CONTRUCTION INDUSTRY HESITATION IN ACCEPTING WEARABLE SENSING DEVICES

TO ENHANCE WORKER SAFETY

A Thesis

presented to

the Faculty of California Polytechnic State University,

San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Civil and Environmental Engineering

by

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June 2022

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ABSTRACT

Construction Industry Hesitation in Accepting Wearable Sensing Devices to Enhance Worker Safety

Harrison Monroe Fugate

The construction industry is one of the most unsafe industries for workers in the United States. Advancements in wearable technology have been proven to create a safer construction environment. Despite the availability of these devices, use within the construction industry remains low. The objective of this research is to identify and analyze the causes behind the reluctance of the construction industry to implement two specific wearable safety devices, a biometric sensor, and a location tracking system. Device acceptance was analyzed from the perspective of the user (construction field labor) and company decision makers (construction managers). A modified unified theory of acceptance and use of technology (UTAUT) model was developed specific to barriers commonly found within technology adoption in the construction industry including: perceived performance expectancy, perceived effort expectancy, openness to data utilization, social influence, data security, and facilitating conditions. A structured questionnaire was designed to test for association between the mentioned constructs and either behavioral intention or actual use. The questionnaire went through an expert review process, and a pilot study was conducted prior to being distributed to industry. Once all data was received Pearson chi-squared analysis was used to test for association between the constructs. A minority (46%) of labor respondents would not agree to voluntarily use the biometric wearable sensing device. Constructs associated with this finding included perceived performance expectancy, perceived effort expectancy, and social influence. A majority (59%) of labor respondents would not agree to voluntarily use the location tracking wearable sensing device. Constructs associated with this finding included perceived performance expectancy, social influence, and data security. A majority (56%) of management respondents would not implement the biometric wearable sensing device. Constructs found to be associated with this finding included perceived performance expectancy, openness to data utilization, and social influence of the client. A supermajority (68%) of management respondents would not implement the location tracking wearable sensing device. Constructs found to be associated with this finding include perceived performance expectancy, perceived effort expectancy, openness to data utilization, social influence, and data security. This study will aid in the successful implementation of wearable sensing devices within the construction industry. Findings from this study can be used to aid those hoping to implement wearable sensing devices by identifying causes of wearable sensing device rejection. The results of this study can be used by both project managers and health and safety professionals to aid in device acceptance by field labor, and by those whose goal is to increase device use among construction firms.

Keywords: Wearable Sensing Devices, Construction Technology & Safety, WSD, Technology Acceptance

ACKNOWLEDGMENTS

This thesis is dedicated to my parents, Harry and Tyffanee. Thank you for always pushing me to be the best I can be. Thank you for supporting me financially, and allowing me to pursue academic endeavors that many do not have the privilege of pursuing. Lastly, thank you for your continued love and support. This work, as well as my entire academic career, would not have been possible without it.

I'd like to thank my advisor, Dr. Hani Alzraiee, for his countless hours and dedication over the last two years in providing me with guidance to complete this research. His patience during the early stages of this research allowed the topic to mature and come to fruition. This research simply would not have been possible without his direction. I'd like to thank him for helping me produce a produce I am truly proud of.

I'd like to thank my committee member Dr. Robb Moss for agreeing to take part in my defense. Dr. Moss had a great impact on my graduate studies. His advanced geotechnical engineering courses taught me how to think critically, and approach problems from different angels. While I may not have specialized in geotechnical engineering his courses prepared me for much more beyond the content of the course itself.

I'd like to thank my committee member Professor Tom Kommer for agreeing to take part in my defense. Professor Kommer had a great impact on my decision to specialize in construction. I began taking his courses during my undergraduate studies as a construction management minor and continuing taking them through my graduate studies. Professor Kommer has taught me a great deal about the industry, as well as assisted me with this research. I'd like to thank him for spending the extra time to help me achieve this goal.

I'd like to thank my aunt, Dr. Amy Fugate, for her many hours of editorial support. Dr. Fugate is a master with words and a great coach. She helped me become a much better writer through this process, and I will be forever grateful.

I'd like to thank Professor Heather Smith from the Statistics Department for assisting in the statistical analysis portion of this research.

I'd like to thank my employer, North Wind, for allowing me to unitize company resources to complete this research.

Lastly, I'd like to thank all my roommates at Boathouse for making sure I stayed focused and got this project finished in a timely manner.

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LIST OF ACRONYMS

WSD	Wearable Sensing Device
IoT	Internet of Things
PPE	Perceived Performance Expectancy
PEE	Perceived Effort Expectancy
ODU	Openness to Data Utilization
SI	Social Influence
DS	Data Security
FC	Facilitating Conditions
BI	Behavioral Intent
AU	Actual Use
TAM	Technology Acceptance Method
TPB	Theory of Planned Behavior
UTAUT	Unified Theory of Acceptance and Use of Technology

1. INTRODUCTION

1.1 Background

Unlike other industries, working on a construction site has the potential to put workers in danger from the moment they step foot on site. Of the 5,333 workers that died on the job in 2019, 1,061 were in the construction industry (OSHA, 2020). This is one fifth of all US workers and the highest level the industry has recorded since 2007. Over half (58.6%) of these fatalities come from what the industry designates as the "fatal four": falls, struck by an object, electrocutions, and caught-in/between (OSHA, 2020). Injuries must be addressed as well. The industry accounted for 19% of work place related hospitalizations in 2015, and 10% of amputations (Michaels, 2016). Developing technology to prevent these situations is at the forefront of construction safety research (Ruoyu Jin et al., 2019). One example of emerging technology is wearable devices. Wearable devices are small electronics worn on the body of a worker or piece of equipment that can aid in construction site safety in several ways. Wearable devices can track a worker's location, physiological condition, proximity to machinery or equipment, or environmental conditions and have the capability to warn the victim or other involved parties prior to the injury occurring (Awolusi et al., 2018; Jae et al., 2020; Nath et al., 2017; Nnaji et al., 2021). With current technological advancements such as these and continued technology development, it seems unfathomable that death rates in the construction industry continue to rise. Is the technology too expensive? Is it too complex to use? Is the technology not accessible? Upon researching this problem, it appears that the construction industry's problem may break down to general acceptance of this new technology.

Current wearable safety devices (WSDs) have a broad spectrum of applications including aiding safety in the fatal four. Proximity detection devices have been designed using Bluetooth to avoid “struck by” incidents. Devices are placed on pieces of heavy machinery, as well as carried by each pedestrian worker. These devices can alert both the operator and the pedestrian prior to a “struck-by” accident occurring (JeeWoong et al., 2016). A cellphones built-in accelerometer has been used to aid in fall privation. Using designed algorithms the device can calculate if a measurement in the accelerometer is astray. If so, the device will produce sound and vibration as well as alert the on-site superintendent with a message (Dzeng et al., 2014). Smart shoes have been designed to detect and alert the wearer of an electric field that could be present on wet suffice (Gupta et al., 2021). These shoes could help avoid electrocutions on wet construction sites. Proximity detection systems have been explored to ensure proper distance from high voltage electrical systems, specifically when a proper lock-out-tag-out procedure has not been completed (McNinch et al., 2019).

However, the fatal four are not the only areas of interest. A wireless sensor system has been designed to detect dangerous temperatures and oxygen levels of workers in confined spaces. The sensors can alert users and supervisors of unsafe work conditions prior to an accident (Riaz et al., 2014). Smart bracelets check the physiological condition of workers working in high heat areas to help anticipate signs of heat stress and fatigue prior to injury (Yi et al., 2016). Hazardous area location systems have been studied and implemented into BIM models (Kim et al., 2016). Sensors have been developed to ensure workers are using the proper personal protective equipment before using hand tools (Yang et al., 2020). Location tracking sensors can be used to alert workers to unauthorized access or high risk construction zones (Rui Jin et al., 2020). These are just a few of the safety applications of wearable sensing devices.

1.2 Problem Statement

There are construction safety concerns that could be resolved with the implementation of wearable safety devices (WSDs). However, there appears to be reluctance in both field labor and management personnel to implement them. The validity of the technology to create wearable devices for construction safety has been heavily studied (Awolusi et al., 2018; Barata & da Cunha, 2019; Kritzler et al., 2015; Nnaji et al., 2020, 2021). It has been found that wearable safety devices could have prevented 34% of the deaths recorded in 2018 in the OSHA archives (Nnaji et al., 2020). Based on the data, WSDs represent a logical option to be adopted by the construction industry to address safety issues. Unfortunately, that has not been the case. A study by McGraw Hill Construction concluded 43% of contractors had no intention of implementing new safety technology (Construction, 2013; Nnaji et al., 2020). The scale of preventable death certainly warrants further research into the field implementation of WSDs.

Why are these devices not being used? What are the barriers to the implementation of these devices? One argument is that worker privacy concerns have hindered the use of wearable technology (Ajunwa, 2018). This recent study found that construction laborers (330 staff) were hesitant to wear a WSD for fear that the device might capture data that they considered to be personal and private. The laborers surveyed also did not like the idea of being consistently monitored while they work.

Another concern raised was whether the collection of private health data would be used for health insurance or employment decisions. (Nnaji et al., 2021).

In addition to answering the above question, it may also be important to consider more general hesitancies that come with the adoption of any new technology. Individuals may want to know how the new technology will aid their work. Given the concerns raised in previous studies, the individuals may need to compare the perceived risks of the WSD to how it will aid their work. For others, there may be concerns that the technology will be hard to learn. There are outside factors that influence ones adoption of new technology such as family or coworkers, and to others, it may all come down to cost (Venkatesh et al., 2003). The question to be answered is whether or not any of these general factors apply to the adoption of wearable sensing devices in the construction industry.

1.3 Research Goal

The objective of this research is to identify and analyze the causes behind the reluctance of the construction industry to implement two specific wearable safety devices, a biometric sensor, and a location tracking system. The researcher will use qualitative tools to collect and analyze the data to address the research objective. The data will be collected from construction management professionals and construction field labor. The data will then be analyzed to subsequently identify the hurdles that hinder the acceptance of WSDs in the construction industry. If the research demonstrates the hurdles, then recommendations to increase usage can be made.

Questions will be tailored in order to gain valuable knowledge into the concerns of construction field labor and construction management regarding the implementation of specific wearable sensing devices; a biometric device and a location tracking system. To achieve this objective the following sub-objectives will be carried out:

1. Conduct a literature review on the current state of construction safety, wearable sensing devices, and technology acceptance methods.
2. Identify the barriers to entry of wearable sensing devices.
3. Develop a research methodology to achieve the research goal.
4. Develop a structured questionnaire to collect data regarding the WSD hesitancies.
5. Identify the study sample and distribute questionnaires to the targeted sample.
6. Analyze the collected data to identify the barriers to entry of these devices.
7. Provide recommendations on how to best implement said devices.

1.4 Thesis Organization

The thesis is organized as follows: Chapter 2 presents a comprehensive literature review of the current state of construction safety, wearable sensing devices, and technology acceptance methods. Chapter 3 presents the methodology used for the design of questionnaires tailored to the key stakeholders and the approach for data collection using the questionnaires. Chapter 4 presents a statistical analysis of the of the field labor results. Chapter 5 presents a statistical analysis of the management results. Chapter 6 presents a conclusion to discuss the contributions, recommendations, prevailing limitations, and proposes areas for future research.

2. LITERATURE REVIEW

2.1 Overview

This chapter describes a detailed literature review of the current state of construction safety research, Internet of Things (IoT), an introduction to wearables sensing devices, technology acceptance methods, and acceptance of wearable sensing devices.

2.2 Construction Safety

Construction safety is a heavily studied field in academia. This section will discuss the main areas of focus within construction safety as a whole. In a recent study, Jin et al. (2019) conducted a holistic review of existing construction safety research recently published. It found the main area of today's construction safety research included:

1. Safety climate and safety culture
2. Information and communication technology in safety management
3. Worker safety perception and behavior,
4. Safety management system, and
5. Hazard identification, accident causation, and risk management in safety (Ruoyu Jin et al., 2019)

The following section of the literature review will address these topics to gain a holistic understanding of current research regarding construction safety.

2.2.1 Safety Climate and Safety Culture

While safety culture has no universally agreed upon definition, one of the most popular is as follows: " safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to and the status and proficiency of organization's health and safety management" (Commission, 1993; T. Lee & Harrison, 2000; Zohar, 1980). Safety climate on the other hand is said to be more superficial. While Safety culture is a set of beliefs of the organization, safety climate includes the effects of environmental and organizational factors on those beliefs (Kalteh et al., 2021; Mearns & Flin, 1999). Research has connected safety climate and culture to safety performance making it a critical part of construction safety as a whole (Choudhry et al., 2009; Teo & Feng, 2009; Wen Lim et al., 2018)

2.2.2 Information and Communication Technology (ICT) in Safety Management

Information and communication technology (ICT) "refers to technologies that provide access to information through telecommunication. It is similar to information technologies (IT) but focuses primarily on communication technologies. This includes the internet, wireless networks, cell phones, and other communication mediums" (Ratheeswari, 2018). Building Information Modeling (BIM) has been used as a safety management tool in existing studies (F. Chen & Liu, 2015; Sulankivi et al., 2010; Zhang, Sulankivi, et al., 2015). Virtual and augmented reality have been studied to help improve construction safety (X. Li et al., 2018; Pedro et al., 2016), and improve communication between designer and builder (Sacks et al., 2015). Databases have been developed to catalog near miss events (Shen & Marks, 2016). ICT also includes wearable sensing devices, which will be discussed further in section 2.3.

2.2.3 Worker Safety Perception and Behavior

Another heavily studied area of construction safety is the influence of worker safety perception and behavior (Ruoyu Jin et al., 2019). Multiple studies have looked into the positive impact of supervision on construction safety practices (Fang et al., 2015; Winge et al., 2019). Factors such as safety awareness and co-worker attitude have been linked to safety performance (Choudhry & Fang, 2008). Research suggests that there are different safety perceptions between individuals of varying demographics on a construction site including experience and position (Han et al., 2019).

2.2.4 Safety Management System

Organizations often adapt a certain safety management system in order to achieve the highest form of safety performance (Wachter & Yorio, 2014). Different aspects of a firm's safety management system have shown to affect safety performance in different ways. Management's commitment to safety management has a significant correlation to safety performance (Abudayyeh et al., 2006). Management's commitment to safety training and education play a significant role in safety performance (Q. Chen & Jin, 2012). Another study suggests that worker engagement levels directly influence accident rate, and in order to decrease this rate the safety management plan must be designed with worker engagement levels in mind (Wachter & Yorio, 2014).

2.2.5 Hazard Identification, Accident Causation, and Risk Management in Safety

The highest priority accident precursor is workers failing to identify hazards or neglection of hazards (Pereira et al., 2018). Hence, "unidentified hazards present the most unmanageable risks" (Carter & Smith, 2006). Modern risk management aims to utilize technology to aid in risk mitigation. Smart personal protective equipment is being studied to help reduce risk (Ammad et al., 2021; B. Lee et al., 2020; Márquez-Sánchez et al., 2021). Construction safety risk management can include placing an emphasis on making safety management decisions during the design phase of the project (Gangolells et al., 2010).

2.3 Introduction to Wearable Devices

Wearable devices, wearables, or wearable technology refer to small electronic and mobile device, or computers with wireless communication capability that are incorporated into gadgets, accessories, or clothes, which can be worn on the human body, or even invasive versions such as micro-chips, or smart tattoos (Luczak et al., 2019; Ometov et al., 2021). Modern wearable technology started in the early 2000s with innovations such as the wireless headset (Ometov et al., 2021). Wearable technology progressed through the 21st century with innovations such as the first wearable fitness trackers by Fitbit in 2009 (Ometov et al., 2021). Today commercial wearables have flooded the market including devices such as the Apple Watch (Figure 2.1), or Whoop a popular commercial biometric device that provides the user with information regarding physical recovery time, fitness statistics, and sleep quality metrics. It does this by collecting data such as heart rate variability, heart rate, strain, and respiratory rate (Whoop, 2022). Wearable devices have expanded out of just consumer products, and industries such as healthcare, athletics, education, manufacturing, and construction

(Affia & Aamer, 2021; Anliker et al., 2004; Bakla, 2019; R. T. Li et al., 2015; Nnaji et al., 2021)

WSDs are a type of wearable device that collects data specific to the user. This data could include physiological data, environmental data, proximity data, and/or location based data. .Examples of these devices will be discussed in sections 2.3.1-2.3.4. While WSDs can be used to increase construction productivity (Mao et al., 2018), and communication (George, 2022) this thesis focuses on WSDs specifically designed to increase construction site safety.

Figure 2.1 Wearable device Apple Watch (Apple, 2022)

Many studies have concluded that WSD's have the potential to enhance worker safety (Awolusi et al., 2018; Jae et al., 2020; Nath et al., 2017; Nnaji et al., 2021). They do this through "efficient data collection, analysis, and the provision of real-time information about safety and health risks to personnel" (Nnaji et al., 2021) Examples of these devices include smartwatches, wristbands, smart hard hats, safety vests, smart boots, clips, tags, etc. (Nnaji et al., 2020).

2.3.1 Physiological Monitoring Wearable Sensing Devices

Physiological WSDs use sensors to measure functions of the human body. These types of wearable devices have been used for many applications outside of the construction industry. One example, from the medical field, is a wearable device used to monitor and alert high-risk cardiac/respiratory patients (Anliker et al., 2004). Physiological wearables are utilized by sports teams to monitor internal and external workloads of athletes (R. T. Li et al., 2015). Other parameters to be measured include heart rate, heart rate variability, respiratory rate, body posture, body speed, body temperature, activity level, skin temperature, environmental temperature, walking steps, blood oxygen, blood pressure, body rotation and orientation, and electroencephalogram (EEG) (Awolusi et al., 2018; Sungjoo et al., 2018). When measuring these metrics in real time health hazards can be identified prior to an accident. Examples of construction related health hazards include stress, heat, strain injuries, skin diseases, breathing or respiratory diseases, excess cold, excess fatigue, carpal tunnel injuries, back injuries, musculoskeletal disorders, preventing falls, evaluating hazard-recognition abilities, and monitoring workers' mental status (Awolusi et al., 2018; Houtan et al., 2018, 2019; R. et al., 2019; Sungjoo et al., 2018). An example of a physiological monitoring WSD can be seen below in Figure 2.2. This device by Kenzen measures core body temperature and heart rate in order to predict warning signs of heat stress or heat stroke helping keep workers safe during hot summer months (Kenzen, 2022)

Figure 2.2 Physiological monitoring WSD (Kenzen, 2022)

2.3.2 Environmental Wearable Sensing Devices

Environmental WSD's use sensors to collect data regarding the environment surrounding the user. Two different environmental risks are posed to construction workers. First, exposure to weather related environmental concerns. Second, exposure to hazardous materials that are inherently needed for construction activates (Ibukun et al., 2021). These sensors measure metrics such as air quality, barometric pressure, carbon monoxide, capacitance, color, gas leaks, humidity, hydrogen sulfide, temperature and light (Swan, 2012). Real time measurement of these metrics can help alert construction workers that they are in a dangerous work environment prior to any accident or imposed illness. An example of an environmental sensing WSD can be seen below in Figure 2.3. The AerBand by AerNos can detect toxic gasses in the vicinity of the user, and alert them prior to prolonged exposure.

Figure 2.3 Environmental Wearable Sensing Device (AerNos, 2022)

2.3.3 Proximity Detection & Location Tracking Wearable Sensing Devices

Tracking the location of workers and equipment can help create a safer work environment. Proximity Detection WSD's determine the distance between two sensors and can alert the wearer if the range is determined to be unsafe. Location Tracking WSDs track the physical location of the wearer or piece of equipment. Tracking, in construction, has used a variety of technologies including, GPS ((Rahman et al., 2021), RFID and RF localization (Montaser & Moselhi, 2014; Zhu et al., 2011), Ultra-Wideband (Saidi et al., 2011; Shahi et al., 2012; Siddiqui et al., 2019). Studies have been conducted into how using these types of tracking technologies can help increase safety on a construction site. GPS tracking has been used to avoid collisions while cranes hoist material (Zhang, Teizer, et al., 2015). The highest amount of construction struck by incidences in 2012 occurred when a pedestrian worker was struck by a piece of construction equipment. Bluetooth proximity detection has been used to help ovoid these incidences (JeeWoong et al., 2016). An example of a location tracking and proximity detecting WSD can be seen below in Figure 2.4. The Spot-r clip by Triax can detect worker identify zone-based worker location (as well as free falls), improving injury avoidance and fall response time by over 90% (Triaxtec, 2022)

Figure 2.4 Proximity and Location tracking device: Spot-r (Triaxtec, 2022)

Another example of a location tracking WSD is the Smart Boot by Sole Power seen below in Figure 2.5. These boots can prevent struck-by incidents, and send emergency alerts caused by a fall from height or environmental concern (SolePowerTech, 2022)

Figure 2.5 Smart Boot location tracking WSD (SolePowerTech, 2022)

2.3.4 Limitations of Wearable Sensing Devices

Wearable sensing devices still have many limitations within the construction industry. Calculating the return on investment of emerging technologies can be difficult, and can be seen as a limiting factor (R. et al., 2019). Energy consumption has been a significant challenge for wearable technology. In order to increase precision, and decrease the size of the device orders of magnitude of energy reduction are needed in sensing, analysis, and wireless communication (Williamson et al., 2015). Limitations on battery life have not allowed for continuous device usage throughout an entire work day (Pavón et al., 2017). When using radio frequency for proximity detection on a construction sites multiple limitations have been observed including, limited power supply for both equipment and ground units, difficulty mounting systems on all necessary parties including all equipment and personnel, and unique environmental concerns on construction sites that limit the performance of the devices (Teizer, 2015). Some WSDs have been manufactured into construction clothing, however questions remain regarding their durability following repeated washing (Callejas Sandoval & Kwon, 2019). Physiological wearable sensing devices are currently being studied to better assess worker perceived risks. Limitations to the implementation of these devices include hindrances to construction work, and variability of a construction field setting compared to a controlled lab setting (B. G. Lee et al., 2021).

2.4 Internet of Things

WSDs can be considered a subset of Internet of Things (IoT). "Wearable IoT is a technological infrastructure that interconnects wearable sensors to enable monitoring human factors including health, wellness, behaviors, and other data useful in enhancing individuals quality of life." (Hiremath et al., 2014; Ibukun et al., 2021). Hence, an understanding of IoT as a whole is necessary to understand the applications of wearable sensing devices.

2.4.1 Introduction to the Internet of Things

"The term Internet of Things generally refers to scenarios where network connectivity and computing capability extends to objects, sensors and everyday items not normally considered computers, allowing these devices to generate, exchange and consume data with minimal human intervention" (Rose et al., 2015). While the IoT has progressed greatly in recent years the concept has been around nearly as long as the internet itself (Suresh et al., 2014). The term was first coined in 1999 by Kevin Ashton in his discussions regarding supply chain management (Ashton, 2009). However, one of the first examples was a toaster that could be turned on and off over the internet created by Interop in 1990 (Romkey, 2016). Today IoT devices have been integrated across many industries including: Transportation, Healthcare, Infrastructure, Public Services, Urban Planning, Commercial Appliances, Manufacturing, Education, etc. (Georgios et al., 2019). In healthcare IoT sensors have the ability to monitor vitals of patients with chronic conditions that once required constant human supervision (Yuehong et al., 2016). IoT technology is being used in the transportation sector to improve infrastructure and transportation systems to reduce traffic congestion (Mehmood et al., 2017). IoT technology has been used to design "smart" warehouses to for the manufacturing industry. The technology implemented real-time visibility and traceability and improved overall warehouse efficiency (Affia & Aamer, 2021). Education researchers have studied IoT devices that measure a student's pattern of sleep and to optimize periods of studying and resting (Bakla, 2019). Overall, IoT technology has many applications across multiple industries.

2.4.2 Internet of Things in Construction

Internet of Things in Construction has been applied to many different aspects of construction. Studies have integrated BIM and IoT devices in aspects such as energy management, construction monitoring, health and safety management, and building management (Dave et al., 2018; Tang et al., 2019). IoT has been used to help automate decision making in repetitive construction operations (Louis & Dunston, 2018). IoT devices have been used to monitor construction sites in order to improve safety (Lam et al., 2017). IoT devices have been used to improve the quality control and quality assurance of prefabricated construction projects (Zhao et al., 2019). IoT devices have been used to help secure construction sites by locating and alarming unauthorized intrusions (Rui Jin et al., 2020).

2.5 Technology Acceptance Theories

Technology acceptance theories and models help us to understand how users may understand new technology (Momani & Jamous, 2017). There are many factors and variables that go into any individuals choice to accept and use new technology (Fishbein & Ajzen, 1975). There are many different types of technology acceptance theories, and each uses different variables or constructs to help explain why an individual accepts or rejects a new technology. Examples of these theories include the technology acceptance model (TAM) ((F. D. Davis, 1985), theory of planned behavior (TPB) (Ajzen, 1991), and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003). For this thesis aspects of various technology acceptance theories will be used to test the acceptance of WSDs in the construction industry.

2.5.1 Technology Acceptance Model (TAM)

The Technology Acceptance Model or TAM (F. D. Davis, 1985) has been one of the most popular models for analyzing user acceptance since its creation (Sharp, 2006). The model is based on two constructs influencing a person's attitude toward using new technology: perceived usefulness, and perceived ease of use. Davis defined these as follows:

- **Perceived usefulness**: The degree to which an individual believes that using a particular system would enhance his or her job performance.
- **Perceived ease of use**: The degree to which an individual believes that using a particular system would be free of physical and mental effort.
- **Behavioral Intention to Use**: After considering perceived usefulness, and perceived ease of use, the intent of an individual to use or not use a system.
- **Actual System Use**: A yes or no answer regarding if the individual started using the system.

The model suggests that perceived usefulness has a direct influence on attitude toward using new technology, while perceived ease of use influences both perceived usefulness and attitude toward using. Finally, attitude toward using has a direct influence on a user's actual system use. The model can be seen visually below in Figure 2.6.

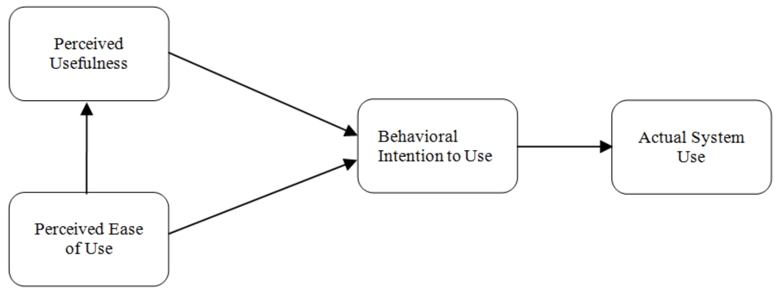

Figure 2.6 The original TAM model (F. D. Davis, 1985).

TAM has been used to analyze technology acceptance in the construction industry. The acceptance of Building Information Modeling (BIM) was analyzed by S.-K. Lee et al.,(2013). The acceptance of web based training in the construction industry was analyzed using TAM by Park et al., (2012). The acceptance of scanners within the industry to create 3D point clouds was analyzed using TAM by Sepasgozaar (et al., 2017). The acceptance of a smart system for prefabricated housing construction used a modified TAM in by Diandian et al., (2018).

While TAM is an excepted model for measuring the acceptance of technology it has limitations. TAM lacks the construct of social influence. Outside influences such as friends, family, coworkers, and competitors can influence ones acceptance of a new technology (Ajibade, 2018). TAM also does not consider external factors such as age, and education level. It can be argued that these factors have a larger effect on technology acceptance than perceived usefulness and perceived ease of use (Zahid et al., 2013).

2.5.2 Theory of Planned Behavior (TPB)

The theory of planned behavior (TPB) was first introduced by Icek Ajzen in 1985 as an extension of his theory of reasoned action (TRA) (Ajzen, 1985). Similar to TAM the theory of planned behavior uses a set of constructs to predict behavioral intent to use a new technology. In TPB these constructs are: attitude toward a behavior, subjective norm, and perceived behavioral control (Ajzen, 1985). These constructs influence ones intention, and in turn influence ones behavior.

- **Attitude toward a behavior**: An individual's positive or negative feelings (evaluative affect) about performing the target behavior.
- **Subjective norm**: The person's perception that most people who are important to him think he should or should not perform the behavior in question.
- **Perceived behavioral control:** The perceived ease or difficulty of performing the behavior.
- **Intention:** After considering ones attitude toward a behavior, subjective norm, and perceived behavioral control. Intention measures ones intention to perform a behavior.
- **Behavior:** A Yes or no response if the individual is performing the behavior in question.

The model suggests that the three constructs directly influence an individual's attitude toward a behavior, which in turn directly influences the actions of said person. (Ajzen, 1985, 2006; Momani & Jamous, 2017). The model can be seen visually below in Figure 2.7.

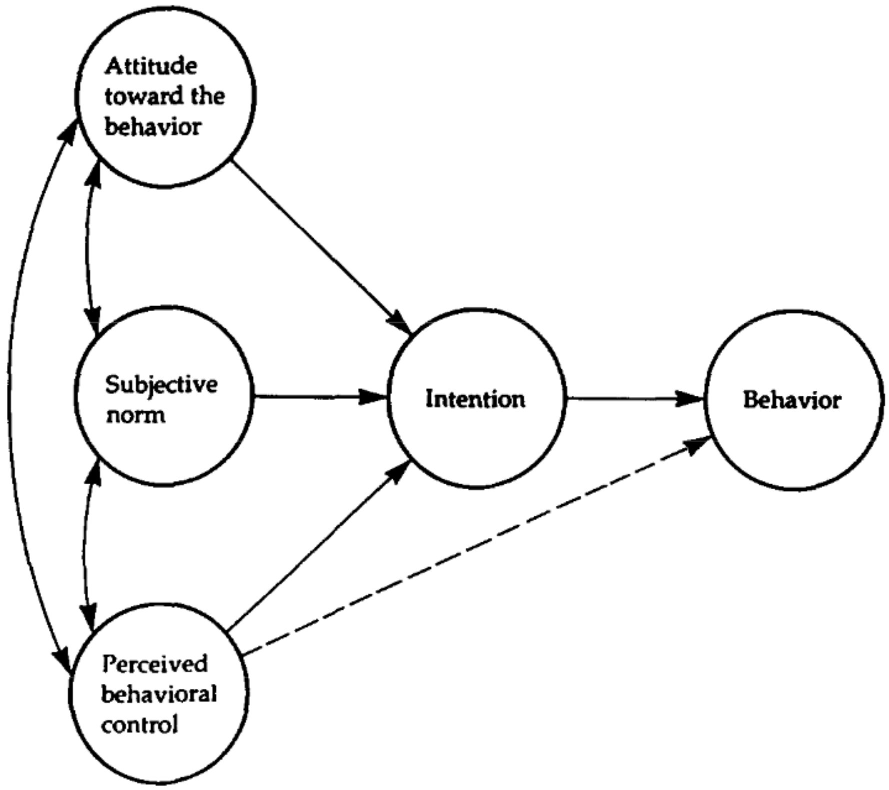

Figure 2.7 The original TPB model (Ajzen, 1985).

TPB has been used to study the construction industry on numerous occasions. An extended version of TPB was used to better understand the critical factors that influence construction waste reduction behavior by contractor employees in China (J. Li et al., 2018). A similar study in India used an extended version of TPB to analyze the attitude of builders towards construction and demolition waste recycling (Jain et al., 2020). Another study used TPB to investigate the organizational and personal factors that underlie the safety behaviors of older construction workers considering their age-related characteristics (Peng & Chan, 2019). A study used TPB aims to explain critical antecedents and cognitive mechanisms of construction workers' safety citizenship behavior (Qing et al., 2020).

One limitation of TPB is the lack a personal norm construct. It has been argued that due to the lack of the personal norm construct that TPB is not as effective outside the United States (Morren & Grinstein, 2021).

2.5.3 Unified Theory of Acceptance and Use of Technology (UTAUT)

UTAUT was created in 2003 by Viswanath Venkatesh. The model was created when eight prominent acceptance models (including TAM and TPB) where compared and combined (Venkatesh et al., 2003). Similar to both TAM and TPB, UTAUT uses a variety of constructs to predict ones behavioral intention to accept a new technology. These constructs include performance expectancy, effort expectancy, social influence, and facilitating conditions. As well as subconstructs of age, gender, experience, and voluntariness of use.

- **Performance expectancy**: *The degree to which an individual believes that using the system will help labor attain gains in a job* (F. Davis et al., 2006; Shin, 2009).
- **Effort Expectancy**: The degree of ease associated with the use of the system (Venkatesh et al., 2003).
- **Social Influence:** *The degree to which a user perceives that significant persons believe technology use to be important* (Diaz & Loraas, 2010).
- **Facilitating Conditions:** The degree to which an individual believes that organizational and technical infrastructure exists to support use of the system (Venkatesh et al., 2003).

- **Behavioral Intention:** After considering performance expectancy, effort expectancy, and social influence the intent of an individual to use or not use a system.
- **Use Behavior:** After considering ones behavioral intention and surrounding facilitating conditions will the individual use the system (yes or no).
- **Gender:** The gender of the respondent can influence performance expectancy, effort expectancy, and social influence.
- **Age:** The age of the respondent, this can influence performance expectancy, effort expectancy, social influence, and facilitating conditions.
- **Experience:** Experience using a new technology can affect effort expectancy, social influence, and facilitating conditions.
- **Voluntariness of Use:** If an individual chooses to use or is forced to use a new technology can affect social influence.

The model suggests four constructs, paired with gender, age, experience, and voluntariness of use, directly influence the behavioral intention of a person to accept a new technology. In the model, behavioral intention directly influences use behavior. The model is depicted visually in Figure 2.8.

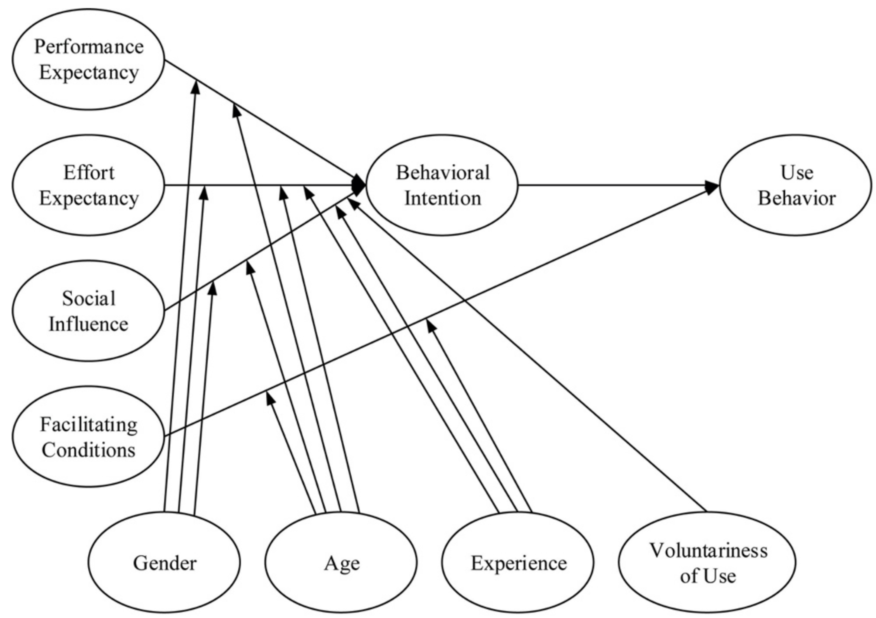

Figure 2.8 The original UTAUT model (Venkatesh et al., 2003).

UTAUT has been used to analyze technology acceptance in the construction industry. One research study used UTAUT to analyze human behaviors that affect the digital transformation of the construction industry (Hewavitharana et al., 2021). Another used UTAUT to identify factors which affect the readiness of local governments in establishing a smart city system (Gunawan, 2018). A study created a hybrid UTAUT model to better understand the factors that influence the acceptance of BIM in facilities management (Hilal & Maqsood, 2017). Another looked analyzed the acceptance and use of wood-technology in the non-residential construction sector (Barrane et al., 2018). In (Okpala et al., 2021) UTAUT was tested specifically on its ability to predict WSD acceptance. It was found that UTAUT outperformed all other models explaining 91% of the variance of WSD actual use.

When looking into the major limitations of UTAUT the majority of studies acknowledged that focusing on a single subject (i.e. community, culture, country organization, agency, department, person, or age group) was a constraint (Rana & Dwivedi, 2015). Another major limitation was focusing on a single task at a single point in time, leading to the potential generalization of findings (Rana & Dwivedi, 2015). Other reported limitations of UTAUT in literature include limited sample size, use of students to explore workplace issues, no use of moderating variables, and lack of exogenous factors (Rana & Dwivedi, 2015).

2.6 Wearable Sensing Device Acceptance

Studying the barriers to entry of wearable safety devices is not entirely new. Multiple studies have looked at this topic from different angles, using different methods, and have drawn different conclusions. In this section of the literature review, these studies will be addressed, both their findings and limitations.

In the study (Schall et al., 2018) a survey was completed to address the barriers to adoption of wearable sensors in the workplace. This study surveyed occupational safety and health professionals from a wide range of industries including manufacturing, construction, oil, energy, and gas, insurance, academia, government, healthcare, transportation, and food processing. The results of this study found that eighty-one percent of respondents would consider using wearables to help track risk factors at work. The most cited barrier to enter was concerns regarding employee privacy/ confidentiality of collected data. Other highly cited barriers included employee compliance, sensor durability, the cost/benefit ratio of using wearables, and good manufacturing requirements.

In (Nnaji & Karakhan, 2020) a survey was completed to (1) identify available technologies for OSH management, (2) identify and rank the benefits and limitations of technologies for OSH management, and (3) identify and quantify barriers to adopting technologies for OSH management and propose solutions to overcome such barriers. The study revealed thirteen barriers to the adoption of safety and health technology in the construction industry with the top five being upfront investment, required training, availability of technical support, doubt concerning technology performance, and clients lack of demand. The limitations of this study are that only "construction managers" and "project managers" were surveyed.

In (Choi et al., 2017) a survey was conducted to analyze what drives construction workers' acceptance of wearable devices in the workplace. This study looked at two devices in particular, a location tracking vest, and a physiological tracking wristwatch. The study used an integrated TAM & UTAUT model to reach their conclusions. The constraints the authors chose for their study included perceived privacy risk, perceived usefulness, perceived ease of use, social influence, and intention to adopt. For the smart vest, the study found that perceived performance expectancy, perceived ease of use, social influence, and perceived privacy risk influenced the adoption of the device. For the physiological tracking wristband perceived usefulness, social influence, and perceived privacy risk were found to influence adoption of the device. However, perceived ease of use and hedonic motivation were found to not have significant associations with adoption of the device. The limitations of the study include limited diversity (three construction sites in similar geographical area), and only construction foreman being surveyed. (Schall et al., 2018).

In (Okpala et al., 2021) multiple technology acceptance methods were tested for their ability to predict usage of WSDs. TAM, TPB, and UTAUT were tested and all displayed a strong ability to explain variance (all above 89%) of the construct *actual use*. This study is confirmation that technology acceptance methods are a reliable way of testing for WSD acceptance. The study then designed a hybrid acceptance model based off its findings. The constructs included in the hybrid model include Openness to Data Utilization, Data Security, User Satisfaction, Performance Expectancy, Effort Expectancy, Social Influence, and Facilitating Conditions. The hybrid conceptual model was not tested in the study and left an opportunity for future research.

In a follow on study by Okpala et al. (2021), an entire success model was developed and tested for assessing the impact of WSDs in the construction industry. The study used the statistic of convergent validity to test if the constructs of subjective norm, perceived behavioral control, perceived usefulness, perceived ease of use, openness to data utilization, and security were related to an individual's use of a WSD. It was found that perceived behavioral control, openness to data utilization and subjective norm were related to individual use. It could not be determined that perceived ease of use, perceived usefulness, and security were related to individual use.

In conclusion, numerous studies have been performed to collect information regarding the barriers to entry of WSDs in the construction industry. These studies have found barriers including employee privacy, data privacy, employee compliance, technology performance, technology durability, cost, client demand, employee training, and user satisfaction.

2.7 Summary of Barriers to Entry

Many barriers to entry of WSDs were identified during the literature review. Barriers to entry were identified under three major categories; device limitations, general technology acceptance barriers, and existing barriers from previous studies. Barriers associated with device limitations included:

- Return on investment of implementing the device.
- Questions regarding device durability.
- Limitations regarding the device battery life.
- Questions regarding device performance.

These device limitations can be considered barriers to entry. The limitations discussed can fall into the category of device performance and cost. Barriers to entry associated with general technology acceptance theories include:

- Performance Expectancy: The degree to which an individual believes that using the system will help labor attain gains in a job.
- Effort Expectancy: The degree of ease associated with the use of the system.
- External Factors (Subjective Norm, Social Influence, and Facilitating Conditions)
    - Subjective norm: The person's perception that most people who are important to him think he should or should not perform the behavior in question.

- Social Influence: The degree to which a user perceives that significant persons believe technology use to important
- Facilitating Conditions**:** The degree to which an individual believes that organizational and technical infrastructure exists to support use of the system

These barriers were collected through a review of the most widely accepted technology acceptance theories: TAM, TPB, and UTAUT. Barriers to entry associated with previous studies regarding the acceptance of WSDs in the construction industry include:

- Concerns regarding employee privacy.
- Concerns regarding storing sensitive data.
- Concerns regarding employee compliance with devices
- Concerns regarding technology performance, and durability, and cost.
- Questions regarding client demand for technology implementation.
- Concerns regarding training employees to use the new technology.
- Questions concerning user satisfaction of devices.

3. METHODOLOGY

3.1 Overview

This chapter details the methodology used to assess the barriers to entry of wearable sensing devices within the construction industry. The methodology outline can be viewed below in Figure 3.1.

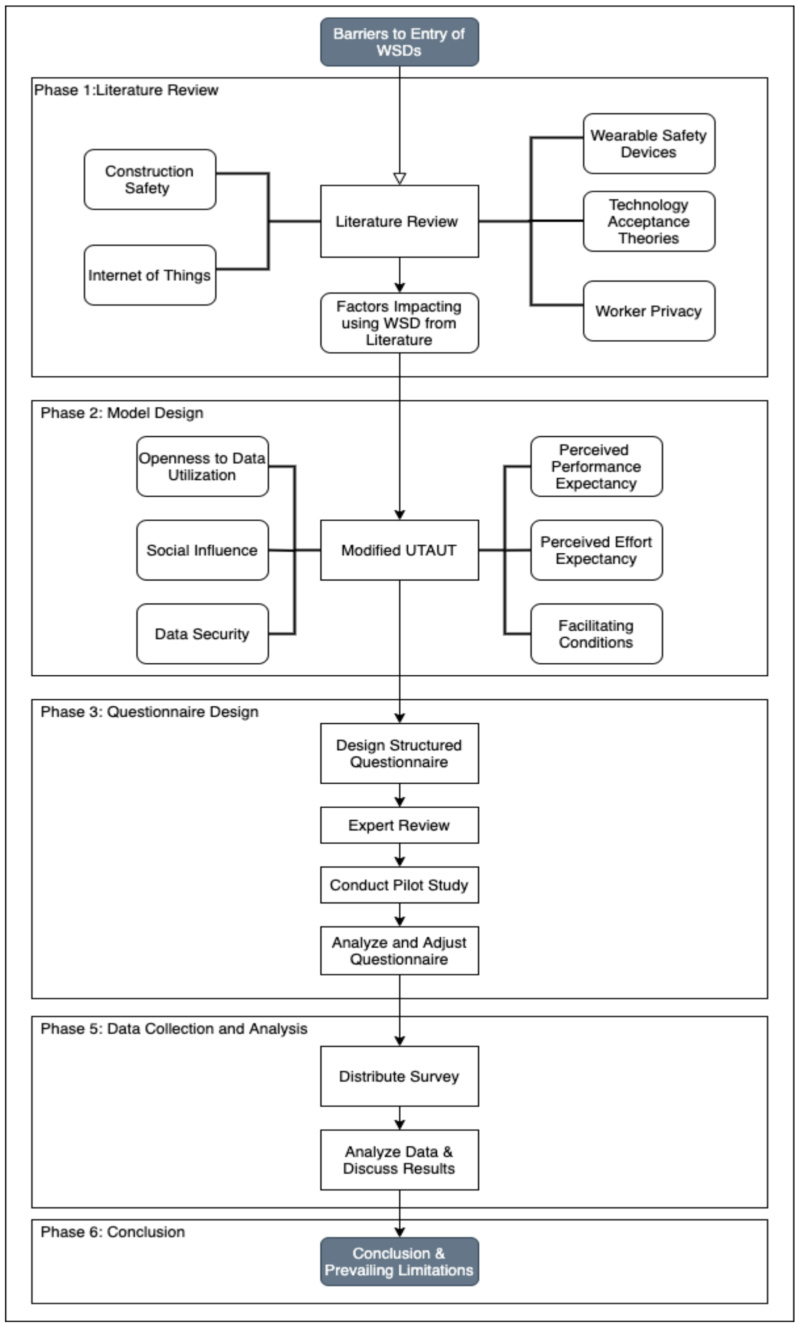

Figure 3.1 A visual representation of the methodology outline.

3.2 Phase I: Literature Review

The literature review was conducted in phase I in order to gain an overall understanding of the wearable sensing devices available to construction workers as well as any potential limitations. An extensive review of current wearable sensing devices was conducted using the existing body of knowledge. The review included research into device safety features, metrics, and sensing technology. After this review was conducted two types of devices were selected to be used in the study due to their popular yet controversial nature. These devices are the biometric WSD and the location tracking WSD. The next step was to review the barriers to entry of these devices.

After the devices were selected, literature was reviewed to consider the various frameworks for technology adoption. These frameworks included: the technology acceptance model (TAM); Theory of Planned Behavior (TPB); and the Unified Theory of Acceptance and Use of Technology (UTAUT). These frameworks were used to aid in generating the case specific acceptance model.

The literature review phase identified a list of constructs from two areas: constructs influencing WSD acceptance and constructs affecting general technology adoption. Constructs were then used to design the hybrid model.

3.3 Phase II: Model Design

After the review of multiple technology acceptance models, a modified UTAUT model was designed to best fit the study. This model breaks up the barriers to entry of WSDs into six constructs. The questionnaire was then designed based on these variables. This model closely resembles a hybrid conceptual model created by (Okpala et al., 2021) with the discriminating factor being the redaction of the user satisfaction variable. This variable was redacted due to the authors' disagreement with the relevance of user satisfaction of a device in a workplace setting. The remaining variables from Okpala's hybrid conceptual model remain. The variables include: Perceived Performance Expectancy (PPE); Perceived Effort Expectancy (PEE); Openness to Data Utilization (ODU); Data Security (DS); Social Influence (SI); and Facilitating Conditions (FS). The modified UTAUT model can be seen visually below in Figure 3.2

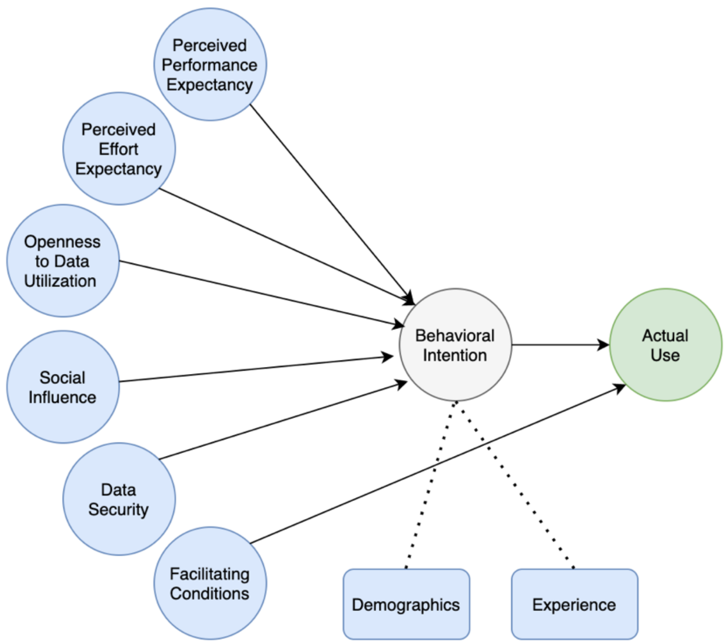

Figure 3.2 A visualization of the Modified UTAUT Model designed for the study.

3.3.1 Perceived Performance Expectancy

Perceived Performance Expectancy (PPE) is the first of the four key constructs of UTAUT. Refer to Section 2.5.4 for a comprehensive review of this variable. A key indicator of the individual's use of the device is whether or not the individual asked to use a new piece of technology believes it will increase their performance. In the context of wearable sensing devices, the questions in the section were designed to understand if the user or manager believes the device will help make their construction site a safer environment.

3.3.2 Perceived Effort Expectancy

Perceived Effort Expectancy (PEE) is the second of the four key constructs of UTAUT. Refer to section 2.5.4 for a comprehensive review of this variable. Questions in this portion of the questionnaire were designed to gauge the preconceived notion of how difficult learning how to use the specific WSD would be. In the questionnaire, the field laborers are asked to assess the level of difficulty they would envision in having to learn the new device. Management individuals were asked to assess the level of difficulty they would envision training their laborers.

3.3.3 Openness to Data Utilization

Openness to Data Utilization (ODU) was identified as a key variable influencing WSD adoption in Section 2.6.1. Field laborers were asked about their concerns regarding how their company uses the data they collect from specific WSDs. Management was asked about their concerns regarding legal issues arising from tracking this type of personal employee data.

3.3.4 Data Security

Data Security (DS) was identified as a key variable influencing WSD adoption in Section 2.6.1. Questions in this section are similar to questions in the Openness to Data Utilization section in that they revolve around data collected by the WSD's. However, questions in this section specifically target the level of concern regarding potential leaks of personal data to the outside world i.e. sensitivity to potential hacking.

3.3.5 Social Influence (SI)

Social Influence is the third of the four key constructs of UTAUT. Refer to section 2.5.4 for a comprehensive review of this variable. In the context of WSDs, users and management are asked if the opinion or action of a variety of groups would influence their acceptance of WSDs. For device users, these groups include family/loved ones and other members of their crew. For management, these groups include competitors in the industry and their clients.

3.3.6 Facilitating Conditions (FC)

Facilitating Conditions is the fourth of the four key constructs of UTAUT. Refer to section 2.5.4 for a comprehensive review of this variable. For simplification in this study, Facilitating Conditions was correlated to the overall total cost of the devices. Therefore, questions in this section were left off the field laborer questionnaires because device cost has no impact on them. However, the management survey included the construct because the cost could potentially play a large factor in the decision to implement a device. Management individuals could have the behavioral intention (BI) to accept WSDs, but due to high device costs choose to not use (AU) the technology.

3.4 Phase III: Questionnaire Design

The questionnaire begins by asking a series of demographic questions including age range, job title, years of industry experience, union status, geographic region, project type, and work sector. The questionnaire was designed to help determine if there is an association between any of the six variables and either behavioral intention or actual use. To do this the questionnaire was designed to ask participants their thoughts on the device with each question paired with a coinciding construct from the model. In order to be able to analyze the data a five point Likert scale was utilized. A brief description of each device was given at the beginning of the survey to inform respondents how the device would make their workplace safer, as well as what metric it would measure in order to do so. These descriptions can be found attached to the surveys in Appendix A & B. The survey concluded with a series of questions regarding the respondents' experience with each specific device. The survey questions distributed to those working in the field can be found below in Table 3.1. The survey questions distributed to those in management positions can be found below in Table 3.2.

3.4.1 Expert Review

Once the survey was designed, a rigorous expert review process was established. The survey was reviewed by two educators, two health and safety professionals, three project managers, and three executive officers in the industry for a total of 10 reviews. Corrections to the surveys were made following their recommendations.

3.4.2 Pilot Study

Following the expert review, a pilot study was conducted. Twenty participants were chosen to take the pilot study, thirteen field labor and eight management surveys were completed. The pilot study was distributed via the online platform Survey Monkey to individuals within the professional network of the author.

Table 3.1 Field Labor Survey Questions

Variable	Device	Question
Demographics	N/A	What is your age range?
		Job Title:
		Years of experience in the industry?
		Union Member?
		Geographic Region:
		Project Type:
		Work Sector:
PPE	Biometric	A Biometric Tracker would make my work environment a safer place.
	Location	The location tracking system would make my work environment a safer place.
PEE	Biometric	Learning how to use a biometric tracker would be easy to me.
	Location	Learning how to use the location tracking system would be easy to me.
ODU	Biometric	Rate your level of concern with how your employer would use the data they collect from the biometric tracker.
	Location	Rate your level of concern with how your employer would use the data they collect from the location tracking system.
SI	Biometric	If the biometric tracking device was provided by my company my family / loved ones would recommend I use it.
	Location	If the location tracking system was provided by my company my family / loved ones would recommend I use it.
	Biometric	If others on my crew were using the biometric tracking device it would increase the likelihood I would use it.
	Location	If others on my crew were using the location tracking system it would increase the likelihood I would use it.
DS	Biometric	Rate your level of concern regarding the security of your biometric data.
	Location	Rate your level of concern regarding the security of your location data.
BI	Biometric	Would you use the biometric tracker if it was provided by your employer?
	Location	Would you use the location tracking device if it was provided by your employer?
Experience	Biometric	Rank your familiarity with biometric sensors.
	Biometric	Have you ever received training using a biometric sensor?
	Biometric	Have you ever used a biometric sensor at this site or another?
	Biometric	Have you ever refused to use a biometric sensor at this site or another?
	Location	Rank your familiarity with location tracking devices.
	Location	Have you ever received training using a location tracking device?
	Location	Have you ever used a Location tracking device at this site or another?
	Location	Have you ever refused to use a location tracking device at this site or another?

3.4.3 Analyze and Adjust Questionnaire

Following the completion of the pilot study, the author had a conversation with each of the participants. The conversation consisted of clarification of topics, questions, and the intended purpose of questions. The author then analyzed the data from the pilot study and concluded the results were likely to yield the intended purpose.

Table 3.2 Management Survey Questions

Variable	Device	Question
Demographics	N/A	What is your age range?
		Job Title:
		Years of experience in the industry?
		Geographic Region:
		Project Type:
		Work Sector:
PPE	Biometric	If used correctly the biometric tracker would increase the level of safety on our construction sites.
	Location	If used correctly the location tracking system would increase the level of safety on our construction sites.
PEE	Biometric	Rate your level of concern associated with training time/effort required to train employees to use the biometric tracker.
	Location	Rate your level of concern associated with training time/effort required to train employees to use the location tracking system.
ODU	Biometric	With regards to the biometric device, describe your level of concern regarding legal issues arising due to tracking of employee health information.
	Location	With regards to the location tracking system, describe your level of concern regarding legal issues arising due to tracking of employee location data.
SI	Biometric	If our competitors were using a biometric safety device we would be more likely to deploy one.
	Location	If our competitors were using a location tracking system we would be more likely to deploy one.
	Biometric	Our clients would support the use of the biometric safety device.
	Location	Our clients would support the use of the location tracking system.
DS	Biometric	Describe your level of concern regarding storing employee health data collected using the biometric safety device.
	Location	Describe your level of concern regarding storing employee location data collected using the location tracking system.
BI	Biometric	If Cost was not a factor, would you implement the biometric safety device at your respective site/sites?
	Location	If Cost was not a factor, would you implement the location tracking system at your respective site/sites?
FC	Biometric	Describe the level of influence that cost of the biometric tracking device would play on your decision to implement the device.
	Location	Describe the level of influence that cost of the location tracking system would play on your decision to implement the device.
AU	Biometric	Taking into account all factors, would you implement a biometric safety device at your respective site/sites?
	Location	Taking into account all factors, would you implement a location tracking system at your respective site/sites?
Experience	Biometric	Rank your familiarity with biometric sensors.
	Biometric	Have you ever used a biometric safety device at any of your sites?
	Biometric	Are you currently using a biometric safety device at any of your sites?
	Biometric	Have you ever chose to terminate the use of a biometric safety device?
	Location	Rank your familiarity with location tracking devices.
	Location	Have you ever used a location tracking system at any of your sites?
	Location	Are you currently using a location tracking system at any of your sites?
	Location	Have you ever chose to terminated the use of a location tracking system?

3.5 Phase IV: Data Collection & Analysis

The survey was distributed using Survey Monkey, and in some instances hard copy was provided. The survey was distributed to the industry through a variety of resources. Due to the difficult nature of recruiting qualified individuals to take the survey random sampling was not a possibility. Instead, a combination of convenient sampling and snowball sampling were used to collect survey data. The survey was distributed by the California Center for Construction Education (CCCE), a liaison between California Polytechnic State University alumni, students, and industry partners. The author used his personal professional network connections to distribute the survey to employees at 15+ contractors across the United States performing residential, commercial, industrial, heavy civil, and environmental construction in both the public and private sectors. LinkedIn was used as a platform to distribute the survey. The author reached out to numerous societies including AGC, ASC, and SAME to aid in survey distribution, but failed to receive a response.

3.5.1 Analysis of Data and Discussion of Results

The raw data was downloaded from Survey Monkey into an excel file. The data was then cleaned and invalid surveys were discounted. Data was then uploaded into statistical analysis program JMP Pro 15 for analysis. The analysis will be broken into two phases.

For the field labor, only phase 1 analysis is needed. In phase 1 analysis a Pearson chi-squared test for association was conducted between each construct (PPE, PEE, ODU, SI, DS) and use variable (BI). This step follows Figure 3.3. This test would be able to determine if there was an association between how individuals answered questions regarding the individual constructs and how they answered the question regarding behavioral intention. If the p-value resulting from the Pearson chi-squared test is less than 5% (or 0.05) then there is deemed to be a statistically significant association between the variables. At this point, there would be strong evidence that how a respondent answered questions regarding the respective construct plays a role in their acceptance of the device.

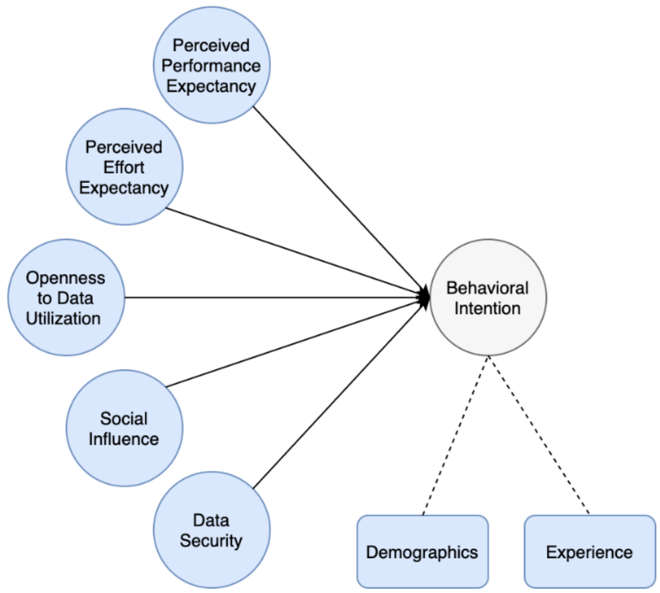

Figure 3.3 A visual of phase 1 analysis logic.

For the management portion of the study the analysis both phase 1 and phase 2 will be conducted. Phase one will follow the same analysis as the field labor with chi-squared tests that follow Figure 3.3. Phase two will consist of a second round of Pearson chi-squared analysis. This round will test for association between the constructions of behavioral intention (BI) and facilitating condition (FC) with actual use (AU). This round of tests follows Figure 3.4.

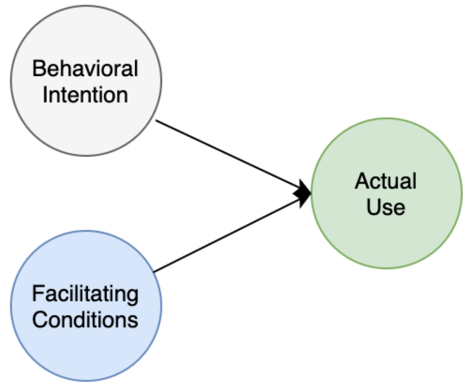

Figure 3.4 A visual of phase 2 analysis logic.

3.6 Phase V: Conclusion and Prevailing Limitations

A summary is presented in the conclusions that covers the phases of this study, and the prevailing results of each construct as they relate to WSD acceptance and construction safety. The challenges encountered during the lifespan of the study and lessons learned are presented. The prevailing limitations following the conclusion of the study are addressed. Lastly, areas of potential future research are discussed.

3.7 Summary

This chapter presented the methodology employed to answer the research question at hand. The literature review conducted in Phase I indicated the current state of construction safety, wearable sensing devices, barriers to their entry, and technology acceptance models that could help us to understand these barriers. In Phase II six constructs were decided upon, and a structured questionnaire was designed. Phase III consisted of making corrections and seeking validation of the structured questionnaire by seeking expert review and conducting a pilot study. In Phase IV the questionnaire was distributed, and the data was collected and analyzed. Finally, Phase V presented the findings from the research along with other prevailing limitations.

4. FIELD LABOR RESULTS AND DISCUSSION

4.1 Introduction

The following section will discuss the results from the field labor survey. First, an overview of demographics and general trends will be discussed. Next, each construct will be analyzed. Beginning with the biometric WSD each construct's trends will be analyzed independently, followed by a Pearson chi-squared analysis to determine if an association exists between each construct and behavioral intention to use the biometric device. Subsequently, the same analysis will be conducted regarding the location tracking WSD.

4.2 Demographics and Sample Data

A total of 73 responses were collected in the field laborer portion of the wearable sensing devices surveys. Of those responses, five had to be discarded due to incompleteness, leaving 68 complete responses. Survey Responses were collected from November 2021 to December 2021. The following Figures 4.1-4.7 summarize the demographics of the respondents.

In Figure 4.1 the sample is broken down by age demographic as a percentage of respondents. The sample is relatively evenly distributed between the main working-age groups with the lowest participation coming from the 45-54 age group.

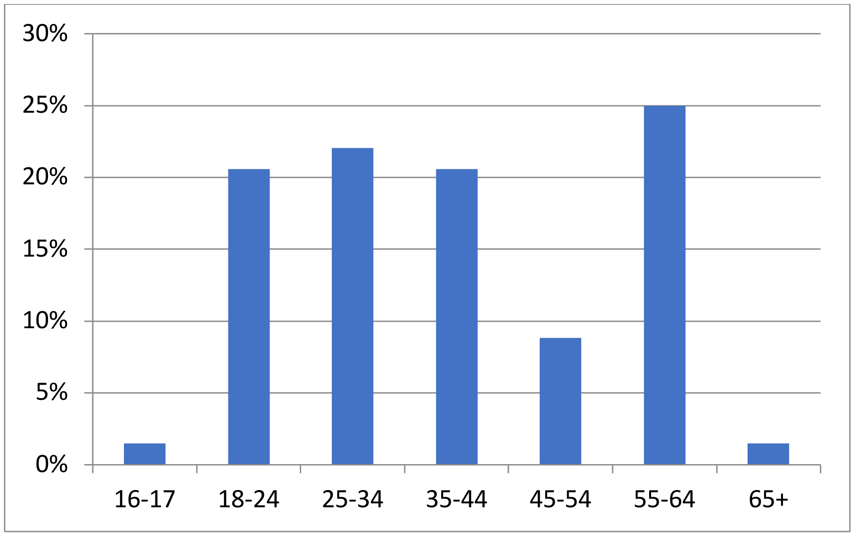

Figure 4.1 Field labor distribution of age demographic by the percentage of respondents.

Figure 4.2 displays the years of industry experience as a percentage of respondents. The sample had higher participation among less-experienced workers. This could have been due to the author's network being in a younger age demographic.

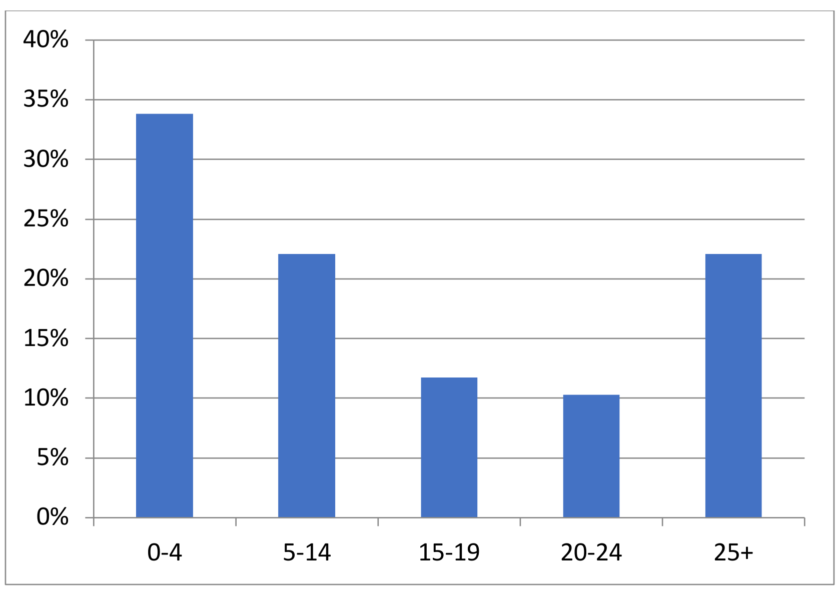

Figure 4.2 Field labor years of industry experience by the percentage of respondents.

Figure 4.3 breaks down the sample by geographic region. The highest participation was in the southwest region. This was most likely due to the author's connections in the region leading to a higher survey distribution in the region

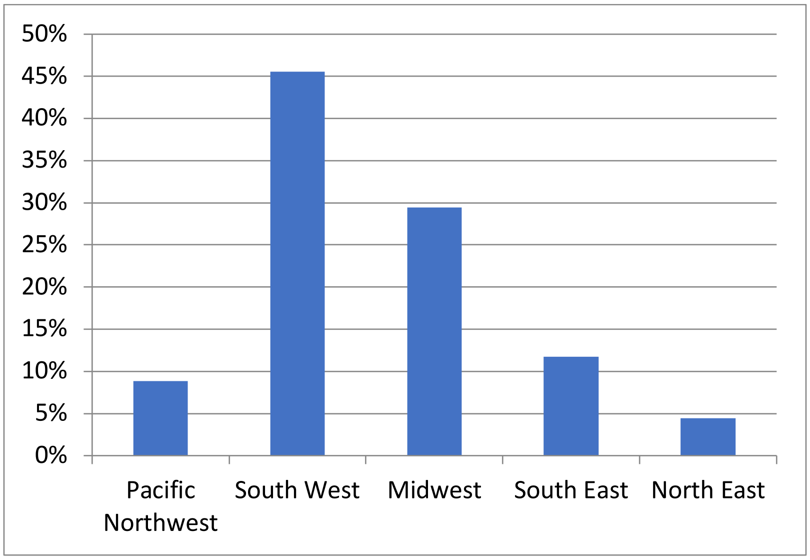

Figure 4.3 Field labor geographic region by the percentage of respondents.

Figure 4.4 displays job titles by a percentage of respondents. The job title was dominated by "other". This result is not explainable. However, it may be the individuals did not see their specific job title on the list and selected "Other".

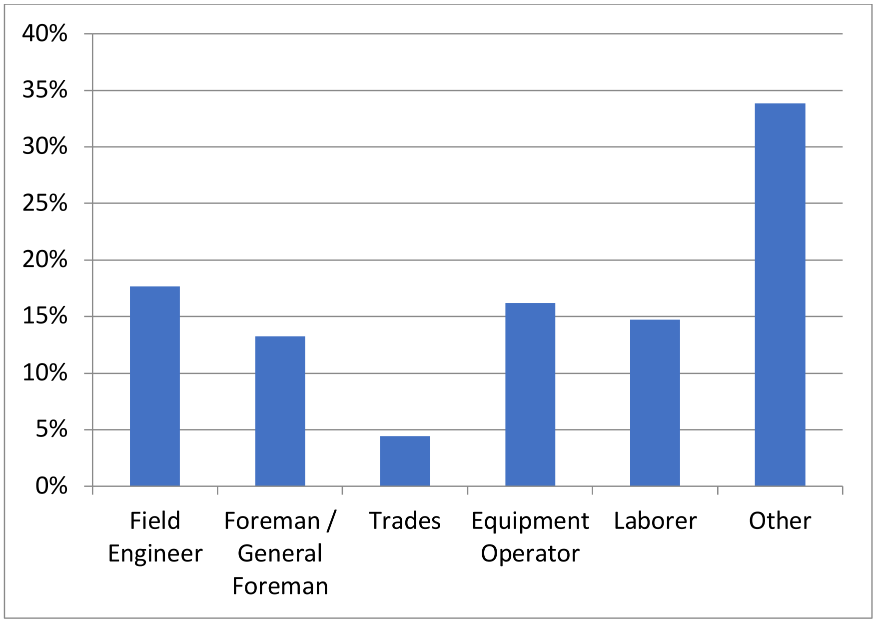

Figure 4.4 Field labor job title by the percentage of respondents.

Figure 4.5 displays the construction sectors by percentage of respondents. A high percentage of respondents work in the environmental construction sector. This is most likely due to the author's access to multiple environmental sites and his face-to-face request to participate in the survey.

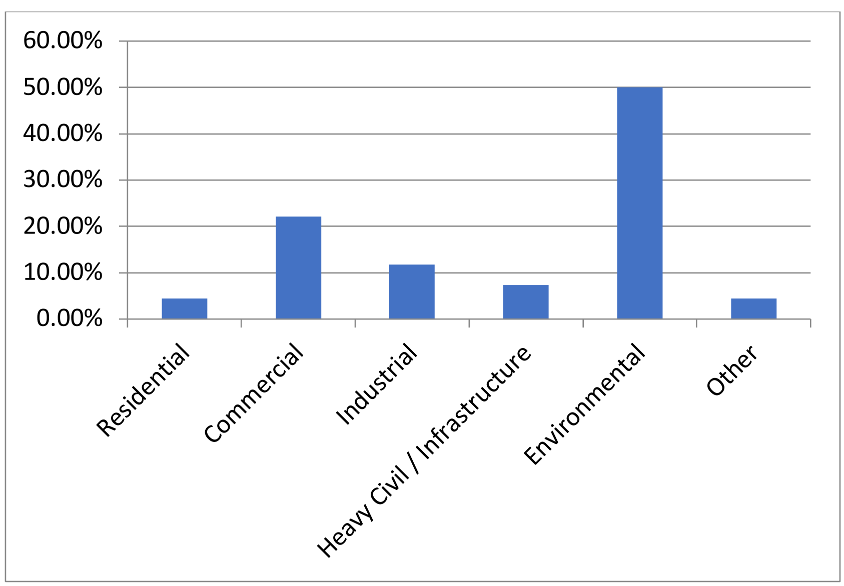

Figure 4.5 Field labor construction sector by the percentage of respondents.

Figure 4.6 displays the private vs public sector participation in the survey. A majority of the respondents worked in the public sector. This again is due to the fact the author had access to and thus administered the survey at multiple government sector sites.

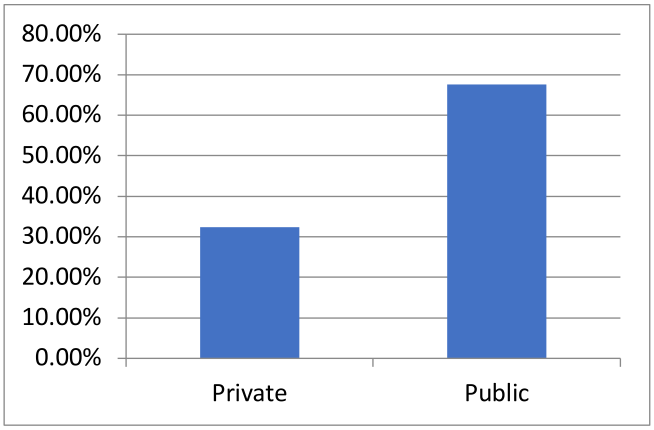

Figure 4.6 Field labor distribution of public-sector or private sector by the percentage of respondents.

Figure 4.7 displays the union member vs non-union member participation in the survey. The survey saw low union member participation.

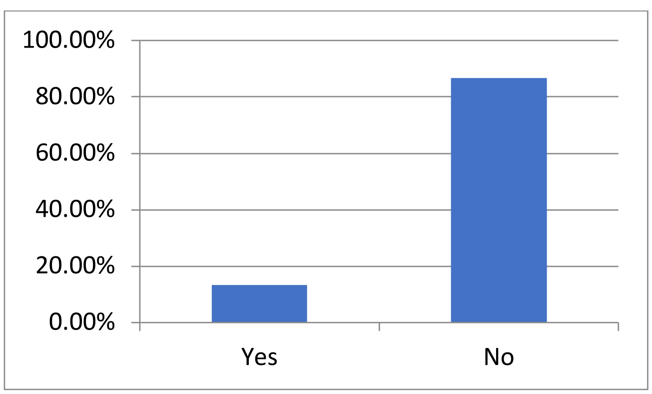

Figure 4.7 Field labor distribution of union membership by the percentage of respondents.

4.3 Field Labor Biometric WSD Previous Experience

The following figures reflect the previous knowledge regarding biometric WSDs. Respondents were asked to rank their level of familiarity with biometric WSDs, these results can be found graphically in Figure 4.8. The majority of respondents (61%) were either not at all familiar or slightly familiar with biometric sensor.

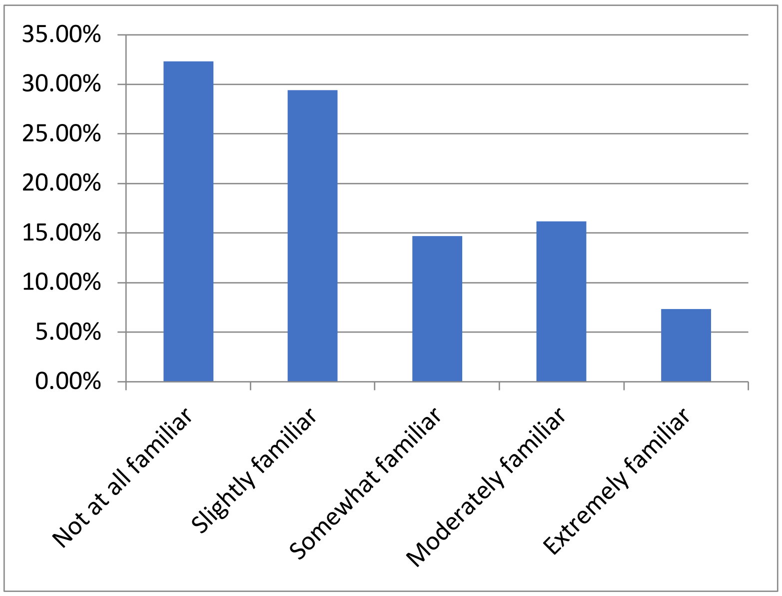

Figure 4.8 Field labor level of familiarity with biometric WSD by percentage of respondents.

Respondents were asked if they had ever used a Biometric WSD. The results can be seen graphically in Figure 4.9. Only 29% reported having used a biometric device.

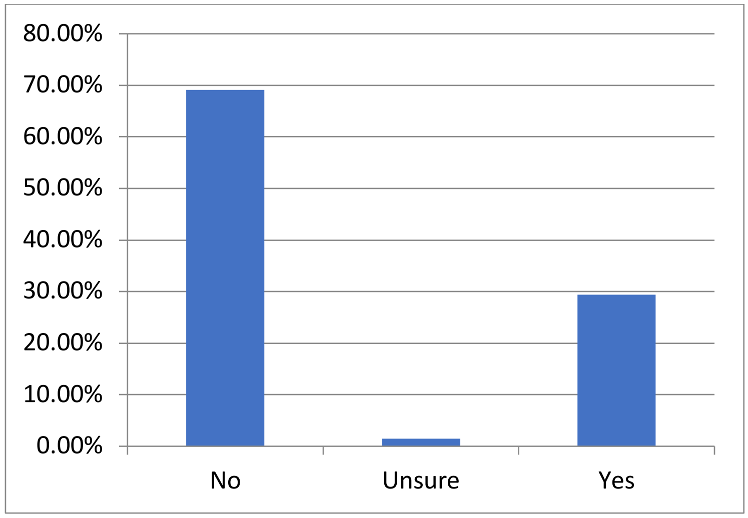

Figure 4.9 Field labor past usage of a biometric WSD as a percentage of respondents.

Next the respondents were asked if they had ever received training on a biometric WSD. The results can be found seen graphically in Figure 4.10. Only 25% reported receiving any sort of training with a biometric WSD. While this represents a low percentage of respondents the results coincide with the number of respondents who reported having used a biometric device.

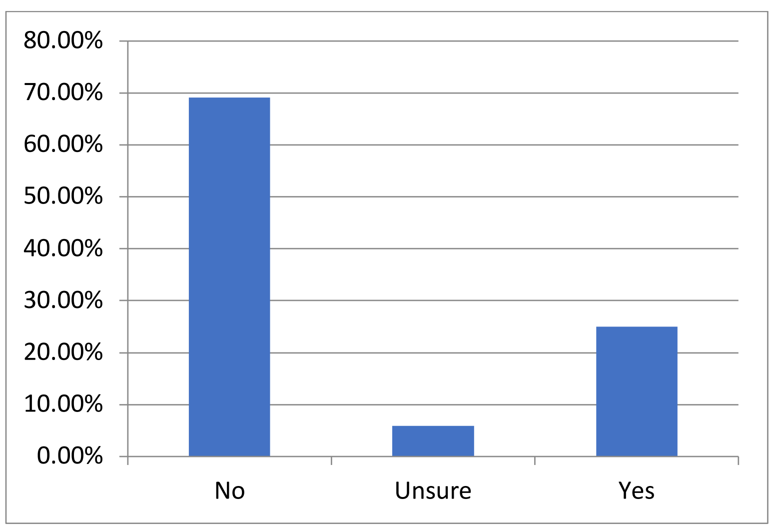

Figure 4.10 Field labor respondents who have received training on a biometric WSD as a percentage of respondents.

Lastly, respondents were asked if they had ever refused to use a biometric WSD at their place of work. The results of this question can be seen graphically in Figure 4.11. A small minority (7%) of respondents have refused to use a biometric WSD.

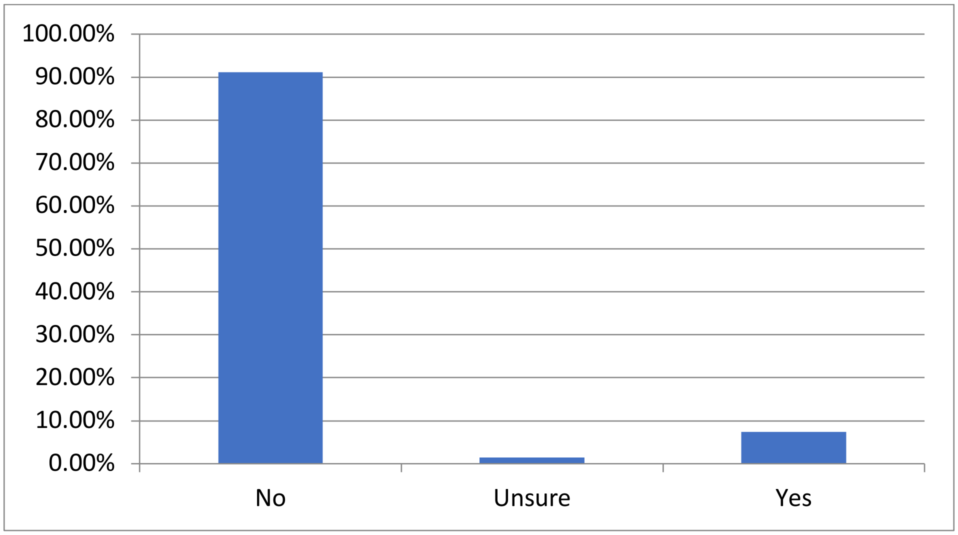

Figure 4.11 Field labor respondents who have refused the use of a biometric WSD as a percentage of respondents.

4.4 Field Labor Location Tracking WSD Previous Experience

The following tables and figures reflect the previous knowledge regarding location tracking WSDs. Respondents were asked to rank their level of familiarity with location tracking WSDs, these results can be seen graphically in Figure 4.12. The majority of respondents (58%) were either not at all familiar or slightly familiar with location tracking devices.

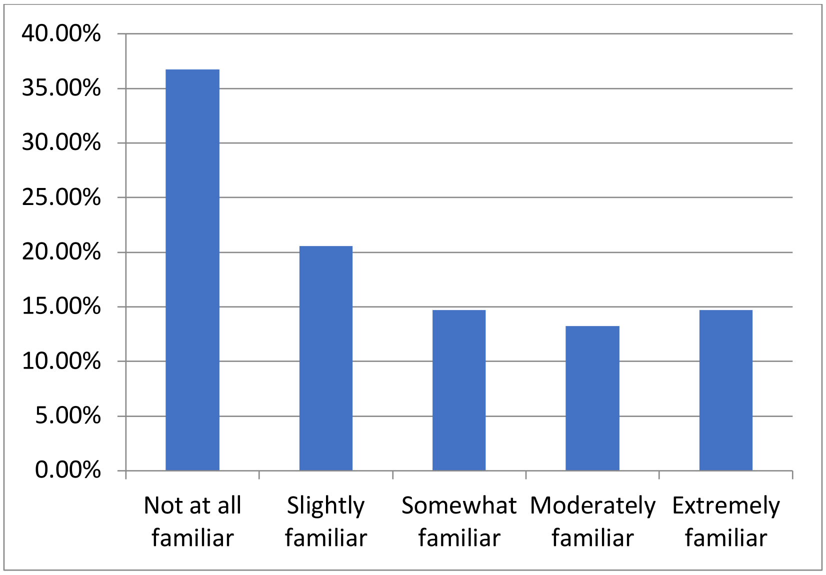

Figure 4.12 Field labor level of familiarity with location tracking WSDs as a percentage of respondents.

Respondents were asked if they had ever used a location tracking WSD. The results can be seen graphically in Figure 4.13. Only 21% reported having used a location tracking WSD.

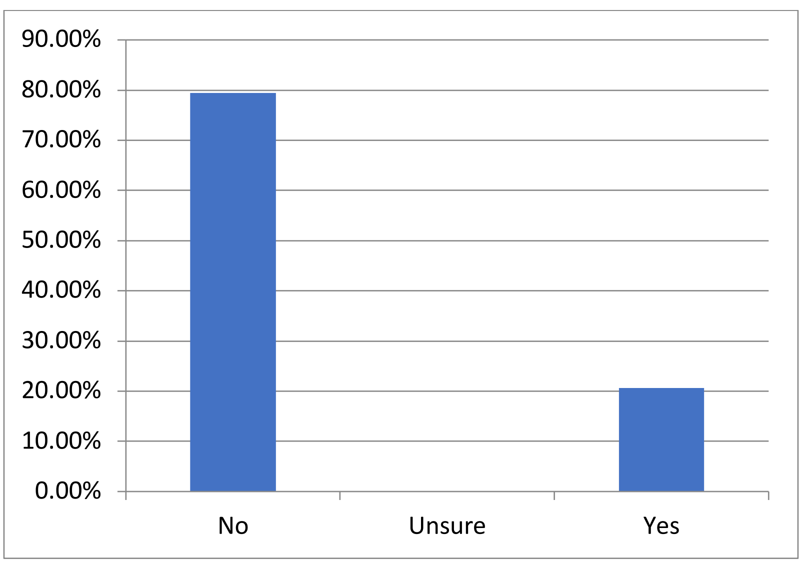

Figure 4.13 Field labor past usage of a location tracking WSD as a percentage of respondents.

Next, the respondents were asked to report if they had ever received training using a location tracking WSD. The results can be seen graphically in Figure 4.14. A minority of 24% reported receiving training with a location tracking WSD. This is interesting considering only 21% of respondents reported using a location tracking device. This could be explained by individuals refusing to use the device.

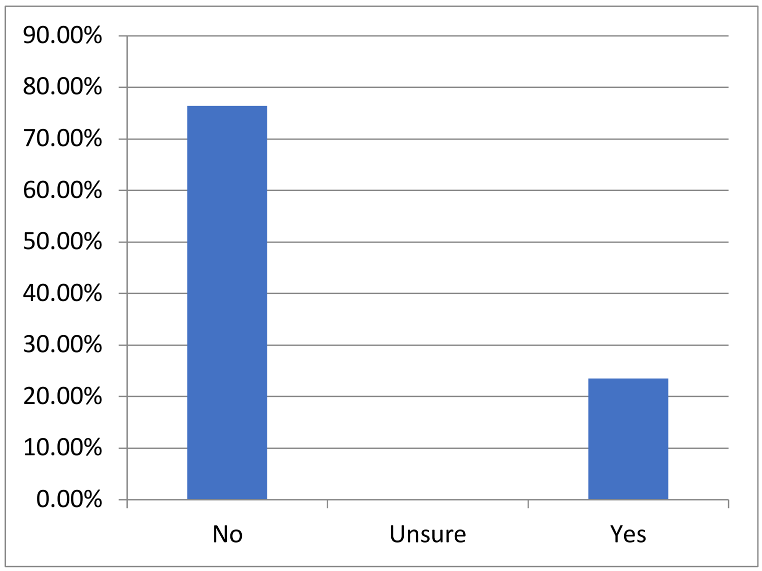

Figure 4.14 Field labor respondents who reported receiving training on a location tracking WSD as a percentage of respondents.

Lastly, respondents reported if they had ever refused to use a location tracking WSD at their place of work. The results of this question can be seen graphically in Figure 4.15. A minority (10%) of respondents reported having refused to use a location tracking WSD.

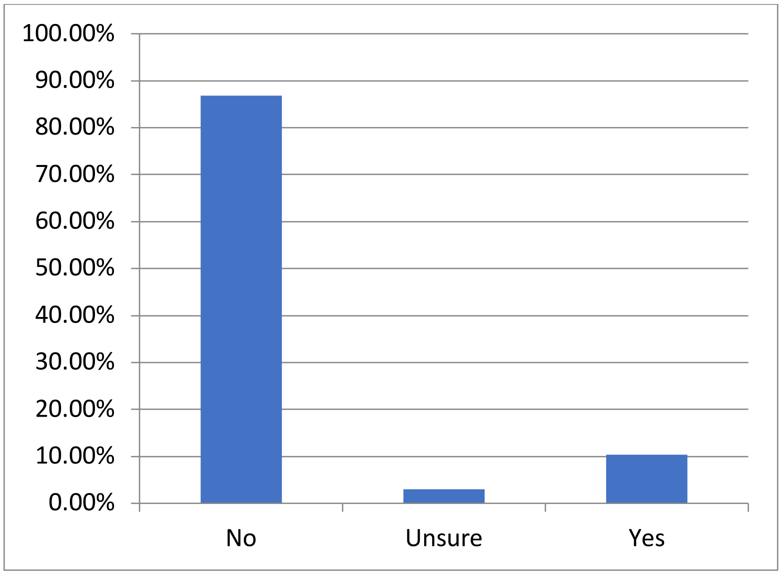

Figure 4.15 Field labor respondents who have refused the use of a location tracking WSD as a percentage of total respondents.

4.5 Field Labor Biometric WSD Analysis

4.5.1 Introduction

The following section will analyze and discuss the results from the biometric WSD portion of the field labor survey. It was found that 46% of construction field laborers surveyed did not agree to use the biometric WSD. Of the five constructs analyzed a statistically significant association between the construct and BI was found for three constructs (PPE, PEE, & SI). For the remaining two constructs (ODU & DS) no association was found. For an association to exist a p-value of less than 0.05 must exist. An association was found with behavior intent for the constructs of perceived performance expectancy, perceived effort expectancy, and social influence. No association was found between behavior intent and openness to data utilization or data security. Further information containing the analysis of each construct can be found in the following sections. A summary table of Pearson chi-squared values and associated p-values can be found below in Table 4.1.

Table 4.1 Field Labor Biometric WSD Pearson Chi-Squared Summary Table

Construct	Pearson Chi-Squared	P-Value
PPE	15.358	<0.0001*
PEE	12.351	0.0004*
ODU	0.361	0.5479
SI (Family)	21.402	<0.0001*
SI (Coworkers)	15.358	<0.0001*
DS	0.474	0.491

4.5.2 Perceived Performance Expectancy

Questions regarding perceived performance expectancy were designed to judge if a respondent believed the biometric device would aid in their safety in the workplace. Respondents were asked their level of agreement with the statement “The biometric tracker would make my work environment a safer place”. The results were a nearly even split with, 51% of respondents not agreeing that the biometric device would make their workplace a safer place. Based on the Pearson Chi-squared value and subsequent P-value of less than 0.0001 a statistically significant association exists between perceived performance expectancy (PPE) and behavioral intent (BI). The supermajority (69%) of the respondents who did not think the device would aid their safety, also did not agree to use the device. In contrast, only 21% of the respondents who reported the device would aid their safety did not agree to use the device. This data can be seen graphically in Figure 4.16 and numerically in Table 4.2. Table 4.2 is a statistical contingency table. To read this table the first number in each cell is the total responses, the second number is the percentage of all respondents, the third number is the percentage of respondents with respect to that specific column, and the fourth number is the percentage of respondents with respect to that specific row. This information can be found in the top left cell of all contingency tables. Table 4.2 will be explained in detail to ensure reader comprehension. When testing for association between PPE and BI it was found that 24 respondents (count) had low perceived performance expectancy of the biometric device and also did not agree to use the device. This represents 35% (Total %) of all respondents. Of all those who fall into the category of "did not agree to use the device" 77% (Column %) had low perceived performance expectancy. Lastly, of all those who responded with low performance expectancy 69% (Row %) did not agree to use the device. This information is repeated in the remaining 3 cells of the contingency table.

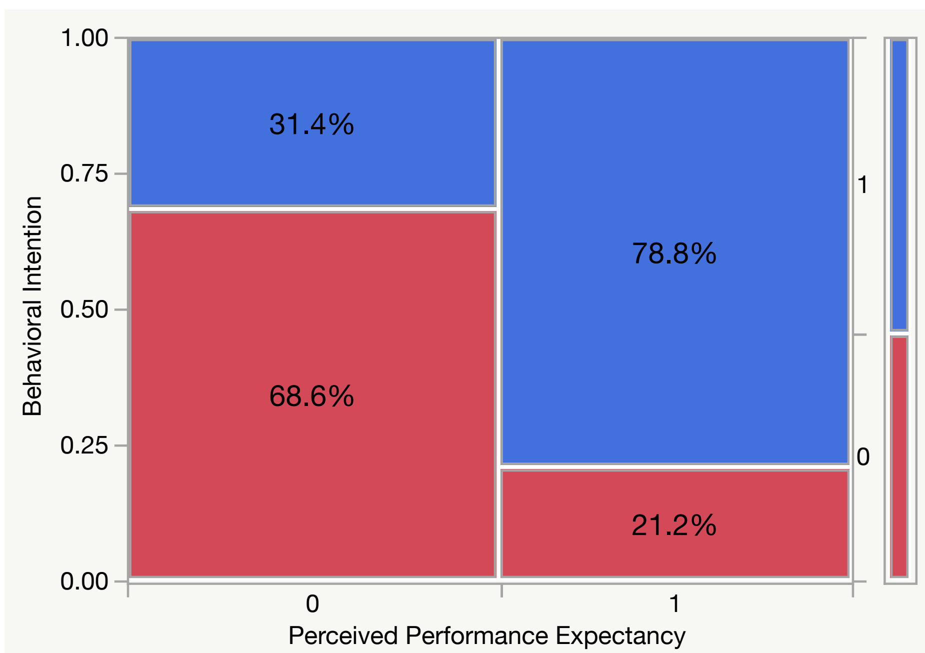

Figure 4.16 Mosaic plot represents the association between PPE and BI concerning the biometric WSD on the field labor survey.

Table 4.2 Field Labor Biometric WSD Contingency Table for PPE by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
Low Performance Expectancy (0)	24 (Count) 35.29 (Total %) 77.42 (Column %) 68.57 (Row %)	11 16.18 29.73 31.43	35 51.47
High Performance Expectancy (1)	7 10.29 22.58 21.21	26 38.24 70.27 78.79	33 48.53
Total	31 45.59	37 54.41	68

These results clearly demonstrate that the preconceived notion of whether the biometric device will keep the worker safe plays a large role in their decision to use the device voluntarily. If an employer wishes to successfully implement a biometric WSD, education of their workforce on the safety effectiveness of the device seems to be a necessary step. Based on the data collected in this study, changing an individual's opinion of the safety value of the device may change their opinion on voluntary use. Analysis of the data would support the contention that without this change, companies will not see an increase in voluntary usage.

4.5.3 Perceived Effort Expectancy

Questions regarding perceived effort expectancy were designed to better understand the preconceived notion of how difficult the device user anticipates learning to use the biometric WSD will be. Respondents were asked their level of agreement with the statement "Learning to use the biometric tracker will be easy for me". A supermajority of the respondents (75%) believed it would be easy for them to learn to use the biometric WSD.

Based on the Pearson Chi-squared value of subsequent P-value of 0.0004 a statistically significant association exists between perceived effort expectancy and behavioral intent. A supermajority (82%) of individuals who thought that learning to use the biometric device would be difficult for them also did not agree to use the device. Alternativity, only 33% of individuals who believed learning to use the biometric device would be easy for them also did not agree to use the device. This data can be seen graphically in Figure 4.17, and numerically in Table 4.3.

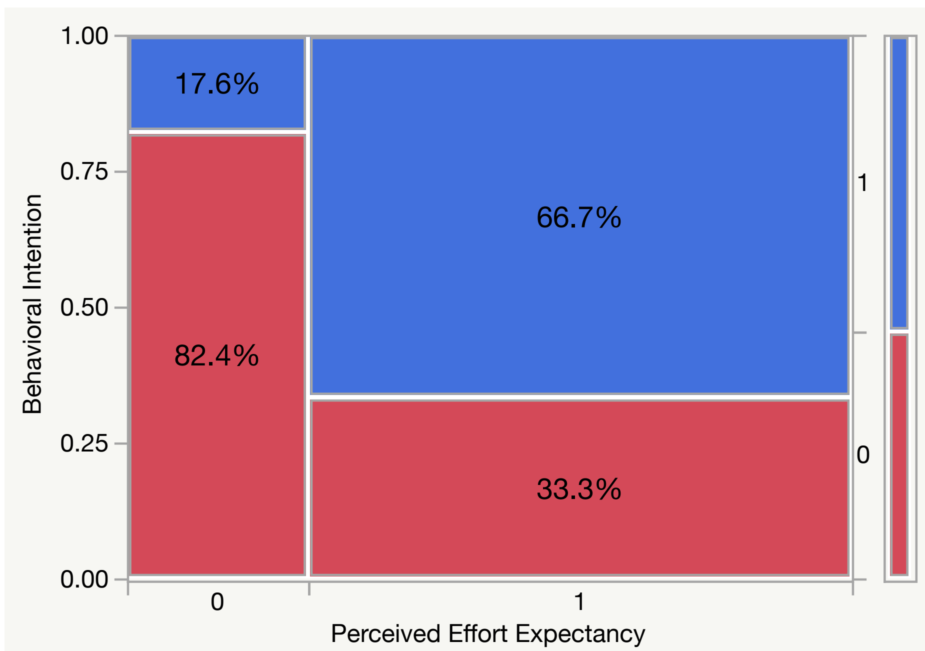

Figure 4.17 Mosaic plot represents the association between PEE and BI concerning the biometric WSD on the field labor survey.

Table 4.3 Field Labor Biometric WSD Contingency Table for PEE by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
High Perceived Difficulty (0)	14 20.59 45.16 82.35	3 4.41 8.11 17.65	17 25.00
Low Perceived Difficulty (1)	17 25.00 54.84 33.33	34 50.00 91.89 66.67	51 75.00
Total	31 45.59	37 54.41	68

Analysis of the data supports that those who feel intimidated by learning to use new technology are more likely to be resistant to adopting the new technology. When selecting the type of device to purchase, ease of use should be a factor. Again, the education of the workforce is critical to the use of the devices. In order to increase acceptance of a biometric WSD, the company may need to demonstrate the ease of use of the device prior to deployment. It will also be important for companies to demonstrate patience while training those who find technology challenging or who fear technology.

4.5.4 Openness to Data Utilization

The purpose of the openness to data utilization questions was to understand the level of concern device users have regarding how their employer may use the health data they collect from the biometric WSD. A majority of respondents (57%) answered little to no concern.

Based on the Pearson Chi-squared value of subsequent P-value of 0.5479 there was no statistically significant association found between openness to data utilization and behavioral intent. While this does not mean that there is no association, this study cannot claim there to be one. The data collected for this question can be seen graphically in Figure 4.18. A contingency table containing percentage values can be seen in Table 4.4.

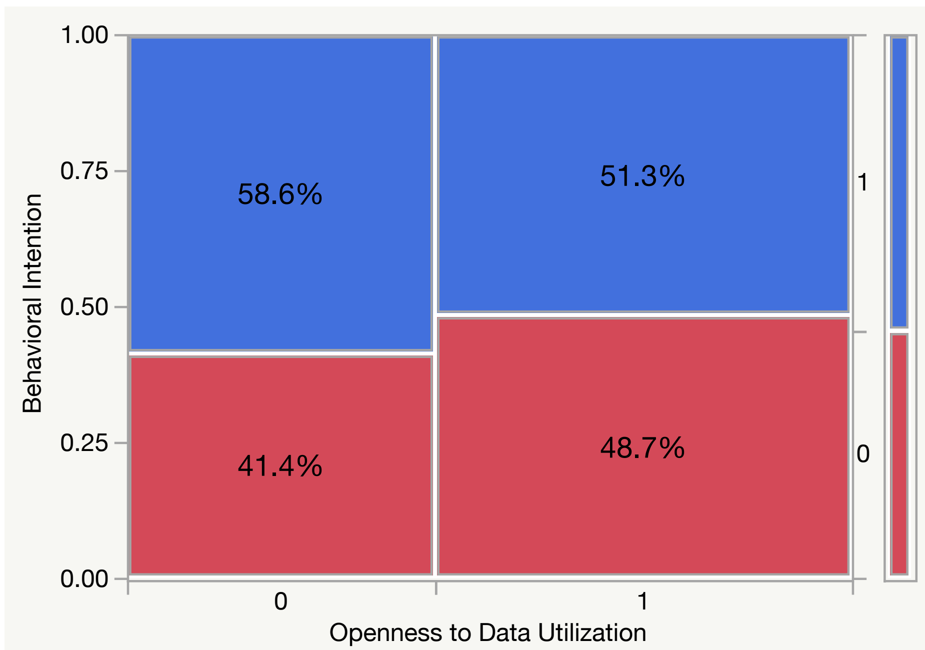

Figure 4.18 Mosaic plot represents the association between ODU and BI concerning the biometric WSD on the field labor survey.

Table 4.4 Field Labor Biometric WSD Contingency Table for ODU by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
More Hesitant about Data Usage (0)	12 17.65 38.71 41.38	17 25.00 45.95 58.62	29 42.65
Less Hesitant about Data Usage (1)	19 27.94 61.29 48.72	20 29.41 54.05 51.28	39 57.35
Total	31 45.59	37 54.41	68

Based on the results from this study an individual's trust in how their company uses the data they collect from the biometric device is not a good predictor of if they will agree to use the biometric device. This is interesting considering multiple previous studies found data utilization and data privacy as significant barriers to entry for wearable sensing devices (Choi et al., 2017; Okpala et al., 2021; Schall et al., 2018). However, a significant portion (43%) of respondents still harbored some level of concern regarding how their employer uses their health data. This would seem to allow for an argument that having open communication with device users regarding how their data is being used and where it is not being used would be a good business practice in building trust. Having this communication might increase the usage for those that were hesitant.

4.5.5 Social Influence of Family or Loved Ones

Questions regarding the social influence of family or loved ones were designed to understand if a respondent believed his or her family or loved ones would recommend they use the biometric WSD. The results were completely split, with 50% of respondents believing their family or loved ones would recommend they use the biometric WSD and 50% feeling it was not a factor.

Based on the Pearson Chi-squared value of subsequent P-value of less than 0.0001 shown in Table 4.8 there was found to be a statistically significant association between the social influence of family or loved ones and behavioral intent. A supermajority (74%) of individuals who answered their family or loved ones would not recommend they use the biometric WSD also did not agree to use the device. Alternativity, only 18% of individuals who answered their family or loved ones would recommend they use the biometric WSD did not agree to use the device. This data can be seen graphically in Figure 4.19, and numerically in Table 4.5.

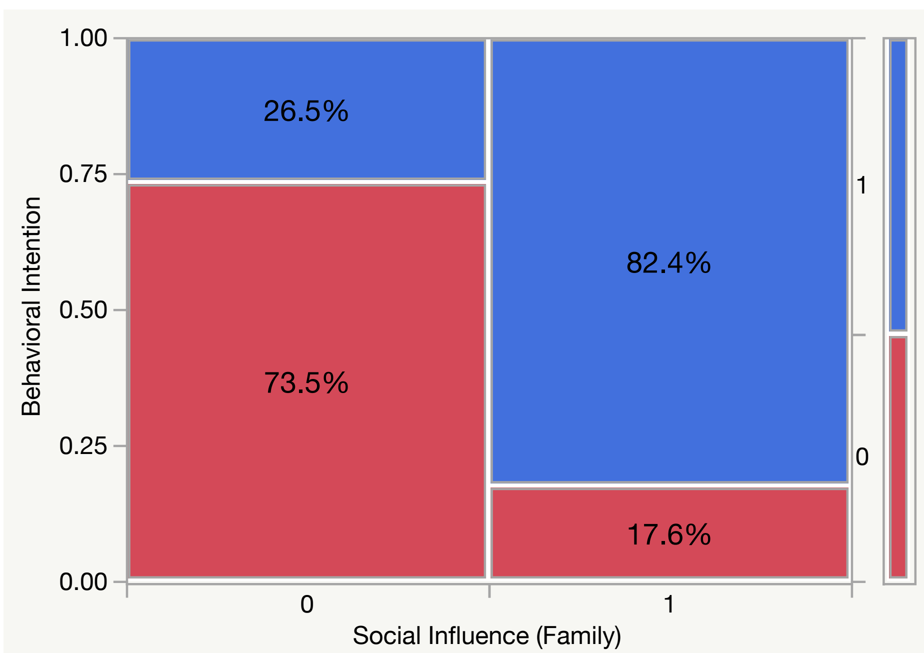

Figure 4.19 Mosaic plot represents the association between SI Family and BI concerning the biometric WSD on the field labor survey.

Table 4.5 Field Labor Biometric WSD Contingency Table for SI Family by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
Family against use of device (0)	25 36.76 80.65 73.53	9 13.24 24.32 26.47	34 50.00
Family for use of device (1)	6 8.82 19.35 17.65	28 41.18 75.68 82.35	34 50.00
Total	31 45.59	37 54.41	68

This shows a strong association for this construct. There is a value in educating the family or loved ones on the importance of the device. If there is greater support and encouragement from family or loved ones, there could be a positive impact on the acceptance of the device within the workforce. It is a challenge how to reach these individuals. One method could be a public campaign marketing the safety impacts of these devices. Something similar to seatbelt campaigns, stop smoking campaigns, and current vaccination campaigns. Another option would be a campaign specific to a company that they manage through promotion of the devices at internal social events.

4.5.6 Social Influence of Coworkers

The question regarding the social influence of coworkers was designed to gauge whether respondents would be more likely to voluntarily use the biometric WSD if others on their crew were using the device. The results were evenly split as 51% of respondents were not in agreement that others on their crew using the device would increase the likelihood they would personally use the device.

Based on the Pearson Chi-squared value of subsequent P-value of less than 0.0001 a statistically significant association exists between the social influence of coworkers and behavioral intent. A supermajority (69%) of individuals who answered their coworker's use of a biometric device would not increase their likelihood of using the device also did not agree to use the device. Alternativity, only 21% of individuals who answered their coworkers using the biometric WSD would increase their likelihood of using the device also did not agree to use the device. This data can be seen graphically in Figure 4.20, and numerically in Table 4.6.

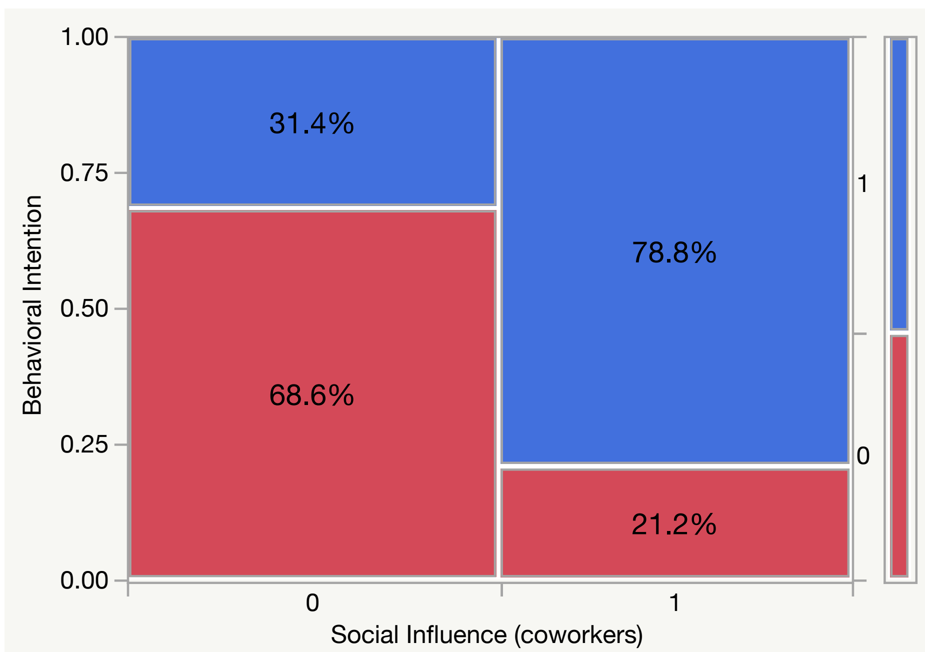

Figure 4.20 Mosaic plot represents the association between SI Coworkers and BI concerning the biometric WSD on the field labor survey.

Table 4.6 Field Labor Biometric WSD Contingency Table for SI Coworkers by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
Coworkers did not have influence. (0)	24 35.29 77.42 68.57	11 16.18 29.73 31.43	35 51.47
Coworkers did have influence (1)	7 10.29 22.58 21.21	26 38.24 70.27 78.79	33 48.53
Total	31 45.59	37 54.41	68

This data is interesting because it suggests that a voluntary use program for implementing a biometric device might not increase device acceptance. While many laborers would still participate and use the device without being forced, this study finds many individuals would still refuse to use the biometric device regardless of their coworker's participation in the program.

4.5.7 Data Security

Questions regarding data security were designed to gauge the level of concern the respondents had regarding the company storing data collected from the biometric WSD. A slight majority (53%) of respondents reported little to no concern regarding the security of their data.

Based on the Pearson Chi-squared value of subsequent P-value of 0.491 there was no statistically significant association found between data security and behavioral intent. While this does not mean that there is no association, this study cannot claim there to be one. The data collected for this question can be seen graphically in Figure 4.21, and numerically in Table 4.7. When analyzing the Mosaic plot you may notice that the survey population was relatively split between the four quadrants. If an individual had high regard for data security there was a 50% chance that they would agree to use the biometric WSD. Alternatively, if an individual had little regard for data security there was a 58% chance they would agree to use the biometric WSD. This small difference in percentages creates a high P-value, and in turn, no association can be found.

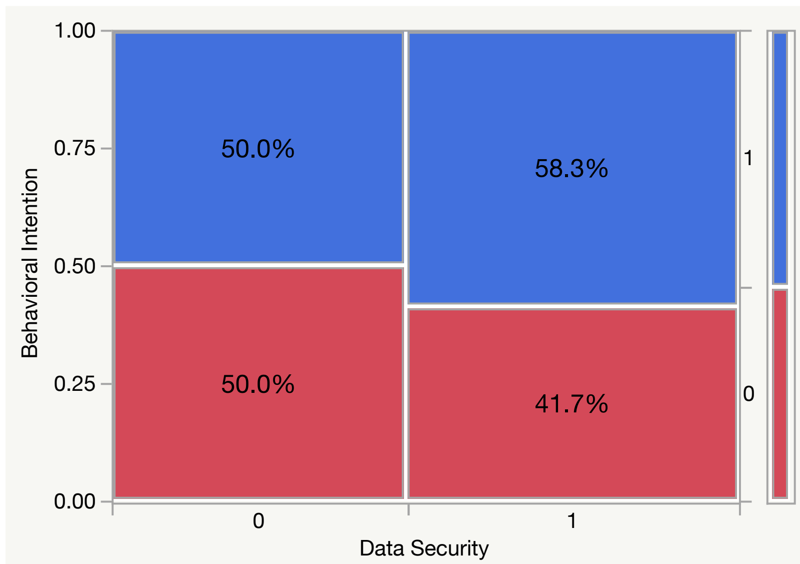

Figure 4.21 Mosaic plot represents the association between DS and BI concerning the biometric WSD on the field labor survey.

Table 4.7 Field Labor Biometric WSD Contingency Table for DS by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
High Concern Regarding Data Security (0)	16 23.53 51.61 50.00	16 23.53 43.24 50.00	32 47.06
Low Concern Regarding Data Security (1)	15 22.06 48.39 41.67	21 30.88 56.76 58.33	36 52.94
Total	31 45.59	37 54.41	68

Having strong internal data security systems is important to a company for many reasons outside WSD acceptance. However, according to the data recorded during this study no association between biometric device acceptance and data security can be drawn. While nearly half (47%) of respondents had concerns over data security it was not a good predictor of a respondent's likelihood to agree to use the device.

4.6 Field Labor Location Tracking WSD Analysis

4.6.1 Introduction

The following section will analyze and discuss the results from the location tracking WSD portion of the Field labor survey. The majority (59%) of construction field laborers surveyed did not agree to use the location tracking WSD. Of the five constructs analyzed a statistically significant association between the construct and BI was found for three constructs. For an association to exist the p-value must be less than 0.05. An association was found with behavior intent for the constructs of perceived performance expectancy, social influence, and data security. No association was found between behavior intent and perceived effort expectancy or openness to data utilization. This data is summarized in Table 4.8. Further information containing the analysis of each construct can be found in the following sections.

Table 4.8 Field Labor Location Tracking WSD Pearson Chi-Squared Summary Table

Construct	Pearson Chi-Squared	P-Value
PPE	11.564	0.0007
PEE	1.673	0.1959
ODU	2.322	0.1275
SI (Family)	13.678	0.0002
SI (Coworkers)	15.508	<0.0001
DS	4.089	0.0432

4.6.2 Perceived Performance Expectancy (PPE)

Questions regarding perceived performance expectancy were designed to judge if a respondent believed the location tracking device would aid in their safety in the workplace. Respondents were asked their level of agreement with the statement “The location tracking device would make my work environment a safer place”. The majority (64%) of respondents did not believe the location tracking WSD would make their workplace a safer place.

Based on the Pearson chi-squared value and subsequent p-value of 0.0007 a statistically significant association exists between perceived performance expectancy and behavioral intent. A supermajority (73%) of individuals who did not think the device would be aid their safety also did not agree to use the device. Alternativity, only 30% of individuals who believed the location tracker would aid in their safety did not agree to use the device. This data can be seen graphically in Figure 4.22, and numerically in Table 4.9.

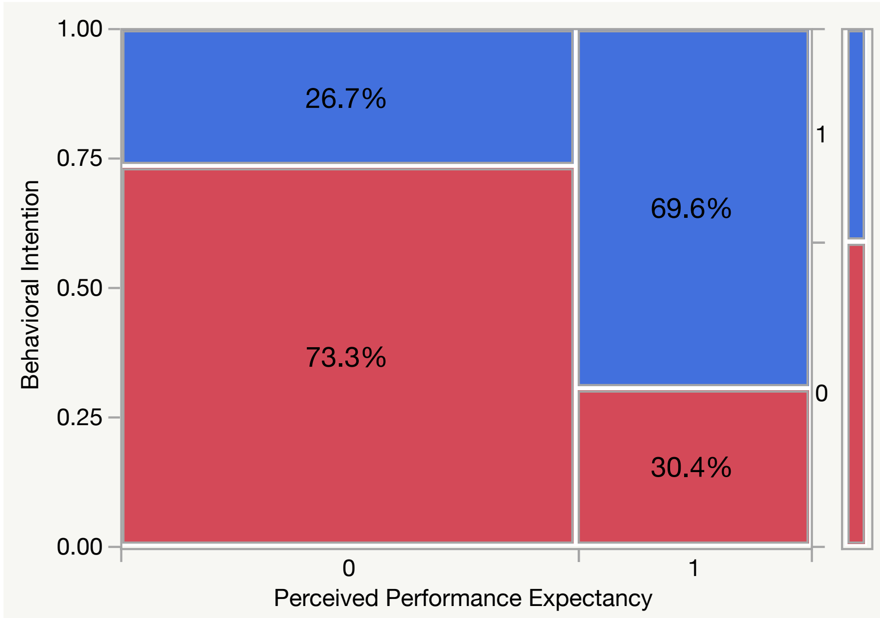

Figure 4.22 Mosaic plot represents the association between PPE and BI concerning the location tracking WSD on the field labor survey.

Table 4.9 Field Labor Location Tracking WSD Contingency Table for PPE by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
Low Performance Expectancy (0)	33 48.53 82.50 73.33	12 17.65 42.86 26.67	45 66.18
High Performance Expectancy (1)	7 10.29 17.50 30.43	16 23.53 57.14 69.57	23 33.82
Total	40 58.82	28 41.18	68

These results demonstrate that the preconceived notion of how a location tracking device will aid in construction site safety plays a large role in the voluntary acceptance of the device. If the employer is unable to convince their laborers that the device is beneficial, the probability of acceptance is low. One way a contractor might increase perceived performance would be through demonstration. For instance, if an excavator operator observed how the location tracking system could help avoid a blind spot struck-by incident with passing by pedestrian then acceptance of the device may increase. Overall, those who believe the device will aid in their safety have a much higher likelihood of accepting the location tracking WSD.

4.6.3 Perceived Effort Expectancy (PEE)

Questions regarding perceived effort expectancy were designed to better understand the preconceived notion of how difficult the device user anticipates learning to use the location tracking WSD will be. Respondents were asked their level of agreement with the statement “Learning to use the location tracking system will be easy for me”. A supermajority of the respondents (78%) believed it would be easy for them to learn to use.

Based on the Pearson Chi-squared value and subsequent P-value of 0.1959 there is no statistically significant association found between perceived effort expectancy and behavioral intent. While this does not mean that there is no association, this study cannot claim there to be. The data collected for this question can be seen graphically in Figure 4.23 and numerically in Table 4.10. An association cannot be made due to the low variance between the Figures. A supermajority (73%) of those with high perceived difficulty would not agree to use the device. However, a majority (55%) of those who had low perceived effort expectancy would still not agree to use the device.

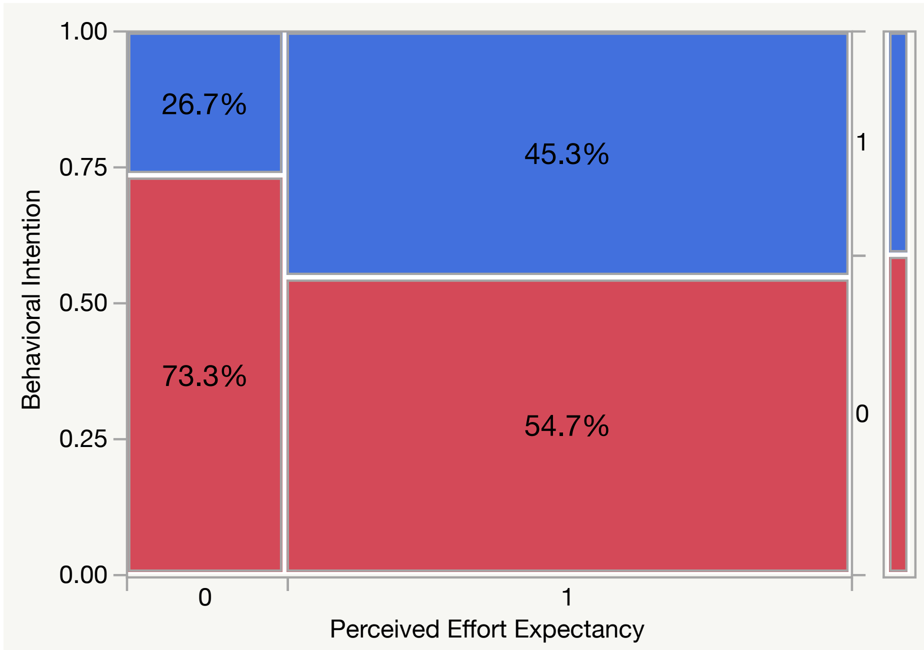

Figure 4.23 Mosaic plot represents the association between PEE and BI concerning the location tracking WSD on the field labor survey.

Table 4.10 Field Labor Location Tracking WSD Contingency Table for PPE by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
High Perceived Difficulty (0)	11 16.18 27.50 73.33	4 5.88 14.29 26.67	15 22.06
Low Perceived Difficulty (1)	29 42.65 72.50 54.72	24 35.29 85.71 45.28	53 77.94
Total	40 58.82	28 41.18	68

While this conclusion differs from the biometric WSD it is not surprising. The location tracking WSD may not be viewed as difficult to use because there is no action on the side of the user. The data confirms with the vast majority of the respondents (78%) answered that they did not believe the location tracker would be difficult to use.

Therefore, many individuals who did not agree to use the device may not have found the ease of use a deciding factor.

4.6.4 Openness to Data Utilization (ODU)

The purpose of the openness to data utilization question was to understand the level of concern device users have regarding how their employer uses the data they collect from the location tracking WSD. A majority of respondents (57%) reported being somewhat too extremely concerned.

Based on the Pearson Chi-Squared value and subsequent P-value of 0.1275 there was no statistically significant association between openness to data utilization and behavioral intent. While this does not mean that there is no association, this study cannot claim there to be. The data collected for this question can be seen graphically in Figure 4.24. A contingency table containing percentage values can be seen in Table 4.11. A supermajority (67%) of those who were more hesitant toward data utilization would not agree to use the device. However, 48% of those who were not worried about data utilization still would not agree to use the device.

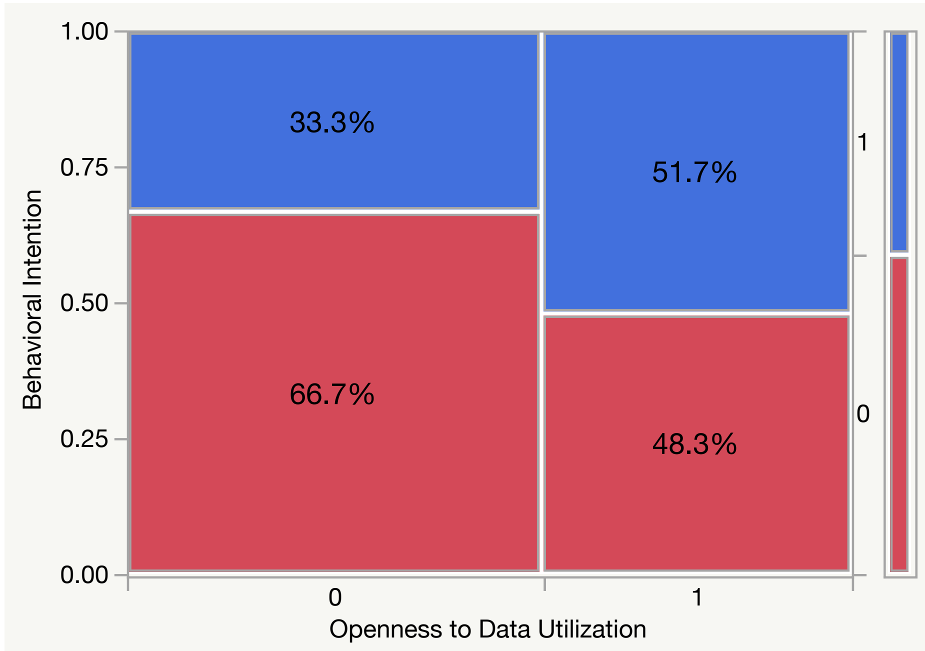

Figure 4.24 Mosaic plot represents the association between ODU and BI concerning the location tracking WSD on the field labor survey.

Table 4.11 Field Labor Location Tracking WSD Contingency Table for ODU by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
More Hesitant about Data Usage (0)	26 38.24 65.00 66.67	13 19.12 46.43 33.33	39 57.35
Less Hesitant about Data Usage (1)	14 20.59 35.00 48.28	15 22.06 53.57 51.72	29 42.65
Total	40 58.82	28 41.18	68

Similar to the biometric device the lack of association between openness to data utilization and behavioral intent comes as a surprise. While openness to data utilization is still a concern to the majority of respondents (57%) it was not as influential on device acceptance as it has been in other studies (Choi et al., 2017; Okpala et al., 2021; Schall et al., 2018). This discrepancy warrants additional research. Is openness to data utilization a predictor of acceptance? Or just good business practice to build trust with employees.

4.6.5 Social Influence of Family or Loved Ones (SI Family)

Questions regarding the social influence of family or loved ones were designed to understand if a respondent believed his or her family or loved ones would recommend they use the location tracking WSD. The majority (62%) believed their family or loved ones would not recommend they use the device or were unsure if they would.

Based on the Pearson Chi-Squared value and subsequent P-value of 0.0002 a statistical association exists between the social influence of family or loved ones and behavioral intention. The supermajority (76%) of individuals who answered their family or loved ones would not recommend they use the location tracking WSD also answered that they would refuse to use the device. Alternativity, only 31% of individuals who answered their family or loved ones would recommend they use the location tracking WSD did not agree to use the device. This data can be seen graphically in Figure 4.25, and numerically in Table 4.12.

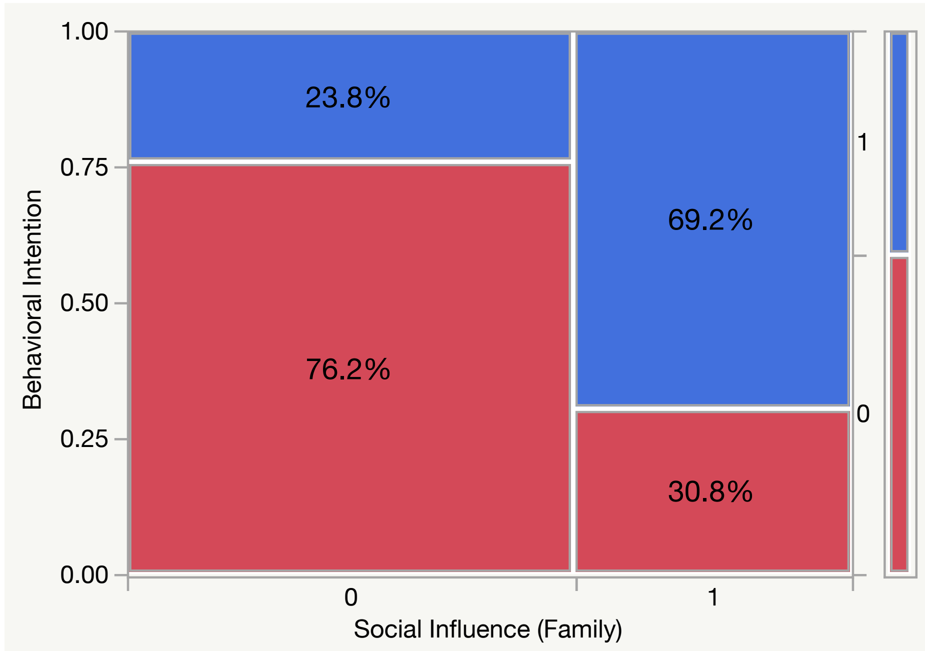

Figure 4.25 Mosaic plot represents the association between SI Family and BI concerning the location tracking WSD on the field labor survey.

Table 4.12 Field Labor Location Tracking WSD Contingency Table for SI Family by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
Family against use of device (0)	32 47.06 80.00 76.19	10 14.71 35.71 23.81	42 61.76
Family for use of device (1)	8 11.76 20.00 30.77	18 26.47 64.29 69.23	26 38.24
Total	40 58.82	28 41.18	68

Similar to the biometric device the perceived opinions of family members or loved ones show a strong association with voluntary use of the location tracking device. This is an interesting finding as it is not stressed in construction literature. A possible strategy to increase acceptance in your workforce would be to highlight the lifesaving ability of location tracking technology to friends and family of the workers through marketing.

4.6.6 Social Influence of Coworkers (SI Coworker)

The question regarding the social influence of coworkers was designed to gauge whether respondents would be more likely to voluntarily use the location tracking WSD if others on their crew were using the device. The majority (63%) of respondents did not believe their co-worker's use of the location tracking device would influence their personal use.

Based on the Pearson Chi-Squared value and subsequent P-value of less than 0.0001 an association exists between the social influence of coworkers and behavioral intent. A supermajority (77%) of individuals who answered their coworkers' use of the location tracker would not increase their likelihood of using the device also answered that they would refuse to use the device. Alternativity, only 28% of individuals who answered their coworkers using the location tracker would increase their likelihood of using the device also did not agree to use the device. This data can be seen graphically in Figure 4.26, and numerically in Table 4.13.

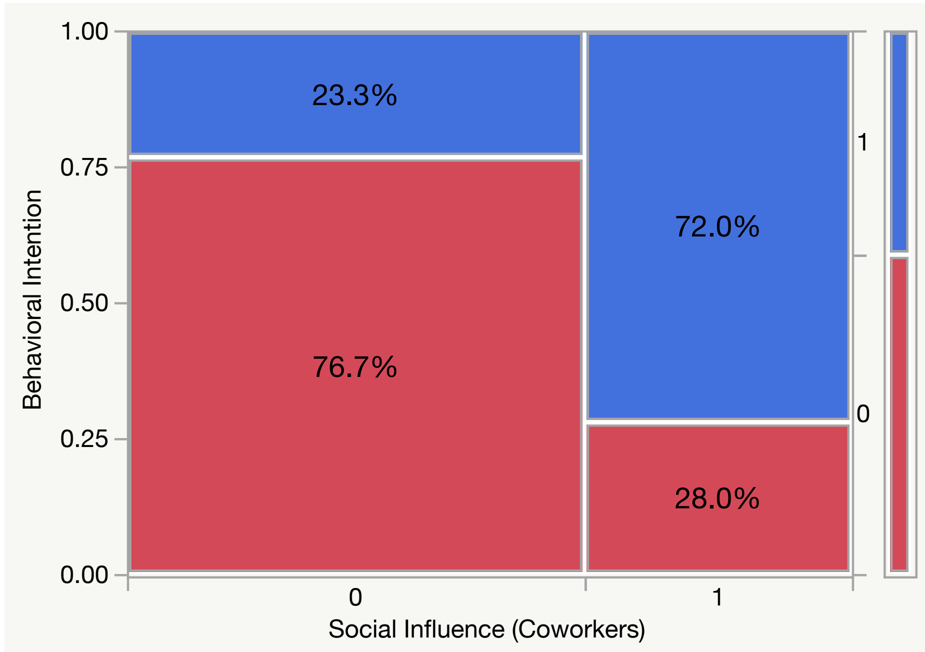

Figure 4.26 Mosaic plot represents the association between SI Coworkers and BI concerning the location tracking WSD on the field labor survey.

Table 4.13 Field Labor Location Tracking WSD Contingency Table for SI Coworkers by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
Coworkers did not have influence. (0)	33 48.53 82.50 76.74	10 14.71 35.71 23.26	43 63.24
Coworkers did have influence (1)	7 10.29 17.50 28.00	18 26.47 64.29 72.00	25 36.76
Total	40 58.82	28 41.18	68

The takeaway from this section is that a voluntary use program of the location tracker would do little to increase involvement. Individuals do not perceive their coworkers' actions to affect them. However, a case study might be of interest to better understand if workers' actions and perceptions of their actions coincided with each other.

4.6.7 Data Security (DS)

Questions regarding data security were designed to gauge the level of concern the respondents had regarding the company storing data collected from the location tracking WSD. The majority (57%) of respondents reported being somewhat to extremely concerned with the security of their location data.

Based on the Pearson Chi-Squared value and subsequent p-value of 0.0432 a statistically significant association exists between data security and behavioral intent. The majority (69%) of individuals who had concerns about the security of their location data also answered that they would refuse to use the device. Alternativity, only 45% of individuals who had little or no concerns regarding the security of their location data did not agree to use the device. This data can be seen graphically in Figure 4.27, and numerically in Table 4.14.

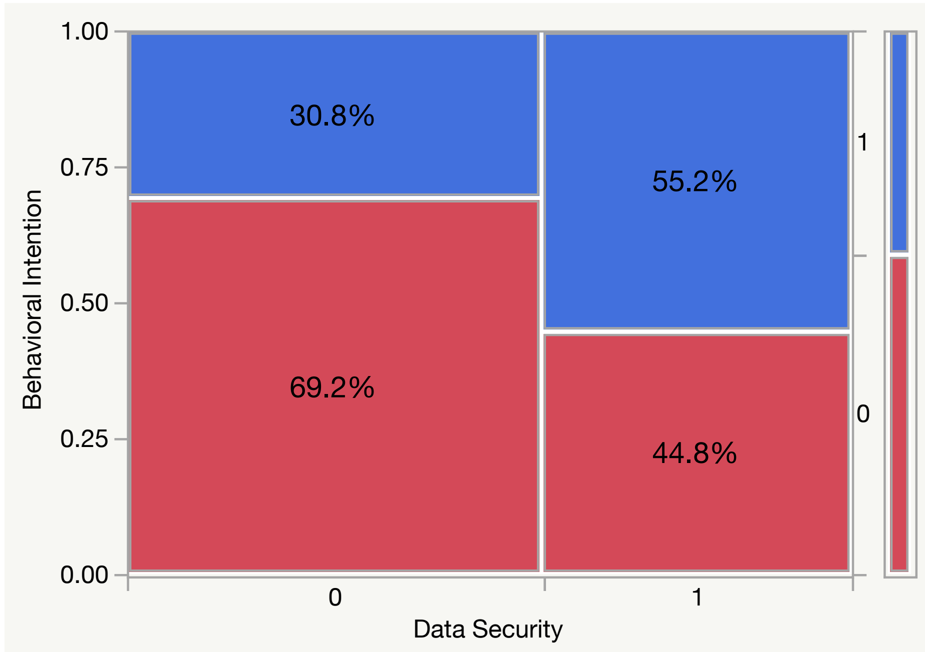

Figure 4.27 Mosaic plot represents the association between DS and BI concerning the location tracking WSD on the field labor survey.

Table 4.14 Field Labor Location Tracking WSD Contingency Table for DS by BI

Count Total % Col % Row %	Did Not Agree to Use the Device (0)	Agreed to Use the Device (1)	Total
High Concern Regarding Data Security (0)	27 39.71 67.50 69.23	12 17.65 42.86 30.77	39 57.35
Low Concern Regarding Data Security (1)	13 19.12 32.50 44.83	16 23.53 57.14 55.17	29 42.65
Total	40 58.82	28 41.18	68

The results from this section confirm that data security should be a priority when deploying a location tracking device. While an association can be found between the two constructs many individuals who agreed to use the location device still harbored concerns regarding data security. For long-term acceptance, it might be smart to implement strong data security, provide transparency of that security to individuals, and continue to demonstrate that the security is in place.

4.7 Field Labor Summary

This section analyzed the results from the field labor survey. It was found that 46% of field labor respondents did not agree to use the biometric WSD. For the biometric WSD, a statistically significant association with behavior intent was found between PPE, PEE, and SI. Based on these findings when implementing a biometric WSD acceptance may be increased when emphasis is placed on high device performance, ease of use, and acceptance among labor social groups (family/loved ones and coworkers). It was found that 59% of field labor respondents did not agree to use the location tracking WSD. For the location tracking WSD, a statistically significant association with behavior intent was found between PPE, SI, and DS. Based on these findings when implementing a location tracking WSD acceptance may be increased when emphasis is placed on high device performance, acceptance among labor social groups (family/loved ones and coworkers), and security of location based data.

5. MANAGEMENT RESULTS AND DISCUSSION

5.1 Introduction

The following section will discuss the results from the management survey. First, an overview of demographics and general trends will be discussed. Next, each construct will be analyzed. The analysis will be conducted in two phases for each device. Beginning with the biometric WSD, in phase 1 PPE, PEE, ODU, SI, and DS will be analyzed independently, followed by a Pearson chi-squared analysis to determine if an association exists between each construct and behavioral intention (BI). Next, in phase two BI and FC will undergo Pearson chi-squared tests to test for association with actual use (AU). Subsequently, both phases of analysis will be repeated with regard to the location tracking WSD.

5.2 Demographics and Sample Data

The management portion of the wearable sensing devices surveys collected 88 total responses. Of those responses, nine had to be discarded due to incompleteness, leaving 79 complete responses. Survey Responses were collected from November 2021 – to December 2021. The following Figures 5.1- 5.6 and Tables 5.1-5.6 summarize the demographics of the respondents.

Below in Figure 5.1 the sample is broken down by age. The sample is skewed to the right as there was higher participation among older age groups. As those in management roles are typically further along in their careers, this is expected.

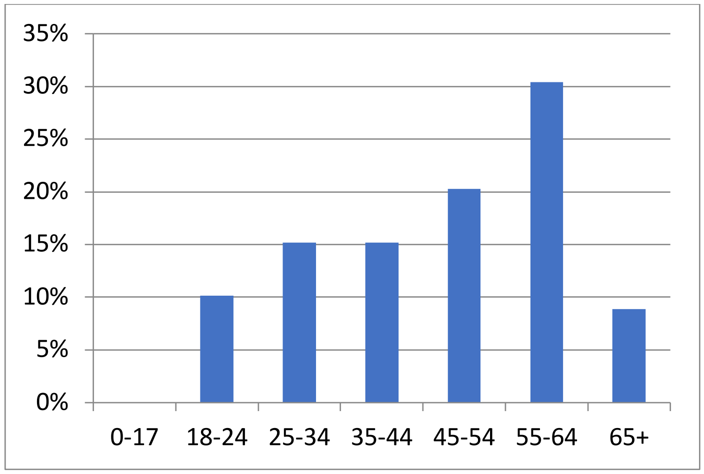

Figure 5.1 Management distribution of age demographic by the percentage of respondents.

In Figure 5.2, the sample is broken down by years of industry experience. The majority of respondents had 25 plus years of experience in industry. The next highest group were those respondents with zero to four years of experience. This could be due to the high percentage of young superintendents.

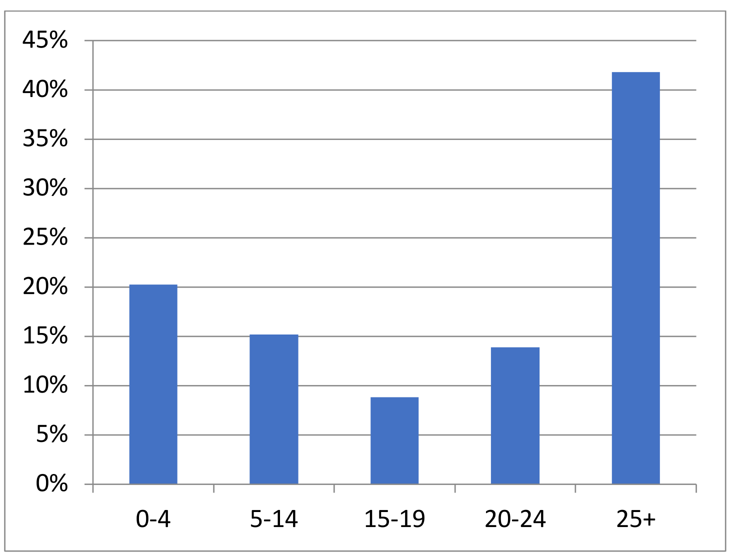

Figure 5.2 Management years of industry experience by the percentage of respondents.

Below in Figure 5.3, the sample is broken down by geographic region. The majority of respondents were located in the western united states. This was most likely due to the author's network in the west.

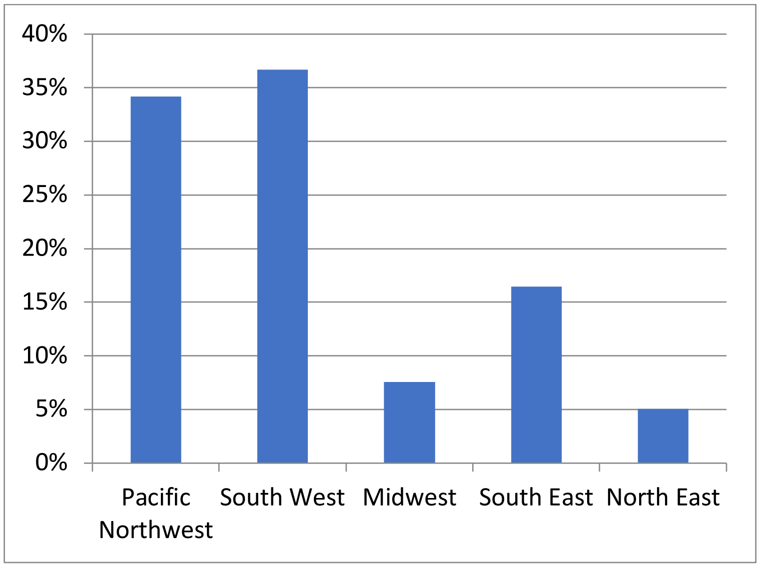

Figure 5.3 Management geographic region by the percentage of respondents.

Below in Figure 5.4, the sample is broken down by job title. The distribution of management job titles was relatively spread. The highest percentage of respondents came from project managers.

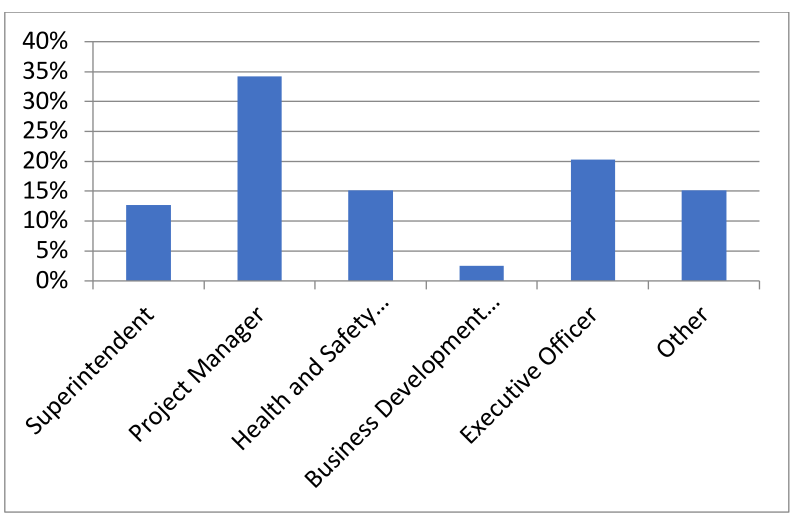

Figure 5.4 Management job title by the percentage of respondents.

Below in Figure 5.5, the sample is broken down by the construction sector. The majority of respondents came from commercial and environmental sectors.

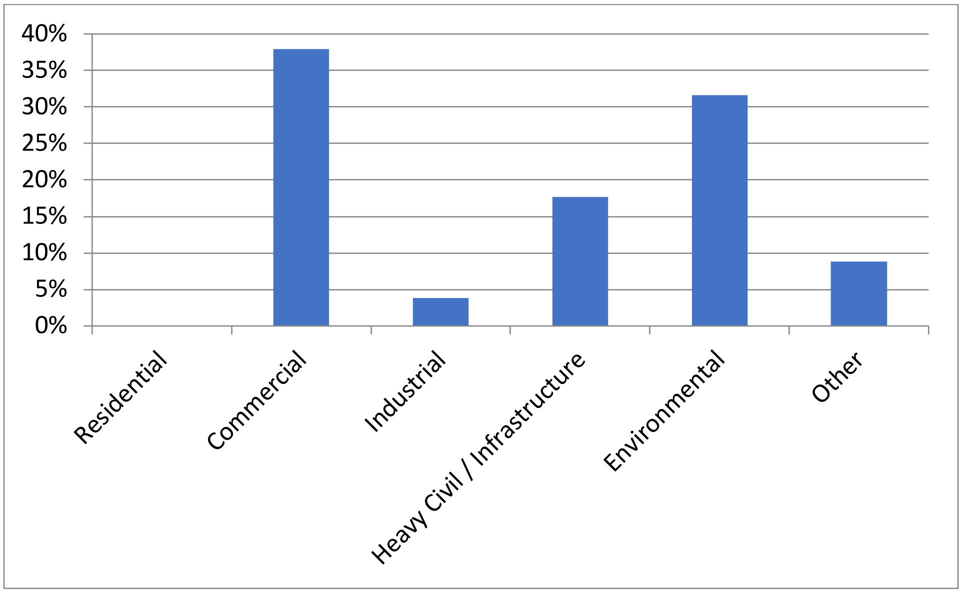

Figure 5.5 Management construction sector by the percentage of respondents.

Below in Figure 5.6, the sample is broken down by public versus private sector managers. The responses were relatively split between the public and private sectors.

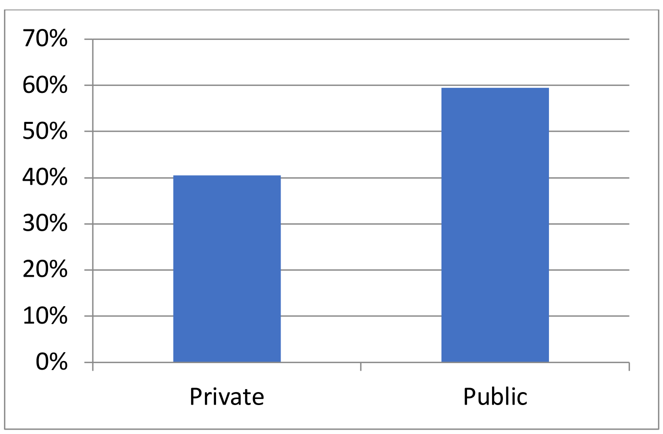

Figure 5.6 Management public versus private sector by the percentage of respondents.

5.3 Management Biometric WSD Previous Experience

The following tables and Figures reflect the previous knowledge regarding biometric WSDs. Respondents were asked to rank their level of familiarity with biometric WSDs, these results can be seen graphically in Figure 5.7. The most common level of familiarity was "somewhat familiar" receiving 30% of the responses. The results follow a semi-normal distribution.

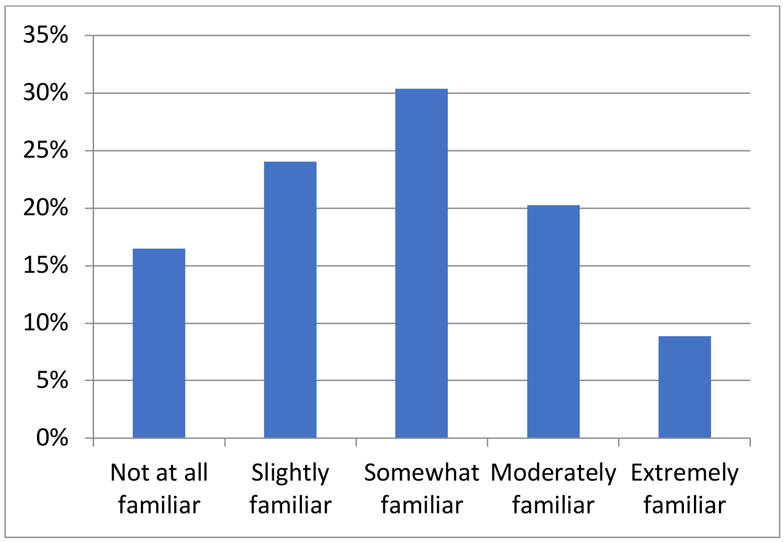

Figure 5.7 Management level of familiarity with biometric WSD by the percentage of respondents.

Respondents were asked if they had ever used Biometric WSD at any of their sites. The results can be seen graphically in Figure 5.8. Only 27% reported having used a biometric device at any of their sites.

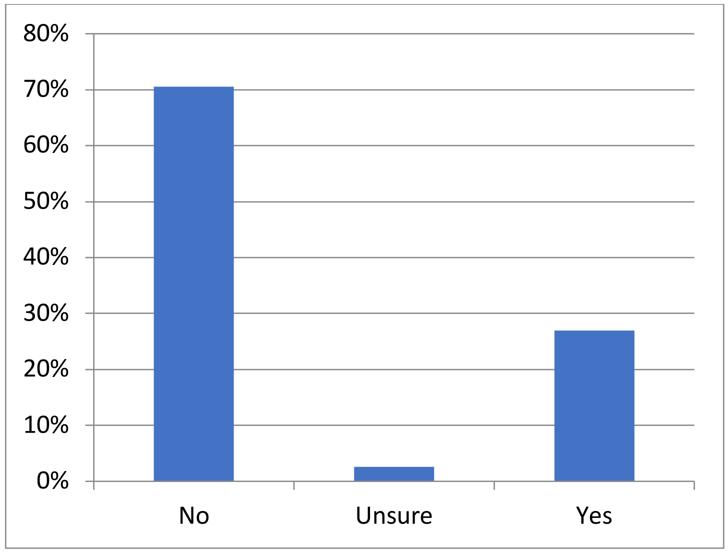

Figure 5.8 Management past usage of a biometric WSD as a percentage of respondents.

Next, the respondents were asked if they are currently using a biometric WSD at any of their sites. The results can be seen in Figure 5.9. Only 11% of respondents reported that they are currently using a biometric WSD.

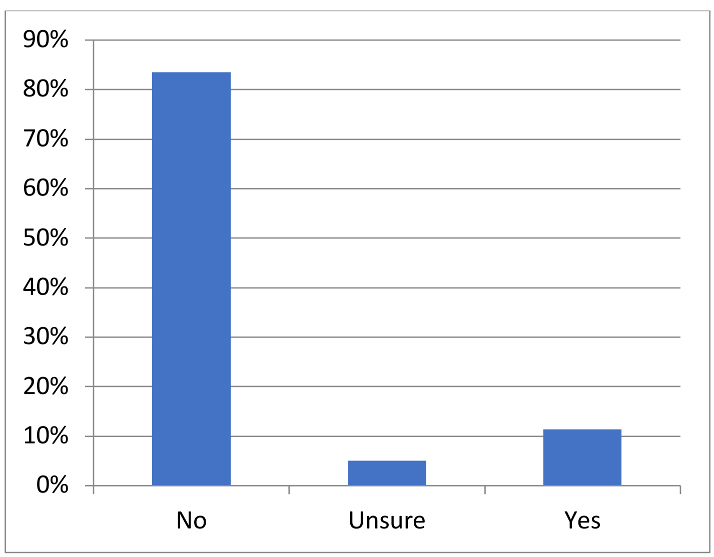

Figure 5.9 Management respondents who are currently using a biometric WSD as a percentage of respondents.

Lastly, respondents reported if they had ever terminated the use of a biometric WSD at any of their sites. The results of this question can be seen graphically in Figure 5.10. A small minority (10%) of respondents reported having terminated the use of a biometric WSD.

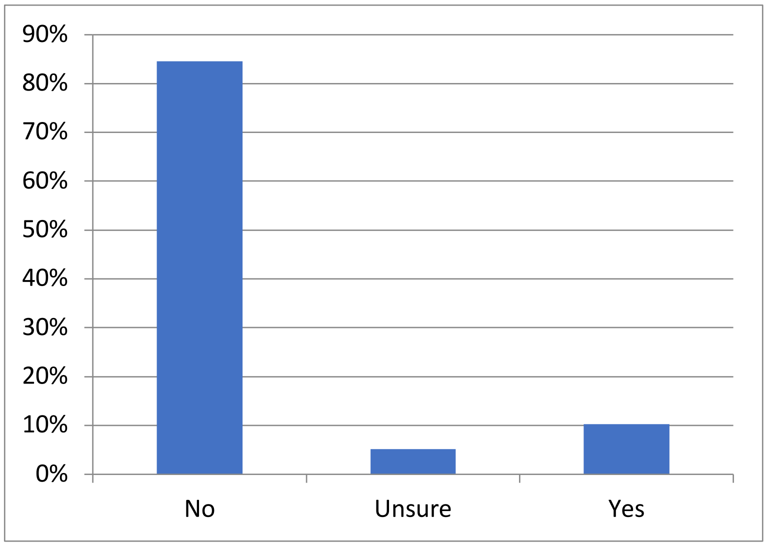

Figure 5.10 Management respondents who have terminated the use of a biometric WSD as a percentage of total respondents.

5.4 Management Biometric WSD Analysis

5.4.1 Introduction

The following section will analyze and discuss the results from the biometric WSD portion of the management survey. It was found that a slight majority (52%) of construction managers would not implement the biometric WSD regardless of price. A similar slight majority (56%) would not implement the biometric WSD while taking into account the price of implementing the device. In Phase I, of this analysis Pearson chi-squared tests were conducted to test the association between five constructs and behavioral intent. Of the five constructs analyzed a statistically significant association was found for the constructs PPE and ODU. For the constructs of PEE and DS no association was found. For the final construct, SI association was dependent upon the source of the social influence (competitor or client). A summary table of Pearson chi-squared values and associated p-values can be found below in Table 5.11. Further information containing the analysis of each construct can be found in sections 5.3.2-5.3.7.

Table 5.1 Management Biometric WSD Phase I Pearson Chi-Squared Summary

Construct	Pearson Chi-Squared	P-Value
PPE	7.864	0.005
PEE	3.584	0.0584
ODU	7.99	0.0047
SI (Competitors)	0.241	0.6236
SI (Clients)	6.649	0.0099
DS	3.703	0.0543

In Phase II of this analysis, Pearson chi-squared tests were conducted to test the association between two constructs (BI & FC) and actual use (AU). An association was found between BI and AU. There was no evidence of an association between FC and AU. A summary table of Pearson chi-squared values and associated p-values can be found below in Table 5.8. Further information containing the analysis of each construct can be found in sections 5.3.8 & 5.3.9.

Table 5.2 Management Biometric WSD Phase II Pearson Chi-Squared Summary

Construct	Pearson Chi-Squared	P-Value
BI	35.613	<0.0001
FC	2.702	0.1002

5.4.2 Perceived Performance Expectancy (PPE)

Perceived performance expectancy questions were designed to judge whether the respondent believed the biometric WSD would make their worksites a safer place. A supermajority (72%) of construction management professionals surveyed believed that the biometric device would make their sites a safer place.

Based on the Pearson Chi-Squared value and subsequent P-value of 0.005 a statistically significant association exists between perceived performance expectancy and behavioral intent. The supermajority (77.27%) of individuals who did not think the device would aid their site safety also had no intention of implementing the biometric device. Alternativity, only 42% of individuals who believed the biometric device would aid in their site safety had no intention of implementing the device. This data can be seen graphically in Figure 5.11, and numerically in Table 5.3.

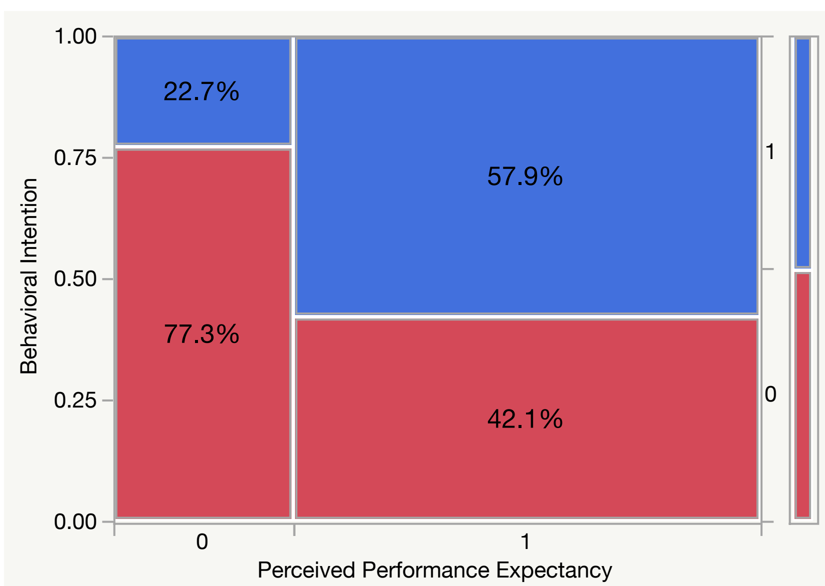

Figure 5.11 Mosaic plot represents the association between PPE and BI concerning the biometric WSD on the management survey.

Table 5.3 Management Biometric WSD Contingency Table for PPE by BI

Count Total % Col % Row %	Would not Implement device disregarding price (0)	Would implement device disregarding price (1)	Total
Low Performance Expectancy (0)	17 21.52 41.46 77.27	5 6.33 13.16 22.73	22 27.85
High Performance Expectancy (1)	24 30.38 58.54 42.11	33 41.77 86.84 57.89	57 72.15
Total	41 51.90	38 48.10	79

The results discussed above make sense, if a decision maker inside a construction firm does not find a new piece of technology to be useful the likelihood of them having the intent to implement the technology decreases. The results of this study confirm this ideology.

5.4.3 Perceived Effort Expectancy (PEE)

Perceived effort expectancy questions were designed to determine if the respondent had concerns regarding the amount of training time or effort that would be required to introduce the biometric WSD. Two-thirds (66%) of those surveyed reported having little to no concern regarding training time and effort.

Based on the Pearson Chi-Squared value and subsequent P-value of 0.058 no association was found between perceived effort expectancy and behavioral intent. The p-value of 5.8% fell slightly outside our 5%. It is possible with more data collected an association could be found, but this study cannot claim there to be. The data is depicted graphically below in Figure 5.12 and numerically in Table 5.4. A supermajority (67%) of respondents who were worried about training their employees on how to use the biometric WSD had no intention of implementing the device. However, 44% of those who had little worry about training still had no intention of implementing the biometric WSD.

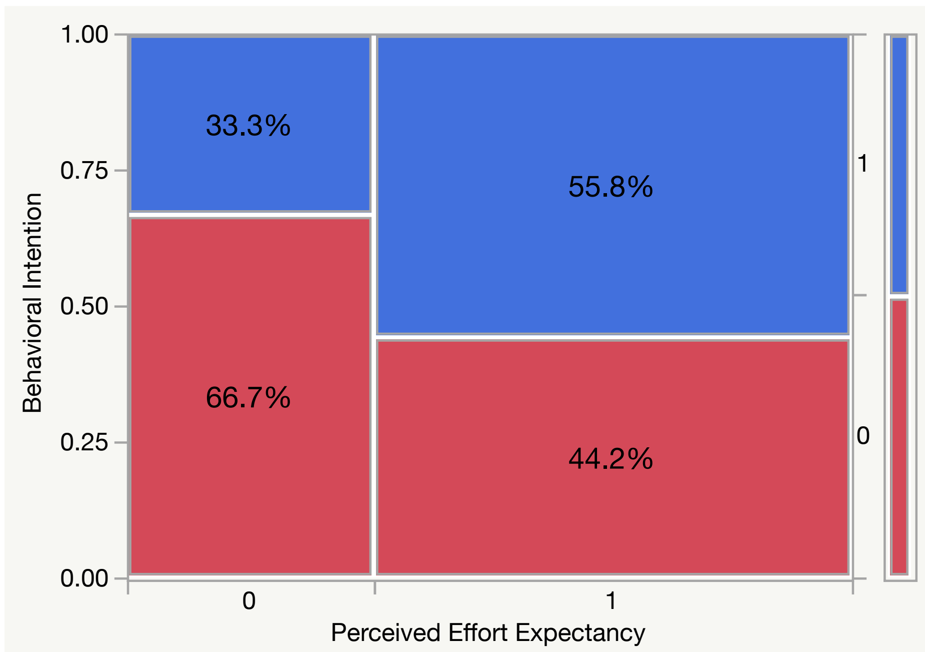

Figure 5.12 Mosaic plot represents the association between PEE and BI concerning the biometric WSD on the management survey.

Table 5.4 Management Biometric WSD Contingency Table for PEE by BI

Count Total % Col % Row %	Would not Implement device disregarding price (0)	Would implement device disregarding price (1)	Total
High Perceived Training Difficulty (0)	18 22.78 43.90 66.67	9 11.39 23.68 33.33	27 34.18
Low Perceived Training Difficulty (1)	23 29.11 56.10 44.23	29 36.71 76.32 55.77	52 65.82
Total	41 51.90	38 48.10	79

This means that there is no distinct correlation between managements concerns regarding training and device implementation. While it is still ideal to make new technology easy to use from the perspective of the device user, this study found it is not a good predictor of device acceptance.

5.4.4 Openness to Data Utilization (ODU)

Openness to data utilization questions was designed to determine if a respondent had concerns regarding legal issues arising from tracking employee biometric health data while on site. It was found that the majority of respondents (63%) reported being somewhat-extremely concerned.

Based on the Pearson chi-squared value and subsequent p-value of 0.0047 a statistically significant association exists between openness to data security and behavioral intent. The majority (64%) of management individuals who were concerned about legal issues arising from storing employee health data also showed no intention of implementing the device. Alternatively, only 31% of those who showed little to no concern over legal issues arising from storing employee health data also showed no intention of implementing the biometric device. The rest of the data can be seen graphically in Figure 5.13, and numerically in Table 5.5.

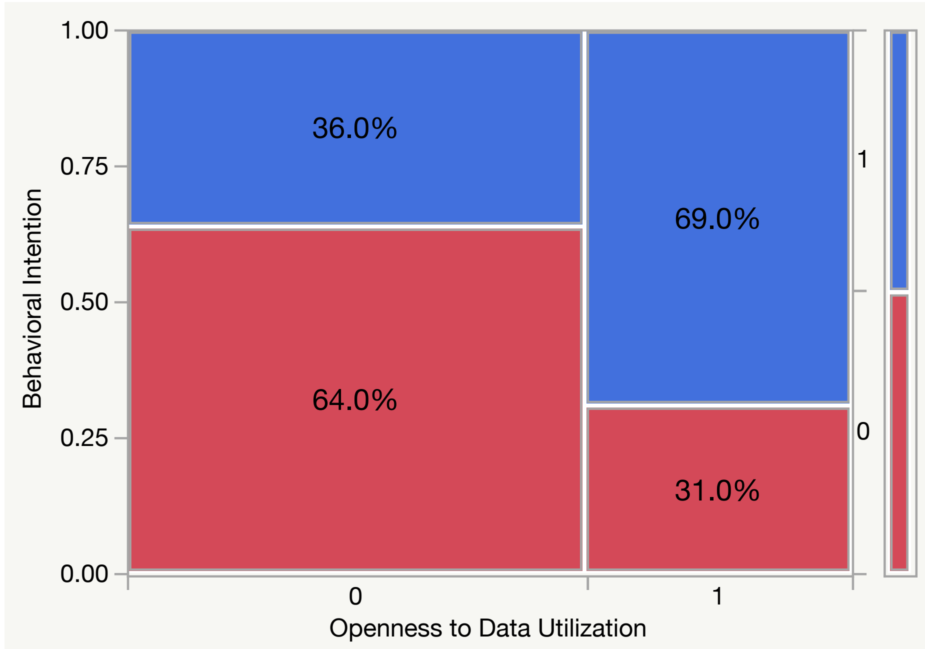

Figure 5.13 Mosaic plot represents the association between ODU and BI concerning the biometric WSD on the management survey.

Table 5.5 Management Biometric WSD Contingency Table for ODU by BI

Count Total % Col % Row %	Would not Implement device disregarding price (0)	Would implement device disregarding price (1)	Total
More Legal Concern (0)	32 40.51 78.05 64.00	18 22.78 47.37 36.00	50 63.29
Less Legal Concern (1)	9 11.39 21.95 31.03	20 25.32 52.63 68.97	29 36.71
Total	41 51.90	38 48.10	79

This shows that those trying to influence construction management individuals to implement a biometric sensing device could target the issue of how to successfully manage employee health data. This could help management justify the risk of using the data. One option might be to have the health data stored locally with the employee. Supervisors would only be alerted of a potentially dangerous situation, and not be able to track and store employee health data collected by the biometric sensing device.

5.4.5 Social Influence of Competitors (SI Competitors)

Questions regarding the social influence of competitors were designed to help determine the level of influence that outside firms would have on the implementation of a biometric WSD. More specifically if one's competitors were to implement a biometric WSD would that increase the likelihood of the respondent implementing a biometric WSD? The majority (63%) of respondents answered that their competitor's actions would have little to no effect on their actions.

Based on the Pearson Chi-Squared value above and the associated p-value of 0.6236 no association was found between the social influence of competitors and the behavioral intention. The results can be seen graphically below in Figure 5.14, and numerically in Table 5.6. While analyzing the mosaic plot in Figure 5.14 it is noticeable that the 4 quadrants are relatively proportionate. 54% of respondents who did not see competitors as having an influence on their own practices did not have the intention of implementing the biometric WSD. However, 48% of respondents who did see their competitors as having an influence on their actions still did not plan on implementing the WSD.

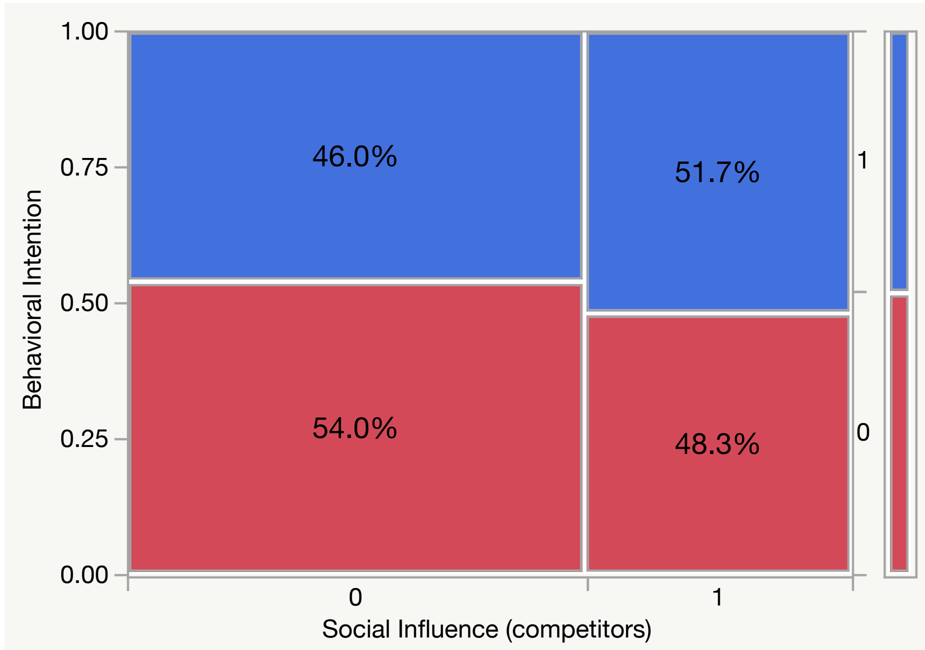

Figure 5.14 Mosaic plot represents the association between SI competitors and BI concerning the biometric WSD on the management survey.

Table 5.6 Management Biometric WSD Contingency Table for SI competitors by BI

Count Total % Col % Row %	Would Not Implement Device Disregarding Price (0)	Would Implement Device Disregarding Price (1)	Total
Competitors Did Not Have Influence. (0)	27 34.18 65.85 54.00	23 29.11 60.53 46.00	50 63.29
Competitors Did Have Influence (1)	14 17.72 34.15 48.28	15 18.99 39.47 51.72	29 36.71
Total	41 51.90	38 48.10	79

The results from this section show that construction management professionals have a wide range of opinions on how a competitor's decisions affect their own internal decisions. As seen above in Figure 5.14 the sample split relatively evenly inside the four quadrants of the mosaic plot. This shows that for those trying to implement a biometric

WSD into industry the actions of competing firms may not have a large impact on each other.

5.4.6 Social Influence of the Client (SI client)

Questions regarding the social influence of the client were designed to determine the respondent's opinion on whether they believed their client would support the implementation of a biometric WSD. The results were nearly split with a slight majority (52%) of respondents answering that they were unsure or disagreed that the client would support the use of a biometric WSD.

Based on the Pearson chi-squared value above and the associated p-value of 0.009 a statistically significant association exists between the social influence of the client and behavioral intention. A majority (67%) of respondents who did not agree their clients would support the implementation of the biometric WSD also did not show behavioral intention of implementing the biometric WSD. Alternatively, only 37% of those who agreed their clients would support the implementation of a biometric WSD also showed no intention of implanting the biometric WSD. This data can be seen graphically below in Figure 5.15, and numerically in Table 5.7.

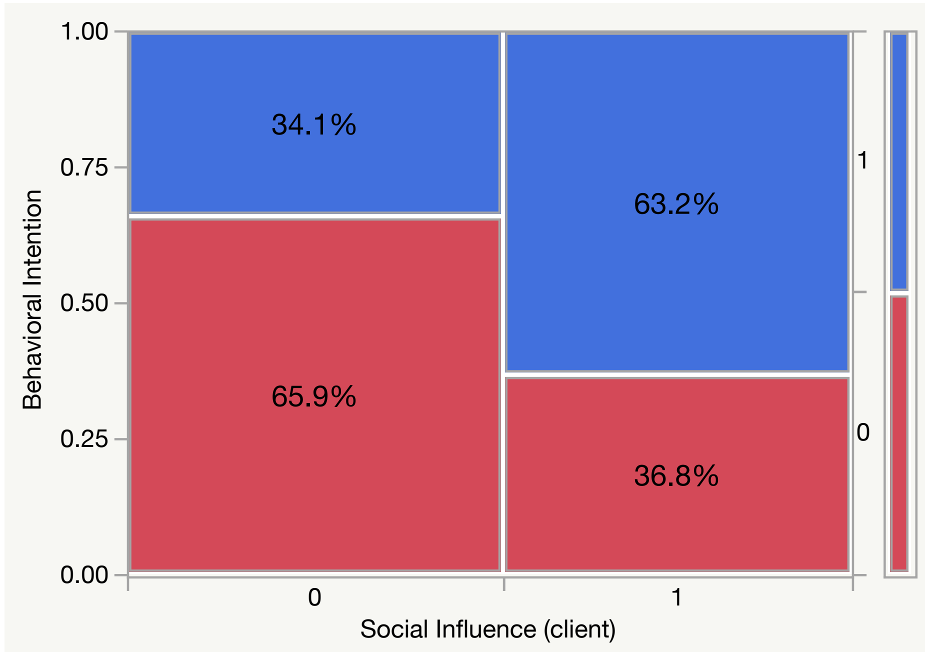

Figure 5.15 Mosaic plot represents the association between SI Client and BI concerning the biometric WSD on the management survey.

Table 5.7 Management Biometric WSD Contingency Table for SI Client by BI

Count Total % Col % Row %	Would Not Implement Device Disregarding Price (0)	Would Implement Device Disregarding Price (1))	Total
Clients Do Not Have influence. (0)	27 34.18 65.85 65.85	14 17.72 36.84 34.15	41 51.90
Clients Do Have Influence (1)	14 17.72 34.15 36.84	24 30.38 63.16 63.16	38 48.10
Total	41 51.90	38 48.10	79

This data shows that there can be an association between the acceptance of a WSD and the preconceived opinion of a client. When trying to implement a biometric WSD it might be helpful to approach the client regarding the device. A client's support of the device could help increase device acceptance. This is an area of potential future research, surveying a large body of clients regarding the use of wearable sensing devices. This research could look specifically into the reasons a client might be in favor or opposed to the biometric WSD such as decreasing liability, bettering their public image, cost to the client, potential impeding of the project, lack of knowledge as to the benefits, and so forth.

5.4.7 Data Security (DS)

Data security questions were designed to judge the level of concern respondents had toward storing the biometric health data of their employees. The majority of those surveyed (68%) were somewhat-extremely concerned about storing the biometric health data.

Based on the Pearson Chi-Squared value and associated P-value of 0.054 no association was found between data security and behavioral intention. The p-value of 5.4% falls just outside of the 5% threshold making a case that in a larger sample size an association may be recognized. However, this study cannot claim association to exist. The data can be displayed graphically below in Figure 5.16, and numerically in Table 5.8. A majority (59%) of respondents who had high concerns regarding data security had no intention of implementing the biometric WSD. However, 36% of respondents who had low concerns regarding data security also showed no intention of implementing the biometric device. There is not enough variance between these two statistics to warrant an association.

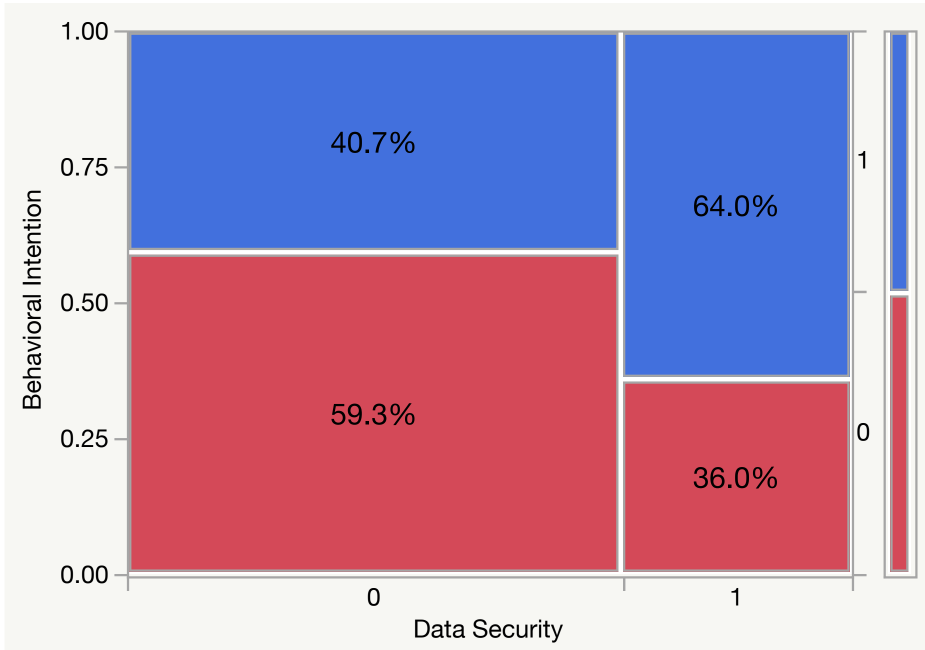

Figure 5.16 Mosaic plot represents the association between DS and BI concerning the biometric WSD on the management survey.

Table 5.8 Management Biometric WSD Contingency Table for DS by BI

Count Total % Col % Row %	Would Not Implement Device Disregarding Price (0)	Would Implement Device Disregarding Price (1)	Total
High Concern Regarding Data Security (0)	32 40.51 78.05 59.26	22 27.85 57.89 40.74	54 68.35
Low Concern Regarding Data Security (1)	9 11.39 21.95 36.00	16 20.25 42.11 64.00	25 31.65
Total	41 51.90	38 48.10	79

While an association cannot be drawn at this moment there are other areas of interest. Over two-thirds (69%) of construction management professionals expressed concern with storing employee health data. This represents a vast majority with concerns in this area. Therefore, it is a topic that should be discussed and evaluated in advance of implementing a biometric WSD.

5.4.8 Behavioral Intention (BI)

This marks the beginning of phase II of this analysis. Questions regarding behavioral intent were designed to determine whether or not the respondent would implement the biometric WSD regardless of price. The results were nearly split with a slight majority (52%) of respondents unwilling to implement the biometric device regardless of the total cost.

Based on the Pearson Chi-Squared value above and associated P-value of less than 0.0001 a statistically significant association exists between the behavioral intention and actual use. A supermajority (88%) of respondents who did not show the behavioral intention to implement the biometric WSD also responded that considering all factors they would not implement the biometric device. Alternatively, only 21% of respondents who showed behavioral intent to implement the biometric WSD did not intend to actually use the device when all factors were considered. This data can be seen graphically below in Figure 5.17, and numerically in Table 5.9.

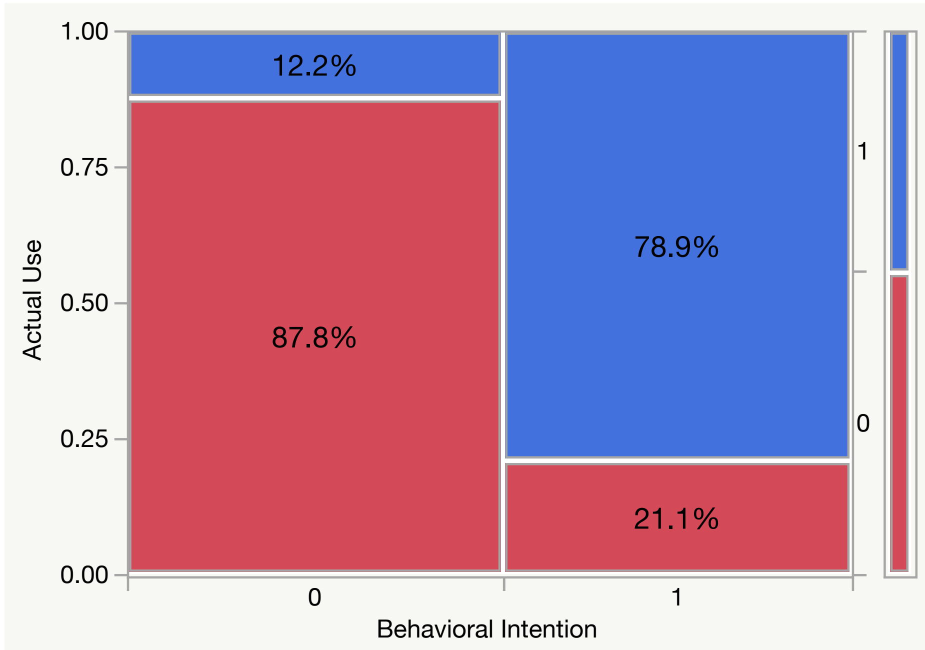

Figure 5.17 Mosaic plot represents the association between BI and AU concerning the biometric WSD on the management survey.

Table 5.9 Management Biometric WSD Contingency Table for BI by AU

Count Total % Col % Row %	Would Not Implement Device (0)	Would Implement Device (1)	Total
Would Not Implement Device Disregarding Price (0)	36 45.57 81.82 87.80	5 6.33 14.29 12.20	41 51.90
Would Implement Device Disregarding Price (1)	8 10.13 18.18 21.05	30 37.97 85.71 78.95	38 48.10
Total	44 55.70	35 44.30	79

This data shows that behavioral intent has a strong association with actual use. This comes as no shock that if an individual believes in a new technology the likelihood of implementation increases. Alternativity, it is surprising that such a low percentage of managers would still not implement the device regardless of the price. Based on previous research, the assumption is that the resistance comes from the workers. The findings of this study suggest that the first group that may need to be convinced of the value of biometric WSDs is management.

5.4.9 Facilitating Conditions (FC)

Questions regarding facilitating conditions were designed to determine the level of influence cost has on implementing a biometric WSD. The supermajority (72%) of respondents considered cost an influential factor in implementing a biometric WSD.

Based on the Pearson chi-squared value and associated P-value of less than 0.1002 no association was found between the facilitating conditions and actual use. A majority (61%) of respondents who found price an influential factor in implementing a biometric WSD also would not implement a biometric. Alternatively, 41% of respondents who did not find the price to be influential also would not implement the biometric WSD. This data can be seen graphically below in Figure 5.18, and numerically in Table 5.10.

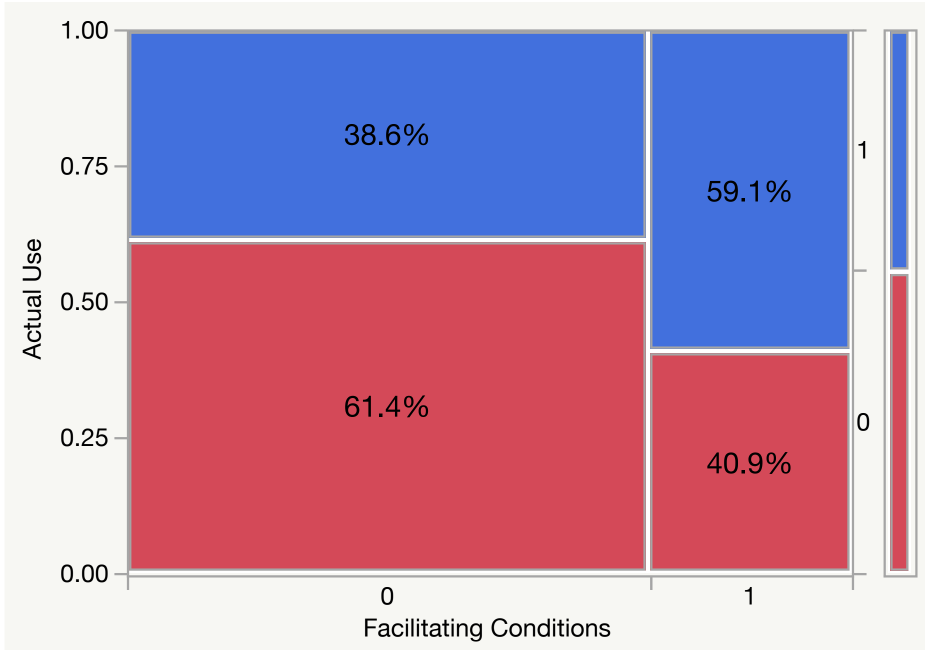

Figure 5.18 Mosaic plot represents the association between FC and AU concerning the biometric WSD on the management survey.

Table 5.10 Management Biometric WSD Contingency Table for FC by AU

Count Total % Col % Row %	Would Not Implement Device (0)	Would Implement Device (1)	Total
High Importance of Cost (0)	35 44.30 79.55 61.40	22 27.85 62.86 38.60	57 72.15
Low Importance of Cost (1)	9 11.39 20.45 40.91	13 16.46 37.14 59.09	22 27.85
Total	44 55.70	35 44.30	79

The vast majority of construction managers consider the price at least somewhat influential. However, this information is not a good indicator if respondents would use the biometric WSD. For instance, a significant portion (28%) of respondents would implement the device regardless of price. The results of this section reflect that while the price is important it may not be the first topic of interest when aiming to increase biometric device acceptance by construction managers.

5.5 Management Location Tracking WSD Analysis

5.5.1 Introduction

The following section will analyze and discuss the results from the location tracking WSD portion of the management survey. It was found that a supermajority (68%) of construction managers would not implement the location tracking WSD. Similarly, the same supermajority (68%) would not implement the location tracking WSD regardless of cost. In Phase I of this analysis, Pearson chi-squared tests were conducted to test the association between five constructs and behavioral intent. A statistically significant association was found between all 5 constructs (PPE, PEE, ODU, SI, & DS) and behavioral intent (BI). A summary table of Pearson chi-squared values and associated p-values can be found below in Table 5.11. Further information containing the analysis of each construct can be found in sections 5.4.2-5.4.7.

Table 5.11 Management Location Tracking WSD Phase I Pearson Chi-Squared Summary

Construct	Pearson Chi-Squared	P-Value
PPE	16.037	<0.0001
PEE	4.135	0.042
ODU	4.382	0.0363
SI (Competitors)	13.773	0.0002
SI (Clients)	15.414	<0.0001
DS	3.927	0.0475

In Phase II of this analysis Pearson chi-squared tests was conducted to test the association between two constructs (BI and FC) and actual use (AU). An association was found between BI and AU. There was no evidence of an association between FC and AU. A summary table of Pearson chi-squared values and associated p-values can be found below in Table 5.12. Further information containing the analysis of each construct can be found in sections 5.4.8 & 5.4.9.

Table 5.12 Management Biometric WSD Phase II Pearson Chi-Squared Summary

Construct	Pearson Chi-Squared	P-Value
BI	39.543	<0.0001
FC	1.662	0.1973

5.5.2 Perceived Performance Expectancy (PPE)

Perceived performance expectancy questions were designed to judge whether the respondent believed the location tracking WSD would make their worksites a safer place. A majority of construction management professionals surveyed (59%) believed that the location tracking device would make their sites a safer place.

Based on the Pearson Chi-Squared value above and the associated p-value of <0.0001 an association exists between the perceived performance expectancy and behavioral intention. Nearly all (94%) of those who did not believe the device would aid in their site safety would not agree to implement the device. Alternatively, only 51% of those who believed the device would aid in site safety also did not agree to implement the location tracking device. These results can be seen graphically below in Figure 5.19, and numerically in Table 5.13.

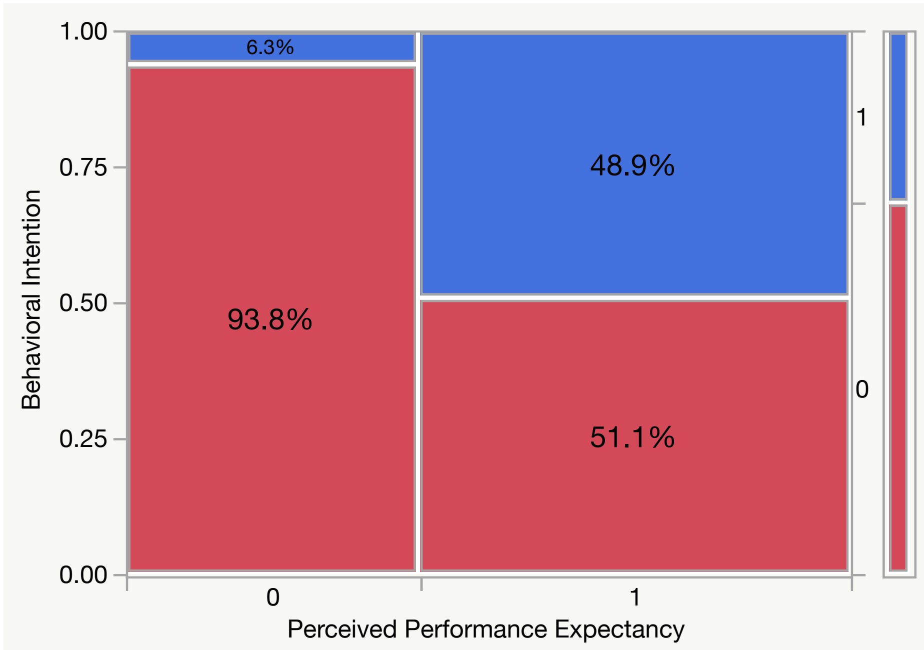

Figure 5.19 Mosaic plot represents the association between PPE and BI concerning the location tracking WSD on the management survey.

Table 5.13 Management Location Tracking WSD Contingency Table for PPE by BI

Count Total % Col % Row %	Would Not Implement Device Disregarding Price (0)	Would Implement Device Disregarding Price (1)	Total
Low Performance Expectancy (0)	30 37.97 55.56 93.75	2 2.53 8.00 6.25	32 40.51
High Performance Expectancy (1)	24 30.38 44.44 51.06	23 29.11 92.00 48.94	47 59.49
Total	54 68.35	25 31.65	79

This shows that focusing on the performance of a location tracking device is crucial for device acceptance. Promoters of the device might need to focus on the lifesaving power of the device to try and change the perception of those who find the device useless. Creating a belief in the value of the location tracking device is fundamentally a first and critical step.

5.5.3 Perceived Effort Expectancy (PEE)

Perceived effort expectancy questions were designed to determine if the respondent had concerns regarding the amount of training time or effort that would be needed to introduce the location tracking WSD. The majority (59%) of those surveyed reported having little to no concern regarding training time and effort (59%).

Based on the Pearson Chi-Squared value and the associated p-value of 0.042 an association exists between perceived effort expectancy and behavioral intention. A supermajority (81%) of those surveyed who had moderate to extreme concerns regarding training also did not have the intention of implementing the location tracking device. Alternatively, 60% of respondents who had little to no concern regarding training also did not have the intention to implement the location tracking device. These results can be seen graphically below in Figure 5.20, and numerically in Table 5.14.

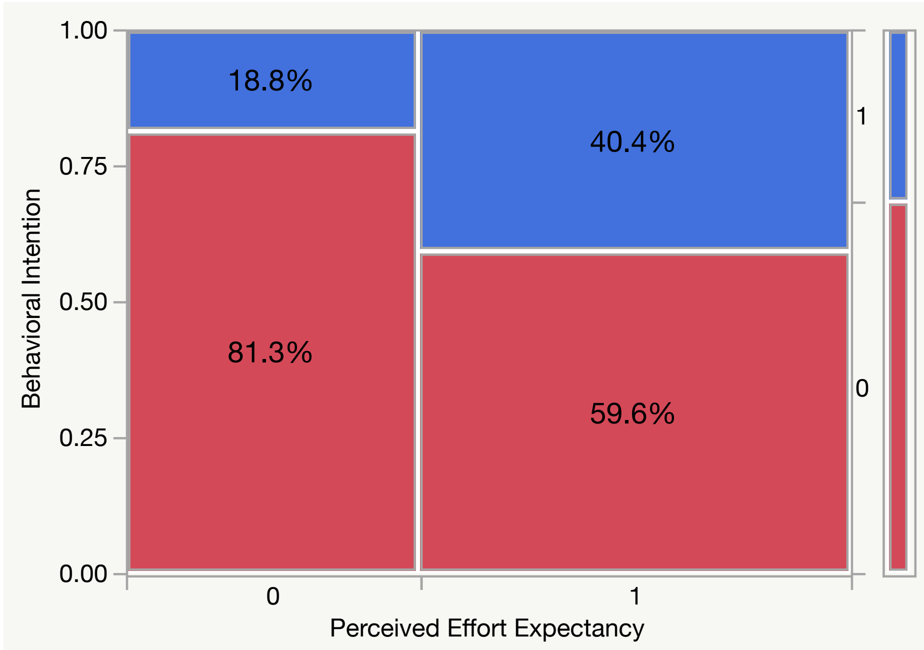

Figure 5.20 Mosaic plot represents the association between PEE and BI concerning the location tracking WSD on the management survey.

Table 5.14 Management Location Tracking WSD Contingency Table for PEE by BI

Count Total % Col % Row %	Would Not Implement Device Disregarding Price (0)	Would Implement Device Disregarding Price (1)	Total
High Perceived Training Difficulty (0)	26 32.91 48.15 81.25	6 7.59 24.00 18.75	32 40.51
Low Perceived Training Difficulty (1)	28 35.44 51.85 59.57	19 24.05 76.00 40.43	47 59.49
Total	54 68.35	25 31.65	79

As with the biometric WSD, the majority of construction managers see training as no obstacle. If training is needed, they appear to be willing to provide it. However, for those opposed to implementing the location tracking WSD, nearly half (48%) had high concerns regarding training therefore it should be addressed.

5.5.4 Openness to Data Utilization (ODU)

The openness to data utilization question was designed to determine if a respondent had concerns regarding legal issues arising from tracking employee location data while on site. It was found that the majority of respondents (65%) reported being somewhat to extremely concerned.

Based on the Pearson Chi-Squared value above and associated p-value of 0.0363 a statistically significant association exists between openness to data utilization and behavioral intention. The supermajority (77%) of those surveyed that had moderate to extreme concerns regarding legal issues arising from location data also did not agree to implement the device. Alternatively, 54% of those who had little to no concerns regarding legal issues arising from location tracking also did not agree to implement the location tracking WSD. These results can be seen graphically below in Figure 5.21, and numerically in Table 5.15.

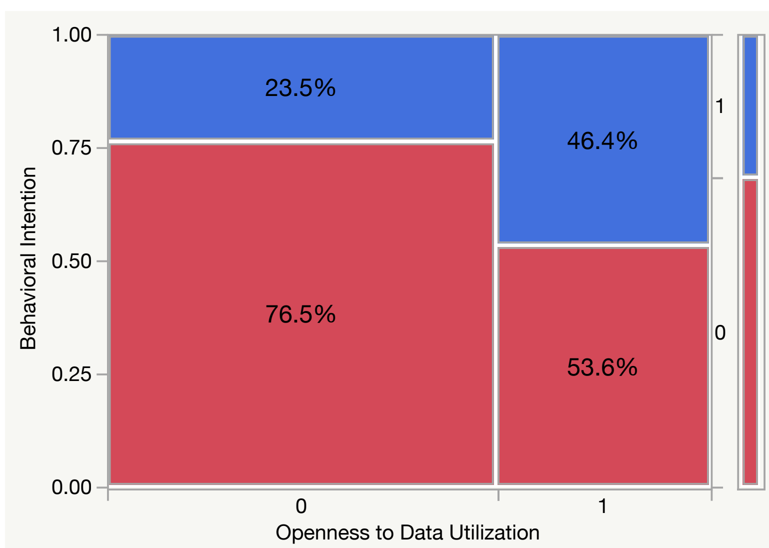

Figure 5.21 Mosaic plot represents the association between ODU and BI concerning the location tracking WSD on the management survey.

Table 5.15 Management Location Tracking WSD Contingency Table for ODU by BI

Count Total % Col % Row %	Would Not Implement Device Disregarding Price (0)	Would Implement Device Disregarding Price (1)	Total
More Legal Concern (0)	39 49.37 72.22 76.47	12 15.19 48.00 23.53	51 64.56
Less Legal Concern (1)	15 18.99 27.78 53.57	13 16.46 52.00 46.43	28 35.44
Total	54 68.35	25 31.65	79

This information suggests that the issue of data utilization is a serious concern for construction management individuals when considering implementing a location tracking WSD. Without a proper solution to this issue in place those who have concerns might oppose the implementation of said device.

5.5.5 Social Influence of Competitors (SI Competitors)

Questions regarding the social influence of competitors were designed to help determine the level of influence that outside firms would have on the implementation of a location tracking WSD. More specifically if one’s competitors were to implement a location tracking WSD would that increase the likelihood of the respondent implementing a location tracking WSD? Three quarters (75%) of respondents answered that their competitors’ actions would have little to no effect on their actions.

Based on the Pearson Chi-Squared value above and the associated p-value of 0.0002 a statistically significant association exists between the social influence of competitors and behavioral intention. A supermajority (80%) of those who did not believe their competitors using a location tracking device would influence them also did not agree to implement the location tracking WSD. Alternatively, only 35% of those who agreed their competitors would play a role in their decision also did not agree to implement the location tracking WSD. These results can be seen graphically below in Figure 5.22, and numerically in Table 5.16.

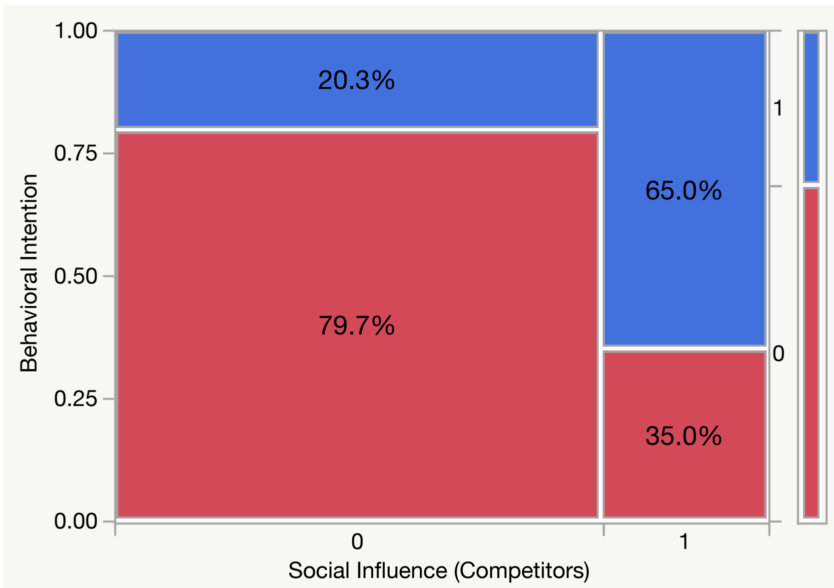

Figure 5.22 Mosaic plot represents the association between SI Competitors and BI concerning the location tracking WSD on the management survey.

Table 5.16 Management Location Tracking WSD Contingency Table for SI competitors by BI

Count Total % Col % Row %	Would Not Implement Device Disregarding Price (0)	Would Implement Device Disregarding Price (1)	Total
Competitors do not have influence (0)	47 59.49 87.04 79.66	12 15.19 48.00 20.34	59 74.68
Competitors do have influence (1)	7 8.86 12.96 35.00	13 16.46 52.00 65.00	20 25.32
Total	54 68.35	25 31.65	79

This could be a lingering reason why new technology adoption is behind in the industry. The vast majority of construction managers responded that their competitors do not influence their decisions. It could be an area of future research to study how firms reach in reality when finding out about the success or failures of competing firms WSD adoption.

5.5.6 Social Influence of the Client (SI client)

Questions regarding the social influence of the client were designed to determine the respondent's opinion on whether they believed their client would support the implementation of a location tracking WSD. A majority (63%) of respondents answered that they were unsure or disagreed that the client would support the use of a location tracking WSD.

Based on the Pearson Chi-Squared value and the associated p-value of less than 0.0001 a statistically significant association exists between the social influence of clients and behavioral intention. The supermajority (84%) of those who did not agree their clients would support a location tracking WSD also did not agree to implement the location tracking WSD. Alternatively, only 41% of those who believed their client would be in favor of implementing the device also did not agree to implement the device themselves. These results can be seen graphically below in Figure 5.23, and numerically in Table 5.17.

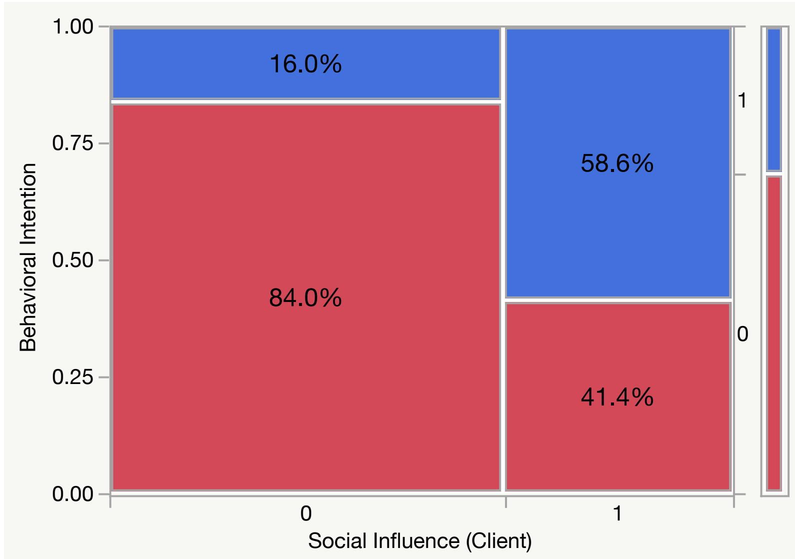

Figure 5.23 Mosaic plot represents the association between SI Client and BI concerning the location tracking WSD on the management survey.

Table 5.17 Management Location Tracking WSD Contingency Table for SI Client by BI

Count Total % Col % Row %	Would Not Implement Device Disregarding Price (0)	Would Implement Device Disregarding Price (1)	Total
Clients do not have influence (0)	42 53.16 77.78 84.00	8 10.13 32.00 16.00	50 63.29
Clients do have influence (1)	12 15.19 22.22 41.38	17 21.52 68.00 58.62	29 36.71
Total	54 68.35	25 31.65	79

This data shows that there is an association between the acceptance of a location tracking WSD and the preconceived opinion of a client. When trying to convince management to use a location tracking WSD it might be helpful to approach the client regarding the device. A client could see many benefits to a location tracking WSD such as decreased liability, and increased security. With the support of the client, management might be more accepting of the device.

5.5.7 Data Security (DS)

Data security questions were designed to judge the level of concern respondents had toward storing the location data of their employees. The study finds that a majority of those surveyed (71%) were somewhat to extremely concerned about storing the location data.

Based on the Pearson Chi-Squared value and the associated p-value of 0.0363 a statistically significant association exists between data security and behavioral intention. A majority (75%) of those surveyed that had moderate to extreme concerns regarding the security of the data collected also did not agree to implement the location tracking WSD. Alternatively, only 52% of respondents who did not harbor concerns regarding data security also did not agree to implement the device. These results can be seen graphically below in Figure 5.24, and numerically in Table 5.18.

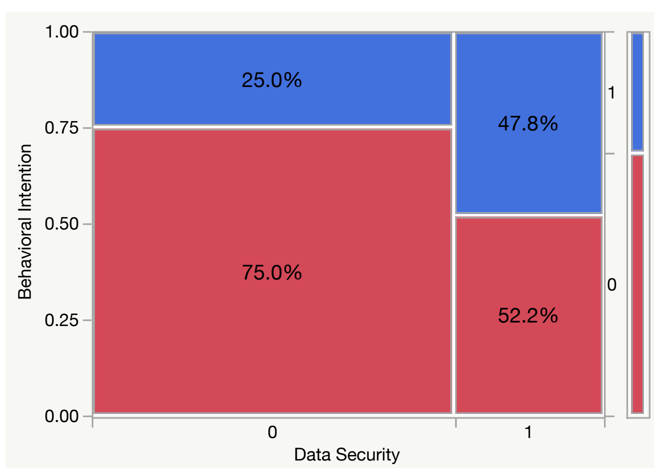

Figure 5.24 Mosaic plot represents the association between DS and BI concerning the location tracking WSD on the management survey.

Table 5.18 Management Location Tracking WSD Contingency Table for DS by BI

Count Total % Col % Row %	Would Not Implement Device Disregarding Price (0)	Would Implement Device Disregarding Price (1)	Total
High Concern Regarding Data Security (0)	42 53.16 77.78 75.00	14 17.72 56.00 25.00	56 70.89
Low Concern regarding data Security (1)	12 15.19 22.22 52.17	11 13.92 44.00 47.83	23 29.11
Total	54 68.35	25 31.65	79

The largest take away from this section is that the vast majority (71%) of construction managers have concerns regarding the security of storing employee location data. One trying to convince construction managers to use a location tracking WSD might pair the pitch for the device with a strong data security system. If the construction managers had their concerns regarding data security put at ease this study finds that their acceptability of the location tracking device would increase.

5.5.8 Behavioral Intention (BI)

This marks the beginning of phase II of this analysis. Questions regarding behavioral intent were designed to determine whether or not the respondent would implement the location tracking WSD regardless of price. The supermajority (68%) of respondents were unwilling to implement the location tracking WSD regardless of the total cost.

Based on the Pearson chi-squared value above and associated P-value of less than 0.0001 a statistically significant association exists between the behavioral intention and actual use. A supermajority (91%) of respondents who did not show the behavioral intention to implement the location tracking WSD also responded that considering all factors they would not implement the device. Alternatively, only 20% of respondents who showed behavioral intent to implement the biometric WSD did not intend to use the device when all factors were considered. This data can be seen graphically below in Figure 5.25, and numerically in Table 5.19.

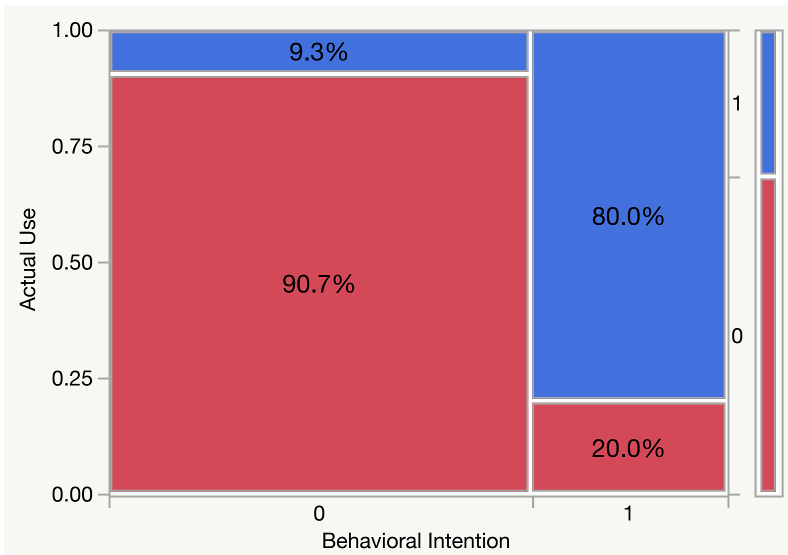

Figure 5.25 Mosaic plot represents the association between BI and AU concerning the location tracking WSD on the management survey.

Table 5.19 Management Location Tracking WSD Contingency Table for BI by AU

Count Total % Col % Row %	Would Not Implement Device (0	Would Implement Device (0)	Total
Low Probability of Implementation Disregarding Price (0)	49 62.03 90.74 90.74	5 6.33 20.00 9.26	54 68.35
High Probability of Implementation Disregarding Price (0)	5 6.33 9.26 20.00	20 25.32 80.00 80.00	25 31.65
Total	54 68.35	25 31.65	79

This data shows that behavioral intent has a strong association with actual use. This comes as no shock that if an individual believes in a new technology the likelihood of implementation increases.

5.5.9 Facilitating Conditions (FC)

Questions regarding facilitating conditions were designed to determine the level of influence cost has on implementing a location tracking device WSD. The supermajority (73%) of respondents considered cost an influential factor in implementing a biometric WSD.

Based on the Pearson chi-squared value and associated P-value of 0.1973 no association was found between the facilitating conditions and actual use. A majority (72%) of respondents who found price an influential factor in implementing a location tracking WSD also would not implement the device. Alternatively, 41% of respondents who did not find the price to be influential also would not implement the location tracking WSD. This data can be seen graphically below in Figure 5.26, and numerically in Table 5.20.

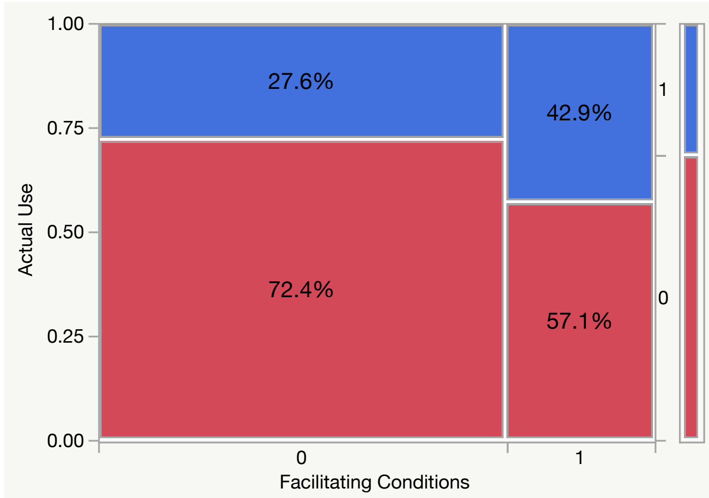

Figure 5.26 Mosaic plot represents the association between FC and AU concerning the location tracking WSD on the management survey.

Table 5.20 Management Location Tracking WSD Contingency Table for FC by AU

Count Total % Col % Row %	Would Not Implement Device (0)	Would Implement Device (0)	Total
High importance of cost (0)	42 53.16 77.78 72.41	16 20.25 64.00 27.59	58 73.42
Low importance of cost (1)	12 15.19 22.22 57.14	9 11.39 36.00 42.86	21 26.58
Total	54 68.35	25 31.65	79

Similarly to the biometric WSD, the vast majority of construction managers consider the price at least somewhat influential. However, this information is not a good indicator of respondents' willingness to use the location tracking WSD. A portion (20%) of respondents would implement the device regardless of price. The results of this section reflect that while the price is important it may not be the first topic of interest when aiming to increase location tracking WSD acceptance by construction managers.

5.6 Management Summary

This section analyzed the results from the management survey. It was found that 56% of management respondents would not implement the biometric WSD, and 52% would not implement the biometric device regardless of device cost. For the biometric WSD, a statistically significant association with behavior intent was found between PPE, ODU, and SI (client). Based on these findings when implementing a biometric WSD acceptance may be increased when emphasis is placed on high device performance, legal liability of collecting employee health data, and client acceptance of the device. It was found that 68% of management respondents would not implement the location tracking WSD. For the location tracking WSD a statistically significant association with behavior intent was found between PPE, PEE, ODU, SI, and DS. Based on these findings when implementing a location tracking WSD acceptance may be increased when emphasis is placed on high device performance, ease of use, legal liability of collecting employee location data, client and competitor acceptance of device use, and security of employee location data.

6. CONCLUSION

6.1 Overview

Chapters two through five present an analysis of the driving factors to the acceptance or rejection of wearable sensing devices in the construction industry. First, a literature review introduces the state of construction safety, wearable sensing devices, various technology acceptance methods, and the current state of wearable sensing technology acceptance. Second, a methodology was developed to test factors associated with wearable sensing device acceptance by the creation of a structured survey based on a hybrid conceptual acceptance model. Third, the study was conducted and data was collected. Fourth, the underlying variables that influence the acceptance of wearable sensing devices by field laborers were analyzed. Next, underlying variables that influence the acceptance of wearable sensing devices by management were analyzed. Finally, these conclusions are presented based on the findings of the study. They include a summary of the information collected as well as comparisons between the devices and survey groups. The conclusion will also include limitations of the study, and potential areas for future research.

6.2 Contribution

Between the two different groups surveyed and two different devices within each survey, a statistically significant association between every construct and behavioral intent was found in at least one case. A summary of these associations can be found below in Table 6.1.

Table 6.1 Summary of Association with Behavioral Intent

Construct	Field Labor Biometric WSD	Field Labor Location Tracking WSD	Management Biometric WSD	Management Location Tracking WSD
PPE	Association	Association	Association	Association
PEE	Association	Not Found	Not Found	Association
ODU	Not Found	Not Found	Association	Association
SI (Family)	Association	Association		
SI (Coworkers)	Association	Association		
SI (Competitors)			Not Found	Association
SI (Clients)			Association	Association
DS	Not Found	Association	Not Found	Association

In the following section, each construct will be summarized with respect to the study as a whole, and conclusions will be drawn. Lastly, an overview of the association between BI and FC with AU is conducted for the management portion. A summary of these associations can be found below in Table 6.2.

Table 6.2 Summary of Association with Actual Use

Construct	Management Biometric WSD	Management Location Tracking WSD
BI	Association	Association
FC	Not Found	Not Found

6.2.1 PPE

This study finds perceived performance expectancy to have the most consistent association with behavioral intent. Regardless of survey group or specific wearable sensing device, a statistically significant association was found. Based on the findings of this study it would be advisable to demonstrate a high level of performance of a wearable sensing device to both management and labor prior to deployment in order to increase device acceptability. This ties back to the main topic of construction safety discussed in section 2.2.2 *information and communication technology* in safety management. As this area of construction safety continues to evolve an emphasis must be placed on showing the true impact of these devices to decrease device hesitancy.

6.2.2 PEE

The study found split and mixed results when conducting an analysis of the potential association between perceived effort expectancy and behavioral intent. In the case of field labor there was a statistically significant association between PEE and BI for the biometric WSD, but not for the location tracking WSD. The opposite was true for the management group, association being found between PEE and BI for the location tracking WSD, but not for the biometric WSD. A takeaway is it is difficult to tell by device and by survey group but there is evidence that ease of use plays a role in device acceptance at some level and should be considered when implementing a WSD. This can be tied back to the construction safety topic discussed in section 2.2.4 *safety management system*. Successful implementation of a WSD could include a specific safety management system put into place to ensure device users receive proper training prior to deployment of a new device.

6.2.3 ODU

The study found that construction managers displayed an association between openness to data utilization and behavioral intent while field laborers did not. While many field laborers were still concerned about how their data collected by a WSD was being used it was not a strong predictor of device acceptance. The opposite was true for the management survey. Construction managers level of concern regarding legal issues arising from the device was strongly associated with their intent to use the devices. When speaking to construction managers about implementing WSDs addressing how to mitigate the legal risk regarding data use could help increase device acceptance.

6.2.4 SI

The study broke the construct of social influence down into by the social influence of different groups on the acceptance of WSDs. For the field labor survey an association with behavioral intent was found in all cases regardless of device or social group (family/loved ones or coworkers). For the management survey an association with behavioral intent was found for both social groups (competitors and clients) for the location tracking WSD, but only for the client social group for the biometric WSD. Why one device saw association with competitors and not the other is unknown, but a theory could be the general hesitancy and distaste toward the location tracking device swaying the results. Regardless, social influence still proved to show a strong association with WSD acceptance across the board. This can be tied back to the construction safety topic discussed in section 2.2.1 *Safety Climate and Culture*. Creating a safety climate and culture that promotes WSDs internally could help increase field labor acceptance while aiming to create a safety climate and culture throughout the industry could have a positive impact on construction manager WSD acceptance.

6.2.5 DS

The study found that association between data security and behavioral intent was not dependent on survey group but instead on the type of device. A statistically significant association was found between data security and behavioral intent on both surveys with respect to the location tracking WSD. However, no association was found for the biometric WSD regardless of survey group. Therefore, based on the findings of this study heavy importance placed on the security of location data when implementing a location tracking WSD might help increase acceptance of the device. The lack of association for the biometric device considering prior studies indicated the security of employee health data is of high concern.

6.2.6 BI (Management)

The study found that for both devices there was a statistically significant association between behavioral intent and actual use. This comes as no surprise, individuals who have the intention of using a WSD were more likely to use the device at their sites. In the context of this study, the result means there can be a more confident reliance on the constructs that influence behavioral intent to in turn influence actual use for construction managers.

6.2.7 FC (Management)

The study found no association between facilitating conditions and actual use. Facilitating conditions in the context of this study represented cost. Finding no association is of interest because it means that for the construction managers surveyed the cost of the devices was not a good indicator of if the devices would be put into use. This comes as a surprise because device cost was a predetermined limiting factor to the implementation of WSDs.

6.3 Recommendations

For employers looking to implement a biometric WSD an emphasis should be placed in three target areas. First, how the device will help keep the worker safe without hindering their work (PPE). Second, how the device will be easy to operate (PEE). Third, focusing on the social influence of employee loved ones, and others on their crew (SI). This could be done by outreach to employee families regarding the benefit of the device, or establishing a safety culture where coworkers encourage each other to utilize the safety device.

For employers looking to implement a location tracking WSD an emphasis should be placed on three target areas. First, the employer must demonstrate that the location tracking device is keeping the user safe, and provides value to them without hindering their work (PPE). Second, similar to the biometric device, an emphasis should be placed on the social influence of loved ones, and coworkers (SI). Last, the employer should implement a strong data security system and ensure device users know that their location data is being safely stored (DS).

For those pitching to implement a biometric WSD to construction managers an emphasis should be placed on three target areas. First, it should be successfully conveyed that the device will increase construction site safety (PPE). Second, a successful data management plan should be in place to ensure legal issues will not arise from collecting employee health data (ODU). Third, prominent clients should be approached about their thoughts on contractors implementing biometric WSDs. If the client is a proponent of the biometric WSD construction managers are more likely to be interested in device implementation (SI client).

For those pitching to implement a location tracking WSD to construction managers an emphasis should be placed on five target areas. First, the value to construction site safety should be successfully conveyed (PPE). Second, a training program should be in place to ease concerns regarding training their workforce to successfully use the new system (PEE). Third, a successful data management plan should be in place to ensure legal issues will not arise from collecting employee location data (ODU). Fourth, research should be done to understand the clients, and competitors stance on location tracking WSDs. If it is found that clients or competitors support/use location tracking WSDs presenting this will increase the likelihood of device acceptance. Fifth, the system should include a strong data security system. If managers are concerned about the security of the data they are collecting they are less likely to approve use of the device.

For those pitching either a biometric WSD or a location tracking WSD to construction manager price should not be viewed one of the most important factors. This study did not find a significant association between cost and device use.

6.4 Limitations

One of the limitations of this study was a relatively small sample size. While the study was similar in size to other studies that were conducted in this area (Choi et al., 2017; Nnaji & Karakhan, 2020) A larger sample size could have produced stronger associations, and potentially new associations. Due to this lack of sample size larger linear regression models were not possible. Meaning, when multiple constructs and/or demographic variables were added to a linear regression model the sample could not generate prediction models that could be deemed reliable.

The sample had much higher participation in the western United States, and results could differ with higher participation from other regions. On a larger scale, this study could differ greatly if conducted in other parts of the world due to cultural differences particularly considering differing views on technology. The lack of union participation could also be seen as a potential limitation. While some of the most prominent WSDs were studied, it was limited to two specific WSDs. Results could vary among various types of WSDs.

6.5 Areas of Future Research

The results of this study lead to six aspects that could be extended upon in future related works. These areas were either outside the scope of this thesis or questions raised while analyzing the results of this thesis.

- The same study could be completed with a different and/or larger sample size in order to increase diversity and allow for different statistical methods to be utilized.
- The study was limited to two specific WSDs. Future studies could include other WSDs such as exoskeletons, or an environmental sensing WSD and compare the results to this study for a more comprehensive view on WSD acceptance.

- Future studies could have a more defined price range for the devices to give the respondents a clearer understanding of the overall cost of the technology to see if the results differ.
- Future studies could survey prominent clients in the industry to see if there is a noticeable opinion regarding the devices. This data could be used to aid in the industry implementation.
- Studies could be conducted on the social influence of coworkers, or competitors by conducting case studies with workers or firms using WSDs and studying the effect they have on non-users.
- Due to the contradicting findings of this study and other similar studies regarding the construct of openness to data utilization future research could target the openness to data utilization construct specifically.

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APPENDICES

Appendix A: Field Labor Survey

WEARABLE SENSING DEVICES

My name is Harrison Fugate, I am a graduate student at California Polytechnic State University studying Construction Engineering. I am researching the acceptance of wearable sensing devices for safety applications in the construction industry. Today you will be taking a survey regarding your thoughts on two wearable sensing devices that could be used in your industry, a biometric sensor, and a location tracking device. Your responses will be used to help gauge whether or not these devices would be accepted by workers.

Device #1: Biometric Sensor

Biometric sensors can help keep you safe while on the job. Many of these sensors have been imbedded in commercial products including the Apple Watch, Fitbit, Whoop, etc. These devices can be applied to workplaces to decrease the chances of injuries and illnesses such as:

- Heat Stroke & Heat exhaustion
- Excess fatigue
- Excess Cold
- Breathing or Respiratory Diseases
- Carpal Tunnel syndrome
- Back injuries

They do this by measuring metrics such as:

- Heart Rate
- Heart Rate Variability
- Respiratory Rate
- Skin Temperature
- Environmental Temperature
- Activity Level
- Walking Steps
- Blood Oxygen
- Blood Pressure
- Body Posture
- Body Rotation and Orientation

The example to the right is a wearable biometric device produced by Kenzen. This wearable device **protects against heat stress, and heat exhaustion** by tracking:

- core body temperature
- heart rate
- worker microclimate
- sweat rate
- activity level

Figure 1: Kenzen Smart PPE Device

Device #2: Location Tracking Device

Location tracking systems can help keep you and your other crew members safe by preventing:

- Slips, Trips, and Falls
- Caught In-Between Accidents
- Struck By Accidents
- Electrocution

It can help reduce the likelihood of these events by tracking the location of all crew members, and equipment on the site. Workers can receive alerts before they enter potentially dangerous areas (i.e. **swing radius of an active excavator, near a high voltage box, near a high drop zone, etc.**)

The example to the rights is the Spot-r by Triax. This device tracks workers by zone to allow for:

- Decrease response time for reported injuries
- Access control
- Rules-based site credentialing, and remote safety check-ins
- Smart evacuation and muster technology
- Real-time, push-button alerts that can be initiated by workers
- Fall from height alerts
- Worker Risk keep performance indicators (KPI) and behavior analytics

Figure 2: Triax Spot-r

General Information

What is your age range?:
1. 0-17
2. 18-24
3. 25-34
4. 35-44
5. 45-54
6. 55-64
7. 65+

Job Title:
1. Field Engineer
2. Foreman / General Foreman
3. Trades
4. Equipment Operator
5. Laborer
6. Other

Years of Experience in the Industry?:
1. 0-5
2. 5-14
3. 15-19
4. 20-24
5. 25+

Union Member?
1. Yes
2. No

Geographic Region:
1. Pacific Northwest
2. South West
3. Midwest
4. South East
5. North East

Project Type:
1. Residential
2. Commercial
3. Industrial
4. Heavy Civil / Infrastructure
5. Environmental
6. Other

Work Sector (Majority):
1. Private
2. Public

Device Outlook

Safety Benefit

1. **The Biometric Tracker would make my work environment a safer place.**
    a. Strongly Disagree
    b. Disagree
    c. Unsure
    d. Agree
    e. Strongly Agree
2. **The location tracking system would make my work environment a safer place.**
    a. Strongly Disagree
    b. Disagree
    c. Unsure
    d. Agree
    e. Strongly Agree

User Difficulty

3. **Learning how to use the biometric tracker would be easy to me.**
    a. Strongly Disagree
    b. Disagree
    c. Unsure
    d. Agree
    e. Strongly Agree
4. **Learning how to use the location tracking system would be easy to me.**
    a. Strongly Disagree
    b. Disagree
    c. Unsure
    d. Agree
    e. Strongly Agree

Data Use

5. **Rate your level of concern with how your employer would use the data they collect from the biometric tracker.**
    a. not at all concerned
    b. Slightly concerned
    c. Somewhat concerned
    d. Moderately concerned
    e. Extremely concerned
6. **Rate your level of concern with how your employer would use the data they collect from the location tracking system.**
    a. not at all concerned
    b. Slightly concerned
    c. Somewhat concerned
    d. Moderately concerned
    e. Extremely concerned

Influence of Others

7. **If the health tracker was provided by my company my family / loved ones would recommend I use it.**
    a. Strongly Disagree
    b. Disagree
    c. Unsure
    d. Agree
    e. Strongly Agree

8. **If others on my crew were using the health tracker it would increase the likelihood I would use it.**
    a. Strongly Disagree
    b. Disagree
    c. Unsure
    d. Agree
    e. Strongly Agree

9. **If the location tracking system was provided by my company my family / loved ones would recommend I use it.**
    a. Strongly Disagree
    b. Disagree
    c. Unsure
    d. Agree
    e. Strongly Agree

10. **If others on my crew were using the location tracking system it would increase the likelihood I would use it.**
    a. Strongly Disagree
    b. Disagree
    c. Unsure
    d. Agree
    e. Strongly Agree

Data Security

11. **Rate your level of concern regarding the security of your biometric data**.
    a. not at all concerned
    b. Slightly concerned
    c. Somewhat concerned
    d. Moderately concerned
    e. Extremely concerned

12. **Rate your level of concern regarding the security of your location data.**
    a. not at all concerned
    b. Slightly concerned
    c. Somewhat concerned
    d. Moderately concerned
    e. Extremely concerned

Future Use

13. **Would you use the biometric tracker if it was provided by your employer?**
    a. Absolutely not
    b. Most likely not
    c. Undecided
    d. Most Likely
    e. Absolutely

14. **Would you use the location tracker if it was provided by your employer?**
    a. Absolutely not
    b. Most likely not
    c. Undecided
    d. Most Likely
    e. Absolutely

Device Experience

Biometric Sensor:

1. **Rank your familiarity with the biometric sensors**
   a. Not at all familiar
   b. Slightly familiar
   c. Somewhat familiar
   d. Moderately familiar
   e. Extremely familiar

2. **Have you received training using a biometric sensor?**
   a. No
   b. Unsure
   c. Yes

3. **Have you used a biometric sensor at this site or another?**
   a. No
   b. Unsure
   c. Yes

4. **Have you ever refused to use a biometric sensor at this site or another?**
   a. No
   b. Unsure
   c. Yes

Location Tracking System:

5. **Rank your familiarity with the location tacking devices**
   a. Not at all familiar
   b. Slightly familiar
   c. Somewhat familiar
   d. Moderately familiar
   e. Extremely familiar

6. **Have you received training using a location tracking device?**
   a. No
   b. Unsure
   c. Yes

7. **Have you used a location tracking device at this site or another?**
   a. No
   b. Unsure
   c. Yes

8. **Have you ever refused to use a location tracking device at this site or another?**
   a. No
   b. Unsure
   c. Yes

Appendix B: Management Survey

WEARABLE SENSING DEVICES

My name is Harrison Fugate, I am a graduate student at California Polytechnic State University studying Construction Engineering. I am researching the acceptance of wearable sensing devices for safety applications in the construction industry. Today you will be taking a survey regarding your thoughts on two wearable sensing devices that could be used in your industry, a biometric sensor, and a location tracking system. Your responses will be used to help gauge the interest of management towards the implementation of these devices.

Device #1: Biometric Sensor

Biometric sensors can help keep you safe while on the job. Many of these sensors have been imbedded in commercial products including the Apple Watch, Fitbit, Whoop, etc. These devices can be applied to workplaces to decrease the chances of injuries and illnesses such as:

- Heat Stroke & Heat exhaustion
- Excess fatigue
- Excess Cold
- Breathing or Respiratory Diseases
- Carpal Tunnel syndrome
- Back injuries

They do this by measuring metrics such as:

- Heart Rate
- Heart Rate Variability
- Respiratory Rate
- Skin Temperature
- Environmental Temperature
- Activity Level
- Walking Steps
- Blood Oxygen
- Blood Pressure
- Body Posture
- Body Rotation and Orientation

The example to the right is a wearable biometric device produced by Kenzen. This wearable device **protects against heat stress, and heat exhaustion** by tracking:

- core body temperature
- heart rate
- worker microclimate
- sweat rate
- activity level

Figure 1: Kenzen Smart PPE Device

Device #2: Location Tracking Device

Location tracking systems can help keep you and your other crew members safe by preventing:

- Slips, Trips, and Falls
- Caught In-Between Accidents
- Struck By Accidents
- Electrocution

It can help reduce the likelihood of these events by tracking the location of all crew members, and equipment on the site. Workers can receive alerts before they enter potentially dangerous areas (i.e. **swing radius of an active excavator, near a high voltage box, near a high drop zone, etc.**)

The example to the rights is the Spot-r by Triax. This device tracks workers by zone to allow for:

- Decrease response time for reported injuries
- Access control
- Rules-based site credentialing, and remote safety check-ins
- Smart evacuation and muster technology
- Real-time, push-button alerts that can be initiated by workers
- Fall from height alerts
- Worker Risk keep performance indicators (KPI) and behavior analytics

Figure 2: Triax Spot-r

General Information

What is your age range?:	Job Title:
1. 0-17 2. 18-24 3. 25-34 4. 35-44 5. 45-54 6. 55-64 7. 65+	1. Superintendent 2. Project Manager 3. Health and Safety Professional 4. Business Development Professional 5. Executive Officer 6. Other
Years of Experience in the Industry?:	**Work Sector (Majority):**
1. 0-5 2. 5-15 3. 15-20 4. 20-30 5. 30+	1. Private 2. Public
Geographic Region:	**Project Type (Majority):**
1. Pacific Northwest 2. South West 3. Midwest 4. South East 5. North East	1. Residential 2. Commercial 3. Industrial 4. Heavy Civil / Infrastructure 5. Environmental 6. Other

Device Outlook

Safety Benefit

1. **If used correctly the biometric tracker would increase the level of safety on our construction sites.**
    a. Strongly Disagree
    b. Disagree
    c. Unsure
    d. Agree
    e. Strongly Agree

2. **If used correctly the location tracking system would increase the level of safety on our construction sites.**
    a. Strongly Disagree
    b. Disagree
    c. Unsure
    d. Agree
    e. Strongly Agree

User Difficulty

3. **Please rate your level of concern associated with training time/effort required to train employees to use the biometric tracker.**
    a. not at all concerned
    b. Slightly concerned
    c. Somewhat concerned
    d. Moderately concerned
    e. Extremely concerned

4. **Please rate your level of concern associated with training time/effort required to train employees to use the location tracking system.**
    a. not at all concerned
    b. Slightly concerned
    c. Somewhat concerned
    d. Moderately concerned
    e. Extremely concerned

Data Use

5. **With regards to the biometric device, describe your level of concern regarding legal issues arising due to tracking of employee health information.**
    a. not at all concerned
    b. Slightly concerned
    c. Somewhat concerned
    d. Moderately concerned
    e. Extremely concerned

6. **With regards to the location tracking system, describe your level of concern regarding legal issues arising due to tracking of employee location data.**
    a. not at all concerned
    b. Slightly concerned
    c. Somewhat concerned
    d. Moderately concerned
    e. Extremely concerned

Influence of Others

7. If our competitors were using a biometric safety device we would be more likely to deploy one.
   a. Strongly Disagree
   b. Disagree
   c. Unsure
   d. Agree
   e. Strongly Agree

8. Our clients would support the use of the biometric safety device.
   a. Strongly Disagree
   b. Disagree
   c. Unsure
   d. Agree
   e. Strongly Agree

9. If our competitors were using a location tracking system we would be more likely to deploy one.
   a. Strongly Disagree
   b. Disagree
   c. Unsure
   d. Agree
   e. Strongly Agree

10. Our clients would support the use of the location tracking system..
   a. Strongly Disagree
   b. Disagree
   c. Unsure
   d. Agree
   e. Strongly Agree

Data Security

11. Describe your level of concern regarding storing employee health data collected using the biometric safety device.
   a. not at all concerned
   b. Slightly concerned
   c. Somewhat concerned
   d. Moderately concerned
   e. Extremely concerned

12. Describe your level of concern regarding storing employee location data collected using the location tracking system.
   a. not at all concerned
   b. Slightly concerned
   c. Somewhat concerned
   d. Moderately concerned
   e. Extremely concerned

Cost

11. Describe the level of influence that cost of the biometric tracking device would play on your decision to implement the device
   a. Not at all influential
   b. Slightly influential
   c. Somewhat influential
   d. Very influential
   e. Extremely influential

12. Describe the level of influence that cost of the biometric tracking device would play on your decision to implement the device
   a. Not at all influential
   b. Slightly influential
   c. Somewhat influential
   d. Very influential
   e. Extremely influential

Intention

13. If Cost was not a factor, would you implement the biometric safety device at your respective site/sites?

a. Absolutely not
b. Most likely not
c. Undecided
d. Most Likely
e. Absolutely

14. If Cost was not a factor, would you implement the location tracking system at your respective site/sites?

a. Absolutely not
b. Most likely not
c. Undecided
d. Most Likely
e. Absolutely

Actual Use

15. Taking into account all factors, would you implement a biometric safety device at your respective site/sites?

a. Absolutely not
b. Most likely not
c. Undecided
d. Most Likely
e. Absolutely

16. Taking into account all factors, would you implement a location tracking system at your respective site/sites?

a. Absolutely not
b. Most likely not
c. Undecided
d. Most Likely
e. Absolutely

Device Experience	
<u>**Biometric Sensor**</u>**:** **1. Rank your familiarity with the biometric sensors** a. Not at all familiar b. Slightly familiar c. Somewhat familiar d. Moderately familiar e. Extremely familiar **2. Have you ever used a biometric safety device at any of your projects?** a. No b. Unsure c. Yes **3. Are you currently using a biometric safety device at any of your projects?** a. No b. Unsure c. Yes **4. Have you ever chose to terminate the use of a biometric safety device?** a. No b. Unsure c. Yes	<u>**Location Tracking System:**</u> **5. Rank your familiarity with the location tacking devices** a. Not at all familiar b. Slightly familiar c. Somewhat familiar d. Moderately familiar e. Extremely familiar **6. Have you ever used a location tracking system at any of your projects?** a. No b. Unsure c. Yes **7. Are you currently using a location tracking system at any of your projects?** a. No b. Unsure c. Yes **8. Have you ever chose to terminated the use of a location tracking system?** a. No b. Unsure c. Yes