and Davis (2000), voluntariness was included in their model as a means of separating the mandatory and voluntary usage contexts. Based on the results of this study explained further in Chapter 5, the voluntary or mandatory nature of implementing FMT should be included as part of a future study. Voluntariness is a moderating factor on the effect of subjective norms on behavioral intention to use FMT, not a latent variable measured through observed variables. The way to measure voluntariness in the future is to complete two separate survey rounds, where one round is completed assuming voluntary implementation and the other is completed using mandatory implementation, and subsequently reviewing the differences between the results from each survey round. While Venkatesh and Davis (2000) hypothesize an effect on the extent to which subjective norms influence behavioral intentions to adopt new technology, the effect of voluntariness could be assessed for all of the latent variables in the model, as well as actual use and experience.

Experience was included in the model released by Venkatesh and Davis (2000) because studies indicated the effects of subjective norms were lessened three months after implementing use of the new system, indicating experience with the technology for its intended purpose influenced the effects of subjective norms on the user's behavioral intent to use the technology. In this study, use of the technology has not been implemented as an official means of monitoring pilot fatigue in the airline industry, so length of experience using the technology for this purpose in this manner cannot be measured. This can be included as part of future longitudinal studies where data is also collected regarding actual use. To better understand the respondent population, survey questions were created to collect demographic data on respondents, to understand if they currently use FMT for personal use.

The exclusion of voluntariness and experience were listed as intentional delimitations of this study. The endogenous variables of perceived usefulness and behavioral intention are identical to the final version of the Extended TAM released by

Venkatesh and Davis (2000). The actual usage behavior factor is not modeled in the hypotheses for this study, as the scope of the study is limited to surveying behavioral intention to use FMT, and will not include an observation or experiment that measures actual pilot use of FMT prior to operating a flight, or its effects on pilot performance.

Structural Equation Modeling. A review of the literature has shown several means of multivariate hypothesis testing using the Extended TAM as the foundational framework, but SEM has been used in most studies referred to in this literature review. Park, Kim, and Ohm (2014) used the SEM analysis methodology to validate the Extended TAM application of measuring drivers' behavioral intention to use car navigation systems. Ducey (2016) also used SEM to validate his application of the Extended TAM to measure pediatricians' behavioral intent to use tablets in the medical field. Richardson (2015) used SEM to validate his adaptation of the ACGAS-TAM with factors of perceived usefulness and perceived ease of use. Kim and Shin (2015) also used SEM to validate their application of the Extended TAM with external factors of affective quality, relative advantage, mobility, availability, and subcultural appeal. Lunney et al. (2016), validated an application of the Extended TAM to wearable fitness tracking devices with respect to the latent constructs of subjective norms, perceived usefulness, and perceived ease of use. Finally, Park et al. (2016) used SEM to validate their application of the Extended TAM to a broader context of wearable technology to various health-related parameters in the healthcare industry.

Alternate analysis methods, aside from SEM, have also been used to validate TAM applications; for instance, Altanopoulou and Tselios (2017) used partial least squares analysis to measure the application of Extended TAM factors to undergraduate students' behavioral intention to use wiki technology. Wang et al. (2016) used linear regression for their analysis on aviation students' acceptance of using augmented reality technology in the aviation maintenance classroom, but they were using a simplified version of the TAM, which excluded external factors, thus removing rigor from the model. Rahman et al. (2017) used a combination of linear and multiple regression analyses to test their hypotheses derived from the Extended TAM, TPB, and UTAUT to measure driver acceptance of FMT in automobiles.

SEM is the preferred analysis method for the proposed study, since it can help assess the reliability and validity of applying a theoretical framework to a practical scenario, such as what is being proposed with the Extended TAM and FMT usage (Byrne, 2016). Conversely, the intent of multiple regression is to develop predictive relationships between constructs, and partial least squares regression projects measured and predicted variables into a new space, such that linear regression can be conducted, neither of which options truly validate the applicability of an established theoretical model, such as the Extended TAM. The proposed study is using an existing foundational framework to measure behavioral intent to use new technology in a new application with established latent variable constructs, and so using SEM is the most sensible approach to validating the model fit to this technology application (Byrne, 2016). In fact, the Extended TAM can be reconstructed using software, after which data can be entered and subsequently analyzed for model fit and modification. Multiple regression can be used but does not provide the advanced analysis capabilities to truly understand model fit.

Summary

A gap in literature has been identified where the Extended TAM has not been used to assess pilots' behavioral intention to use personal, wearable technology to monitor their fatigue levels prior to operating a flight, thus giving this study theoretical significance. While the Extended TAM has shown applicability in many scenarios with aspects found in the proposed research for this dissertation, including new modern technology, general wearable technology, safety enhancing systems, health parameter monitoring, the field of aviation, and even FMT outside of the airline industry, it has not been used for the purposes proposed in this dissertation.

Practical significance is demonstrated by the implications of improved aviation safety when the airline pilots adopt wearable technology to monitor their personal fatigue levels, after the factors affecting their behavioral intention to use the technology have been identified through this study and properly mitigated. In Chapter 3, the methodology for this study will be discussed in detail, including how a survey instrument was used to collect data in accordance with the Extended TAM framework, and subsequently analyzed using confirmatory factor analysis in conjunction with SEM.

CHAPTER III

METHODOLOGY

In this chapter, the methodology for the study is discussed in detail. First, the research method is presented, followed by the population and sample selection, and the data collection process. Next, the data collection process is discussed, along with ethical considerations and details regarding the measurement instrument. Finally, the data analysis approach is provided, the results of which will be presented in Chapter 4. At a high level, the research was conducted using a survey instrument to collect data from United States certified airline transport pilots using the established Extended TAM framework. The survey questionnaire was further validated using a pilot study with a subset of respondents prior to mass distribution. Following the data collection phase of this research, the data was analyzed using confirmatory factor analysis in conjunction with SEM to understand the factors that have a statistically significant influence on a pilot's behavioral intent to use wearable technology to monitor their personal fatigue levels prior to operating an aircraft.

Research Method Selection

The research design for this study was quantitative, in that numerical data was required to be generated, which was then analyzed statistically (Creswell, 2014). Quantitative research is useful in quantifying the behaviors, attitudes, opinions, or other variables of a sample population, which can then be generalized to a greater population (Creswell, 2014). The Extended TAM theoretical framework was used to develop a survey instrument, which utilized a series of Likert-scale questions to evaluate a pilot's behavioral intention to use personal, wearable FMT for the purpose of increasing awareness and accountability for his or her personal fatigue level, ideally reducing the likelihood of the pilot operating an aircraft while fatigued. A non-experimental survey was the appropriate research method for collecting data for multiple reasons. Each question in the survey corresponded to a variable measured with regards to the respondent's behavior, attitude, and opinions. The Extended TAM which was the framework for this study comes with a standard questionnaire, which by design of Venkatesh and Davis (2000), was easily modifiable to suit this new FMT application. Additionally, a survey was useful for quickly collecting self-reported data from a large volume of respondents to understand a psychological phenomenon and was minimally intrusive and more cost effective when compared to experimental data collection (Vogt, Gardner, & Haeffele, 2012).

Population/Sample

Population and sampling frame. The targeted population was approximately 158,000 active United States airline transport pilot certificate holders, which included passenger airline, corporate, cargo, and military operators (FAA, 2016). The sampling frame is the list of United States airline transport pilot certificate holders maintained by the FAA. The purpose of this research was to assess the factors that affect a pilot's intention to use wearable technology to monitor their fatigue levels prior to operating a flight. The population and sampling frame for this study was selected due to the impact this population has on the flying public, as well as the accessibility of this population for research. Commercial passenger airline pilots in the United States transported nearly 850 million passengers in 2017, an all-time annual high, up more than three percent from the previous highs (United States Department of Transportation, 2018). Once the factors that influence United States commercial airline pilots to use wearable technology to monitor their fatigue levels are understood, steps can be taken in the airline industry to help encourage the airline population to utilize these devices.

Sample size. Using the Westland (2010) formula for calculating sample size for SEM on Dr. Daniel Sloper's website (2019), to achieve an 80% confidence level with a 20% response distribution and effect size, the recommended survey minimum sample size was 444 responses. Westland's (2010) formula for calculating lower bounds on sample size for SEM considers the anticipated effect size, desired statistical power level, quantity of latent variables, quantity of observed variables, and the desired probability level. For this study, the anticipated effect size was 0.2, the desired statistical power level was 0.8, the quantity of latent variables was 8, the quantity of observed variables was 23, and the probability was 0.05. The recommended minimum sample size to defect the effect was 444 responses.

Sampling strategy. The survey was distributed using an established personal and professional network of airline pilots through social media networking. DeLongis, King, and O'Rourke (2014) found that distributing survey information through Facebook to collect data was efficient in terms of time and cost. They also found Facebook allowed researchers to research populations directly, and that it allowed respondents to participate in the research in accordance with their individual schedules on their personal devices (DeLongis et al, 2014). Survey distribution using Facebook was an effective method of reaching the quantity of airline transport pilots required to meet the minimum sample size for this study, as pilots have variable schedules including flight, simulator, commuting, rest, and personal time (Baltar & Brunet, 2012). Using Facebook as a tool to reach potential respondents allows users to view the content in one of 37 different languages and connect with individuals and groups that share common interests or traits, such as airline transport pilots (Baltar & Brunet, 2012). Baltar and Brunet (2012) also believe that using Facebook to contact respondents has the potential to minimize concerns associated with "spam" messaging, impersonal contact, and low response rates. Facebook and other social networks provide users with the ability to utilize "chain-referral methods" while maximizing the strengths of online surveys, which was a technique employed by the researcher in this study by enabling sharing of the survey link by respondents with other individuals in their networks to increase the response rate.

The researcher distributed the survey to large groups that would have members belonging to the targeted sample population, including *Female Aviators Sticking Together (FAST), Flights Above the Pacific Northwest,* and *Flights Above the Mountain Southwest, and Professional Jet Pilots*. The researcher also posted the survey to her personal Facebook and Instagram network to reach members of the sample population. Using forums that the respondents already trust facilitates a sufficient survey response rate (Ison, 2010). Social networks can be difficult to trust, but groups such as *Female Aviators Sticking Together (FAST), Flights Above the Pacific Northwest,* and *Flights Above the Mountain Southwest, and Professional Jet Pilots,* are specifically designed for aviation professionals, amateurs, and enthusiast's. One of the limitations with surveys is the authenticity of the responses, and it was assumed if someone responded to the survey that he or she was a United States Airline Transport Pilot. The respondents were asked a question prior to beginning the survey to confirm that they were a member of this population, just to give an opportunity to vet out anyone who clicks on the link not previously understanding this requirement. The SurveyMonkey® questionnaire displaying this question is located in Appendix B.

Respondent honesty was thoroughly considered as a limitation when using social media as a distribution platform, but it was determined to be a strategic means of obtaining the high sample size required for this size population. It was also determined to be one of the most efficient and cost effective methods to reach a population of this size. The power of sharing on social media provided a means of reaching pilots that would not otherwise be reachable by the researcher.

Distribution to as many members of the population as possible increased the generalizability of the results, thereby increasing the external validity of the study (Creswell, 2014). Participants were contacted through distribution of a link to the survey via social media and personal networking, which subsequently directed respondents to the SurveyMonkey® website link to participate. To increase the response rate, first a primary communication was distributed to inform the population of the study, including information about the purpose and methods to answering the questionnaire. The distribution information, including verbiage for the social media distributions, is included in Appendix D.

Data Collection Process

The survey was created using SurveyMonkey®, and allowed for rapid collection of data, the ability to reach the sample size required of this population, and be economically feasible with the use of an online questionnaire (Creswell, 2014). The data was collected, and participants provided their consent prior to beginning the survey. The questionnaire administered online is shown in Appendix A, with screen captures of the instrument developed in **SurveyMonkey®** shown in Appendix B.

Design and procedures. A survey design was used for this quantitative study, in accordance with the Extended TAM. The procedure for this study was to (a) complete all pre-survey work, (b) distribute the pilot study questionnaire, (c) analyze the pilot study data, (d) make any required changes to the survey instrument, (e) distribute the final questionnaire, (f) establish survey completion, (g) analyze data, and (h) report results. The Step (a) *pre-survey work* consisted of the following steps:

1. Obtain Institutional Review Board approval
2. Order business cards with link to survey

The Step (b), *Distribute Pilot Study Questionnaire,* consisted of the following steps:

1. Distribute electronic link to survey to respondent pool
2. Continue distributing survey link until sample size is achieved
3. Compile data into database as survey responses are completed while monitoring the data for errors
4. Conclude data collection phase once quantity of records to fulfill pilot study sample size requirements is achieved

The procedure for Step (c), *Analyze the Pilot Study Data,* was conducted using the SEM technique, which is explained in further details later in this chapter. The results were used to validate the survey instrument, which lead to step (d), *Modifying the Survey Instrument*, as required. Step (e), *Distribute the Final Questionnaire,* followed the same sub-steps as the Step (b) pilot study, and was concluded formally with Step (f), *establish survey completion.* Once the survey was completed, Step (g), *analyze the data*, was completed using the SEM technique explained in depth later in this chapter. Step (h), *report results,* was completed with the presentation of results in Chapter 4 of this dissertation.

Apparatus and materials. There were several apparatuses and materials required to complete a survey-based study. The required apparatuses and materials required to complete this study were:

- a laptop computer for creating and monitoring the survey, as well as collecting and analyzing data
- a SurveyMonkey® account for creating the survey to be distributed to respondents
- Facebook social media account for electronic distribution of the survey link
- an IBM SPSS Statistics license and an SPSS Amos software license for analyzing data

Sources of the data. The data source for this study was the comprehensive collection of responses to a 33-question survey instrument, which is shown in Appendices A and B. The questionnaire has ten sections: one for informed consent, one for each of the eight factors depicted in the proposed model, and one to collect demographic data on the respondents, including a free-form question for any additional items the researcher should consider. The questionnaire was directly adapted from the standard questionnaire developed by Venkatesh and Davis (2000) for their Extended TAM, but the questionnaire sections for voluntariness and actual use were eliminated, since they were not included in the hypothetical model for this study. The questions in the sections for each of the model factors were set up so the respondents replied using a seven-point Likert-scale. Each of the survey questions corresponded to a variable in the confirmatory factor analysis and SEM. These are further outlined in the *Constructs* section. Demographic data was collected regarding the pilot respondents, specifically regarding the following characteristics:

- type of operation as a certified Airline Transport Pilot
    - airline, private or corporate, cargo, military, or other
- length of time as a certified pilot
    - less than one year, between one and five years, between five and ten years, between ten and twenty years, or more than 20 years
- whether he or she wears a watch on a regular basis while they fly (binary, yes or no)
- whether he or she currently wears a fatigue or sleep monitoring device for personal use (binary, yes or no)
- geographic region within the United States with which the pilot most closely identifies as home base operations (northeast, southeast, midwest, central mountain, northwest, or southwest)
- pilot age (fill in the blank text entry)

At the beginning of the survey, there was an informed consent section in alignment with the Embry-Riddle Aeronautical University IRB template for survey research that included sections for the purpose of the research, participant eligibility, risks or discomforts, benefits, confidentiality of records, statement for use of sensitive information, compensation, contact information, voluntary participation, and the ability to indicate informed consent. There was a scenario set up for the respondents that explained the pilots were to consider the use of *wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.* When proceeding through each question in the survey, corresponding to the variables in the Extended TAM, the question wording also specifically referred to *wearable fatigue monitoring technology, such as a Fitbit or Apple Watch,* as the device that the respondents are considering when answering each question. No additional data from other studies was used to determine the results of this study.

Ethical Consideration

To promote the integrity of the study and protect the interests of the human participants, ethical considerations were necessary. As suggested by Creswell (2014), researchers must be knowledgeable of anticipated ethical issues occurring during each phase of research to prevent misconduct. Several steps were taken to address potential ethical issues for this study:

First, prior to beginning the study, familiarization with the code of ethics and professional standards for human research took place, including refresher training for Human Subjects Research (HSR) through the CITI Program and obtaining Institutional Review Board (IRB) approval through Embry-Riddle Aeronautical University. Since the study was a survey design, thus involving minimal risks to participants, it was exempt from 45 CFR 46, Subpart A, regulations of the U.S. Department of Health & Human Services, under Category 3, not requiring an ongoing IRB review (HHS, 2009). Upon IRB approval, the survey was conducted. A copy of the Embry-Riddle Aeronautical University IRB application and approval letter is included in Appendix C.

Second, before the participants began the survey, they each received a disclosure statement for informed consent regarding the purpose of the study, voluntary terms of participation, their ultimate right to refuse and discontinue participation at any point while they are taking the survey, and the protection of any identifiable information, such as their IP address. The online questionnaire began with the standard informed consent template required by the Embry-Riddle Aeronautical University IRB (Embry-Riddle Aeronautical University, 2018). The participant's consent was documented by their answering a question as to whether he or she agreed with the terms of the informed consent form. Respondents had to check a box on that screen indicating informed consent, as shown in Appendix B. Treatment of participants was equal, as it was conducted online and in the privacy and timeline of wherever and whenever the participant elected to complete the survey. The data is being stored indefinitely and securely by the researcher, but without reference to identifiable or sensitive information.

Upon completion of the dissertation defense, the research will be published in accordance with Embry-Riddle Aeronautical University academic policy. Credit will be given to all sources of literature and reference, the researcher, dissertation committee chairperson, and any applicable dissertation committee members, for the purpose of documenting participation, ownership, and advisement.

Measurement Instrument

Upon completion of the literature review and receipt of IRB approval, the hypothetical model and corresponding survey questions were constructed. In this study and in alignment with the Extended TAM framework, a survey was the optimum means of collecting data to support this research. The survey instrument is included in

Appendix A for clearly viewing the questionnaire elements; screen captures of the instrument developed in SurveyMonkey® are shown in Appendix B. Previous studies using the Extended TAM framework were used to develop and verify the survey instrument and were discussed in the literature review. It is important to note respondents were provided with a clear definition of *"system,"* prior to responding to the survey questions. In this study, the *"system"* was a personal, wearable, fatigue monitoring device, such as a Fitbit, Apple Watch, or other commercially available actigraphy device.

Pilot study. Prior to conducting the full survey, a pilot study was conducted on a limited number of respondents to test the reliability and validity of the survey instrument. This process was used to validate the survey instrument. The required pilot study sample size was approximately 10% of the minimum sample size, or 44 respondents (Hertzog, 2008). A total of 58 usable responses were collected as part of the pilot study, thus exceeding the minimum pilot study sample size requirement. The respondents were primarily contacted through social media groups. Confirmatory factor analysis and SEM were used to analyze the model fit results of the pilot study, as well as to test the reliability and validity of the model. Any issues with model fit resulted in adjustments being made to the survey instrument prior to distribution of the full study

Constructs. In total, there were eight latent variables (constructs in the hypothesized model), each of which were validated through the literature review. Each of the variables were included in the Venkatesh and Davis (2000) Extended TAM and multiple relevant, scholarly studies since then have used the factors from the original model and found them to be statistically significant. An explanation of these studies was included in the *Extended Technology Acceptance Model Applications* section of Chapter 2. The observed variables corresponded to the standard questions for each of the latent variables in the Extended TAM, validated by Venkatesh and Davis (2000) as well as other researchers, since the Extended TAM was originally published. During the Confirmatory Factor Analysis (CFA) process, it was determined that the factor structure was not too complex, and only one observed variable was removed from the model. The details of this are explained further in Chapter 4.

Latent variables can either be exogenous or endogenous; exogenous variables are those which influence other factors in the model, indicated by outgoing arrows from the factor in the proposed model, and endogenous variables are those which are influenced by other factors in the model, indicated by incoming arrows from their exogenous influencing factors in the proposed model. The exogenous variables in this study were perceived ease of use, subjective norms, job relevance, output quality, and results demonstrability, which acted as independent variables that influenced the values of the other latent variables (Byrne, 2016). Subjective norms, job relevance, output quality, and perceived ease of use were all exogenous to perceived usefulness. Subjective norms and perceived ease of use were also influencing factors on intention to use. The endogenous variables were perceived image, perceived usefulness, and intention to use FMT, which acted as dependent variables influenced by the exogenous variables in the model (Byrne, 2016). The full list of latent variable model constructs is listed below in Table 2, including the variable name, description, and variable type. The variable descriptions were excerpted from Venkatesh and Davis' original publication of the Extended TAM (2000).

Table 2

List of Latent Variables

Variable Name	Description	Variable Type
Perceived Usefulness	The degree to which an individual believes that using a particular system would enhance his or her job performance.	Endogenous
Perceived Ease of Use	The degree to which an individual believes that using a particular system would be free of physical and mental effort.	Exogenous
Intention to Use	A person's behavioral intent to use a particular system.	Endogenous
Subjective Norm	A person's perception that most people who are important to him or her think he or she should or should not perform the behavior in question.	Exogenous
Perceived Image	The degree to which use of an innovation is perceived to enhance one's status in one's social system.	Endogenous
Job Relevance	An individual's perception of regarding the degree to which the target system is applicable to his or her job.	Exogenous
Output Quality	The user's perception of how well the system performs the required tasks.	Exogenous
Result Demonstrability	The tangibility of the results using the innovation.	Exogenous

Variables and scales. In addition to the eight latent variable constructs, there were 23 observed variables (corresponding survey questions for each latent variable), and seven categorical variables (demographic measurement questions). The survey design made use of a seven-point Likert-scale questionnaire and was comprised of questions consistent with the standard Extended TAM questionnaire developed by Venkatesh and

Davis (2000), each of which corresponded to an observed variable in the model. The full list of variables is shown below in Table 3, and descriptions of the observed variables are the survey questions provided in Appendices A and B. Each of the observed variables is listed below its parent latent variable construct. The corresponding survey ID numbers for each variable are also listed. The observed variables were measured on a Likert scale of 1-7, indicated as strongly agree, agree, somewhat agree, neither agree or disagree, somewhat disagree, disagree, or strongly disagree in the questionnaire. At the end of the questionnaire, there was also an exploratory, open-ended question to collect any additional factors the pilot may consider as influencing his or her behavioral intention to use FMT for the purposes of monitoring his or her personal fatigue levels prior to operating a flight. A preliminary qualitative assessment was performed to suggest which additional factors should be included for future research and possible iterations of the theoretical model.

Table 3

Comprehensive List of Variables

Variable Name	Variable ID	Survey Question ID	Type of Variable
Intention to Use	**IU0**	**N/A**	**Latent Construct (ENDO)**
General intent to use	IU1	3	Observed
Prediction of use with guaranteed device	IU2	4	Observed
Perceived Usefulness	**PU0**	**N/A**	**Latent Construct (ENDO)**
Job Performance	PU1	5	Observed
Job Productivity	PU2	6	Observed
Job Effectiveness	PU3	7	Observed
General usefulness	PU4	8	Observed
Perceived Ease of Use	**PEU0**	**N/A**	**Latent Construct (EXO)**
Clarity and Understandability	PEU1	9	Observed
Level of Effort	PEU2	10	Observed
General Ease of Use	PEU3	11	Observed
Ease of Manipulation	PEU4	12	Observed
Subjective Norm	**SN0**	**N/A**	**Latent Construct (EXO)**
Influencing People	SN1	13	Observed
Important People	SN2	14	Observed
Image	**I0**	**N/A**	**Latent Construct (EXO)**
Prestige	I1	15	Observed
High Profile	I2	16	Observed
Status Symbol	I3	17	Observed
Job Relevance	**JR0**	**N/A**	**Latent Construct (EXO)**
Importance	JR1	18	Observed
General Relevance	JR2	19	Observed
Output Quality	**OQ0**	**N/A**	**Latent Construct (EXO)**
High Quality Perception	OQ1	20	Observed
Issues with Quality	OQ2	21	Observed
Result Demonstrability	**RD0**	**N/A**	**Latent Construct (EXO)**
Telling Others	RD1	22	Observed
Known Consequences	RD2	23	Observed
Apparent Results	RD3	24	Observed
Difficulty Explaining Benefit	RD4	25	Observed
Type of Pilot Operation	**PT**	**26**	**Categorical (Scale)**
Length of Time as a Pilot	**LT**	**27**	**Categorical (Scale)**
Regularly Wears Watch	**WW**	**28**	**Categorical (Binary)**
Regularly Wears FMT	**WF**	**29**	**Categorical (Binary)**
Geographic Region	**GR**	**30**	**Categorical (Scale)**
Gender	**G**	**31**	**Categorical (Scale)**
Age Range	**AR**	**32**	**Categorical (Scale)**
Additional Factors (Free Form)	**AF**	**33**	**Narrative**

Data Analysis Approach

Data preparation. After the survey data were collected, they were examined for missing data, outliers, normality, and other errors by importing the raw Excel data into SPSS Statistics. Outliers were checked using Mahalanobis Distance (D^2). In terms of normality, understanding the effects of skewedness and kurtosis on the results was important, particularly with kurtosis, which often has a greater effect on SEM. The acceptable range for kurtosis values is between 0 and 5, with the ideal value being less than 3 (Byrne, 2016). The variables were coded appropriately in SPSS Statistics prior to completing analysis by inputting the label, name, and variable type for each, and then importing the survey response data such that it aligned with each of the variables. All cases with missing responses were removed from that dataset in Microsoft Excel prior to being imported to SPSS Statistics. The data were evaluated using SPSS Statistics for descriptive statistics, followed by SPSS AMOS for CFA and full SEM analysis (Byrne, 2016).

Participant demographics. Demographic data on the survey participants was collected using four survey questions that assessed the following:

- Type of airline transport pilot operation
- Length of time as a certified pilot
- Whether the pilot typically wears a watch while he or she flies
- Whether the pilot typically wears a sleep monitoring device, such as a FitBit, for personal use
- The geographic region with which the pilot identifies as his or her home-base
- Pilot gender

- Pilot age

These demographic characteristics were used for descriptive statistics to understand the respondent pool characteristics and assess the generalizability of results to the greater U.S. certified airline transport pilot population. Several of the demographics were aligned to demographics measured by the FAA on this pilot population, including age, gender, and geographic region, which aided in understanding the generalizability of the study results and how well the respondent population represented the overall airline transport pilot population.

Reliability assessment method. A method recommended by Hair, Black, Babin, and Anderson (2010) was used for assessing reliability and validity of the model. Construct reliability was tested using Cronbach's Alpha and Composite Reliability, both of which needed to be greater than 0.7. Composite reliability (CR) is a measure of the extent to which the latent variable constructs in the model share in their measurements of each construct and is calculated as a function of standardized factor loadings and error variance from CFA outputs. Cronbach's alpha is a measure of how closely related a set of factors are as a group and was computed using *Reliability Analysis* in SPSS for each construct in the model (Hair et al., 2010). Though all incomplete Likert-scale responses were removed from the dataset prior to analysis, the Chi Square statistic was used to perform non-response bias testing using the pilot demographic data.

Validity assessment method. Construct validity was tested in terms of convergent validity and discriminant validity using CFA outputs. Convergent validity was used to test the extent of correlation between constructs, demonstrating if factors that should be related were indeed related. It was determined by assessing whether items of a specific construct had high variance or converged, as a function of the sum of factor loadings or a calculation of the Average Variance Extracted (AVE) (Hair et al., 2010). AVE was calculated as the sum of squared factor loadings divided by the number of items, which needed to be greater than or equal to 0.5, ideally greater than 0.7, to indicate the items of a factor converge (Truong & Jitpaiboon, 2016).

Discriminant validity was used to assess which constructs were distinct, as evidence as to whether a construct was unique, or in other words, captured a phenomenon not captured by other constructs. This was calculated using the maximum shared variance (MSV) as well as the AVE calculation for each construct. The MSV is the square of the greatest correlation coefficient between each of the latent variable constructs (Hair, et al., 2010). To be discriminately valid, the MSV needed to be less than the AVE result for a given construct because the observed variables should relate more strongly to their modeled latent variable construct than a different latent variable construct. The squared correlation between two constructs should also be less than the corresponding AVE values for each construct (Hair et al., 2010).

Data analysis process/hypothesis testing. The survey response data was analyzed using SEM. SEM was used to represent processes that generate observations on multiple variables (Byrne, 2016). SEM was an appropriate method because this study was collecting actual data and using it to test hypotheses based on a phenomenon, which in this case, was a theoretical model. SEM was also an appropriate method for this study because it is a confirmatory technique used to test a hypothesis-driven model, determine model fit, and estimate errors (Byrne, 2016). In this case, the existing model was the

Extended TAM that provided a factor structure for variables which affect a pilot's ultimate behavioral intent to use FMT.

CFA was first used to assess the covariance between the observed variables to gather knowledge on their underlying factors or latent constructs and determine goodness of model fit (Byrne, 2016). CFA was also used to validate whether the data supported the relationships between the latent variables and their observed variable indicators. The CFA was followed by the full SEM analysis, when the path diagram depicting the directional influence of each latent variable construct on the next was validated, corresponding to the testing of hypotheses. The following CFA and full SEM analysis process was used (Byrne, 2016):

1. Construct the path diagram in SPSS AMOS by connecting observed variables to their latent variable constructs, but not reflecting directional hypotheses.
2. Perform CFA to evaluate model fit, using model fit indices, such as Comparative Fit Index (CFI), Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Normed Fit Index (NFI), Root Mean Square Error of Approximation (RMSEA), and the minimum discrepancy divided by its degrees of freedom (CMIN/Df).
3. Assess model for normality and outliers.
4. Assess model reliability and validity.
5. Complete post-hoc analysis and model re-specification, as required, in accordance with CFA results prior to running full SEM, to adjust for any

issues determined with reliability and validity of the constructs as originally modeled.

6. Modify the path diagram in SPSS AMOS used for CFA to reflect directional hypotheses by changing the solid lines to be arrows flowing in the direction of the expected relationship.
7. Perform full SEM analysis to evaluate model fit, using same analysis techniques as listed in Step 2.
8. Perform hypothesis testing by evaluating standard regression weights, *t*-values, and *p*-values.

   Note: *p*-values should be less than .05 to indicate statistical significance, and *t*-values (or CR values in SPSS AMOS) should be greater than 1.96 to be statistically significant ($p < .05$) (Byrne, 2016).
9. Complete a post-hoc analysis by reviewing modification indices (MI) to evaluate the model for potential new relationships that could be validated using additional research. Potential new relationships are identified as high MI values, representing a covariance between error terms and cross-factor loading.
10. Iterate the model making any required modifications until desired model fit is achieved. Report which hypotheses are supported and which are not.

The hypotheses to be tested are represented graphically in Figure 9.

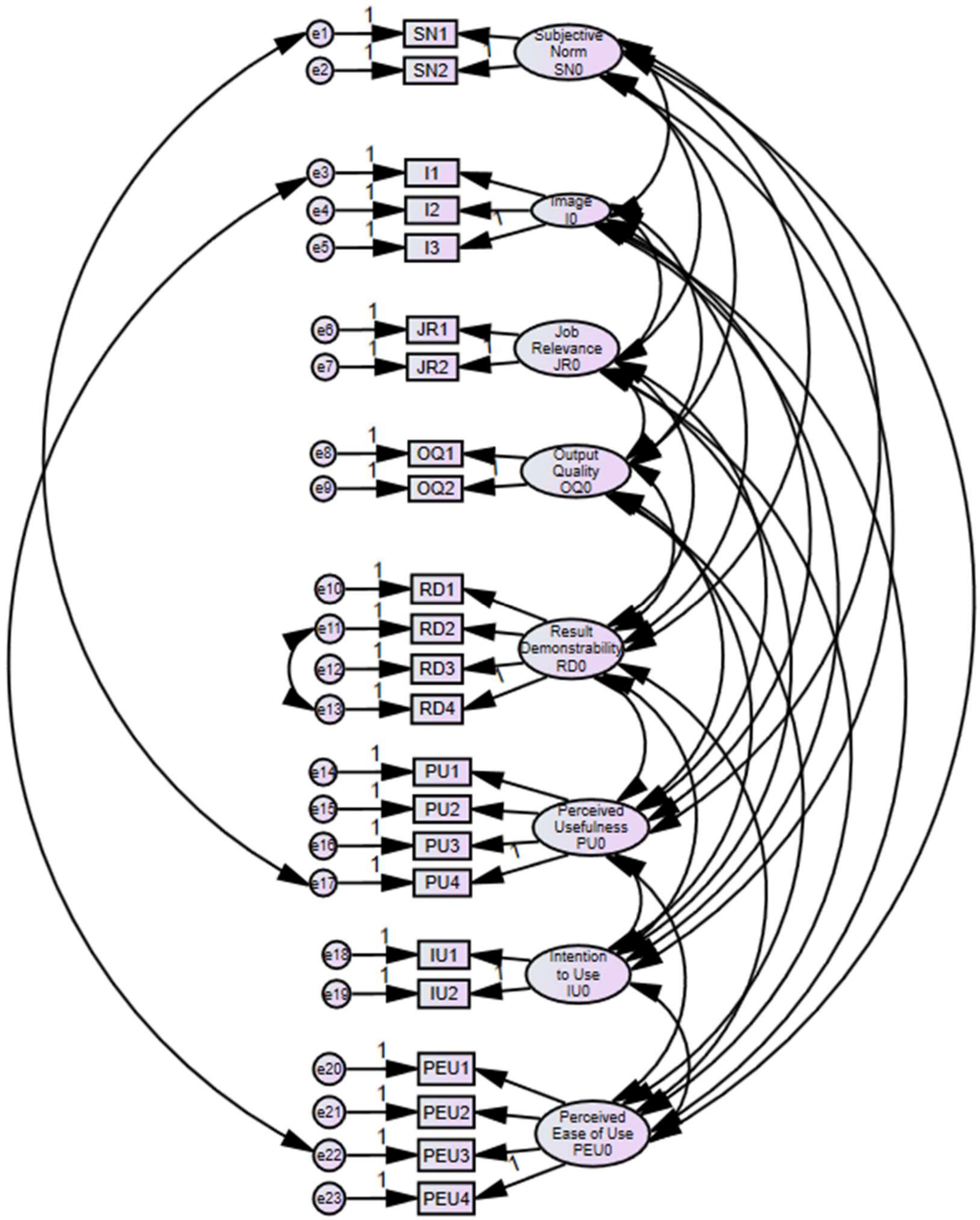

Figure 9. Proposed path diagram developed for testing using confirmatory factor analysis and structural equation modeling in this study.

Summary

In this chapter on methodology, the research method selection, population, sample, data collection process, ethical considerations, measurement instrument, and approach to data analysis were discussed. The Extended TAM framework was defined as the theoretical framework for this study, which provided a standard questionnaire and set of latent variables to be used to measure behavioral intent of pilots to use wearable technology to monitor personal fatigue levels prior to operating an aircraft. The questionnaire was administered in the form of an online survey using SurveyMonkey®, and the procedure for administering the survey was approved through the Embry-Riddle Aeronautical University Institutional Review Board. Once the data were collected, the process for CFA and SEM was followed. The results, conclusions, and recommendations are presented and discussed in Chapters 4 and 5.

CHAPTER IV

RESULTS

This study investigated the extent to which the Extended TAM explained United States certified airline transport pilots' behavioral intention to use personal, wearable FMT for the purpose of monitoring their personal fatigue levels. In this chapter, the results of the study in terms of the pilot study, full survey responses and sample demographic results, descriptive statistics, CFA, SEM analysis, qualitative assessment of additional factors to consider, and overall results summary are presented.

Pilot Study

A pilot study was conducted using the proposed survey questionnaire approved by the IRB. The pilot study data was collected using SurveyMonkey® and yielded 103 total responses, of which 58 were usable and 44 were required at a minimum to demonstrate model effect. The usable subset of responses was comprised of those which were 100% complete, with the exception of the optional demographic questions, meaning that all questions corresponding to the observed variables in the model were answered by the respondent. Per the IRB requirements and agreement regarding informed consent, all incomplete responses were removed from the dataset prior to beginning CFA using the pilot study data.

Confirmatory factor analysis. To determine if any changes needed to be made to the questionnaire prior to completing the full study, a preliminary CFA was completed to assess model fit, reliability, and validity. Kurtosis values were examined for the assessment of normality, and all values were less than 3, except for one value less than 5, which was still acceptable. The acceptable range for kurtosis values to indicate normality is between 0 and 5, with the ideal value being less than 3 (Byrne, 2016). In this case, no transformation of variables was required to achieve model fit. The data was examined for outliers using Mahalanobis D^2, and no values were over 100, so there was no need to delete any data points.

Model fit. Upon running the analysis, model fit was evaluated using the model fit indices Comparative Fit Index (CFI), Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Normed Fit Index (NFI), Root Mean Square Error of Approximation (RMSEA), and the minimum discrepancy divided by its degrees of freedom (CMIN/Df). To be considered good model fit, CFI should be greater than 0.93; GFI, AGFI, and NFI should be greater than 0.9; RMSEA should be less than 0.06; and CMIN/DF should be less than or equal to 3 (Byrne, 2016). On the first iteration, the only value indicating acceptable model fit at this point was CMIN/DF, and the other five had poor model fit. After numerous iterations to re-specify the model, making only one change at a time using modification indices to add covariances between error terms and cross-factor loadings, goodness of model fit was able to be achieved according to CFI, CMIN/DF, and RMSEA. The values for GFI, AGFI, and NFI were close to 0.9 but not acceptable. After a review of the data, it was determined that the model fit results were good enough to proceed with the full study, based on the limited responses used to evaluate results during a pilot study. The specified pilot study CFA model is shown below in Figure 10, and both the initial and final specified corresponding model fit results are shown below in Table 4.

During the model specification process using the pilot study data, five cross-factor loadings were observed. The cross-factor loadings were between Output Quality and

Question 12 (PEU4), Perceived Usefulness and Question 15 (I1), Subjective Norms and Question 10 (PEU2), Intention to Use and Question 9 (PEU1), and Perceived Image and Question 25 (RD4). Typically, one would consider removing these items from the questionnaire. This, however, requires substantiation through a literature review, since this is a confirmatory analysis technique based on ground theory. Prior to adding any cross-factor loadings, six covariances between error terms were added that resulted in an acceptable CFI (.960) and CMIN/DF (1.210) model fit values. RMSEA was close to acceptable (.061). Given that adding cross-factor loadings did not help achieve goodness of model fit in terms of GFI, NFI, and AGFI, and that RMSEA was only greater than the acceptable value by .001 before adding cross-factor loadings, it was determined that Questions 9, 10, 12, 15, and 25 would not be removed from the model, solely based on the cross-factor loadings. Question 25, however, was ultimately removed based on the reliability and validity results associated with the Results Demonstrability construct, presented next.

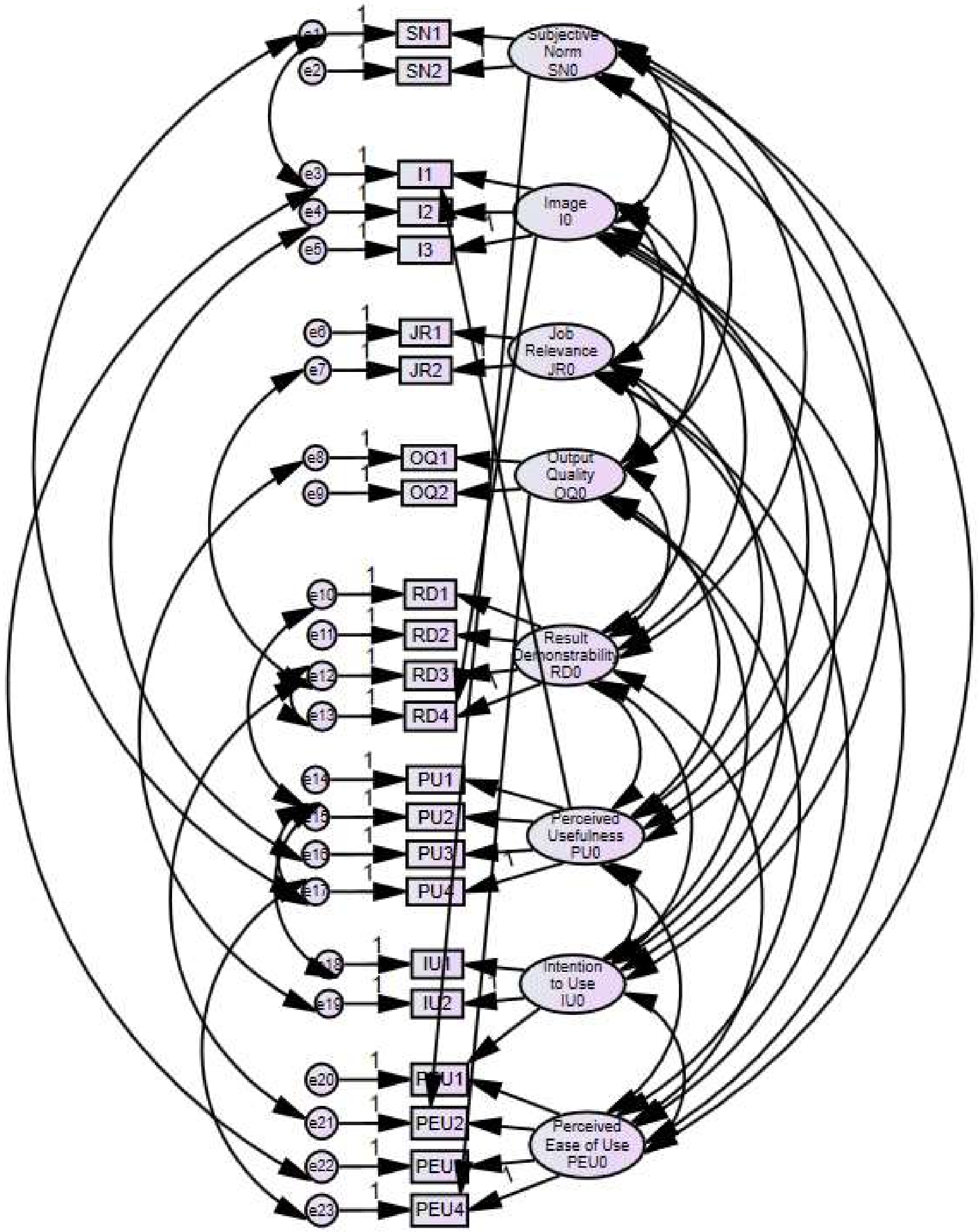

Figure 10. Specified confirmatory factor analysis model. IU = Intention to Use; PU = Perceived Usefulness; PEU = Perceived Ease of Use; SN = Subjective Norms; I = Perceived Image; JR = Job Relevance; OQ = Output Quality; RD = Results Demonstrability.

Table 4

Pilot Study Model Fit Results

Model Fit Index	Acceptance Criteria	Initial Model Value	Acceptable (Yes/No)	Specified Model Value	Acceptable (Yes/No)
CFI	>.93	.922	No	1.00	Yes
GFI	>.9	.728	No	.825	No
AGFI	>.9	.628	No	.739	No
NFI	>.9	.781	No	.871	No
RMSEA	<.06	.084	No	.000	Yes
CMIN/df	<=3	1.399	Yes	.901	Yes

Reliability and validity. The CFA results were also used to assess reliability and validity of the model. Reliability was assessed using construct reliability (CR) and Cronbach's Alpha, both of which should be greater than 0.7 for each factor to be acceptable. Initial results indicated good CR, with all values greater than 0.7. Cronbach's Alpha values for all factors were also acceptable, except for the Results Demonstrability (RD0) construct, with a Cronbach's Alpha value of 0.254. Construct validity was assessed in terms of convergent validity using standardized factor loadings, and convergent validity was assessed by calculating the AVE for each factor. All factor loadings were greater than the acceptable value of 0.5, except RD4 (.066), corresponding to Question 25 in the survey. All AVE values were greater than the acceptable value of 0.5, except the RD0 construct (0.297). These results are shown below in Table 5.

Table 5

Pilot Study Construct Reliability and Validity Results

Contstruct (Latent Variable Factor)	Item (Observed Variable)	Standardized Factor Loading (≥ .5)	AVE (≥ .5)	Composite Reliability (≥ 0.7)	Cronbach's Alpha (≥.7)
Intention to Use (IU0)	IU1 IU2	.901 1.042	.948	.947	.968
Perceived Usefulness (PU0)	PU1 PU2 PU3 PU4	.914 .936 .941 .930	.865	.945	.958
Percevied Ease of Use (PEU0)	PEU1 PEU2 PEU3 PEU4	.749 .572 .928 .886	.634	.765	.859
Subjective Norms (SN0)	SN1 SN2	.901 .788	.716	.609	.855
Perceived Image (I0)	I1 I2 I3	.804 .948 .680	.669	.767	.840
Job Relevance (JR0)	JR1 JR2	.877 .798	.703	.687	.772
Output Quality (OQ0)	OQ1 OQ2	.948 .940	.891	.891	.940
Results Demonstrability (RD0)	RD1 RD2 RD3 RD4	.549 .604 .720 .066*	.297*	.295	.254*

Note. * Indicates unacceptable value for reliability or validity measure.

Discriminant validity, the extent to which constructs are distinct, was evaluated by comparing the maximum shared variance (MSV) with the AVE for each construct. The MSV is the maximum of the squared correlations corresponding to each factor, and so the squared correlations are used to compare with the AVE values. To indicate acceptable discriminant validity, the squared correlation between two factors should be less than the corresponding AVE values. Results indicated most squared correlations were greater than the corresponding AVE values for each of the factors, with only seven exceptions out of 28 total squared correlation combinations, shown below in Table 6. Of the seven cases where MSV is greater than the corresponding AVE values, they all have the RD0 construct in common.

Table 6

Pilot Study Discriminant Validity Corresponding to Each Combination of Latent Variable Constructs

Factor 1	Factor 2	AVE 1	AVE 2	Squared Correlation	Acceptable (Yes/No)
SN0	I0	.716	.669	.293	Yes
SN0	JR0	.716	.704	.558	Yes
SN0	OQ0	.716	.891	.401	Yes
SN0	RD0	.716	.297	.764	No
SN0	PU0	.716	.865	.483	Yes
SN0	IU0	.716	.949	.131	Yes
SN0	PEU0	.716	.634	.256	Yes
I0	JR0	.669	.703	.291	Yes
I0	OQ0	.669	.891	.187	Yes
I0	RD0	.669	.297	.440	No
PU0	I0	.865	.669	.236	Yes
IU0	I0	.945	.669	.059	Yes
PEU0	I0	.634	.669	.029	Yes
JR0	OQ0	.703	.891	.334	Yes
JR0	RD0	.703	.297	.824	No
PU0	JR0	.865	.703	.583	Yes
IU0	JR0	.948	.703	.130	Yes
PEU0	JR0	.633	.865	.149	Yes
OQ0	RD0	.891	.297	.450	No
PU0	OQ0	.865	.891	.383	Yes
IU0	OQ0	.949	.891	.037	Yes
PEU0	OQ0	.634	.891	.218	Yes
PU0	RD0	.865	.297	.729	No
IU0	RD0	.949	.297	.362	No
PEU0	RD0	.634	.297	.362	No
IU0	PU0	.949	.865	.162	Yes
PU0	PEU0	.865	.634	.168	Yes
IU0	PEU0	.949	.634	.191	Yes

Results demonstrability investigation. It was determined that a closer examination of the RD0 construct was required, given that all unacceptable values were associated with the RD0 construct. Inter-item correlation results were examined for the RD0 construct, and several of the values were less than 0.3. SPSS Statistics was used evaluate the potential effect of removing one of the observed variables from the model, or in other words, one of the survey questions from the questionnaire. Using Item Total Statistics and the *Cronbach's Alpha if Item Deleted* results, Cronbach's Alpha decreased with the removal of the questions corresponding to observed variables RD1, RD2, and RD3, but increased to 0.657 with the removal of RD4.

Further investigation was completed with regards to RD4, corresponding to Question 25. It was determined that the question was worded in the opposite direction of all other survey questions, where a response of "7" indicating "*strongly agree*" implied a negative context:

> *I **would have difficulty** explaining why using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, may or may not be beneficial.*

It was proposed that the final wording of the question be modified, such that a response of "7" indicating "*strongly agree*" implied a positive context:

> *I **would <u>not</u> have difficulty** explaining why using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, may or may not be beneficial.*

The model was re-run to test the effect of this change by swapping the responses between strongly agree (7) with strongly disagree (1), agree (6) with disagree (2), and somewhat agree (5) with somewhat disagree (3). While results indicated an increase in Cronbach's Alpha from 0.254 to 0.580, it was still indicated that Cronbach's Alpha would increase to 0.657 by Removing RD4, corresponding to Question 25.

Finally, the intent of Question 25 (RD4) was reviewed in comparison with the other questions corresponding to the RD0 construct. Question 25 (RD4) was very similar to Question 23 (RD2), and nearly redundant in concept, but Question 23 (RD2) had better wording for respondents and accomplished a similar intent.

Question 25, *after changing the direction as previously mentioned*:

> *I would not have difficulty explaining why using wearable fatigue monitoring technology, such as a Fitbit or Apple watch, may or may not be beneficial*.

Question 23:

> *I believe I could communicate to others the consequences of not using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.*

Furthermore, each of the latent variable constructs in the model had between two and four corresponding observed variables, and this still left RD0 with three remaining observed variables after removing the question corresponding to RD4. After reviewing the comprehensive pilot study results, it was decided RD4, corresponding to Question 25 in the survey, would be removed from the questionnaire and model as part of the full study.

Survey Responses and Sample

The full study data collection was completed using SurveyMonkey®. The final questionnaire with the question corresponding to RD4 removed is shown in Appendix E. The survey was primarily distributed via social media to established groups, such as Flights Above the Pacific Northwest, Flights Above the Mountain Southwest, Female Aviators Sticking Together, and Professional Jet Pilots, as well as individuals in the researcher's personal Facebook network who met the participation criteria, using a link to the website or corresponding Quick Response (QR) code and the pre-approved IRB social media distribution notice. Responses were voluntary and anonymous, and no compensation was provided. The questions corresponding to the model were indicated as mandatory, and the questions corresponding to respondent demographic information were indicated as optional.

A total of 947 responses were collected during a two-week time period and exported to Excel and SPSS to review and clean the data. Upon completion of the review, it was determined 539 of the 947 responses were useable, yielding a 57% response rate. Per the IRB requirements and agreement regarding informed consent, all incomplete responses were removed from the dataset. Table 7 shows the quantity and rationale for deleted cases during the data review and cleaning process.

The remaining 539 usable responses were those that had responses to every Likert-scale question corresponding to an observed variable in the model, not including the optional demographic questions. These responses also met the requirements for informed consent and the respondent holding a United States Airline Transport Pilot (ATP) Certificate. The total responses required to achieve the minimum sample size for the U.S. ATP population was 444, which was exceeded by 21%.

Table 7

Summary of Deleted Cases

Rationale	Number of Cases
Total Responses Received	947
Respondent indicated “disagree” for informed consent	5
Respondent indicated “agree” for informed consent, but indicated “no” regarding possession of a US-ATP certificate	53
Respondent failed to answer one or more of the Likert-scale questions corresponding to observed variables in the model	350
Valid responses after all unusable cases deleted	539

In total, 409 incomplete responses were discarded, which mitigated any potential non-response bias that would be potentially introduced if the incomplete responses were kept as part of the sample. To further test for non-response bias, a Chi-Square comparison test between respondents and non-respondents was completed for the demographic variables in the dataset, the details of which are shown in Table 8. Non-responses were considered as those where any one of the demographic questions was not answered. It should be noted that the Chi-Square statistic could not be computed for pilot age or type of pilot operation, due to the question and response structure. *Pilot age* was a free-form response, and *type of pilot operation* allowed for more than one response. None of the Chi-Square statistics result for the demographic categories of *length of time as a pilot, wears a watch while flying, wears FMT for personal use, geographic region, or gender* were statistically significant, indicating no non-response bias and further generalizability of results to the United States airline transport pilot population.

Table 8

Chi-Square Comparison Between Respondents and Non-Respondents

Demographic	Chi-Square (X2)	Probability (p)	Significant (Yes/No)
Length of time as a pilot	1.741	.783	No
Wears watch while flying	.650	.420	No
Wears FMT for personal use	.077	.781	No
Geographic Region	9.842	.080	No
Gender	5.345	.069	No

Demographics Results

Demographic data was collected on the respondents in three major categories: pilot history, wearable technology device usage, and general demographics. Pilot history data collected included length of time as a pilot and type of pilot operation. Wearable technology device usage data collected included whether the pilot regularly wears a watch during flight and whether the pilot wears FMT for personal use. General demographic data collected included pilot gender, age range, and geographic home region. The pilot demographic information is shown in Table 9, determined using data collected at the end of the survey. It should be noted that only the demographic responses from questionnaires where 100% of the Extended TAM questions were completed were considered.

Table 9

Summary of Respondent Demographics

Demographic Characteristic	Sub-Categories	Frequency (N=539)	Percentage of Responses
Length of Time as a Pilot	Less than one year	2	0.37%
	Between one and five years	17	3.2%
	Between five and ten years	73	13.5%
	Between ten and twenty years	194	36.0%
	More than 20 years	243	45.1%
		10*	1.9%
Type of Pilot Operation**	Airline Transport Pilot – Airline	347	64.4%
	Airline Transport Pilot – Private or Corporate	128	23.7%
	Airline Transport Pilot – Cargo	104	19.3%
	Airline Transport Pilot – Military	104	19.3%
	Airline Transport Pilot – Other	17	3.2%
		4*	0.7%
Regularly Wears Watch (while flying)	Yes	468	86.8%
	No	61	11.3%
		10*	1.9%
Regularly Wears FMT (personal use)	Yes	218	40.4%
	No	310	57.5%
		11*	2.0%
Geographic Region	Northeast	90	16.7%
	Southeast	127	23.6%
	Midwest	132	24.5%
	Central Mountain	27	5.0%
	Northwest	64	11.9%
	Southwest	88	16.3%
		11*	2.0%
Gender	Male	418	77.6%
	Female	103	19.1%
	Prefer not to ientify	8	1.5%
		10*	1.9%
Age Range	23-29 years	69	12.8%
	30-39 years	203	37.7%
	40-49 years	120	22.3%
	50-59 years	88	16.3%
	60-69 years	34	6.3%
	70-79 years	11	2.0%
		10*	1.9%
		4***	0.7%

Note. *Number of respondents who chose not to answer. **Respondents allowed to select more than one response, so percentage may exceed 100%. ***Responses excluded due to implausible nature (0-22 is too young to be a U.S. certified ATP, and 100 is an outlier in the data by over 20 years).

Demographic results indicate that of the pilots who responded to all of the Extended TAM questions, 77.6% were male and 19.1% were female, with the remainder choosing to not identify a gender. These percentages are different than the overall U.S. citizen population, where 50.8% are female and 49.2% are male (U.S. Census Bureau, 2019). They are closer in percentage to, but still different than, the percentages of females and males within the United States certified airline transport pilot population, where only 4.36% are female and 95.64% are male (FAA, 2016).

The majority of respondents (89%) were between the ages of 23 and 59 years old, and the majority of respondents (64%) classified their type of pilot operation as *ATP – Airline*. These results make sense, as Federal Aviation Regulations require pilots to be a minimum of 23 years of age to receive an Airline Transport Pilot certificate, and 14 CFR Part 121.383 requires pilots be less than 65 years of age (FAA, 2019). It is reasonable and expected that the majority of pilots fall into the age range that matches the minimum and maximum age limitations associated with the largest percentage of pilot operation type.

The majority of respondents (93% of respondents) identified similarly with each of the top five geographic regions as their home base: Northeast (16.7%), Southeast (23.6%), Midwest (24.5%), Southwest (16.3%), and Northwest (11.9%). Though the regions offered on the questionnaire were not the exact same as the FAA geographic regions, they are similar in geographic scope to the six highest-populated FAA geographic regions for certified airline transport pilots within the United States (87% of total ATP population): Southern (18.2%), Eastern (16.4%), Southwest (13.8%), Western-

Pacific (13.6%), and Great Lakes (13.3%) (FAA, 2016). This is also expected and indicates some generalizability of the results to the greater U.S. ATP population.

Regarding wearable technology usage, survey respondents indicated that a vast majority (87%) regularly wear a watch while operating an aircraft. Conversely, only 40% of respondents indicated they wear an FMT device for personal use, such as a Fitbit or Apple Watch, while nearly 60% indicated they do not. This is not comparable to existing general United States or FAA data, so it will be treated as new demographic context regarding this population. The significance of this will be discussed in the next chapter.

Descriptive Statistics

Descriptive statistics for the variables in the model are shown below in Table 10, including the mean, standard deviation, skewness, and kurtosis. These statistics were calculated using the questions corresponding to the 22 observed variables in the model, measured using a seven-point Likert scale, where 1 indicated negative as *strongly disagree,* 7 indicated positive as *strongly agree*, and 4 indicated neutral as *neither agree nor disagree*. The observed variables are grouped according to their respective latent variable constructs.

Table 10

Descriptive Statistics by Construct

Construct	Average Mean for Construct	Average SD for Construct	Observed Variable (Survey Question)	Mean (N=539)	Standard Deviation (SD)	Skewness	Kurtosis
Intention to Use (IU0)	2.812	1.925	IU1	2.828	1.913	1.017	-.231
			IU2	2.796	1.937	1.029	-.272
Perceived Usefulness (PU0)	3.946	1.791	PU1	3.900	1.782	.078	-1.024
			PU2	3.631	1.851	.315	-1.053
			PU3	3.989	1.792	.040	-1.013
			PU4	4.262	1.739	-.176	-.903
Percevied Ease of Use (PEU0)	2.380	1.374	PEU1	2.534	1.495	1.117	.641
			PEU2	2.189	1.294	1.598	2.757
			PEU3	2.215	1.296	1.412	2.021
			PEU4	2.581	1.411	1.026	.736
Subjective Norms (SN0)	4.578	1.522	SN1	4.657	1.467	-.059	-.553
			SN2	4.499	1.576	-.108	-.704
Perceived Image (I0)	5.382	1.354	I1	5.308	1.342	-.330	-.823
			I2	5.293	1.367	-.369	-.741
			I3	5.544	1.352	-.684	-.331
Job Relevance (JR0)	3.609	1.545	JR1	4.417	1.886	-.178	-1.226
			JR2	2.800	1.203	.333	-.876
Output Quality (OQ0)	3.544	1.598	OQ1	3.583	1.579	.520	-.396
			OQ2	3.505	1.617	.479	-.542
Results Demonstrability (RD0)	3.505	1.705	RD1	3.228	1.676	.695	-.350
			RD2	3.846	1.683	.211	-.803
			RD3	3.440	1.755	.594	-.606

A review of the average mean and standard deviation for each of the constructs provided an assessment of the general effect of each latent variable in the model. The average mean and standard deviation for each construct is also shown in Table 9. In the order from highest to lowest average mean, where a high average mean indicates a greater positive effect in accordance with the Likert-scale definition, the factors are ranked as follows: Perceived Image (5.382), Subjective Norms (4.578), Perceived Usefulness (3.946), Job Relevance (3.609), Output Quality (3.544), Results Demonstrability (3.505), Intention to Use (2.812), and Perceived Ease of Use (2.380). The only two factors with an overall positive average mean (>4) were Perceived Image and Subjective Norms, both in the range between neutral and somewhat agree. The remaining factors of Perceived Usefulness, Job Relevance, Output Quality, Results Demonstrability, Intention to Use, and Perceived Ease of Use had an overall negative average mean (< 4) between neutral and disagree.

An assessment of normality was completed using SPSS descriptive statistics outputs for kurtosis, as well as the CFA and SEM outputs regarding normality. Based on the SPSS descriptive statistics outputs shown in Table 9, all observed variables, with the exception of those associated with PEU0 displayed platykurtic, or negative kurtosis, values. Regarding the platykurtic values, all were between 0 and -1, with the exception of PU1, PU2, PU3, and JR1, where values between 1 and -1 are generally considered acceptable. Regarding the leptokurtic, or positive kurtosis, values associated with PEU0, PEU1 and PEU4 were both between 0 and 1, and PEU2 and PEU3 were both greater than 1, where values between -1 and 1 are generally considered acceptable. In summary, of the 22 observed variables, all met the criteria for assumption of normality with the exception of PU1, PU2, PU3, JR1, PEU1, and PEU4, where the upper bound was 2.757 (PEU2) and the lower bound was -1.226 (JR1). CFA outputs from SPSS AMOS were also examined for kurtosis values in a secondary assessment of normality. All values were less than three, including those which were indicated unacceptable using SPSS descriptive statistics outputs, and therefore were determined to be overall acceptable (Byrne, 2016). A review of the normality results led to no transformation of variables being required to facilitate goodness of model fit.

Confirmatory Factor Analysis

CFA was completed using SPSS AMOS v26 and the data from the 539 survey responses. Labels were created for all latent variables, observed variables, and error terms in the model, and covariances were added between all latent variables. Examination of the results for normality, missing data, outliers, model fit, reliability, and validity was included as part of the CFA process.

Normality. An assessment of normality was completed using SPSS AMOS CFA outputs for kurtosis values corresponding to each observed variable in the model. Acceptable kurtosis values are typically less than three (Byrne, 2016). In this case, the greatest kurtosis value corresponded to PEU2 (2.720), which is less than three. The assumption of normality was considered met, and thus no transformation of variables was required to facilitate goodness of model fit.

Missing data. As previously mentioned, during the data screening process, any responses where the respondent did not complete 100% of the Likert-scale questions corresponding to the Extended TAM were discarded from the dataset, thus leaving a sample of 539 complete responses with no missing data to be used in the CFA process. As a result, the CFA model ran on the first try with no issues.

Outliers. The data was examined for outliers using the SPSS AMOS CFA outputs for observations farthest from the centroid, or Mahalanobis d-squared values. Outliers are those with Mahalanobis d-squared values greater than 100, and the greatest Mahalanobis d-squared value in the dataset was for 99.012. Since no values were greater than 100, no data points were investigated for removal from the dataset (Hair et al., 2010).

Model fit results. An assessment of model fit was completed using model fit indices, including Comparative Fit Index (CFI), Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Normed Fit Index (NFI), Root Mean Square Error of Approximation (RMSEA), and the minimum discrepancy divided by its degrees of freedom (CMIN/Df). The CFA results for model fit are shown in Table 11. Goodness of model fit was indicated according to each of the model fit indices, and therefore no model respecification was required to improve model fit.

Table 11

Confirmatory Factor Analysis Model Fit Results

Model Fit Index	Acceptance Criteria	Model Value	Acceptable (Yes/No)
CFI	>.93	.982	Yes
GFI	>.9	.942	Yes
AGFI	>.9	.919	Yes
NFI	>.9	.966	Yes
RMSEA	<.06	.045	Yes
CMIN/df	<=3	2.1	Yes

The specified CFA model is shown in Figure 11. It should be noted that the specified model in the full study is much simpler than the one required to achieve good model fit during the pilot study, as no covariances between error terms were required to achieve goodness of model fit. The primary differences between the pilot study and full study was the increased response sample and the removal of the RD4 observed variable.

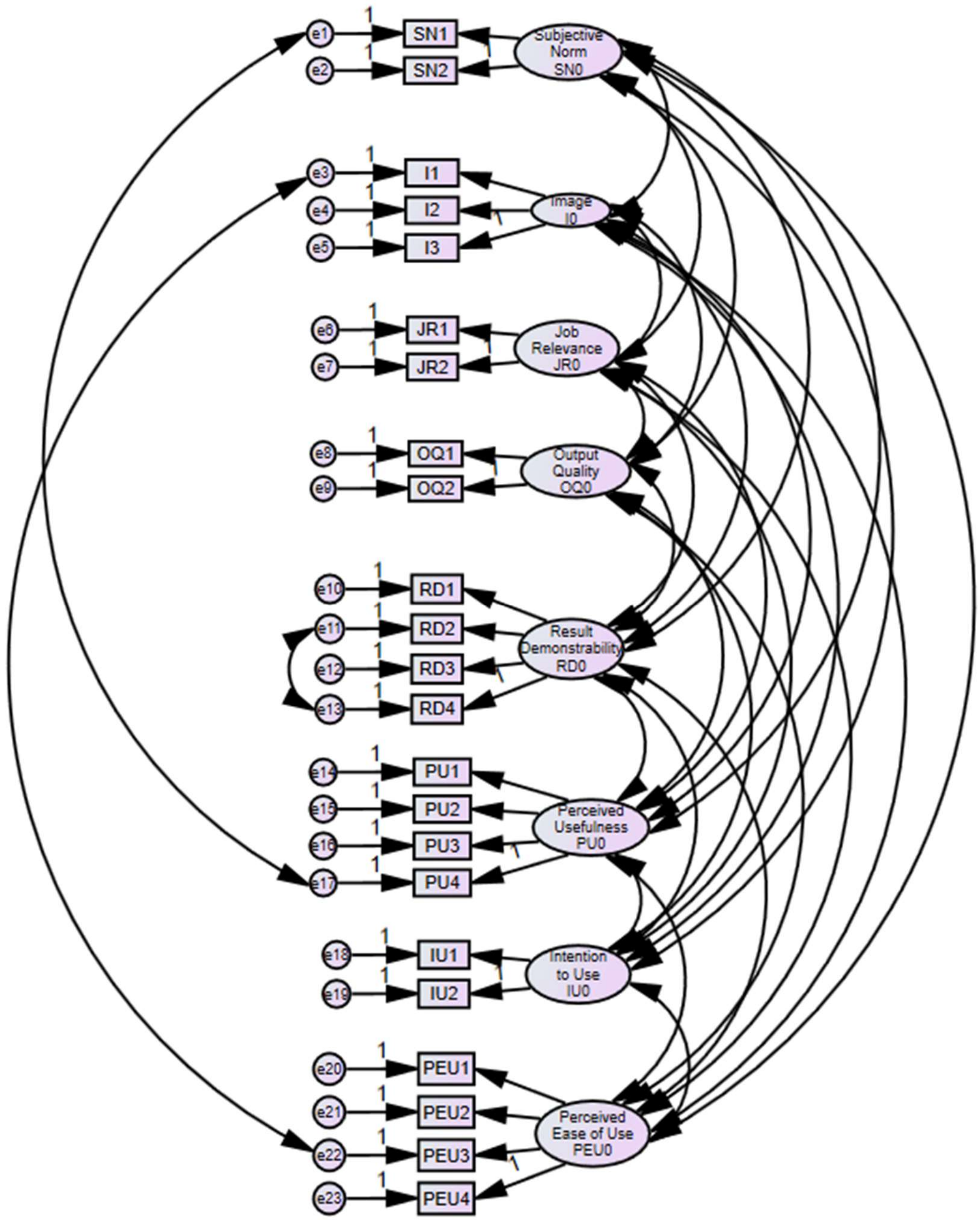

Figure 11. Specified confirmatory factor analysis model. IU = Intention to Use; PU = Perceived Usefulness; PEU = Perceived Ease of Use; SN = Subjective Norms; I = Perceived Image; JR = Job Relevance; OQ = Output Quality; RD = Results Demonstrability.

Reliability and Validity Testing Results

After good model fit was achieved, the CFA model was assessed for reliability and validity using similar methodology to that which was used to evaluate the pilot study results. Construct reliability was measured in two ways using composite reliability (CR) and Cronbach's alpha, both of which should be greater than 0.7 for each construct in the model. Construct validity was evaluated using standardized factor loadings, and convergent validity was evaluated using the AVE for each factor. Typically, desirable factor loadings are greater than or equal to 0.7, but acceptable values are those greater than or equal to 0.5. The AVE value for each factor should be greater than 0.5 to be acceptable. These results are all shown in Table 12.

Table 12

Construct Reliability and Validity Results

Construct (Latent Variable Factor)	Item (Observed Variable)	Standardized Factor Loading (≥ .5)	AVE (≥ .5)	Composite Reliability (≥ 0.7)	Cronbach's Alpha (≥.7)
Intention to Use (IU0)	IU1 IU2	.985 .977	.962	.932	.981
Perceived Usefulness (PU0)	PU1 PU2 PU3 PU4	.930 .915 .946 .891	.848	.875	.956
Percevied Ease of Use (PEU0)	PEU1 PEU2 PEU3 PEU4	.828 .827 .948 .854	.749	.861	.919
Subjective Norms (SN0)	SN1 SN2	.816 .919	.755	.732	.856
Perceived Image (I0)	I1 I2 I3	.908 .950 .799	.788	.859	.914
Job Relevance (JR0)	JR1 JR2	.911 .811	.744	.729	.802
Output Quality (OQ0)	OQ1 OQ2	.963 .841	.817	.775	.895

Results	RD1	.685			
Demonstrability	RD2	.773	.574	.583	.799
(RD0)	RD3	.810			

As depicted in Table 12, all the CR values were greater than 0.7, with the exception of RD0 (0.583), but Cronbach's alpha was greater than 0.7 for all factors, including RD0 (.799), indicating overall acceptable construct reliability for the model. All standardized factor loadings were greater than the desirable value of 0.7, except RD1 (0.685), which was still greater than the acceptable value of 0.5, indicating acceptable construct validity for the model. All AVE values were greater than 0.5, indicating acceptable convergent validity for the model.

Inter-item correlation results were also examined for the model, based on SPSS Statistics outputs, which should be greater than 0.3 to be acceptable. All inter-item correlation results for the model were greater than 0.3, indicating the results of the survey maintain an appropriate balance of consistency across the dataset without having redundant measures across items within a factor (Hair et al., 2010).

Discriminant validity was assessed by comparing the maximum shared variance (MSV) for each combination of factors in the model with the AVE values for the respective two factors being compared. The results for discriminant validity testing are shown in Table 13. All MSV values were less than the corresponding AVE values for each pair of constructs, with the exception of PU0 and RD0 combination (.585), where it is less than the AVE for PU0 (.848), but slightly greater than the AVE for RD0 (.574).

Table 13

Discriminant Validity Results

Factor 1	Factor 2	AVE 1	AVE 2	Squared Correlation	Acceptable (Yes/No)
IU0	PU0	0.962	0.848	0.449	Yes
IU0	SN0	0.962	0.755	0.211	Yes
IU0	JR0	0.962	0.744	0.354	Yes
IU0	OQ0	0.962	0.817	0.300	Yes
IU0	RD0	0.962	0.574	0.407	Yes
IU0	I0	0.962	0.788	0.140	Yes
IU0	PEU0	0.962	0.749	0.216	Yes
PU0	PEU0	0.848	0.749	0.231	Yes
PU0	SN0	0.848	0.755	0.384	Yes
PU0	I0	0.848	0.788	0.276	Yes
PU0	JR0	0.848	0.744	0.591	Yes
PU0	OQ0	0.848	0.817	0.423	Yes
PEU0	SN0	0.749	0.755	0.142	Yes
PEU0	I0	0.749	0.788	0.064	Yes
PEU0	JR0	0.749	0.744	0.144	Yes
PEU0	RD0	0.749	0.574	0.336	Yes
SN0	I0	0.755	0.788	0.304	Yes
SN0	JR0	0.755	0.744	0.404	Yes
SN0	OQ0	0.755	0.817	0.245	Yes
SN0	RD0	0.755	0.574	0.342	Yes
I0	JR0	0.788	0.744	0.275	Yes
I0	OQ0	0.788	0.817	0.180	Yes
I0	RD0	0.788	0.574	0.212	Yes
JR0	OQ0	0.744	0.817	0.392	Yes
JR0	RD0	0.744	0.574	0.526	Yes
PU0	RD0	0.848	0.574	0.585	No
OQ0	RD0	0.817	0.574	0.540	Yes
PEU0	OQ0	0.749	0.817	0.335	Yes

Overall, the results for reliability and validity across the model were deemed acceptable for most criteria corresponding to the eight latent variable factors and 22 observed variable items. The only exceptions to the acceptability criteria were CR for RD0 (.583) and the MSV for the correlation between PU0 and RD0 (0.585). Based on these results, it was determined that no model respecification was required, and the SEM would be performed using the first specified CFA model. RD0 had an acceptable value for the other method of determining construct reliability, Cronbach's alpha (.799), and in terms of discriminant validity, the squared correlation (.585) was only slightly greater than one of its AVE values (.574) and less than the other (.847).

Structural Equation Model Analysis

Upon achieving good model fit using CFA, SEM analysis was performed. A confirmatory technique was used by building a single model based on the Extended TAM theory and then using the collected survey data to test the fit of the original hypothesized model. The SEM process included construction of the full SEM followed by an assessment of model fit, with an additional focus during respecification to identify any potential new relationships in the model based on the collected data.

Model construction. To create the SEM, the CFA model was modified using the data already connected to it in SPSS AMOS v26. The covariances between factors were deleted, and one-way arrows were added to represent the hypotheses. Residual items were added to the endogenous variables, or those which are affected by other variables in the model: Perceived Image (I0), Perceived Usefulness (PU0), and Intention to Use (I0). Covariances were added between the exogenous variables, or those which affect other variables in the model: Subjective Norms (SN0), Perceived Ease of Use (PEU0), Results Demonstrability (RD0), Output Quality (OQ0), and Job Relevance (JR0). Model geometry was rearranged to make it easier to read. The research hypotheses were labeled and color-coded blue to facilitate easier visualization of the Extended TAM theory. The SEM is shown in Figure 12.

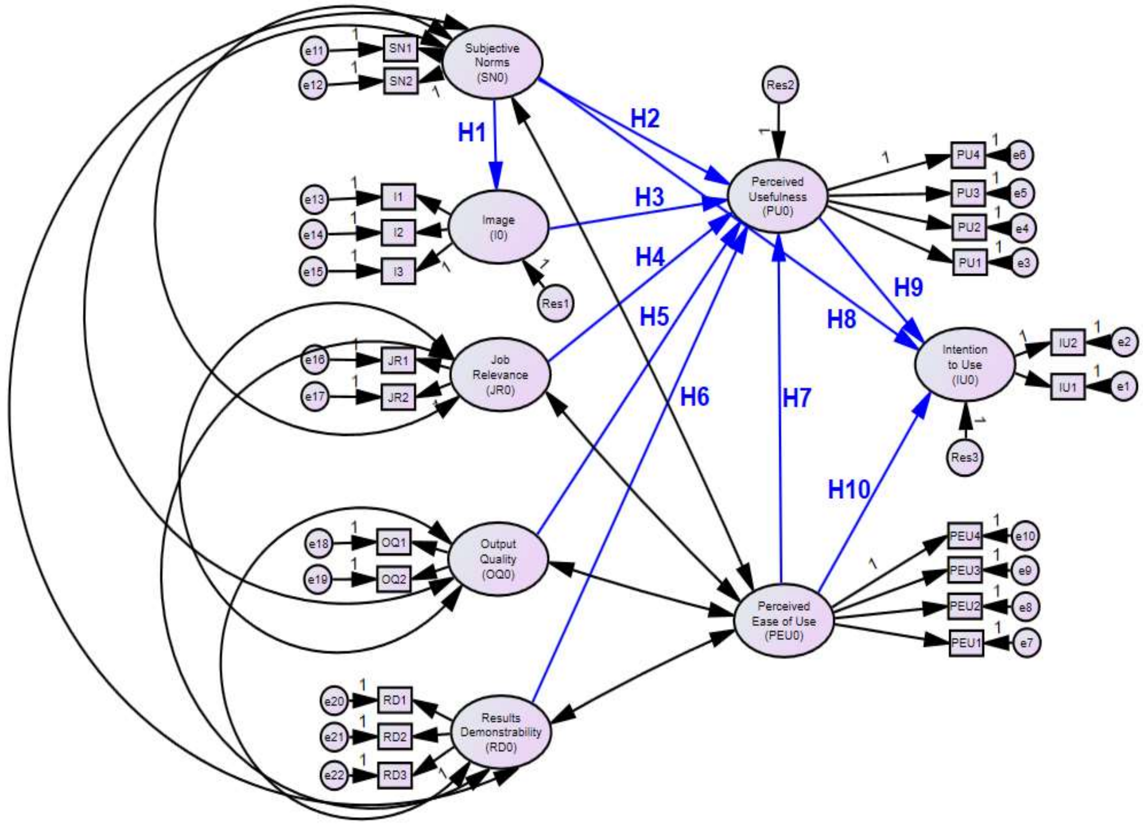

Figure 12. Structural equation model (hypothetical model). IU = Intention to Use; PU = Perceived Usefulness; PEU = Perceived Ease of Use; SN = Subjective Norms; I = Perceived Image; JR = Job Relevance; OQ = Output Quality; RD = Results Demonstrability.

The same procedures were followed to evaluate model fit for the SEM as in the CFA process. On the initial iteration of the model, good model fit was achieved in all criteria, including CFI, GFI, AGFI, NFI, RMSEA, and CMIN/df. The model fit results are shown in Table 14. Due to the goodness of model fit on the initial iteration, no post-hoc analysis was required to achieve improved model fit. Modification indices were still examined for potential new relationship, the results of which are presented later in this chapter.

Table 14

Structural Equation Modeling Model Fit Results

Model Fit Index	Acceptance Criteria	Model Value	Acceptable (Yes/No)
CFI	>.93	.978	Yes
GFI	>.9	.935	Yes
AGFI	>.9	.913	Yes
NFI	>.9	.961	Yes
RMSEA	<.06	.049	Yes
CMIN/df	<=3	2.28	Yes

Hypothesis testing. The fully specified SEM is shown in Figure 13, where the hypotheses are depicted in blue, and the standardized regression weights are now depicted for each relationship in the model. Hypothesis testing was performed using the SEM analysis results for linear regression weights, standardized regression weights, Critical Ratio (t-value), and p-value for each relationship in the model, the results of which are depicted below in Table 15. It should be noted that for a relationship to be statistically significant, the Critical Ratio (t-value) should be greater than 1.96, and the *p*-value should be less than .001.

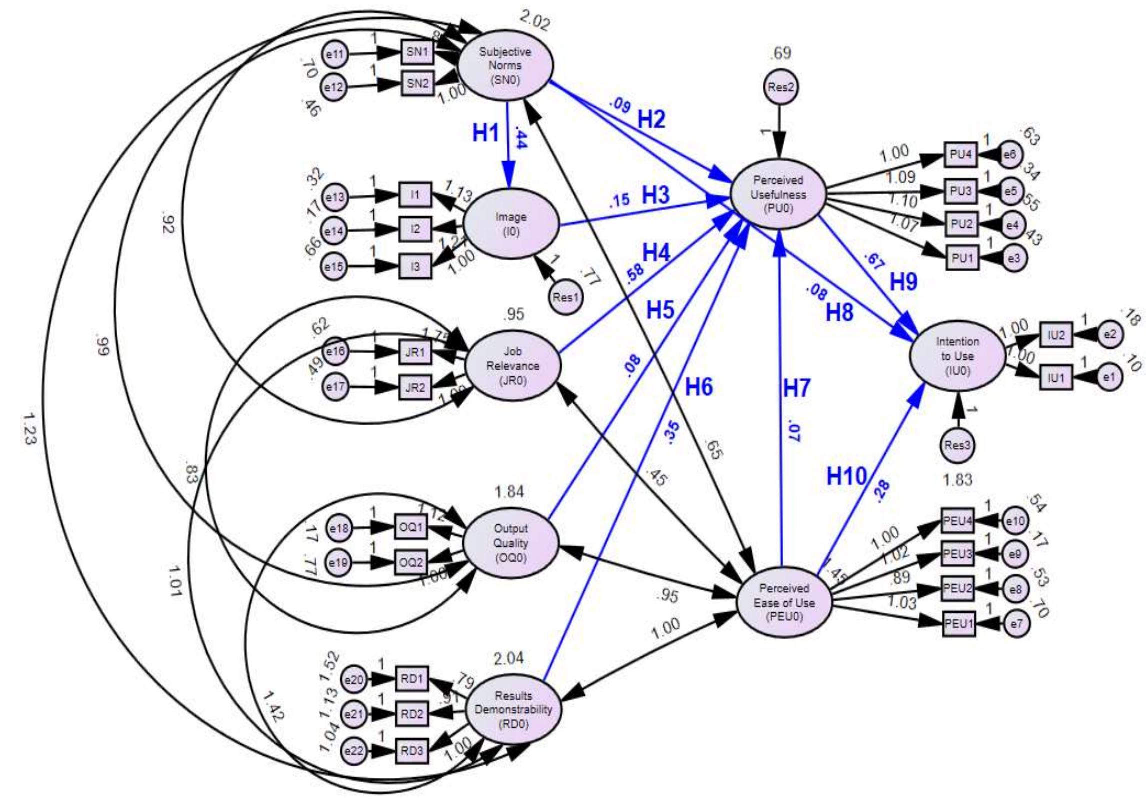

Figure 13. Structural equation model (with unstandardized regression weight results). IU = Intention to Use; PU = Perceived Usefulness; PEU = Perceived Ease of Use; SN = Subjective Norms; I = Perceived Image; JR = Job Relevance; OQ = Output Quality; RD = Results Demonstrability.

Table 15

Hypothesis Testing Results

Hypothesis	Relationship	Regression Weight	Standardized Regression Weight	Critical Ratio (t-value)	*p*-value	Result
H1	Subjective Norms (SN0) positively affects Perceived Image (I0)	.441	.581	12.319	***	Supported
H2	Subjective Norms (SN0) positively affects Perceived Usefulness (PU0)	.094	.087	1.717	.086	Not Supported
H3	Perceived Image (I0) positively affects Perceived Usefulness (PU0)	.148	.104	2.939	***	Supported
H4	Job Relevance (JR0) positively affects Perceived Usefulness (PU0)	.581	.370	6.445	***	Supported
H5	Output Quality (OQ0) positively affects Perceived Usefulness (PU0)	.076	.068	1.403	.160	Not Supported
H6	Results Demonstrability (RD0) positively affects Perceived Usefulness (PU0)	.347	.323	4.694	***	Supported
H7	Perceived Ease of Use (PEU0) positively affects Perceived Usefulness (PU0)	.074	.058	1.530	.126	Not Supported
H8	Subjective Norms (SN0) positively affects Intention to Use (IU0)	.075	.057	1.192	.233	Not Supported
H9	Perceived Usefulness (PU0) positively affects Intention to Use (IU0)	.675	.550	10.994	***	Supported
H10	Perceived Ease of Use (PEU0) positively affects Intention to Use (IU0)	.281	.180	4.635	***	Supported

Note. *** Significant at $p<.001$.

Six out of the ten hypotheses in the model were supported, as indicated by a Critical Ratio (t-value) greater than 1.96 and a *p*-value less than .001. The supported hypotheses were H1, H3, H4, H6, H9, and H10. Four out of the ten hypotheses in the model were not supported, as indicated by a Critical Ratio (t-value) less than 1.96 and a *p*-value greater than .001. The not supported hypotheses were H2, H5, H7, and H8. The standardized regression weights are used to explain the strength of influence of each relationship in the model with respect to one another. A higher standardized regression weight corresponds to a stronger effect in the model. Considering the six supported hypotheses, their ranking from strongest to weakest with regards to their respective standardized regression weights are H1 (.581), H9 (.550), H4 (.370), H6 (.323), H10 (.180), and H3 (.104).

Hypothesis 1 (H1) was supported with a Critical Ratio (t-value) greater than 1.96 ($t = 12.319$) and a *p*-value less than .001. The standardized regression weight was .581, indicating subjective norms had a statistically significant positive effect on a pilot's perceived image of FMT. These results indicate if a pilot's perception that those who are important to him believe he should use FMT increases, his perception of the degree to which wearing an FMT device enhances his status in his social system also increases.

Hypothesis 2 (H2) was not supported with a Critical Ratio (t-value) less than 1.96 ($t = 1.717$) and a *p*-value greater than .001 ($p = .086$). These results indicate subjective norms did not have a statistically significant effect on perceived usefulness of FMT. An increase in a pilot's perception that those who are important to him believe he should use FMT does not correspond to an increase in the extent to which the pilot believes using FMT will increase his job performance.

Hypothesis 3 (H3) was supported with a Critical Ratio (t-value) greater than 1.96 ($t = 2.939$) and a *p*-value less than .001. The standardized regression weight was .104, indicating perceived image had a statistically significant positive effect on perceived usefulness of FMT. These results indicate that as a pilot's perception of the degree to which wearing an FMT device use enhances his status in his social system increases, the extent to which the pilot believes using FMT will enhance his job performance also increases.

Hypothesis 4 (H4) was supported with a Critical Ratio (t-value) greater than 1.96 ($t = 6.445$) and a *p*-value less than .001. The standardized regression weight was .370, indicating job relevance had a statistically significant positive effect on perceived usefulness of FMT. These results indicate that as a pilot's perception of the degree to which an FMT device usage is applicable to his profession increases, the extent to which the pilot believes using FMT will enhance his job performance also increases. From a professional pilot perspective, this relationship makes sense, in that job applicability is directly related to device usefulness.

Hypothesis 5 (H5) was not supported with a Critical Ratio (t-value) less than 1.96 ($t = 1.403$) and a *p*-value greater than .001 ($p = .160$). These results indicate output quality did not have a statistically significant effect on perceived usefulness of FMT. These results indicate, unlike perceived image and job relevance, an increase in the ability of an FMT device to perform its intended task does not correspond to an increase in a pilot's perception of FMT device usefulness.

Hypothesis 6 (H6) was supported with a Critical Ratio (t-value) greater than 1.96 ($t = 4.694$) and a *p*-value less than .001. The standardized regression weight was .323, indicating results demonstrability had a statistically significant positive effect on perceived usefulness of FMT. As a pilot's perception regarding the tangibility of the results produced by an FMT device increases, the extent to which the pilot believes using FMT will enhance his job performance also increases.

Hypothesis 7 (H7) was not supported with a Critical Ratio (t-value) less than 1.96 ($t = 1.530$) and a *p*-value greater than .001 ($p = .126$). These results indicate perceived ease of use did not have a statistically significant effect on perceived usefulness of FMT. As the extent to which a pilot believes using FMT will be free of effort increases, the extent to which the pilot believes using FMT will enhance his job performance does not increase.

Hypothesis 8 (H8) was not supported with a Critical Ratio (t-value) less than 1.96 ($t = 1.192$) and a *p*-value greater than .001 ($p = .233$). These results indicate subjective norms did not have a statistically significant effect on behavioral intention to use FMT. As a pilot's perception that most people who are important to him think he should use FMT increases, his behavioral intention to use FMT does not increase. In other words, if an important person in his life thinks he should use FMT, he is not necessarily more likely to use it.

Hypothesis 9 (H9) was supported with a Critical Ratio (t-value) greater than 1.96 ($t = 10.994$), and a *p*-value less than .001. The standardized regression weight was .550, indicating perceived usefulness had a statistically significant positive effect on behavioral intention to use FMT. As the extent to which a pilot believes that using FMT will enhance his job performance increases, his behavioral intention to use FMT also increases.

Hypothesis 10 (H10) was supported with a Critical Ratio (t-value) greater than 1.96 ($t = 4.635$) and a *p*-value less than .001. The standardized regression weight was .180, indicating perceived ease of use had a statistically significant positive effect on behavioral intention to use FMT. As the extent to which a pilot believes that using FMT will be free of effort increases, his behavioral intention to use FMT also increases.

Possible new relationships. As previously mentioned, although post-hoc analysis was not required to improve model fit, the modification indices were examined to identify any potential new relationships, exemplified as eigen values with high regression weights between two factors in the model. There were three potential new relationships identified in the model, based on their high regression weights. The potential new relationships are shown in Table 16, listed from strongest to weakest in terms of likelihood of potential new relationships, based on the regression weight values. Prior to adding any new relationships to the model, existing literature must be reviewed to determine if inclusion of the new relationship is supported, since both CFA and SEM are theory-driven methods (Hair et.al., 2010).

Table 16

Potential New Relationships

Factor 1	Factor 2	Regression Weight
Perceived Image (I0)	Job Relevance (JR0)	11.903
Perceived Image (I0)	Output Quality (OQ0)	11.400
Perceived Image (I0)	Results Demonstrability (RD0)	8.676

It is worth noting that all three potential new relationships involve Perceived Image (I0) influencing three of the otherwise exogenous variables. Perceived Image (I0) is the only external factor in the model otherwise hypothesized to influence another external factor, Subjective Norms (SN0). The other external factors in the model were hypothesized to exclusively affect primarily Perceived Usefulness (PU0) but also

Intention to Use (IU0). A review of the literature was completed, and while it is common to test new external factors to the model in Extended TAM theory, they are typically modeled as influencing behavioral intention to use the technology and not hypothesized for effects on other external factors. Examples of this include Park, Kim, and Ohm (2014), where they tested new external factors of service and display quality, as well as locational accuracy, and found a statistically significant effect on a driver's intention to use a car navigation system. Additionally, Rahman et al. (2017) tested external factors of subjective norms, behavioral control, social influence, and effort expectancy to their model, which all had a statistically significant influence on automobile operator intention to use FMT, but again, not on the other external factors.

From a practical standpoint, it also doesn't make sense that the way a pilot perceives his or her perceived image while wearing FMT would influence the actual relevance to their job, output quality of the FMT device, or results demonstrability of the FMT device the same way that his or her perceived image hypothetically influences subjective norms, or the way the pilot perceives the opinions of others with regards to his or her appearance while wearing FMT. While it may be a topic to pursue for future research, it was determined that there was not sufficient theoretical or practical support for adding the influence of Perceived Image (I0) on Job Relevance, Output Quality, or Results Demonstrability into the model as part of the results from this study.

Qualitative Data Analysis Results

At the end of the survey, an open-ended question was asked of participants to capture any additional comments they felt were pertinent to this study after completing the remainder of the questionnaire. The question was as follows:

Are there any additional factors which would affect your intention to use Fatigue Monitoring Technology, such as a Fitbit or Apple Watch, for the purposes of monitoring your personal fatigue levels prior to operating a flight?

Of the 539 responses in the sample, 328 participants provided a response to the open-ended question at the end of the survey. A summary of these responses is shown in Table 17.

Table 17

Summary of Open-Ended Question

Response Type	Number of Responses
Total responses received to open-ended question	328
Response was left blank	211
Response provided a concern, negative feedback, or question regarding the use of FMT in their field	208
Response provided conditions under which they would use the device or positive feedback regarding the use of FMT in their field	40
Response entered was equivalently blank (respondent answered “no,” “none,” or “N/A”)	78
Response entered was a general negative comment about the questionnaire or research	2

After reviewing each of the individual responses, several key concerns were evident by those pilots who were apprehensive or against implementation of FMT for the purposes of monitoring their personal fatigue levels prior to flight. The primary concern was with regards to use of the data collected by the device, which was conveyed in terms of sharing the data with their companies, unions, the FAA, or NTSB in the case of any investigative measures. This concern was also frequently accompanied by a secondary concern regarding punitive measures taken against the pilot by any of those parties using the data collected from the FMT device. Additional concerns were presented regarding the accuracy of the data, cost of the device, and elements of inconvenience associated with wearing FMT on a regular basis, such as personal comfort, battery life, and regular charging of the device. There were also several respondents who indicate they regularly use this type of a device, such as a Fitbit or Apple Watch, find that the associated FMT functionality does not accurately represent their actual fatigue level, and thus claim it would not be an effective means of mitigating pilot fatigue.

Multiple positive responses were provided by participants who claim to already use personal, wearable FMT, such as a Fitbit or Apple Watch for the purposes of monitoring their fatigue levels, as well as other available health and fitness monitoring functions provided by those types of devices. Several respondents indicated their support of using FMT as a potential solution to a long-standing problem in their industry, and that they would personally consider using it. Multiple respondents indicated support of conditional device usage, including the privacy of their data being protected and the device being provided by their company.

It is worth noting that typically respondents were either considered with privacy, data accuracy, and punitive action, or with device cost, convenience, and comfort. Those who wished for the company to provide the device were not typically concerned with their company having access to the data, and the opposite is also true, that those who wanted privacy and protection of their personal data were not necessarily concerned with purchasing the device themselves. Recommendations for future research using the results of this question are further discussed in the next chapter.

Summary

In a time period spanning two weeks, 539 usable responses were collected to test the hypothetical model proposed as part of this study and determine if the Extended TAM could be applied to U.S. Airline Transport Pilots' behavioral intention to use FMT for the purposes of monitoring their personal fatigue levels as a means of mitigating the risk of operating a flight while fatigued. There were eight latent variable factors in the model, three of which corresponded to the basic TAM of Perceived Usefulness, Perceived Ease of Use, and Intention to Use, and the other five are external factors from the Extended TAM, including Perceived Image, Subjective Norms, Job Relevance, Output Quality, and Results Demonstrability.

The majority of the respondents operated in the United States commercial airline sector, with an age range of 23-64 years old. Among the respondents, there was a relatively even distribution between geographic home regions and a gender distribution with a greater female representation than that of the greater FAA population for airline transport pilots. A vast majority of the respondents claimed to regularly wear a watch during flight operations, but there was a relatively even distribution amongst the respondents who claimed to wear FMT for personal use.

Model fit was achieved on the first iteration using the full survey dataset with acceptable measures of reliability and validity. The strongest relationship in the model was the positive effect of Subjective Norms on Perceived Image. Perceived Usefulness and Perceived Ease of Use both had a positive effect on Intention to Use, though the effect of Perceived Usefulness is stronger than that of Perceived Ease of Use. Job Relevance, Results Demonstrability, and Perceived Image positively affected Perceived Usefulness, though Perceived Image had the weakest effect. While three new potential relationships were identified in the SEM outputs, none of them were added to the model, due to lack of theoretical or practical support. The meaning of these results will be discussed further in the next chapter.

CHAPTER V

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this study was to examine the factors that affect a pilot's behavioral intention to use FMT for the purposes of monitoring their personal fatigue level as a means of mitigating the risk of operating an aircraft while fatigued. This research was performed to assess to what extent the Extended TAM explained these factors and their influence on pilots' behavioral intention to use FMT. In addition to the primary objective of this study, demographic information was obtained from the respondents that provides a new context for regulatory agencies, employers, and researchers alike.

The version of the Extended TAM tested during this study was developed based on a review of the scholarly literature, as well as ground theory established by the Technology Acceptance Model and Theory of Planned Behavior, which included the latent variable constructs of Perceived Usefulness, Perceived Ease of Use, and Behavioral Intention to Use FMT. The external factors used in this study were Perceived Image, Subjective Norms, Job Relevance, Output Quality, and Results Demonstrability. Data for this study was collected using the Extended TAM questionnaire with sets of questions corresponding to each of the factors in the model. Each individual survey question corresponded to an observed variable in the model, of which there were a total of 22. It should be noted that the pilot study was conducted using 23 variables, and one of them was deleted to improve the reliability of the survey instrument, which was also supported by a review of the scholarly literature. The survey was hosted through SurveyMonkey® and distributed through social media. Analysis of the data was completed using descriptive statistics techniques, as well as the CFA and SEM process to test the 10 hypotheses proposed as part of this study in accordance with the Extended TAM.

CFA and SEM study results indicated acceptable model fit, reliability, and validity. Based on the established acceptance criteria for factor loadings, Critical Ratios, and *p*-values, it was confirmed that six of the ten original hypotheses were supported (H1, H3, H4, H6, H9, H10) by the data and four were not (H2, H5, H7, H8). Three potential new relationships were identified as part of this study, whereby Perceived Image would influence Job Relevance, Output Quality, and Results Demonstrability; however, none of these three relationships were added to the model due to a lack of evidentiary support in both the scholarly literature and practical context of the new relationships. This final chapter is comprised of three major sections that provide a discussion of the results, conclusions, and recommendations for future research.

Discussion of Results

The results presented in Chapter 4 helped assess the applicability of the Extended TAM as it pertains to pilots' behavioral intention to use FMT. In this case, the population studied was the collection of United States certified airline transport pilots, of which there are approximately 158,000 in total. The study made use of a sample containing 539 complete survey responses, which was greater than the 444-response minimum sample required to adequately detect and achieve good model fit for this population. A Chi-Square statistics test was completed to determine there was no statistically significant effect due to a non-response bias.

Pilot demographics. Demographic data was obtained from the respondents in five categories, including the length of time served as a pilot, type of pilot operation(s) served in an airline transport pilot capacity, whether the pilot regularly wears a watch while flying or wears an FMT for personal use, and the pilot's gender, age, and geographic home region.

Pilot experience and age. The majority of respondents had been a pilot between 5 and 10 years and worked in the United States commercial passenger airline sector, with an age range of 23-64 years old. The remaining respondents served in a nearly equal distribution of corporate, cargo, and military aviation capacities. The regulatory minimum age range to obtain an airline transport pilot certificate in the United States is 23 years of age, and 14 CFR Part 121 air carrier operations require pilots to be no older than 64 years of age (FAA, 2019). The results are consistent in that the majority of respondents fit into the age range established by the minimum and maximum ages corresponding to the highest percentage of respondents by type of pilot operation, thus contributing to the generalizability of results to the greater United States certified airline transport pilot population.

Geographic regions. Among respondents, there was a relatively even distribution between geographic home regions within the contiguous United States, including the northeast (16.7%), southeast (23.6%), midwest (24.5%), northwest (11.9%), and southwest (16.3%). The only exception was the central mountain region, which captured only 5% of respondents. These results were similar in comparison to the overall population of United States certified airline transport pilots, thus contributing to the generalizability of results.

Gender. Nearly 20 percent of survey respondents were female. This is significantly higher than the 4.4 percent of all U.S. certified airline transport pilots who identify as female (FAA, 2016). It is, however, significantly lower than the 51 percent of U.S. citizens who identify as female (U.S. Census Bureau, 2019). It is possible that the greater percentage of female respondents as compared to the overall U.S. airline transport pilot population was a result of including a social networking group specific to female aviators, only accessible to other female aviators, as part of the survey distribution process. Male researchers would not have had access to this exclusive all-female pilot group and would likely have seen a female respondent percentage more representative of the general United States certified airline transport pilot population.

Wearable technology use. Respondents were asked two questions regarding their current wearable technology usage, to better understand how big of a change it would be for pilots to wear FMT on a regular basis. When asked if they wore a watch while flying on a regular basis, nearly 87 percent of pilots responded that they did indeed wear a watch regularly while operating an aircraft. This result is meaningful because, if 87 percent of pilots already wear a watch while flying, they are used to wearing a device on their wrist during the job, even though it is not necessarily used in the capacity of, or have the capability of, an FMT device. When asked if they wore FMT, such as a Fitbit or Apple Watch, for personal use, only 40 percent responded as affirmative. Future research could be pursued to understand if this population is greater than that of the general population, including non-pilots. If a significantly higher percentage of pilots use wearable technology than the general population, this could lead to additional findings regarding pilot acceptance of wearable FMT.

Approximately 44 percent of those who indicated they regularly wear a watch while flying also indicated they regularly wear an FMT device, such as a Fitbit or Apple

Watch, for personal use. These results are important, because it means the population has already come a long way in accepting the use of FMT and other forms of wearable technology. Given that so many pilots already wear technology with fatigue monitoring capability, it now becomes a matter of pairing the pilots with the right applications and device-monitoring behavior to help increase their personal fatigue awareness, in accordance with 14 CFR Part 117 requirements.

Research question. The research question posed at the beginning of this study was: *What factors affect pilots' behavioral intention to use personal, wearable fatigue monitoring technology, and to what degree?*

Internal factors. Based on the results, it was determined that the internal factors of perceived usefulness and perceived ease of use both had a significant, positive effect on a pilot's behavioral intention to use FMT. Perceived usefulness had a significantly stronger positive effect than perceived ease of use on United States airline transport pilots' behavioral intention to use FMT, as demonstrated by standardized regression weights of .550 and .180, respectively. In a practical sense to pilots, these results indicate the usefulness of FMT is more influential than the ease of use of FMT by a factor of approximately 2.4. Pilots are technically competent and highly trained professionals, so it is reasonable to assume if they find a device to be useful, they will have a tolerance for some degree of difficulty in terms of its ease of use, even though ease of use is still a statistically significant driver toward their overall intention to use FMT.

Perceived usefulness. Perceived usefulness, or the extent to which a pilot believes using FMT will enhance his or her job performance, is the most significant factor affecting pilots' behavioral intention to use FMT ($p < .001$), thus supporting H9. It is an internal factor in the model, based on the ground theory of the original TAM and TPB. It was hypothesized that the external factors of subjective norms, perceived image, job relevance, output quality, and results demonstrability would all have a significant, positive effect on pilots' perceived usefulness of FMT, but that was not the case. Only perceived image (H3), job relevance (H4), and results demonstrability (H6) had a significant, positive effect on perceived usefulness, while subjective norms (H2) and output quality (H5) did not.

These results generally indicate that pilots find FMT most useful when it makes them look stylish to increase their social status and provides information to them that they find tangible and applicable to their jobs. According to the results of the Extended TAM portion of the questionnaire, the pilots did not consider the accuracy of the FMT results or the opinions of others as statistically significant contributing factors to overall FMT device usefulness. The pattern demonstrated through these results is that pilots expect technology to do what it was designed to do, and they want it to improve their status amongst their peers. If there was an overwhelming impression that the devices are unreliable, or if other pilots expressed a dislike or distrust of FMT, it is reasonable to expect that other pilots would be less likely to use FMT. If it became the status quo that FMT was reliable, and it was associated with higher social status amongst pilots, then other pilots would be more inclined to use it.

Perceived ease of use. Perceived ease of use, or the extent to which a pilot believes that using FMT will be free of effort, had a significantly positive effect on pilots' behavioral intention to use FMT ($p < .001$), thus supporting H10. It was also hypothesized in H7, in accordance with the original TAM and TPB theory, that perceived ease of use would have a significant, positive effect on perceived usefulness, but that hypothesis was not supported ($p = .126$). This means that while perceived usefulness was independently shown to directly affect pilots' behavioral intention to use FMT, it wasn't necessarily a contributing factor to how useful pilots found the device. Behaviorally for pilots, perceived ease of use and perceived usefulness are independent and unrelated factors in terms of influencing their intention to use FMT.

External factors. In accordance with the Extended TAM, five external factors were evaluated for their effects on perceived usefulness, which thereby were hypothesized as secondary factors influencing behavioral intention to use FMT, including subjective norms, perceived image, job relevance, output quality, and results demonstrability. Of the five external factors, only job relevance, results demonstrability, and perceived image had a statistically significant effect on perceived usefulness, and thus a secondary influence on behavioral intention to use FMT. Output quality and subjective norms did not have a statistically significant effect on perceived usefulness, and thus did not have a secondary influence on behavioral intention to use FMT. The external factors which had a statistically significant effect on perceived usefulness all demonstrated a positive effect, which means an increase in a pilot's perception of job relevance, results demonstrability, or personal image directly corresponds to an increase in perceived usefulness of FMT, which thereby also corresponds to an increase in behavioral intention to use FMT.

Job relevance. Job relevance, or a pilot's perception regarding the degree to which FMT is applicable to his or her job, was the statistically significant external factor on perceived usefulness in the model, thus supporting H4 ($p < .001$). It carried a standardized regression weight of .370, which means it positively affected perceived usefulness, and perceived usefulness was shown to positively affect behavioral intention to use FMT. Based on the data, pilot behavior suggests job relevance is the highest priority factor in determining the usefulness of an FMT device. The practical implications of these results, in terms of Extended TAM theory, is when a pilot is considering to use an FMT device, such as a Fitbit or Apple Watch, perceived usefulness is the most significant consideration, and when determining usefulness, relevancy to their occupation is the most significant device characteristic. If the pilot does not find the information provided by FMT applicable to his or her job, he or she will find it less useful, and therefore will also be less likely to use it.

Results demonstrability. Results demonstrability, or the tangibility of the results of using FMT, was the second-most influential and statistically significant external factor on perceived usefulness in the model, thus supporting H6 ($p < .001$). It carried a standardized regression weight of .323, which means it positively affected perceived usefulness, and perceived usefulness was shown to positively affect behavioral intention to use FMT. Based on the data, pilot behavior suggests results demonstrability is almost as important as job relevance in determining the usefulness of an FMT device. The practical implications of these results, in terms of Extended TAM theory, is when a pilot is considering to use an FMT device, such as a Fitbit or Apple Watch, usefulness is the most significant consideration, and when determining usefulness, results demonstrability is nearly as significant as job relevance as a device characteristic. If the pilot does not understand how to use the information provided by FMT, he or she will find it less useful, and therefore will also be less likely to use it.

Perceived image. Perceived image, or the degree to which use of FMT is perceived to enhance the pilot's status in his or her social system, was the least influential and statistically significant external factor on perceived usefulness in the model. While statistically significant ($p < .001$), and therefore supporting H3, it only carried a regression weight of .148, less than half the weight of results demonstrability and job relevance. It still positively affects perceived usefulness, which was shown to positively affect behavioral intention to use FMT. Based on the data, however, pilot image or social status is not as important as job relevance or results demonstrability and is therefore the least significant device characteristic of those which have a statistically significant effect on perceived usefulness of FMT.

Pilots prioritize the reliability and functionality of the FMT device over their increased social status as a result of using the device. Airline transport pilots are highly trained professionals who use complex, technical equipment on a daily basis in their line of work. It is understandable that while the social status element associated with human behavior does apply to pilots, it is not as significant of a contributing factor as to how well the technology performs its intended mission. Implications of these results are that in order to increase pilot behavioral intention to use FMT, a device must be useful primarily in terms of job relevance and results demonstrability. The focus should not be placed as much on the FMT hardware design, as it should on the FMT sleep tracking application software design, such that it can deliver results in a way that is both meaningful and useful to professional airline transport pilots.

Subjective norms. Subjective norms, or a pilot's perception that most people who are important to him or her think he or she should or should not use FMT, was not a statistically significant external factor in terms of influencing perceived usefulness (p = .086) or behavioral intention to use FMT (p = .233), thus not supporting H2 or H8, respectively. Subjective norms, however, did have a statistically significant positive effect on perceived image ($p < .001$). Even though subjective norms did not directly influence perceived usefulness, it did have a strong influence on perceived image, which had a slightly significant positive effect on perceived usefulness and therefore equated to a positive tertiary effect on a pilot's behavioral intention to use FMT.

In a practical sense, it means that a pilot's sense of others' opinions of him or her significantly influences his or her perception of his or her social status, which in turn influences how useful he or she finds the device, and subsequently influences his or her intention to use it. However, even though the relationship between subjective norms and perceived image has the largest regression weight (H1=.581), the effect of perceived image on perceived usefulness is low (H3=.104). H1, while carrying theoretical significance in terms of supporting the behavioral relationship between subjective norms and perceived image defined by the Extended TAM, offers little in terms of practical significance toward perceived usefulness and pilot intention to use FMT.

This study was established to assess general pilot acceptance of FMT, independent from the context of voluntary or mandatory system use; however, Hypothesis 1 in this study was that subjective norms would have a positive effect on behavioral intention to use FMT, which corresponded to Venkatesh and Davis' (2000) Hypothesis 1a in the Extended TAM for a mandatory context of technology adoption. It was originally assumed that in order to implement FMT for airline transport pilots, it would require a policy-driven change by a regulatory or company authority, though it was not specified in the questionnaire whether adoption would be voluntary or mandatory, which left interpretation of the voluntary or mandatory nature up to the pilots. This provided the researcher with an opportunity to gain more qualitative feedback from the pilots through an open-ended question at the end of the study asking for them to elaborate on any specific concerns they had regarding FMT adoption as pilots. Many of the pilots used the open-ended response question to indicate they would wear the devices if it was mandatory, though they would be in constant fear of punitive action due to a third party's inaccurate interpretation of the FMT data regarding their personal fatigue levels.

Results of this study indicate pilots may have primarily responded under the impression it was a voluntary implementation scenario, as their responses did not demonstrate a statistically significant positive effect on behavioral intention to use FMT. This actually supported Hypothesis 1b by Venkatesh and Davis (2000), where there is no significant effect by subjective norms on behavioral intention to use when the technology is adopted in a voluntary context. Since the voluntary or mandatory nature of FMT adoption was not specified in the questionnaire, this cannot be stated conclusively, but it is recommended in future testing to split the questionnaire into two groups, one with a voluntary context and the other with a mandatory context, to test the effect of subjective norms on behavioral intention to use FMT with voluntariness as a moderating variable. The idea is that subjective norms have a compliance effect in a mandatory scenario but are simply a recommendation or opinion regarding use in a voluntary scenario, which changes the extent of the effect of subjective norms on an individual's behavioral intention to use the technology.

Output quality. Output quality, or the degree to which FMT performs its intended tasks, was not a statistically significant external factor in terms of influencing perceived usefulness (p = .160) and therefore did not influence the perceived usefulness of FMT, which means H5 was not supported. Since output quality did not have a significant effect on perceived usefulness, it did not have a secondary effect on behavioral intention to use FMT. Interestingly, even though pilot respondents didn't indicate a statistically significant influence of output quality on their opinion regarding the perceived usefulness of FMT during the Extended TAM portion of the survey, there were several responses to the open-ended question at the end of the survey indicating concerns regarding items that could be categorized as output quality, in terms of data accuracy, how well the device performs its intended tasks, and how adequately the device represents reality.

Many of the respondents indicated concerns that they did not trust the data, or that they have observed through previous wearable device usage that the fatigue-related data output is not consistent with how they personally feel about their fatigue level at any given time, and therefore the output quality would need to be improved before using the device. A review of the survey questions corresponding to the output quality construct was completed to determine if there was a lack of clarity, and the questions were clear and direct in asking about the respondent's opinion regarding output quality:

> *Question 20: The quality of the output I get from wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is high.*
>
> *Question 21: I have no problem with the output quality of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.*

Several responses were reviewed comparing a qualitative concern written regarding output quality with that individual's responses to the Extended TAM questions corresponding to output quality. One pilot wrote, "*I don't feel like a technology device can properly assess fatigue 100%. I use it for personal fitness teaching, but nothing more,"* even though he or she had previously responded *"agree"* to both Questions 20 and 21 in the survey. This would be an opportunity for future research, as output quality did not have an effect as modeled based on the Extended TAM portion of the questionnaire, but would have been listed as a contributing factor had the research been solely based on a qualitative data assessment.

Conclusions

This study was conducted to assess the applicability of the Extended TAM as it pertained to airline transport pilots' behavioral intention to use FMT for the purposes of monitoring their personal fatigue levels. Upon removing one question from the survey as a result of the pilot study, and subsequently collecting the full survey dataset, good model fit was achieved with acceptable measures of reliability and validity. There were ten hypotheses in the original model, six of which were supported by the data and four of which were not. A gap in the literature was filled, as it was demonstrated that a modified version of the Extended TAM does apply to pilots' behavioral intention to use FMT. The most significant internal factor is perceived usefulness, followed by perceived ease of use. The three external factors which influence perceived usefulness, and thus have a secondary effect on the intention to use are job relevance, results demonstrability, and perceived image. A tertiary positive effect on behavioral intention to use is actually the strongest relationship in the model, which is the positive effect of subjective norms on perceived image. Neither output quality nor perceived image was determined to have a statistically significant effect on perceived usefulness, and therefore not on the pilot's behavioral intention to use FMT.

The purpose of this research was to determine the factors that significantly affect airline transport pilots' acceptance of FMT, such that it could be better understood how to influence pilot behavior in a way that would increase FMT usage and ideally help pilots increase their personal fatigue awareness in accordance with 14 CFR Part 117 requirements. Using the ground theory provided by the Extended TAM, survey data collected from 539 U.S.-certified airline transport pilots, and SEM analysis, it was determined that the greatest way to increase pilots' intention to use FMT is to increase their perceived usefulness of FMT as a function of job relevance and results demonstrability. The job relevance and results demonstrability of FMT are largely controlled by the basic fatigue models that are used by the device software to determine or predict fatigue and the ensuing ability to provide sleep tracking data in a way that is meaningful to pilots and can help them understand when they may be approaching their personal fatigue limits for operating an aircraft. It was also determined that pilot FMT acceptance is also increased if people whose opinions the pilots respect believe they should be tracking their sleep performance using FMT, therefore increasing the pilot's social status. A marketing campaign would be useful if renowned and respected pilots advocated for the use of FMT, and the devices were crafted in a way that made the pilots feel stylish and of increased social status.

Theoretical contributions. The theoretical significance of this study was three-fold. The first theoretical objective was to provide a contribution to the body of knowledge by using the Extended TAM to determine the factors that affect a pilot's behavioral intention to use personal, wearable FMT devices. Additionally, after a review of the literature, while there were numerous studies regarding FMT accuracy, applying the Extended TAM to pilots using types of technology other than FMT, and applying the Extended TAM to automobile operators using FMT, a second theoretical objective was to apply the Extend TAM to pilots using FMT, for which no studies were found to be previously completed. The third theoretical objective was to demonstrate the generalizability of the results to the greater United States certified airline transport pilot population using respondent demographics. The study was able to accomplish all three theoretical objectives, thus contributing to the body of knowledge.

In addressing the first objective, the primary factors determined to influence a pilot's behavioral intention to use personal, wearable FMT are perceived usefulness (H9) and perceived ease of use (H10). The secondary factors that influence a pilot's behavioral intention to use personal, wearable FMT are job relevance (H4), results demonstrability (H6), and perceived image (H3) through perceived usefulness. The tertiary factor that influences a pilot's behavioral intention to use personal, wearable FMT is subjective norms through perceived image and perceived usefulness (H1). It should also be noted that neither output quality, subjective norms, or perceived ease of use were determined to have a statistically significant effect on perceived usefulness (H5, H2, H7) and that subjective norms did not have a direct statistically significant effect on behavioral intention to use FMT (H8).

This was an interesting finding because when Rahman et al. (2017) performed a similar study on FMT acceptance by automobile operators, perceived ease of use, output quality, and subjective norms were all determined to have a statistically significant effect on driver behavioral intention to use FMT. The FMT evaluated by Rahman et al. (2017) was comprised of two sets of applications, with one set to monitor the vehicle to detect driver fatigue onset and another set to monitor the driver directly. Data was collected from the drivers after the experimental study was completed, which was evaluated using factors from the TAM, TPB, and UTAUT frameworks.

One would expect greater commonality between the factors influencing behavioral acceptance by automobile drivers and aircraft pilots, but it appears pilots are less concerned about output quality, subjective norms, and perceived ease of use than drivers. Future research could be completed assessing the differences in FMT acceptance between automobile operators and aircraft pilots, and why the airline transport pilot population did not have more influencing factors in common with automobile operators. As previously mentioned, it is reasonable that pilots are less concerned with these three factors because they are trained to trust technology manufacturers, make their own decisions through aeronautical decision making, and operate highly complex technical equipment. It appears to come down to the basics with pilots – the device should strike a balance between improving their social status and providing data that is useful in terms of fatigue awareness.

In addressing the second objective, SEM analysis was conducted to evaluate the applicability of the Extended TAM. Goodness of model fit was evaluated using the model fit indices of Comparative Fit Index (CFI), Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Normed Fit Index (NFI), Root Mean Square Error of Approximation (RMSEA), and the minimum discrepancy divided by its degrees of freedom (CMIN/Df). Good construct reliability was demonstrated in terms of acceptable composite reliability and Cronbach's alpha. Only one CR value was less than 0.7 (RD0), but the corresponding Cronbach's alpha was greater than 0.7. Good construct validity was demonstrated in terms of AVE, good convergent validity was demonstrated in terms of acceptable standardized factor loadings, and good discriminant validity was demonstrated in terms of the squared correlations, where only one squared correlation (SC) value ($SC_{PU0 \rightarrow RD0} = .585$) was higher than one of the corresponding AVE values ($AVE_{RD0} = .574$) but still less than the other ($AVE_{PU0} = .848$).

In addressing the third objective, generalizability was able to be achieved in terms of pilot age and geographic distribution, where the respondent demographics were largely comparable to those of the greater U.S. ATP population. There was, however, a higher percentage of female respondents (19%) when compared to the overall percentage of females in the greater U.S. ATP population (5%), which was explained by the researcher being a female and having the ability to distribute the survey to an exclusive female aviator social media group to which male researchers would not have access, thus increasing the likelihood of female responses to the survey. While including an all-female pilot group as part of the distribution may have slightly decreased the generalizability of the results to the greater U.S. airline transport pilot population, the survey was also distributed to multiple gender-neutral social media groups and individuals, and most respondents indicated as being of the male gender, adding to the generalizability of the results. A separate study could be completed as part of future research to specifically assess the differences between genders accepting FMT use to monitor pilot fatigue.

There were respondents from the various types of airline transport pilot operations, including commercial passenger airline, cargo, military, and corporate aviation, also contributing to results generalizability, though the highest percentage of respondents corresponded to commercial passenger airline pilots (64.4%). Though the pilot lives of all air transport categories are important, the passenger transport category has the highest compounding effect on safety, with the domestic transportation of nearly 850 million passengers and growing, each year across the United States (United States Department of Transportation, 2018). As such, the significant representation of commercial passenger airline transport pilots was beneficial to this study, in terms of having the potential ability to comprehensively increase overall pilot and passenger safety.

Practical contributions. The practical significance of this study was understanding the factors that contribute to a pilots' acceptance of using FMT to monitor their fatigue levels prior to flight, such that the factors can then be addressed to maximize the likelihood of FMT use and increase awareness of their personal fatigue levels, making it so they are more capable of complying with 14 CFR Part 117 requirements. Given that we now understand the most significant factors influencing behavioral intention to use FMT – in priority order – are perceived usefulness, perceived ease of use, job relevance, results demonstrability, perceived image, and subjective norms, steps can now be taken to increase the likelihood of airline transport pilots using FMT to increase their personal fatigue level awareness. This is an important finding, as it is the key to unlocking multiple potential mitigation strategies for pilots operating flights while fatigued.

In practical terms, pilots find FMT most useful when the device is applicable to their jobs, provides tangible results, and increases their social status perception. It is also beneficial if others around them think they should use FMT, and that if they use FMT, their social status perception increases. Solutions to increase the likelihood of pilot FMT device usage should provide features that directly apply to the pilot profession, report data in ways that make sense to pilots and make the pilot look and feel stylish. Almost 87 percent of pilots already wear a watch while flying, and over 40 percent of pilots already wear some form of FMT for personal use, so the challenge going forward is to make the right improvements to the devices to increase usage for the purposes of fatigue monitoring. Such improvements should include new aviation-themed applications that appeal to pilots and provide results tailored to their profession and can help them make more informed decisions, while simultaneously improving the device aesthetic to drive an increase in social pressures to regularly wear the FMT devices.

Limitations of the Findings

There are four key limitations to the findings presented as a result of this study, the first of which is the generalizability of the results. Respondents were required to be a United States certified airline transport pilot to participate in this study. While the minimum sample size for the target population was exceeded and is generalizable to the U.S. certified airline transport pilot population, the results are not necessarily generalizable to the equivalent of airline transport pilots outside of the U.S. certified by other regulatory agencies, nor are they necessarily generalizable to other pilot certificate types within the U.S., such as commercial or private pilots. The generalizability of the results may also be considered limited to U.S. certified airline transport pilots who use social media and are capable of completing an online survey. The research could easily be applied to other countries or types of pilots by redistributing the questionnaire to the additional populations and following the same method for analysis.

Demographic results of this study also affected the generalizability to the greater U.S. certified airline transport pilot population. A significant majority of respondents fit the profile of 23-54 years old with 5-10 years of pilot experience, and currently serving in the passenger transport industry. Though the age range of respondents is consistent with the U.S. airline transport pilot population, most respondents having only 5-10 years of pilot experience may affect the overall generalizability of the results. Furthermore, gender distribution of respondents was 20% female, compared to the only 5% of females in the greater U.S. airline transport population. This means researcher was able to capture a greater representation of female pilot behavior versus male pilot behavior, in terms of population sample size.

Second, the survey data for this study was collected using a cross-sectional administration of the instrument over a two-week period in late 2019, and as such does not capture the change of behavior and technology advancement over time. A longitudinal study can be completed again in the future to determine if the percentage of pilots who use FMT on a regular basis increases over time. While it is not expected that there is a significant difference in the results between when the data were collected and when the results were reported, technology acceptance can change over time, and it may be prudent to conduct similar research in the future to monitor trends.

Third, the model results as presented are based on the hypotheses derived from the extended TAM. The Extended TAM is not technology-specific and uses a Likert-scale questionnaire to operationalize conceptual variables as part of a general theoretical model. While it is now understood to what extent the internal and external latent variable factors from the Extended TAM influence pilot acceptance of wearable FMT a result of this study, the quantitative data does not offer much in terms of the rationale for the pilot responses. To mitigate this limitation, qualitative data was also collected to better understand some of the specific details regarding the pilot responses. As indicated by the qualitative analysis results, there are potentially factors not included in the model that may have an equal or greater influence on a pilot's acceptance of FMT, such as personal device preference, privacy, security, data protection, and fear of punitive action or repercussions due to potentially flying when an FMT device suggests the pilot is fatigued. It is also important to understand the variability of individual pilot behavior by evaluating cognitive ability to process information, technical aptitude, and human factors in the flight deck, such as how pilots respond to crew alerting and distractions while having to safely operate an aircraft while potentially being fatigued. These factors would be difficult to assess through a questionnaire methodology, like what was used in this study, but would be essential to include as part of future research that utilizes experimental elements. These factors are important and should be considered for future research, as the widespread implementation of policy regarding FMT would likely be contingent on pilot acceptance with regards to these factors not included in the model. It is possible they could be included as external factors in the SEM after collecting quantitative, Likert-scale data regarding these factors in a future iteration of the study.

Fourth, the model resulting from this study does not include the variables of actual use, experience, or voluntariness from the Extended TAM, for reasons previously explained in this dissertation. They are a limitation of this study, but this study provides a starting point for future research regarding actual pilot use of FMT, increased pilot experience with FMT capabilities, and the complex effects of voluntary or mandatory implementation as it pertains to pilot behavioral intention to use FMT. In summary, the current SEM is limited to the quantitative data collected regarding the eight latent variable constructs from the Extended TAM and can be expanded in numerous ways as part of future studies.

Recommendations

At the conclusion of this study, two sets of recommendations are being made. The first set is for stakeholders and the opportunity that currently exists to improve aviation safety using FMT. The second set is for future research in the field of aviation human factors and pilot fatigue mitigation strategies.

Recommendations for stakeholders. The first set of recommendations is for stakeholders, including regulators, employers, unions, and technology innovators. The challenge for these stakeholders is to use the information in this study to help identify the right technical solutions and motivational strategies to increase pilot use of FMT, in accordance with the recommendations made by the NTSB (2016). Stakeholders have the opportunity to use the demographic data identified in this study to target specific populations in an attempt to increase FMT usage.

The technology exists to help humans reliably monitor their personal fatigue levels using various parameters and is readily available to the public to purchase in the form of personal, wearable technology devices. In this study, United States airline transport pilots were asked what factors influenced their behavioral intention to use this type of technology to increase their awareness of their personal fatigue levels, and the most significant factors were perceived usefulness and perceived ease of use, which were driven by job relevance, results demonstrability, and perceived image or social status. It is recommended that a smartwatch application for devices like the Apple Watch, Fitbit, or Samsung Gear be developed specifically for pilot fatigue monitoring that delivers results in a way that is useful for pilots and meets 14 CFR Part 117 requirements for personal fatigue awareness. It is specifically recommended to develop an application that is fully validated for the pilot population, applying human factors and user-centered design principles. A large percentage of the airline transport population already wears FMT-capable devices, and based on the significant influence of job relevance and results demonstrability on pilots' intention to use FMT, an application developed specifically for airline transport pilots would likely help increase device usage.

Recommendations for future research. Several recommendations are being provided for future research regarding pilot fatigue mitigation strategies, including pilot acceptance of and behavioral intention to use FMT. First, generalizability should be increased by expanding the scope of this study to include pilots in other countries outside the United States certified by regulators other than the FAA. This study should also be expanded to include pilots who hold private and commercial pilot certificates. It would also be beneficial to determine minimum sample size targets for specific demographic categories within the United States airline transport population, such as gender, age range, type of pilot operation, and years of pilot experience, to improve overall generalizability of the results in a future study.

Second, effort should be made to incorporate results of the qualitative analysis from this study into a future questionnaire, such that the factors of personal device preference, privacy, security, data protection, punitive actions, and repercussions can be properly tested for possible inclusion in the model. As a part of this, higher fidelity should be added to the output quality construct with additional questions to help capture some of the concerns that pilots expressed in the open-ended question at the end of the survey.

Third, an experimental or observational element of the study could be added in the future to measure actual use of FMT and determine if the Extended TAM theory can be applied to actual use, as well as the other factors included in the model evaluated during this study. An observational or experimental study would be useful in assessing the variability of individual pilot behavior by evaluating cognitive ability to process information, technical aptitude, and human factors in the flight deck, such as how pilots respond to crew alerting and distractions while having to safely operate an aircraft while potentially being fatigued. An additional consideration as part of measuring actual use would be to consider alternative existing fatigue assessment tools that do not make use of wearable technology. A comparison could then be made between wearable FMT and non-wearable FMT device acceptance, as it pertains to the pilot population, which would be similar to a study completed using commercial truck drivers by Dinges et al. (2005). It would be beneficial to see the results of actual FMT use to better understand which factors should be specifically addressed to increase the likelihood of pilot FMT device usage in the future. As part of future research, it is also recommended to use a consistent sample of respondents, such that their experience using FMT over time can be measured, therefore enabling researchers to better understand the extent to which both actual FMT use and FMT experience influence pilot behavioral intention to use FMT changes over time.

Fourth, as future longitudinal studies are developed to measure actual pilot FMT use and pilot experience with FMT over time, they should also be deployed in a way that assesses the influence of mandatory or voluntary implementation of FMT with pilots. It is recommended the survey be completed in two groups, one with a voluntary adoption scenario and the other with a mandatory adoption scenario. This will help researchers make better practical recommendations regarding how to increase the likelihood of pilot FMT adoption as a means of understanding their personal fatigue levels.

Finally, this research should be extrapolated to include other industries, such as automobile operators, with increased usage of applications such as Uber and Lyft. It can also be used as a method update to FMT research in the commercial truck driving or locomotive transportation industries. The hazards and risks associated with operating any vehicle while fatigued can be devastating, and so understanding how to better influence various populations to increase FMT device usage by operators can be a beneficial exercise for marketing firms around the world in many industries.

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APPENDIX A

Data Collection Device – Pilot Study

Likert-Scale Response Legend
1 – Strongly Disagree
2 – Disagree
3 – Somewhat Disagree
4 – Neutral
5 – Somewhat Agree
6 – Agree
7 – Strongly Agree

Intention to Use								
Question ID	Question							
3	Assuming I have access to wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, I intend to use it.	1	2	3	4	5	6	7
4	Given that I have access to wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, I predict that I would use it.	1	2	3	4	5	6	7
Perceived Usefulness								
Question ID	Question							
5	Using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, improves my performance in my job.	1	2	3	4	5	6	7
6	Using wearable fatigue monitoring							

	technology, such as a Fitbit or Apple Watch, in my job increases my productivity.	1	2	3	4	5	6	7
7	Using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, enhances the effectiveness in my job.	1	2	3	4	5	6	7
8	I find wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, useful in my job.	1	2	3	4	5	6	7
Perceived Ease of Use								
Question ID	Question							
9	My interaction with wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is clear and understandable.	1	2	3	4	5	6	7
10	Interacting with wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, does not require a lot of my mental effort.	1	2	3	4	5	6	7
11	I find wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, to be easy to use.	1	2	3	4	5	6	7
12	I find it easy to get wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, to do what I want it to do.	1	2	3	4	5	6	7
Subjective Norm								
Question ID	Question							
13	People who influence my behavior think that I should use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.	1	2	3	4	5	6	7
14	People who are important to me think I							

	should use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.	1	2	3	4	5	6	7
Image								
Question ID	Question							
15	People in my organization who use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, have more prestige than those who do not.	1	2	3	4	5	6	7
16	People in my organization who use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, have a high status profile.	1	2	3	4	5	6	7
17	Having wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is a status symbol in my organization.	1	2	3	4	5	6	7
Job Relevance								
Question ID	Question							
18	In my job, usage of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is important.	1	2	3	4	5	6	7
19	In my job, usage of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is relevant.	1	2	3	4	5	6	7
Output Quality								
Question ID	Question							
20	The quality of the output I get from wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is high.	1	2	3	4	5	6	7
21	I have no problem with the output quality of wearable fatigue monitoring	1	2	3	4	5	6	7

	technology, such as a Fitbit or Apple Watch.							
Result Demonstrability								
Question ID	Question							
22	I have no difficulty telling others about the results of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.	1	2	3	4	5	6	7
23	I believe I could communicate to others the consequences of not using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.	1	2	3	4	5	6	7
24	The results of using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, are apparent to me.	1	2	3	4	5	6	7
25	I would have difficulty explaining why using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, may or may not be beneficial.	1	2	3	4	5	6	7
Demographic Data								
Question ID	Question	Answer Selections						
26	How would you classify yourself as a pilot? Select all that apply.	a. Airline Transport Pilot - Airline b. Airline Transport Pilot – Private or Corporate c. Airline Transport Pilot - Cargo d. Airline Transport Pilot – Military e. Airline Transport Pilot – Other						

27	How long have you been a pilot (minimum private pilot certificate)?	a. Less than one year b. Between one and five years c. Between five and ten years d. Between ten and twenty years e. More than twenty years
28	Do you wear a watch while you fly?	a. Yes b. No
29	Do you typically wear a fatigue or sleep monitoring device, such as a Fitbit, for personal use?	a. Yes b. No
30	With which geographic location within the United States do you most closely identify?	a. Northeast b. Southeast c. Midwest d. Central Mountain e. Northwest f. Southwest
31	Please specify your gender.	a. Male b. Female c. Prefer not to identify
32	Please specify your age range.	Fill in the blank response
33	Are there any additional factors which would affect your intention to use Fatigue Monitoring Technology, such as a Fitbit or Apple Watch, for the purposes of monitoring your personal fatigue levels prior to operating a flight?	[Open-ended freeform narrative response]

APPENDIX B

SurveyMonkey® Screen Captures

Pilot Acceptance of Wearable Fatigue Monitoring Technology

Welcome to my survey!

Purpose of this Research: I am asking you to take part in a research project for the purpose of ascertaining public sentiment on Pilot Acceptance of Personal, Wearable Fatigue Monitoring Technology. The purpose of the research is to use the Technology Acceptance Model framework to assess the factors which affect pilots' behavioral intention to use a wearable fatigue monitoring technology device for the purpose of monitoring their personal fatigue levels as part of their normal process for assessing their ability to safely operate an aircraft. During this study, you will be asked to complete a brief online survey about your opinions concerning the use of your acceptance of personal, wearable fatigue monitoring technology as a pilot. The completion of the survey will take approximately 10-15 minutes.

Eligibility: To be in this study, you must be a United States Airline Transport Pilot (ATP) certificate holder.

Risks or Discomforts: The risks of participating in this study are no greater than what is experienced in daily life.

Benefits: While there are no benefits to you as a participant, your assistance in this research will help gauge behavioral intention of pilots to use fatigue monitoring technology to help assess their fatigue levels in accordance with 14 CFR Part 117 requirements.

Confidentiality of Records: Your individual information will be protected in all data resulting from this study. Your responses to this survey will be anonymous. No personal information will be collected other than basic demographic descriptors. The online survey system will not save IP addresses or any other identifying information. In order to protect the anonymity of your responses, I will keep your responses in a password-protected file on a password-protected computer. No one other than the researcher will have access to any of the responses. Information collected as part of this research will not be used or distributed for future research studies.

All survey responses that the investigator receives will be treated confidentially and stored in an encrypted file on a password protected computer. However, given that the surveys can be completed from any computer (personal, work, school, etc.), we are unable to guarantee the security of the computer on which you choose to enter your response. As a participant in this study, the investigator wants you to be aware that certain "keylogging" software programs exist that can be used to track or capture data that you enter and/or websites that you visit. Information collected as part of this research will not be used or distributed for future research studies.

Compensation: There is no compensation offered for taking part in this study.

Contact: If you have any questions or would like additional information about this study, please contact Rachelle Strong, gigowskr@my.erau.edu, or the faculty member overseeing this project, Dr. D. Liu, liu89b@erau.edu. For any concerns or questions as a participant in this research, contact the Institutional Review Board (IRB) at 386-226-7179 or via email teri.gabriel@erau.edu.

Voluntary Participation: Your participation in this study is completely voluntary. You may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Should you wish to discontinue the research at any time, no information collected will be used.

CONSENT. By checking AGREE below, I certify that I am a resident of the U.S., understand the information on this form, and voluntarily agree to participate in the study.

If you do not wish to participate in the study, simply close the browser or check DISAGREE

* 1. I am a United States Airline Transport Pilot certificate holder.

- Yes
- No

* 2. Please answer the following question to indicate your informed consent:

Do you understand and agree to the terms of this survey?

- Yes
- No

Pilot Acceptance of Wearable Fatigue Monitoring Technology

Intention to Use

This section pertains to your overall intent to use a wearable fatigue monitoring technology device.

3. Assuming I have access to wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, I intend to use it.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

4. Given that I have access to wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, I predict that I would use it.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Pilot Acceptance of Wearable Fatigue Monitoring Technology

Perceived Usefulness

This section pertains to how useful you think wearable fatigue monitoring devices are.

5. Using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, improves my performance in my job.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

6. I find wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, useful in my job.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

7. Using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, enhances the effectiveness in my job.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

8. Using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, in my job increases my productivity.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Pilot Acceptance of Wearable Fatigue Monitoring Technology

Perceived Ease of Use

This section pertains to how easy you think wearable fatigue monitoring technology devices are to use.

9. My interaction with wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is clear and understandable.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

10. Interacting with wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, does not require a lot of my mental effort.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

11. I find wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, to be easy to use.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

12. I find it easy to get wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, to do what I want it to do.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Pilot Acceptance of Wearable Fatigue Monitoring Technology

Subjective Norms

This section pertains to how important or influential people around you feel about your use of a wearable fatigue monitoring technology device.

13. People who influence my behavior think that I should use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

14. People who are important to me think I should use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Pilot Acceptance of Wearable Fatigue Monitoring Technology

Perceived Image

This section pertains to your perceived image associated with wearing a fatigue monitoring technology device.

15. People in my organization who use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, have more prestige than those who do not.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

16. People in my organization who use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, the system have a high profile.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

17. Having wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is a status symbol in my organization.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Pilot Acceptance of Wearable Fatigue Monitoring Technology

Job Relevance

This section pertains to your opinion regarding the relevance of wearable fatigue monitoring technology to your job.

18. In my job, usage of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is important.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

19. In my job, usage of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is relevant.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Pilot Acceptance of Wearable Fatigue Monitoring Technology

Output Quality

This section pertains to your opinion of the output quality of wearable fatigue monitoring technology devices.

20. The quality of the output I get from wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is high.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

21. I have no problem with the output quality of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Pilot Acceptance of Wearable Fatigue Monitoring Technology

Results Demonstrability

This section pertains to your opinion regarding demonstrated results from wearable fatigue monitoring technology devices.

22. I have no difficulty telling others about the results of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

23. I believe I could communicate to others the consequences of not using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

24. The results of using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, are apparent to me.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

25. I would have difficulty explaining why using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, may or may not be beneficial.

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

Pilot Acceptance of Wearable Fatigue Monitoring Technology

Pilot Demographic Data

This is the final section, and it pertains to your demographic information as a pilot.

Reminder: Please only answer as you feel comfortable.

26. How long have you been a pilot (minimum private pilot certificate)?

- Less than one year
- Between one and five years
- Between five and ten years
- Between ten and twenty years
- More than 20 years

27. How would you classify yourself as a pilot? Select all that apply.

- Airline Transport Pilot - Airline
- Airline Transport Pilot - General Aviation (Private or Corporate)
- Airline Transport Pilot - Cargo
- Airline Transport Pilot - Military
- Airline Transport Pilot - Other

28. Do you wear a watch while you fly?

- Yes
- No

29. Do you typically wear a fatigue or sleep monitoring device, such as a Fitbit, for personal use?

- Yes
- No

30. With which geographic location within the United States do you most closely identify as your home-base?

- Northeast
- Southeast
- Midwest
- Central Mountain
- Northwest
- Southwest

31. Please specify your gender.

- Male
- Female
- Prefer not to identify

32. Please specify your age.

23 100

33. Are there any additional factors which would affect your intention to use Fatigue Monitoring Technology, such as a Fitbit or Apple Watch, for the purposes of monitoring your personal fatigue levels prior to operating a flight?

APPENDIX C

ERAU Institutional Review Board Approval Letter and Application

Embry-Riddle Aeronautical University
Application for IRB Approval
EXEMPT Determination Form

Principal Investigator: Rachelle Strong

Other Investigators: Dahai Liu

Role: Student **Campus:** Daytona Beach **College:** Aviation/Aeronautics

Project Title: Pilot acceptance of personal, wearable fatigue monitoring technology: An application of the Extended Technology Acceptance Model

Review Board Use Only

Initial Reviewer: Teri Gabriel **Date:** July 24, 2019 **Approval #:** 20-009

Determination: Exempt

Dr. Michael Wiggins
IRB Chair Signature: Michael E. Wiggins, Ed.D. **Date:** 07/24/2019

Brief Description:

This proposed study will be using the Extended Technology Acceptance Model framework to assess United States commercial airline pilots' behavioral intention to use wearable fatigue monitoring technology (FMT), like an Apple Watch, Fitbit, or Samsung Galaxy Gear, to evaluate their fatigue levels prior to operating a flight. An online survey will be conducted through Survey Monkey, social media, and in-person networking using business cards.

This research falls under the **EXEMPT** category as per 45 CFR 46.104:

✓ (2) Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met: (Applies to Subpart B [Pregnant Women, Human Fetuses and Neonates] and does not apply for Subpart C [Prisoners] except for research aimed at involving a broader subject population that only incidentally includes prisoners.)

EMBRY-RIDDLE Forms

Human Subject Protocol Application

The University fully complies with the Federal Regulations on the use of ***human subjects*** as required by U.S. Department of Health & Human Services. Any proposed research involving ***human subjects***, as defined by 45 CFR 46 2018 Regulations, requires approval by the University ***Institutional Review Board (IRB) for the Protection of Human Subjects in Research.***

Applicant Information

Applicant's First Name: Rachelle

Applicant's Last Name: Strong

ERAU ID: 1229931

Email: gigowskr@my.erau.edu

Confirm Email: gigowskr@my.erau.edu

Campus: Daytona Beach

College: College of Aviation

What is your primary affiliation to ERAU? (•) Student ( ) Faculty ( ) Staff/Administration

Select Faculty Advisor: LIU89B

Please be sure to choose the appropriate faculty member. Failure to do so may delay your application.

Project Information

Type of Project: Survey

Project Title: Pilot acceptance of personal, wearable fatigue monitoring technology: An application of the Ext

Principal Investigator: Rachelle Strong

If undergraduate student, faculty advisor must be listed as the principal investigator.

Degree Level of Principal Investigator: Master

List all Other Investigators: Dahai Liu (dissertation chair)

If graduate student, list research advisor and all other investigators.

Expected Beginning Date: 05/01/2019 (mm/dd/yyyy)

Does this project have funding support? No

Please answer the following questions and provide a brief explanation of the answer for each. The answers to the questions need not be long, but they should be sufficiently detailed so that an "intelligent non-expert" reviewer can accurately assess the risks and benefits associated with your study.

1. **Background and Purpose:** Briefly describe the background and purpose of the research.

Statement of the Problem
Pilot fatigue has been referenced as a causal factor in multiple aviation accidents; to mitigate the risk of pilots operating an aircraft while fatigued, the United States Federal Aviation Administration published 14 CFR Part 117, Flight and Duty Limitations and Rest Requirements for Flight Crew Members. The Federal Aviation Administration provides 14 CFR Part 117 with multiple sections, including the following definitions (2015):

2. **Time:** Approximately how much time will be required of each participant?

20 minutes

3. **Design, Procedures and Methods:** Describe the details of the procedure(s) to be used and the type of data that will be collected.

At a high level, the research will be conducted using a survey instrument to collect data from United States certified airline transport pilots using the established extended TAM framework. The survey questionnaire will be further validated using a pilot study with a subset of respondents prior to mass distribution. Following the data collection phase of this research, the data will be analyzed using confirmatory factor analysis in conjunction with structural equation modeling to understand the factors which have a statistically significant influence on a pilot's behavioral intent to use wearable technology to

4. **Measures and Observations:** What measures or observations will be taken in the study?

In total, there are 8 latent variables (constructs in the hypothesized model), each of which were validated through the literature review. Each of the variables were included in the Venkatesh and Davis (2000) extended TAM, and multiple relevant, scholarly studies since then have used the factors from the original model and found them to be statistically significant. An explanation of these studies are located in the Extended Technology Acceptance Model Applications section of the literature review. The observed variables correspond to the standard questions each for each of the latent variables in

If any questionnaires, tests, or other instruments are used, provide a brief description.

A PDF is attached of the Survey Monkey questionnaire which will be distributed to respondents. Each question in the survey corresponds to a variable in the study.

Attach a copy for review (computer programs may require demonstration at the request of the IRB).

Change (Allowed File Types: PDF, ZIP) Remove

Survey Monkey Screen Shots.pdf

5. **Participant Population and Recruitment Procedures:** Who will be recruited to be participants and how will they be recruited. Any recruitment email, flyer or document(s) must be reviewed by the IRB. Note that except for anonymous surveys, participants must be at least 18 years of age to participate.

This is an anonymous survey. Respondents will be contacted through email, social media, or business card distribution. A PDF is attached with screen captures of the business card, email, and social media distribution information for respondents.

Attach recruitment document(s) here.

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Distribution Bus-Card_Email_Soc-Med.pdf

6. **Risks and Discomforts:** Describe any potential risks to the dignity, rights, health or welfare of the human subjects. All other possible options should be examined to minimize any risks to the participants.

There are no risks. No personally identifiable information will be collected as part of the survey, and respondents can discontinue the survey at any time.

7. **Benefits:** Assess the potential benefits to be gained by the subjects as well as to society in general as a result of this project.

The practical significance of this study is understanding the factors which contribute to a pilots' acceptance of using FMT to monitor their fatigue levels prior to flight, such that the factors can then be addressed to maximize the likelihood of FMT use and increase awareness of their personal fatigue levels, making it so they are more capable of complying with 14 CFR Part 117. By surveying pilots regarding their acceptance of and behavioral intent to use wearable FMT, there is potential to influence their behavior in such a way that it increases their likelihood to use a device which is inexpensive and quick to

8. **Informed Consent:** Describe the procedure you will use to obtain informed consent of the subjects. How and where will you obtain consent? See ***Informed Consent Guidelines*** for more information on Informed Consent requirements.

Informed consent will be indicated by a question on the first page of the survey where they agree to terms and conditions of the survey. The Survey Monkey capture is on page 1 of the attached PDF.

Attach informed consent here. See ***Informed Consent Guidelines*** for more information on Informed Consent requirements.
No informed consent document is required if you are using existing data.

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Survey Monkey Screen Shots.pdf

9. **Confidentiality of Records:** Will participant information be:

- (●) Anonymous
- ( ) Confidential
- ( ) Public

Justify the classification and describe how privacy will be ensured/protected.

Survey Monkey will not collect information on the respondents, and I have not put any questions in the survey which ask for personally identifiable information.

10. **Privacy:** Describe the safeguards (including confidentiality safeguards) you will use to minimize the risks. **Indicate what will happen to data collected from participants that choose to "opt out" during the research process**. If video/audio recordings are part of the research, describe how long that data will be stored and when it will be destroyed.

If the participants opt out of the survey, they can simply close their browser window, and the data will be discarded. Additionally, will not be using any incomplete results as part of the data collection process.

11. **Economic Considerations:** Are participants going to be paid for their participation?

- (●) No
- ( ) Yes

If yes, what will the compensation be?
Describe your policy for dealing with participants who 1) Show up for research, but refuse informed consent; 2) Start but fail to complete research.

Attach a copy of the survey / interview questions / other supporting documents for review (max 3 files)

Change (Allowed File Types: PDF, ZIP) Remove

Survey Monkey Screen Shots.pdf

Change (Allowed File Types: PDF, ZIP) Remove

Distribution Bus-Card_Email_Soc-Med.pdf

Select file (Allowed File Types: PDF, ZIP)

Electronic Signature Rachelle L. Strong

Date 03/30/2019

By submitting this application, you are signing that the Principal Investigator and any other investigators certify the following:

1. The information in this application is accurate and complete
2. All procedures performed during this project will be conducted by individuals legally and responsibly entitled to do so
3. I will comply with all federal, state, and institutional policies and procedures to protect human subjects in research
4. I will assure that the consent process and research procedures as described herein are followed with every participant in the research
5. That any significant systematic deviation from the submitted protocol (for example, a change in the principal investigator, sponsorship, research purposes, participant recruitment procedures, research methodology, risks and benefits, or consent procedures) will be submitted to the IRB for approval prior to its implementation
6. I will promptly report any adverse events to the IRB

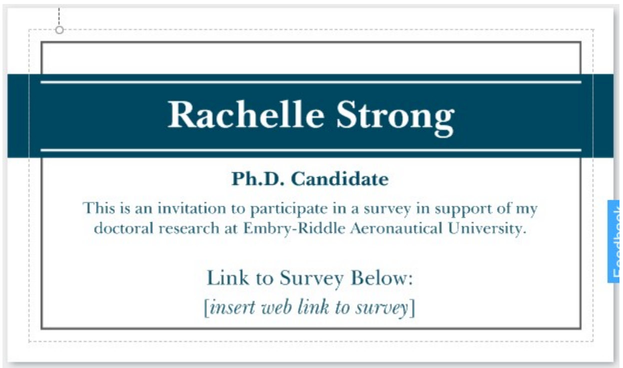
Save my Progress

Submit (no additional changes allowed)

APPENDIX D

Survey Distribution Information

Business Card Distribution
(Note: Back of card blank)



Email and Social Media Distribution

Hello!

My name is Rachelle Strong, and I am a Ph.D. in Aviation candidate at Embry-Riddle Aeronautical University. I would like to cordially invite you to participate in an aviation research survey.

Purpose of this Research: I am asking you to take part in a research project for the purpose of ascertaining public sentiment on Pilot Acceptance of Personal, Wearable Fatigue Monitoring Technology. The purpose of the research is to use the Technology Acceptance Model framework to assess the factors which affect pilots' behavioral intention to use a wearable fatigue monitoring technology device for the purpose of monitoring their personal fatigue levels as part of their normal process for assessing their ability to safely operate an aircraft. During this study, you will be asked to complete a brief online survey about your opinions concerning the use of your acceptance of personal, wearable fatigue monitoring technology as a pilot. The completion of the survey will take approximately 10-15 minutes.

Eligibility: To be in this study, you must be a United States Airline Transport Pilot (ATP) certificate holder.

Risks or Discomforts: The risks of participating in this study are no greater than what is experienced in daily life.

Confidentiality of Records: Your individual information will be protected in all data resulting from this study. Your responses to this survey will be anonymous. No personal information will be collected other than basic demographic descriptors. The online survey system will not save IP address or any other identifying information. In order to protect the anonymity of your responses, I will keep your responses in a password-protected file on a password-protected computer. No one other than the researcher will have access to any of the responses. Information collected as part of this research will not be used or distributed for future research studies

All survey responses that the investigator receives will be treated confidentially and stored in an encrypted file on a password protected computer. However, given that the surveys can be completed from any computer (personal, work, school, etc.), we are unable to guarantee the security of the computer on which you choose to enter your response. As a participant in this study, the investigator wants you to be aware that certain “keylogging” software programs exist that can be used to track or capture data that you enter and/or websites that you visit. Information collected as part of this research will not be used or distributed for future research studies.

Compensation: There is no compensation offered for taking part in this study.

Contact: If you have any questions or would like additional information about this study, please contact Rachelle Strong, gigowskr@my.erau.edu, or the faculty member overseeing this project, Dr. D. Liu, liu89b@erau.edu. For any concerns or questions as a participant in this research, contact the Institutional Review Board (IRB) at 386-226-7179 or via email teri.gabriel@erau.edu.

Voluntary Participation: Your participation in this study is completely voluntary. You may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Should you wish to discontinue the research at any time, no information collected will be used.

If you are interested in participating, please click on the link below to access the survey: *https://www.surveymonkey.com/r/W32M9FP*

Thank you!
Rachelle L. Strong

APPENDIX E

Data Collection Device – Full Study

Likert-Scale Response Legend
1 – Strongly Disagree
2 – Disagree
3 – Somewhat Disagree
4 – Neutral
5 – Somewhat Agree
6 – Agree
7 – Strongly Agree

Intention to Use								
Question ID	Question							
3	Assuming I have access to wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, I intend to use it.	1	2	3	4	5	6	7
4	Given that I have access to wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, I predict that I would use it.	1	2	3	4	5	6	7
Perceived Usefulness								
Question ID	Question							
5	Using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, improves my performance in my job.	1	2	3	4	5	6	7
6	Using wearable fatigue monitoring							

	technology, such as a Fitbit or Apple Watch, in my job increases my productivity.	1	2	3	4	5	6	7
7	Using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, enhances the effectiveness in my job.	1	2	3	4	5	6	7
8	I find wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, useful in my job.	1	2	3	4	5	6	7
Perceived Ease of Use								
Question ID	Question							
9	My interaction with wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is clear and understandable.	1	2	3	4	5	6	7
10	Interacting with wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, does not require a lot of my mental effort.	1	2	3	4	5	6	7
11	I find wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, to be easy to use.	1	2	3	4	5	6	7
12	I find it easy to get wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, to do what I want it to do.	1	2	3	4	5	6	7
Subjective Norm								
Question ID	Question							
13	People who influence my behavior think that I should use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.	1	2	3	4	5	6	7
14	People who are important to me think I							

	should use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.	1	2	3	4	5	6	7
Image								
Question ID	Question							
15	People in my organization who use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, have more prestige than those who do not.	1	2	3	4	5	6	7
16	People in my organization who use wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, have a high status profile.	1	2	3	4	5	6	7
17	Having wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is a status symbol in my organization.	1	2	3	4	5	6	7
Job Relevance								
Question ID	Question							
18	In my job, usage of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is important.	1	2	3	4	5	6	7
19	In my job, usage of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is relevant.	1	2	3	4	5	6	7
Output Quality								
Question ID	Question							
20	The quality of the output I get from wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, is high.	1	2	3	4	5	6	7
21	I have no problem with the output quality of wearable fatigue monitoring	1	2	3	4	5	6	7

	technology, such as a Fitbit or Apple Watch.							
Result Demonstrability								
Question ID	Question							
22	I have no difficulty telling others about the results of wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.	1	2	3	4	5	6	7
23	I believe I could communicate to others the consequences of not using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch.	1	2	3	4	5	6	7
24	The results of using wearable fatigue monitoring technology, such as a Fitbit or Apple Watch, are apparent to me.	1	2	3	4	5	6	7

Demographic Data		
Question ID	Question	Answer Selections
25	How would you classify yourself as a pilot? Select all that apply.	a. Airline Transport Pilot - Airline b. Airline Transport Pilot – Private or Corporate c. Airline Transport Pilot - Cargo d. Airline Transport Pilot – Military e. Airline Transport Pilot – Other
26	How long have you been a pilot (minimum private pilot certificate)?	a. Less than one year b. Between one and five years c. Between five and ten years d. Between ten and twenty years e. More than twenty years

27	Do you wear a watch while you fly?	a. Yes b. No
28	Do you typically wear a fatigue or sleep monitoring device, such as a Fitbit, for personal use?	a. Yes b. No
29	With which geographic location within the United States do you most closely identify?	a. Northeast b. Southeast c. Midwest d. Central Mountain e. Northwest f. Southwest
30	Please specify your gender.	a. Male b. Female c. Prefer not to identify
31	Please specify your age range.	Fill in the blank response
32	Are there any additional factors which would affect your intention to use Fatigue Monitoring Technology, such as a Fitbit or Apple Watch, for the purposes of monitoring your personal fatigue levels prior to operating a flight?	[Open-ended freeform narrative response]