EVALUATING THE IMPACTS OF THE INTERNET OF THINGS TO REDUCE RUNWAY INCURSIONS: UNDERSTANDING THE WHY, HOW, AND WHEN

by

SAMUEL INANORE OKATE

Presented to the Faculty of the Graduate School of
The University of Texas at Arlington in Partial Fulfillment
of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

THE UNIVERSITY OF TEXAS AT ARLINGTON
August 2016

Acknowledgements

Therefore, since we have been justified through faith, we have peace with God through our Lord Jesus Christ, through whom we have gained access by faith into this grace in which we now stand. And we boast in hope of the glory of God. Not only so, but we also glory in our sufferings, because we know that suffering produces perseverance; perseverance, character; and character, hope. Romans 5:1-4

First and foremost I want to thank my Lord and Savior Jesus Christ. Without Him, I am nothing. With Him, I am everything.

I want to thank everyone who has helped me along the way, professors, bosses, colleagues, friends and family. I am truly thankful for all your support. This dissertation was a collective effort of all of you and I could have not done it without you all. Furthermore, I cannot mention everyone, so if you feel you did not fall in any one of those categories, my thanks goes out to you as well.

August 22, 2016

Abstract

EVALUATING THE IMPACTS OF THE INTERNET OF THINGS TO REDUCE RUNWAY INCURSIONS: UNDERSTANDING THE HOW, WHY, AND WHEN

Samuel Okate, PhD

The University of Texas at Arlington, 2016

Supervising Professor: Erick C. Jones

The Federal Aviation Administration's (FAA) mission is to maintain the safest and most efficient aerospace system in the world. The FAA has stated that runway safety is one of their top priorities, which encapsulates pilots, air traffic controllers, and airport vehicle drivers and workers (Federal Aviation Administration, June 2015). Federal Aviation Administration categorizes a runway incursion as a hazardous event that can occur in the Air Operations Area (AOA) that involves an incorrect presence of an aircraft, vehicle or person in the protected area of a surface designated for the landing and takeoff of an aircraft (Federal Aviation Administration, June 2015). Runway Incursion is one of the most crucial issues in airport safety. Analysis into the underlying causes of why and how a runway incursion event occurs can be vital for the development of an effective prevention plan to reduce these occurrences.

This research seeks to enhance the safety on the AOA by introducing a framework to reduce the potential of a runway incursion event. Moreover, this research aims to investigate various human causal elements that may have played a crucial role in why the occurrence took place. Furthermore, chi-square test of independence will be used in order to examine the independence between runway incursion types and location of a runway incursion event to see if a significant relationship exists. In addition, the human causal elements will be examined using Analysis of Variance (ANOVA) in efforts to understand the primary causes of occurrence. Moreover, this research focuses on the event when people enter into restricted areas without Air Traffic Control (ATC) authorization and how this can be minimized by exploring the phenomena of the Internet of Things (IoT) through the use of automated technology. In addition, we want to investigate the economic feasibility of employing such systems compared to other solutions that may be possible. Also, this research seeks to investigate legal aspects in terms of liability when an occurrence arises. Also, this research plans to explore various case law surrounding severe runway incursion incidents in efforts to understand the liability ownership of the incursion and put these results in a repository database to create one shared location at airports to be accessed by anyone who has a need for such information such as lawyers, pilots, and air traffic controllers to keep them informed when such an event arises. This research explores a framework to prevent runway incursions and increase safety and awareness in the aviation industry while furthering knowledge and understanding on a broad front of emerging technologies.

Table of Contents

Acknowledgements ... iii
Abstract ... iv
List of Illustrations ... viii
List of Tables ... x
Chapter 1 Introduction ... 1
  1.1 What is a Runway Incursion ... 1
    1.1.1 Runway Incursion Classifications ... 1
  1.2 Why is there a Need for Runway Incursion Research ... 3
  1.3 Purpose of this Research ... 4
  1.4 Research Objectives ... 5
  1.5 Organization of this Dissertation ... 9
Chapter 2 Background ... 11
  2.1 Runway Safety ... 11
    2.1.1 Runway Safety Metrics ... 11
    2.1.2 Runway Safety Data Collection ... 15
      2.1.2.1 Runway Incursion Databases ... 15
    2.1.3 Runway Safety Programs ... 16
    2.1.4 Similar Research & Relevant Funded Projects ... 17
  2.2 Human Factors ... 18
    2.2.1 Visual and Auditory Performance ... 20
  2.3 Communication Technologies ... 20
    2.3.1 Internet of Things ... 21
    2.3.2 Radio Frequency Identification Technology ... 22
      2.3.2.1 Radio Frequency Identification Theory ... 22

2.3.2.2 Radio Frequency Identification Tag Types 24
2.3.3 ZigBee Technologies 25
2.4 Aviation Law 26
2.5 Chapter Summary 26
Chapter 3 28
3.1 Research Approach 28
3.2 Research Questions and Hypotheses 30
3.3 Research Objectives and Specific Tasks 32
3.4 Equipment and Location 46
Chapter 4 47
4.1 Research Question 1 Results 47
4.2 Research Question 2 Results 55
4.3 Research Objective 3 Results 71
Chapter 5 75
5.1 Conclusions 75
5.2 Limitations 78
5.3 Contributions to the Body of Knowledge 78
5.4 Future Work 78
5.5 Related Coursework 79
Appendix A Human Causal Element Data Collection per Airport 80
Appendix B Randomized Data for Experiment 1 System Reliability 88
References 91
Biographical Information 95

List of Illustrations

Figure 1-1: Classification of Runway Incursions by Increasing Severity (Transportation, 2015) 2

Figure 1-2: Runway Incursion Totals Fiscal Year 2011 to Fiscal Year 2016 4

Figure 1-3: Runway Incursion Totals per Fiscal Year 4

Figure 1-4: Runway Incursion Reduction Framework 7

Figure 1-5: Runway Incursion Reduction Framework 7

Figure 2-1: 2013-2014 Category A & B Incursions 12

Figure 2-2: 2013-2014 Category C & D Incursions 13

Figure 2-3: 2013 Runway Incursion Totals by Type (Federal Aviation Administration, 2015) 13

Figure 2-4: 2014 Runway Incursion Totals by Type (Federal Aviation Administration, June 2015) 14

Figure 2-5: Human Factor Errors that Effect Aviation Industry 19

Figure 2-6: RFID Operation 23

Figure 2-7: More Frequent RFID Frequency Bands 24

Figure 2-8: Less Common RFID Frequency Bands 24

Figure 3-1: Design for Six Sigma Research (DFSS-R) Methodology 29

Figure 4-1: Box Plot Distribution of Runway Incursion Rates by Human Causal Element 53

Figure 4-2: Interaction Plot for Human Causal Elements and Airports 55

Figure 4-3: Normal Probability Plot (RSSI) 59

Figure 4-4: Fitted Value vs Residuals Plot (RSSI) 60

Figure 4-5: Observation Order vs Residual Plot (RSSI) 61

Figure 4-6: Main Effects Plot for RSSI 62

Figure 4-7: Interaction Plot for RSSI 63

Figure 4-8: Normal Probability Plot (Read Rate) 65

Figure 4-9: Fitted Value vs Residuals (Read Rate) 66

Figure 4-10: Observation Order vs Residual (Read Rate) 67

Figure 4-11: Main Effect Plot for Read Rate 68

Figure 4-12: Interaction Plot for Read Rate 69

List of Tables

Table 1-1: Severity Type Definition (Federal Aviation Administration, June 2015) 2

Table 1-2: Research Objectives 8

Table 3-1: 3 P's Methodology with Specific Tasks 30

Table 4-1: Observed Incursion Incident vs Region 47

Table 4-2: Expected Incursion Incident vs Region 48

Table 4-3: Observed Incursion Incident vs. TX Airport 49

Table 4-4: Expected Incursion Incident vs. TX Airport 49

Table 4-5: Runway Incursion Events Contributed to Human Causal Element per Airport 50

Table 4-6: Descriptive Statistics for Human Causal Elements 51

Table 4-7: Factor Information for Complete Block Design 51

Table 4-8: ANOVA Results for Complete Block Design Model 51

Table 4-9: ANOVA Results Type I SS 51

Table 4-10: ANOVA Results Type III SS 52

Table 4-11: Model Summary 52

Table 4-12: Least Squares Means Adjustment for Multiple Comparisons: Tukey 53

Table 4-13: Least Square Means for Effect Human Causal Elements 53

Table 4-14: LS Mean with 95% Confident Limits 54

Table 4-15: Tukey's Simultaneous 95% Confidence Limits 54

Table 4-16: Experiment 1 Output Table with Decoded Factors and Responses 56

Table 4-17: Factor Information with Levels for Experiment 1 57

Table 4-18: ANOVA Results for Full Model RSSI vs Antenna Configuration, Distance, and Device Position 57

Table 4-19: Model Summary 58

Table 4-20: ANOVA Results for Full Model Read Rate vs Antenna Configuration, Distance, and Device Position 63

Table 4-21: Model Summary 64

Table 4-22: Experiment 2 Output Table with decoded Factors and Response 69

Chapter 1

Introduction

1.1 What is a Runway Incursion

The Federal Aviation Administration is a government agency of the United States Department of Transportation who is tasked with the regulation, safety, and oversight of civil aviation within the United States. Moreover, the FAA is responsible for the operation and development of the National Airspace System (NAS), including promoting safety initiatives that support a safe and efficient aerospace system. In 2007, the Federal Aviation Administration (FAA) adopted the definition of a runway incursion from the International Civil Aviation Organization (ICAO) as “any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft” (Federal Aviation Administration, June 2015).

1.1.1 Runway Incursion Classifications

In efforts to prevent runway incursions, it is necessary to understand the “how” of a runway incursion by the different classification types of an occurrence. Runway incursions can be classified into three types of surface events defined as vehicle and pedestrian deviation (VPD), pilot deviations (PD), and operational incidents (OI). According to the National Runway Safety Report 2015-2017, a vehicle and pedestrian deviation (VPD) takes place when any entry or movement on the movement area or safety area by a vehicle (including aircraft operated by a non-pilot or an aircraft being towed) or a pedestrian that has not been authorized by Air Traffic Control (Federal Aviation Administration, 2016). The National Runway Safety Reports also defines a pilot deviation (PD) as any action of a pilot that infringes any federal aviation regulation and defines an operational incident (OI) to be a surface event attributed to Air Traffic Control action or inaction (Federal Aviation Administration, 2016). In the event of a runway incursion, the occurrence can also be classified by the severity of the event. There are four categories that runway incursions can be classified into in terms of severity:

Figure 1-1: Classification of Runway Incursions by Increasing Severity (Transportation, 2015)

Table 1-1: Severity Type Definition (Federal Aviation Administration, June 2015)

Category A	A serious incident where a collision was barely avoided.
Category B	An incident where there is a significant potential for collision and time critical corrective or evasive reaction is necessary to avoid a collision.
Category C	An incident characterized by sufficient time and/or distance to circumvent a collision.
Category D	An incorrect present of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and take-off of aircraft but with little or no risk of a collision is present.

An accident is defined as an incursion that leads to a collision. Runway incursions are one of the most crucial issues in airport safety and security management.

1.2 Why is there a Need for Runway Incursion Research

In December of 2015 at Mumbai airport, an airport technician died after a fatal accident occurred where the worker was sucked into the engine of an Air India plane in preparation from being taxied out to take off (Mullen & Singh, 2015). Could this fatal accident have been avoided? This accident is an example of a runway incursion. Approximately, one runway incursion occurs each day in the United States, and the potential for a catastrophic accident is “unacceptable,” according to the FAA’s risk/severity matrix (Airline Pilots Association, International, 2007). At its extreme, runway incursions have been identified to be able to cause hundreds of deaths in a single air traffic accident (Airline Pilots Association, International, 2007). With these alarming statistics, it is no secret why runway safety is one of the most crucial issues in aviation safety. The likelihood for runway incursions grows exponentially as a function of air traffic growth within the U.S. National Airspace System (NAS) (Airline Pilots Association, International, 2007).

From figure 1-2, it is clear that runway incursion rates are increasing per fiscal year. One should also note that the data for FY 2016 is through July 19th, 2016 and, at present, at a high rate with six months of the year left. At this pace, it is projected to surpass the FY 2015 totals. With these increasing rates, runway incursion research for prevention is of the utmost importance. The key element into preventing runway incursions and increasing runway safety is to know why and how the occurrence happened in the first place. Runway incursions are a problematic area in aviation safety, which comes to no surprise why this is a national and international problem.

1.3 Purpose of this Research

Figure 1-2: Runway Incursion Totals Fiscal Year 2011 to Fiscal Year 2016

This research seeks to enhance the safety on the AOA by investigating the use of automated technology to reduce the potential of a runway incursion event caused by vehicle and pedestrian deviation (VPD), pilot deviations (PD), operational incidents (OI),

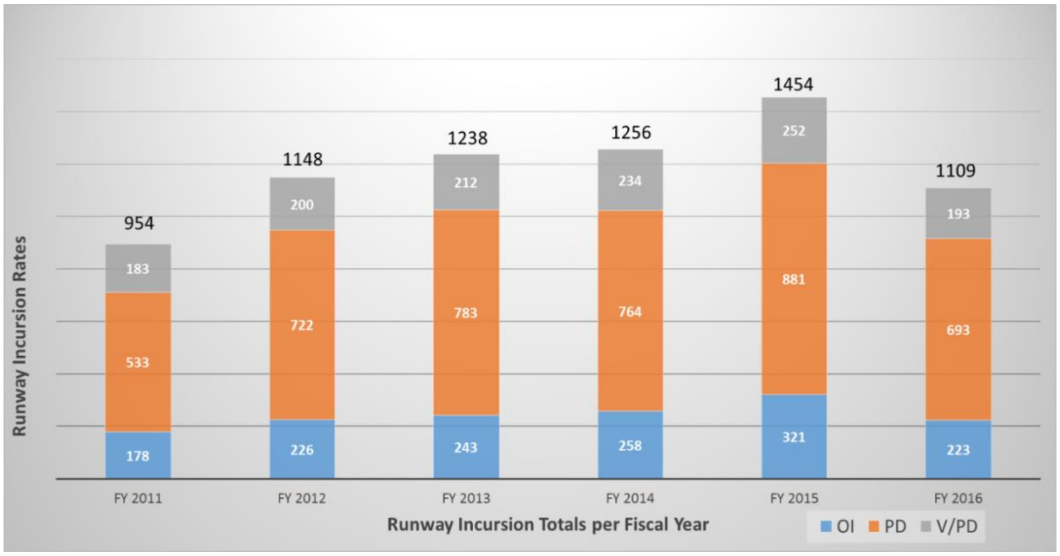


Figure 1-3: Runway Incursion Totals per Fiscal Year

and other occurrences. Moreover, this research seeks to use statistical analysis to examine human causal elements, also called human factor errors, which may have played a crucial role in “why” the occurrence took place. Understanding the underlying root causes in why an incursion event took place can lead to the development of numerous technological advancements to assist the workers in performing their job safely and reliably. Moreover, by reducing the number of runway incursions can lead to fewer delays on the runway, which in turn leads to more revenue for the airport to invest in various technologies to improve safety. The overall purpose of this research aims to reduce an occurrence of a runway incursion by exploring a framework that leverages automated technology, investigates human factor errors, and looks at the economic feasibility of using that technology. In addition to the use of automated technology and understanding the economic feasibility, this research seeks to reduce runway incursions by understanding “why” runway incursions occur, “how” they occur, and the legal ramifications in terms of liability “when” they occur.

Outcomes of this research have potential benefit to the long-term growth of civil aviation and Commercial Space Transportation. This research explores a framework to prevent runway incursions and increase safety in the aviation industry while furthering knowledge and understanding on a broad front of emerging technologies. Furthermore, the hopes of this research are that it will bring forth learning, growth, and improvement to a vital area in the aviation industry.

1.4 Research Objectives

The overall objective of this research is to investigate a framework that leverages automated technology, human causal factors, data analytics & a legal repository of information surrounding a runway incursion incident, and employee training & a decision support system for the purposes of reducing runway incursions. In the first stage of the framework, it is necessary to define and investigate human causal elements for the purpose of understanding their roles in “why” the incursion took place. Also, in the first stage of the framework, it is necessary to investigate the types of runway incursions that occur in efforts to understand “how” runway incursions happen. The outcome of this will be to develop a device that can reside on a worker or can be mounted in a worker vehicle and provide audible, visual, and vibrating alerts to the employee that alerts them of their location when they are approaching a hazardous zone or encroaching a runway incursion boundary zone. The second stage of the framework will provide data analytics and a legal information repository surrounding the issue of runway incursions in terms of liability when a severe incursion takes place. The last stage of the framework will be to utilize the data analytics and develop an employee training and decision support system that will facilitate the reduction of runway incursion events.

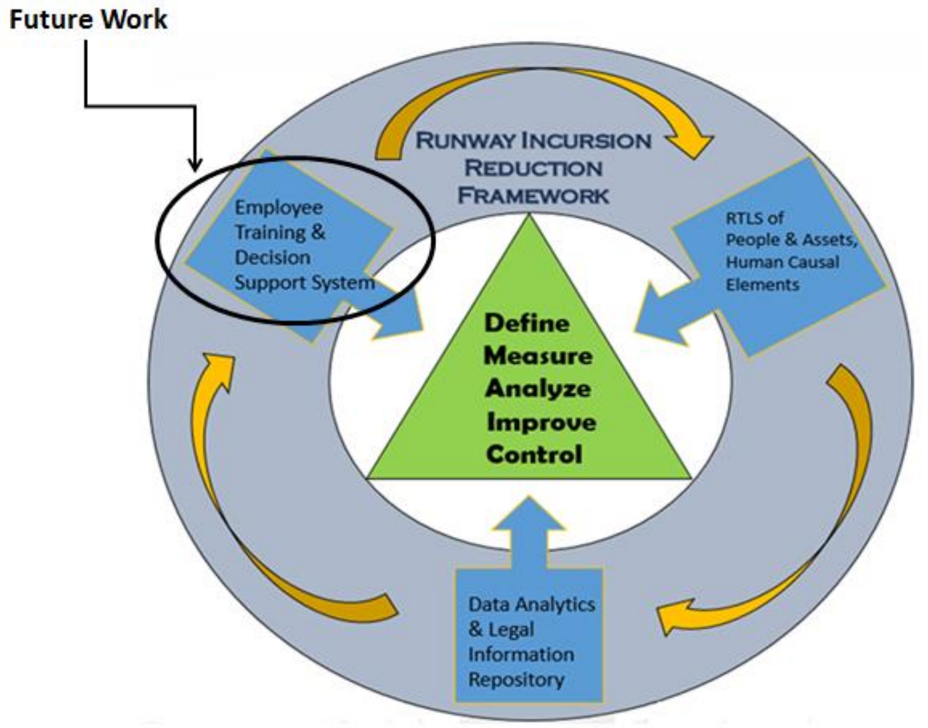


Figure 1-4: Runway Incursion Reduction Framework

Figure 1-5: Runway Incursion Reduction Framework

This research will focus on the 1st and 2nd stages of the Runway Incursion Reduction Framework as our overall objective of this research at this point. Investigating stage 3 of this framework will be future work of this research. The first and second stages of this research will investigate two research questions. The first question is, “Does human causal elements have a significant relationship with runway incursion rates?” The second research question is, “Can automated technologies platform be utilized to reduce the occurrence of a runway incursion?” The research questions will be addressed by following three research objectives:

Table 1-2: Research Objectives

Research Objective #1	Evaluate human causal elements that contribute to runway incursions on the Air Operations Area at an airport.
Research Objective #2	Determine system architecture configuration for maximum reliability. Develop runway incursion detection module. Perform an operational demonstration with selected personnel.
Research Objective #3	Perform economic analysis and evaluate the financial impacts with other solutions. Determine the best automated technology to use. Determine legal aspect of runway incursion in terms of liability.

The research problem we wish to investigate is the likelihood of increasing runway safety and minimizing the risk of runway incursions through the use of automated technologies. Furthermore, we wish to increase the body of knowledge and understanding into why runway incursions happen and the legal risks associated when they happen. The innovation of this research is that it proposes a framework to utilize automated technologies to alert workers for the purpose of minimizing runway incursion incidents and enhancing the safety on the Air Operations Area (AOA). The proposed system utilizes RFID technologies integrated with ZigBee technologies to and alert technicians when they enter into aircraft movement areas and aircraft non-movement areas that require authorization that represent safety concerns for the purpose of minimizing any forms of runway incursions.

The intellectual merit of this dissertation is that it builds upon modern automation technologies in the effort of enhancing the safety and security in an AOA. These technologies can be applied both inside of an operations vehicle, on ramp operations, and on the airport operations airfield, which can be easily carried by people, or placed in an operations vehicle that may accidentally enter the prohibited area. Furthermore, this research seeks to enhance the understanding of how a runway incursion happens, why they happen, and the legal ramifications when they happen.

The broader impact of this research is that it provides an opportunity for engineering students to apply their knowledge in a multidisciplinary field, including industrial engineering science and software engineering science to solve real problems that airports all over the world face on a daily basis.

1.5 Organization of this Dissertation

This dissertation is organized in a manner that is consistent with the five point engineering format of introduction, background, methodology, results, and conclusion.

Chapter 1 is the introduction where the definition of a runway incursion is introduced. Furthermore, chapter one discusses why runway incursion research is needed and why it is relevant at every airport around the world. In addition, the introduction discusses the purpose of this research and how automated technology could be one avenue to reduce this problem area in aviation safety. Moreover, the research objectives of this research are discussed.

Chapter 2 sets in motion the background of the dissertation that includes the purpose of runway safety, runway safety data collection and analysis, and relevant funded projects. It also discusses the literature review of human factors, Internet of Things (IoT) definition and applications, RFID technologies, ZigBee technologies, and aviation law.

Chapter 3 discusses the research problem and defines the research methodology to be used is this dissertation. Furthermore, the chapter discusses the research questions, research objectives and tasks, and hypotheses.

Chapter 4 discusses and interprets the results of the experiments. Moreover, Minitab and SAS outputs, statistical data, and the economic viability of the various technology is discussed, as well as, various case law.

Chapter 5 is the conclusion of the dissertation, which discusses the summary of the experiments and the outcomes of the research objectives. Furthermore, this chapter will discuss the limitations and future work of the research.

Chapter 2

Background

2.1 Runway Safety

The sector of aviation is very important industry to the United States economy. In 2012, the civil aviation sector led to $1.5 trillion in economic activity, sustained 11.8 million jobs which generated $459.4 billion in earnings (United States Department of Transportation, January 2015). The aviation industry relies heavily on the safe operations of the National Airspace System (NAS). The Federal Aviation Administration is tasked with managing the safety of the National Air Space System. The Federal Aviation Administration's (FAA) mission is to maintain the safest and most efficient aerospace system in the world. The FAA has stated that runway safety is one of their top priorities, which encapsulates pilots, air traffic controllers, and airport vehicle drivers and workers [8]. Runway safety is described as having a safe flight from the moment the start of the flight when it leaves the gate and takes off until the flight lands and taxis back to the gate and is concluded [7]. This problem of runway incursions is a national and international problem. The Flight Safety Foundation, an aviation safety research organization, has estimated that ground accidents worldwide cost air carriers $10 billion annually, including costs associated with injuries and fatalities and other indirect costs such as canceled flights.

2.1.1 Runway Safety Metrics

The FAA is constantly working towards improving safety performance by recognizing and finding new ways to manage safety risks. For the purpose of monitoring these safety risks, the National Runway Safety Report 2013 – 2014 states that runway safety is measured by three different metrics:

- Rate of seriousness of Runway Incursion

- Severity of Runway Incursion
- Types of Runway Incursion

These three metrics helps the FAA quantify and measure runway incursion data in terms of occurrence and location.

Figure 2-1 displays runway incursion data from the fiscal year of 2013 & 2014 separated by category type A and B. Figure 2-2 displays runway incursion data from the fiscal year of 2013 & 2014 separated by category type C & D. From this figure, we see that of the runway incursion taking place in 2013 and 2014, most of the occurrences were of category C and D.

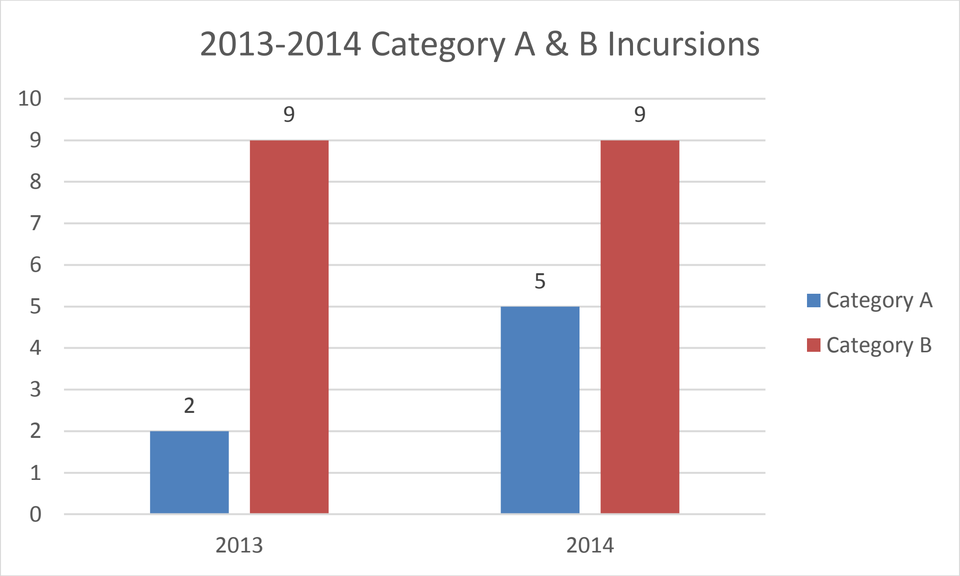


Figure 2-1: 2013-2014 Category A & B Incursions

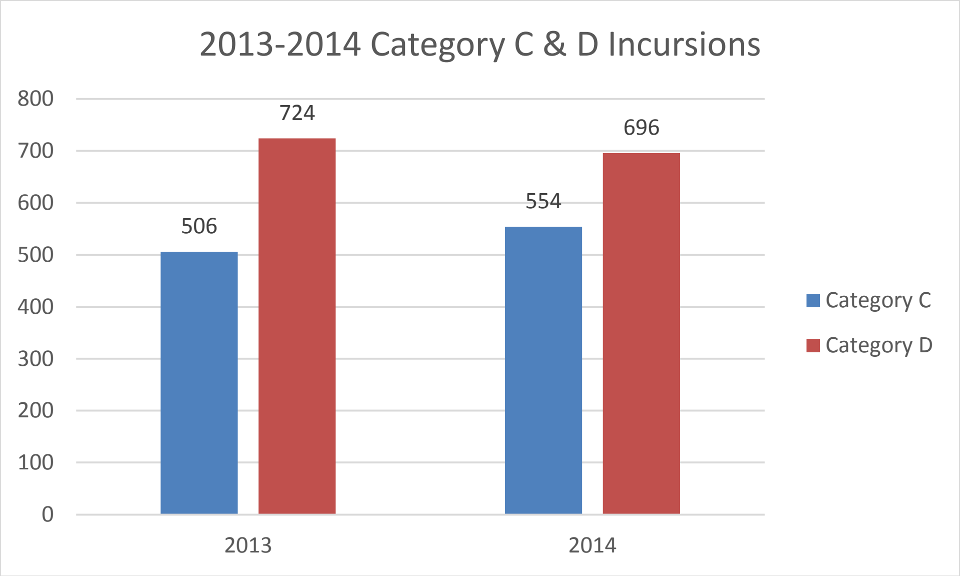
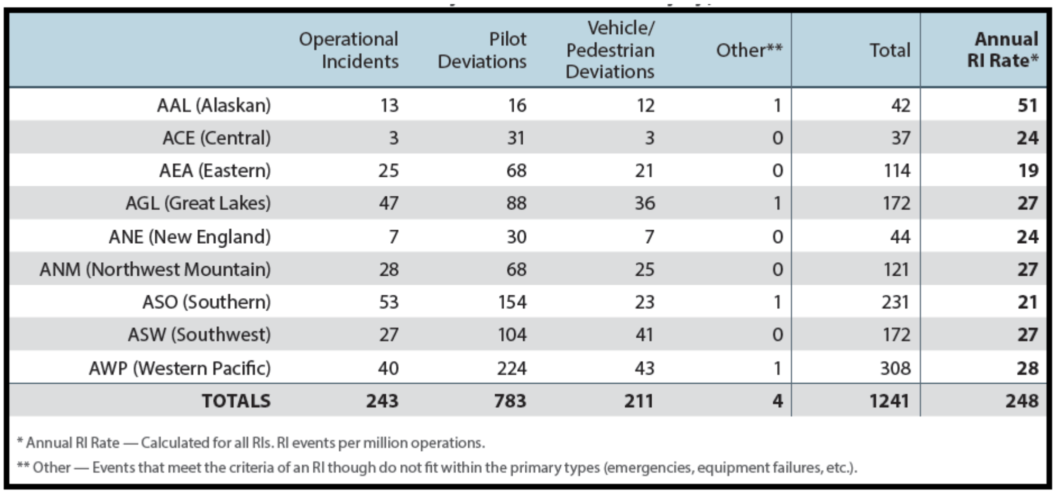


Figure 2-2: 2013-2014 Category C & D Incursions

According to the National Runway Safety Report 2013-2014, Figure 2-3 displays all the regions for the fiscal year 2013 in the nation and calculates the total for runway incursions per region in terms of the number of occurrences per inicident type and annual rate for that region.

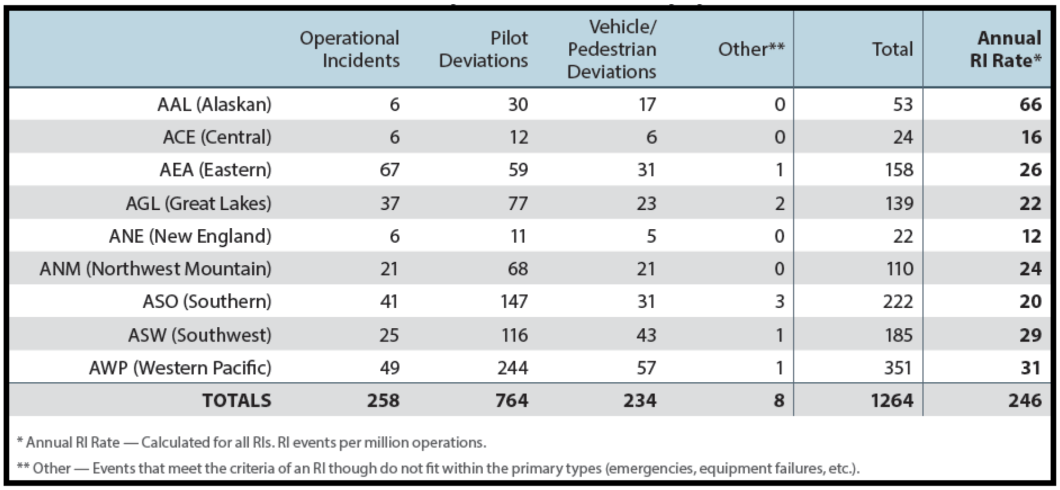
Figure 2-4 displays all the regions for the fiscal year 2014 in the nation and



	Operational Incidents	Pilot Deviations	Vehicle/ Pedestrian Deviations	Other**	Total	**Annual RI Rate***
AAL (Alaskan)	13	16	12	1	42	**51**
ACE (Central)	3	31	3	0	37	**24**
AEA (Eastern)	25	68	21	0	114	**19**
AGL (Great Lakes)	47	88	36	1	172	**27**
ANE (New England)	7	30	7	0	44	**24**
ANM (Northwest Mountain)	28	68	25	0	121	**27**
ASO (Southern)	53	154	23	1	231	**21**
ASW (Southwest)	27	104	41	0	172	**27**
AWP (Western Pacific)	40	224	43	1	308	**28**
TOTALS	**243**	**783**	**211**	**4**	**1241**	**248**

* Annual RI Rate — Calculated for all RIs. RI events per million operations.
** Other — Events that meet the criteria of an RI though do not fit within the primary types (emergencies, equipment failures, etc.).

Figure 2-3: 2013 Runway Incursion Totals by Type (Federal Aviation Administration, 2015) calculates the total for runway incursions per region in terms of the number of occurrences per classification type and annual rate for that region.



	Operational Incidents	Pilot Deviations	Vehicle/ Pedestrian Deviations	Other**	Total	**Annual RI Rate***
AAL (Alaskan)	6	30	17	0	53	**66**
ACE (Central)	6	12	6	0	24	**16**
AEA (Eastern)	67	59	31	1	158	**26**
AGL (Great Lakes)	37	77	23	2	139	**22**
ANE (New England)	6	11	5	0	22	**12**
ANM (Northwest Mountain)	21	68	21	0	110	**24**
ASO (Southern)	41	147	31	3	222	**20**
ASW (Southwest)	25	116	43	1	185	**29**
AWP (Western Pacific)	49	244	57	1	351	**31**
TOTALS	**258**	**764**	**234**	**8**	**1264**	**246**

* Annual RI Rate — Calculated for all RIs. RI events per million operations.

** Other — Events that meet the criteria of an RI though do not fit within the primary types (emergencies, equipment failures, etc.).

Figure 2-4: 2014 Runway Incursion Totals by Type (Federal Aviation Administration, June 2015)

In 2103 – 2014, approximately 60% of runway incursions were attributed to pilot deviations, 20 % were attributed to operational incidents, and 20 % were attributed to vehicle/pedestrian deviations (Federal Aviation Administration, June 2015). Runway incursions, along with its associated risks and efforts for reduction and prevention, have been studied intensively. The Commercial Aviation Safety Team (CAST) is a group of key aviation stakeholders working collectively to lead the national and international aviation community to the highest levels of global commercial aviation safety (Federal Aviation Administration, June 2015). The FAA has implemented several CAST safety improvements, a Safety Management System (SMS), and a Runway Incursion Mitigation (RIM) program in efforts to reduce the occurrence of a runway incursion.

2.1.2 Runway Safety Data Collection

The FAA uses various databases and reporting systems that allow different personnel at all levels to get a deeper look into safety data to have a better understanding of runway safety issues. One of the newly implemented systems for critical runway safety data is called the Comprehensive Electronic Data and Analysis Reporting (CEDAR) system. The CEDAR system is currently being used in place of the old the manual safety event reporting system used for record keeping, documenting, collecting, and processing safety event reporting in air traffic facilities (Federal Aviation Administration, 2016). Another database that the FAA uses is the Airport Facility Directory. This directory gives information on various hot spots at airports all over the nation sorted by region. The FAA defines a “hot spot” as being a position on the airport movement area where heightened attention by pilots and airport vehicle drivers is required because that location has a history of potential risk of a runway incursion (U.S. Department of Transportation FAA, 2016). By identifying these spots, makes it easier for pilots and ground workers to be more aware and alert of the potential of an incursion event.

2.1.2.1 Runway Incursion Databases

The FAA has also developed a system that allows users to look at safety data from numerous databases in one place. The name of this system is the Aviation Safety Information Analysis and Sharing (ASIAS) System. The ASIAS system allows users to perform queries over multiple databases. Various databases within ASIAS include FAA Accident and Incident Data Systems (AIDS), NASA Aviation Safety and Reporting System ASRS, National Transportation Safety Board (NTSB) Aviation Accident and Incident Data, just to name a few. In this research, most of the runway incursion rates data due to human causal elements will be used from the Aviation Safety Reporting

System. The Aviation Safety Reporting System (ASRS) is a program that accumulates aviation safety occurrences that have been submitted voluntarily by pilots, controllers, and others (Aviation Safety Reporting System, 2016). The purpose of the ASRS is to gather and investigate these reports to reduce the likelihood of aviation accident event that compromises safety (Aviation Safety Reporting System, 2016). ASRS data are used for three main purposes:

1.) Identify inconsistencies in the National Airspace System (NAS) so that these can be remedied by proper authorities (Aviation Safety Reporting System, 2016).
2.) Support the design of policy, planning, and enhancements to the NAS (Aviation Safety Reporting System, 2016).
3.) Reinforce the base of aviation human factors safety research (Aviation Safety Reporting System, 2016).

2.1.3 Runway Safety Programs

The FAA has employed various programs to improve runway safety. Order 7050.1b is a directive handbook that is used by the Air Traffic Organization (ATO) Safety and Technical Training staff to adhere to the FAA's long-term goal of improving runway safety by reducing the number of runway incursions and its associated incidents. The ATO Safety and Technical Training office serves as a central point for all of the runway safety efforts made by the FAA. Its primary role is to develop a National Runway Safety Plan that aids them in a wide-ranging strategy to implement runway safety. Various programs range from runway safety action plans to regional and local runway safety plans.

2.1.4 Similar Research & Relevant Funded Projects

The Federal Aviation Administration is constantly looking into different emerging technologies to help improve the area of runway safety. A current technology that the FAA has installed at 35 of the busiest U.S. airports is the Airport Surface Detection Equipment, Model X, otherwise known as the ASDE-X. This runway incursion technology uses surveillance sensors, surface movement radars to display aircraft position about on the Air Operation Area, and Safety Logic, which is detection and alerting technology that uses complex algorithms to alert controllers of a potential incursion with aircrafts and/or vehicles (Ranieri, 2016). The difference from this researched technology and the one aforementioned in this dissertation are that ASDE-X only provides alerts to the air traffic controllers and not the vehicle drivers. Another technology used by airports to avert from runway incursions is Runway Status Lights (RWSL). RWSL tell pilots and vehicle operators to stop when runways are not safe. Embedded in the pavement of runways and taxiways, the lights automatically turn red when other traffic makes it dangerous to enter, cross, or begin takeoff (Federal Aviation Administration, 2013). In addition to RWSL, airports also employ the Airport Movement Area Safety System (AMASS). AMASS visually and aurally prompts tower controllers to respond to situations which potentially compromise safety. AMASS is an add-on enhancement to the host Airport Surface Detection Equipment Model 3 (ASDE-3) radar that provides automated aural alerts to potential runway incursions and other hazards (SKYbrary Aviation Safety, 2013).

The Federal Aviation Administration has funded runway safety research that has led to the testing and new deployment of a technology of other measures (United States Government and Accountability Office, 2007). During the fiscal year of 2006, FAA spent about 3.5 million on runway incursion prevention research at the William J Hughes

Technical Center (United States Government and Accountability Office, 2007). Runway safety, runway incursions, in particular, is a topic in aviation safety that continuously researches ways to mitigate risks associated with hazards on the runway. Another funded research project on runway safety was employed at the Miami International Airport. The Transportation Security Administration funded the 3.1 million dollar project for a Runway Incursion Detection System. This Runway Incursion Detection System integrated ground-based radar, high-resolution digital cameras, and target-analytics software for the purpose of detecting and verifying runway and taxiway incursions (Wysocky, 2014). The benefits of this new system are that it provides a faster and more reliable way of detection and verification of these runway and taxiway incursions (Wysocky, 2014). Correspondingly, the FAA recently announced that it will fund $11 million through the Airport Improvement Program (AIP) to eight U.S. airports for risks pertaining to runway incursions to reduce occurrences by funding projects that are used to mitigate incursion hazards (Sadler, 2015).

2.2 Human Factors

When talking about runway safety, runway incursions, in particular, it is essential to discuss human factors. Approximately, over two-thirds of all aviation accidents and incidents have their roots in human performance errors (Federal Aviation Administration, 2011). Since most aviation accidents are caused by human error instead of a mechanical failure of the equipment. The term “human factor” has become gradually more popular in the aviation industry. Human factors are primarily concerned with the integration of technology and humans and how this interaction can successfully sustain a safe flying environment. Human factors can be classified into several disciplines from clinical psychology, medical science to computer science and safety engineering. For the purpose of this dissertation, we will discuss human factors from an aviation industry standpoint. Human error can be defined as an error or operational mistake made by a human. Because of the fact that we as human beings are not perfect, error in work performance is bound to occur. The key is learning about it and finding new ways through technology to address it. Figure 2-4 is a list of human factor errors that affect the aviation industry.

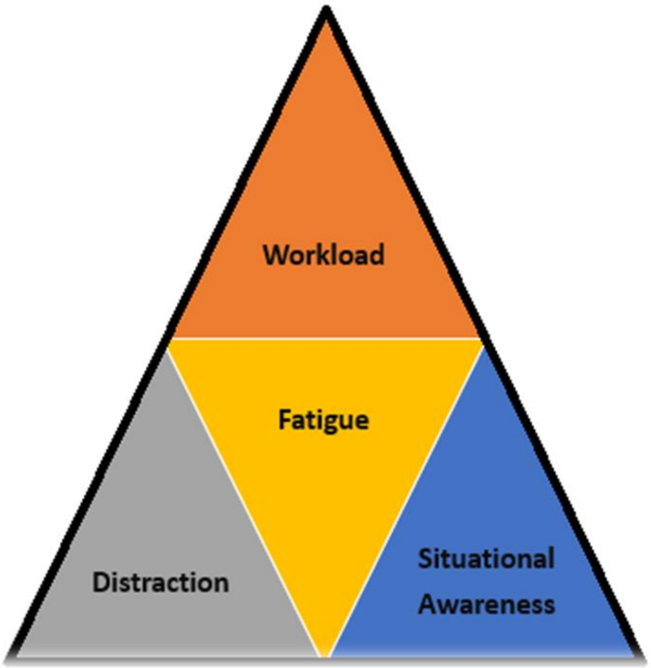


Figure 2-5: Human Factor Errors that Effect Aviation Industry

It is important to note that this list is not exhaustive. The FAA has employed numerous human factor specialists that work in the Aviation Safety (AVS) organization to improve the impact of human error in aviation systems. They perform their duties by developing regulations, guidance and procedures that support the certification of pilots, mechanics, and other aviation workers.

2.2.1 Visual and Auditory Performance

Another part of human factors that are of concern in this dissertation are the visual and auditory performance. This information is of interest because we would like to know at what auditory level and what type of visual indicator should the runway incursion device be equipped with to provide the worker with an adequate visual and auditory alert that can be seen and heard. Auditory and visual stimuli account for more than 95% of the way a person receives information (Groover, 2007). It comes to no surprise that vision is the most import of the five basic human senses. Light is what stimulates the eyes, which comes from electromagnetic radiant energy that is within the visible spectrum (Groover, 2007). In knowing this, it is very important that the appropriate color of light be used on the device that is within the visible spectrum to effectively alert the worker. Furthermore, it is essential that the auditory alert on the runway incursion detection device is loud enough to alert the worker, even in the presence of background noise. The average human being with no hearing defects can perceive sound frequencies in the range of approximately 20 Hz to 20,000 Hz, with normal conversation frequencies lying in the range of 500 Hz to 3000 Hz (Cambell & Bagshaw, 2002). Moreover, the auditory environment can have a significant effect on the worker. Two major factors that play into the auditory environment are the intensity of the noise and the duration of exposure to the noise source (Groover, 2007). It is important that we assess the noise environment of the worker so that a reliable detection device can be produced.

2.3 Communication Technologies

Target Tech define communication technologies as, "…an umbrella term that includes any communication device or application, encompassing: radio, television, cellular phones, computer and network hardware and software, satellite systems and so on, as well as the various services and applications associated with them, such as videoconferencing and distance learning" (Rouse, 2016). There have been several projects and developments in communication technology regarding the aviation industry that have been employed in order to mitigate the risk of a runway incursion event, no matter the severity. Within this chapter, we will investigate Internet of Things, Radio Frequency Identification, and Zigbee Technologies.

2.3.1 Internet of Things

The Internet of Things (IoT) is a technological solution we can employ to help reduce these occurrences of runway incursions. When we talk about the internet of things, it can be defined in several different ways. However, at the root of all the definitions for the internet of things, IoT can be defined as, "the network of physical objects or "things" embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data" (Wikipedia Foundation Inc., 2016). Taking a deeper look into the definition, let's take a closer look at the term. The "internet" everyone can identify with as being a system of communication networks that connects individuals to have all-encompassing knowledge at their fingertips. When we talk about "things" this can be people, devices, sensors, phones and the list could be endless. However, when we combine these two terms, we talk about the world where everything is connected. For example, being able to close your garage door from the comfort of your office, or being able to send your doctor real-time health information at the touch of a button. The Internet of Things is a phenomenon that is rapidly growing and finding more widespread use on a daily basis. Just as any other industry, we can expand IoT into the aviation industry to assist with real-time data for the purpose of supporting the safety aspect of aviation. Radio Frequency Identification (RFID) was known as one of the early technologies for the development of IoT, however, as of late wireless sensor networks and Bluetooth-enabled technology assisted the advancement of the IoT trend (Buyya & Vahid, May 2016). In order to implement a reliable use of IoT, we look to Radio-Frequency Identification technology integrated with ZigBee technologies.

2.3.2 Radio Frequency Identification Technology

Radio-Frequency Identification (RFID) is a communication technology that has been around for over 80 years. RFID is most commonly used for tracking and identification of various assets and unique objects by way of the movement of radio waves of information from point to point (Clampitt & Jones, 2006). Early on, RFID was used in the military for the purpose of detecting certain aircraft and determining whether that aircraft was a friend or foe. As time went on, RFID was used in the toll tag industry, tracking animals, and heavily used in the supply chain industry. Now RFID is used across numerous industries with several different applications.

2.3.2.1 Radio Frequency Identification Theory

RFID uses radio-frequency electromagnetic fields to transfer data wirelessly for the purpose of identifying, detecting, and tracking tags attached to various objects. A RFID system is made of a tag, reader, antenna, and a host computer and software system. The basis of how it RFID works is that it uses electromagnetic waves as a communication medium between the reader and the tag. As the tag enters the reader's zone, the reader excites the tag allowing the antenna to send these signals back to the reader (Clampitt & Jones, 2006). Figure 2-5 below gives an overview of this operation.

The reliability of the tags being able to read and send information to reader depends on a number of factors. Different factors include the tag type, distance, environment, and its frequency band of use. The various frequency bands that RFID operates in include low-frequency (LF), high-frequency (HF), and ultra-high-frequency (UHF). Figures 2-6 and 2-7 describes the more and less common frequencies used in RFID.

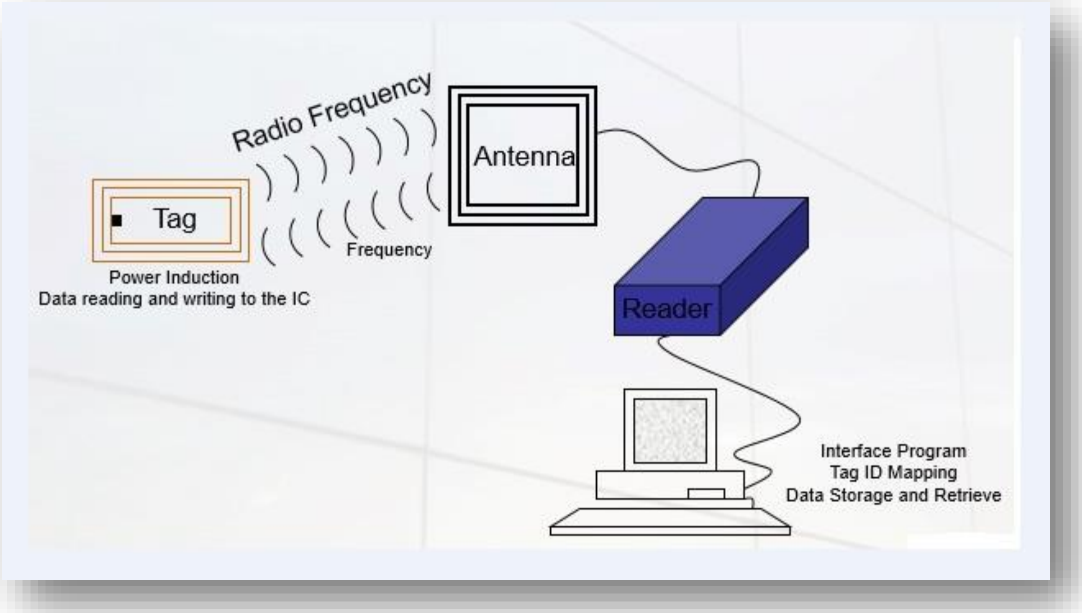


Figure 2-6: RFID Operation

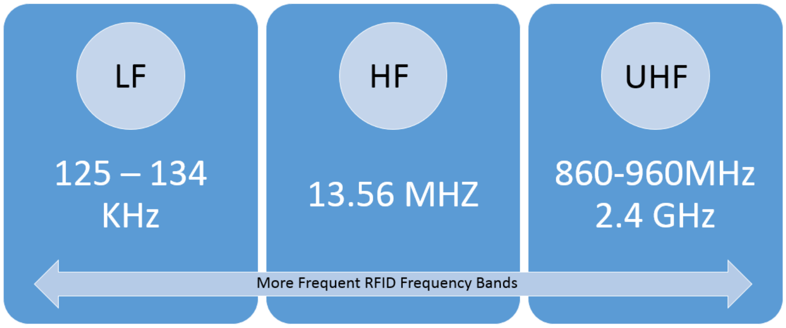


Figure 2-7: More Frequent RFID Frequency Bands

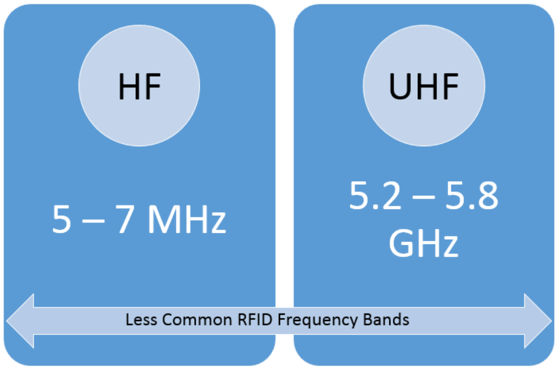


Figure 2-8: Less Common RFID Frequency Bands

2.3.2.2 Radio Frequency Identification Tag Types

There are two main RFID tag types: passive tags and active tags. Passive tags do not have a battery on board, therefore it relies on the energy of the reader to wake up and excite the tag to begin the information sharing process. Between passive and active tags, passive tags are the least costly. Consequently, passive tags do not have a long read range as the active tags do. However, they do have a lower installation, infrastructure, and maintenance cost. Active tags have a battery on board used to power the tag and respond to the reader. Because of this, active tags have a longer read range and higher accuracy. Subsequently, they are more expensive than passive tags.

Another tag type is what's known as a semi-active tag. This tag type is of newer technology which combines the best of both tag types. Semi-active tags come equipped with the on-board battery; however, it uses the reader's energy to respond back. Generally, a semi-active tag last longer than active tags and has a higher accuracy rate and read range than passive tags. A semi-active tag is also cheaper than an active tag.

2.3.3 ZigBee Technologies

ZigBee is the name of a specification for a pool of high-level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs) that is proposed to be cheaper and simpler than other WPANs such as Bluetooth (Digi International Inc., 2016). We choose to integrate ZigBee technologies with RIFD because it is targeted at radio-frequency (RF) applications which require a low data rate, long battery life, and secure networking (Digi International Inc., 2016). Radio-frequency identification (RFID) and ZigBee are two automated technologies that have made a name for themselves in several different applications (Abdulla & Ismail, 2011). Some benefits of RFID is that it can provide wireless tracking of people and assets, while ZigBee provides advanced sensor networks (Abdulla & Ismail, 2011). With the integration of these two technologies, it is possible to create a ZigBee mesh network with integrated RFID wireless reader to provide tracking capability in which RFID tags within the network can communicate with each other (Abdulla & Ismail, 2011).   We will employ a RFID system integrated with ZigBee technologies that will send audible, visual, and vibrating alerts that warn personnel and contractors of their location when they are approaching or when they are in a hazardous zone in efforts to reduce the occurrence of a runway incursion event.

2.4 Aviation Law

Aviation law is the type of law that deals with air travel and the accompanying legal and business aspects associated therein (Wikipedia Foundation Inc., 2016). Federal and state governments are the regulating body for aviation law. However, since the terrorist attacks that happened on September 11, 2001, Congress enacted the Aviation and Transportation Security Act of 2001, which now has aviation mostly governed by federal law (Cornell Univeristy Law School, 2016). With over 4000 airports in the country, most of them are owned by governments. Since aviation law is a topic that spans across all other law subjects like property law, contracts, torts, and criminal law, to name a few, aviation law can be considered a diminutive course for all other legal industries (Larsen, Sweeny, & Gillick, 2006). For the purpose of this research, it would be helpful to know what happens when an accident takes place and who is liable. Since this problem of runway incursions is a national and international problem of significance, it would be helpful to provide legal research to the airport legal community surrounding such occurrences that would be beneficial to the airport owners, operators, and airport workers in providing information surrounding legal issues and airport related law.

2.5 Chapter Summary

Furthermore, we seek to reduce runway incursions by understanding the “why” a runway incursion takes place by investigating the underlying causes that play a primary role in a runway incursion event. These underlying causes can be defined as human causal elements. Human causal elements are the errors that Air Traffic Control, pilots, and workers routinely make that have a direct impact in a runway incursion event (Federal Aviation Administration, 2011). By gaining an understanding of why these runway incursions happen will give us insight on how to prevent them. Moreover, we seek to use statistical analysis and determine if a significant relationship exists between the human causal elements and an event of an incursion. Furthermore, we attempt to determine which human causal element has the highest impact on the likelihood of an occurrence.

Additionally, when there is an aircraft accident, the question arises of whether or not the airport is liable for the related damages associated with the accident. The question arises whether the liability is being placed on the airport owner or the actual operator, pilot or air traffic controller, who may have played a role in the runway incursion incident. We plan to explore various case law surrounding severe runway incursion incidents in efforts to understand the liability ownership of these severe incursions and put these results of our findings in a repository database to create one shared location to be accessed by anyone who has a need for such information such as lawyers, pilots, and air traffic controllers to keep them informed when such an event arises.

Overall, this research aims to reduce an occurrence of a runway incursion by exploring our framework that will bring forth learning, growth, and improvement to a vital area in the aviation industry. In addition to the use of automated technology and understanding the economic feasibility, this research seeks to reduce runway incursions by understanding how runway incursions occur, why they occur, and the legal ramifications in terms of liability when they occur.

Chapter 3

Methodology

The significance of this research is that we seek to contribute to the body of knowledge and understanding of the various reasons why these incidents take place by investigating the human causal elements and what role they played into an incursion. Furthermore, we seek to develop a prototype will allow technicians to easily carry the device on person or mounted in a vehicle, for both indoor and outdoor environments, including while driving on the Airport Operations Area. Moreover, we seek to investigate the legal ramifications when a runway incursion takes place by researching case law, and at its extreme, the legal ramifications when loss of life occurs. With regard to the significance of this research, the next logical research questions that we seek to investigate are, “Does human causal elements have a significant relationship with runway incursion rates?” Furthermore, “Can automated technologies platform be utilized to reduce the occurrence of a runway incursion?” We investigate these questions by exploring a framework that evaluates the relationships between human causal elements and runway incursions and uses RFID and ZigBee Technologies for the purpose of developing a device that alerts technicians if they are approaching a boundary on the AOA that will cause an incursion incident.

3.1 Research Approach

We will use Design for Six Sigma Research (DFSS-R) methodology for our problem-solving approach developed by Dr. Erick C. Jones in 2006. This framework is based on a common operational theme that requires development teams to plan, predict, and perform (3P). The DFSS-R process steps are define, measure, analyze, identify, design, optimize, and verify (Jones & Chung, 2011). In the define step, a clear problem definition is defined. Next, the measure step sets up accurate metrics through various statistical analysis techniques. In the analyze step, we want to assess and analyze the current situation. Next, we want to identify relevant technology. After this has been identified, our following step is to design new technology from our current knowledge. Our future steps within the methodology are to optimize our new technology by testing it in a live environment and improve any drawbacks. After this is done, we want to validate the technology in a live situation. The DFSS-R process steps are organized within the 3P framework in figure 3-1 below.

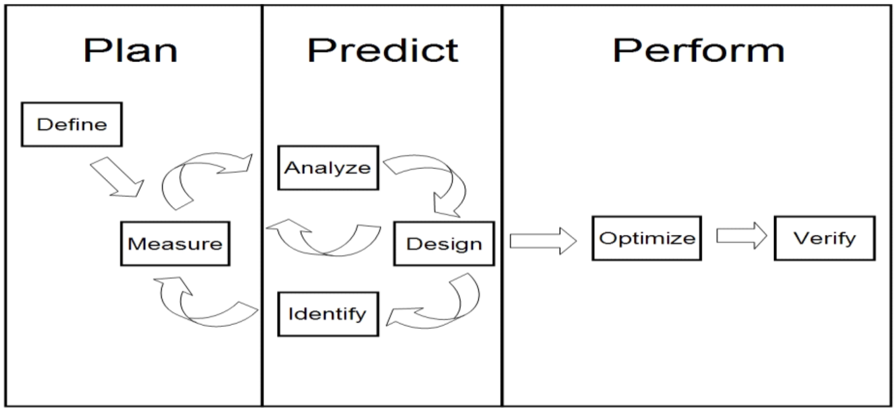


Figure 3-1: Design for Six Sigma Research (DFSS-R) Methodology

For this research, we have separated our specific task into our 3P framework in table 3-1 below.

Table 3-1: 3 P's Methodology with Specific Tasks

Plan	Define Measure	***Task 1*** ***Task 2*** ***Task 3*** ***Task 4*** ***Task 5*** ***Task 6*** ***Task 7*** ***Task 8*** ***Task 16***
Predict	Analyze Identify Design	***Task 1*** ***Task 2*** ***Task 3*** ***Task 4*** ***Task 9*** ***Task 10*** ***Task 11***
Perform	Optimize Verify	***Task 12*** ***Task 13***

3.2 Research Questions and Hypotheses

There are two primary research questions that will be investigated. As stated earlier, the research questions that of are interest are, “Does human causal elements have a significant relationship with runway incursion rates?” Furthermore, “Can automated technologies platform be utilized to reduce the occurrence of a runway incursion?" To explore these research questions, hypothesis testing will be used. The hypotheses associated with these research questions are below.

Research question #1 hypothesis statement:

Null Hypothesis

H_o: There is not a significant relationship between human causal elements and runway incursion rates.

Alternative Hypothesis

H_a: There is a significant relationship between human causal elements and runway incursion rates.

Decision Rule: Reject H_o if the p-value from the main effect is less than the 0.05 significance level.

Research question #2 hypothesis statement:

Null Hypothesis

H_o: Automated technology system is not reliable to reduce runway incursion incidents

Alternative Hypothesis

H_a: Automated technology system is reliable to reduce runway incursion incidents

Decision Rule: Reject H_o if main effects for linear model of statistical reliability show p-value less than the 0.05 significance level.

The research questions and hypothesis statements are summarized in Table 3-1 below.

Table 3-2: Research Questions and Hypotheses Statements

Research Questions	**Null Hypothesis**	**Alternative Hypothesis**	**Decision Rule**
Research Question #1 Do human causal elements have a significant relationship with runway incursion rates?	H_o: There is not a significant relationship between human causal elements and runway incursion rates.	H_a: There is a significant relationship between human causal elements and runway incursion rates.	Reject H_o: if the p-value from the main effect is less than the 0.05 significance level
Research Question #2 Can automated technologies platform be utilized to reduce the occurrence of a runway incursion?	H_o: Automated technology system is not reliable to reduce runway incursion incidents	H_a: Automated technology system is reliable to reduce runway incursion incidents	Reject H_o: if main effect for the linear model of statistical reliability shows p-value less than the 0.05 significance level.

3.3 Research Objectives and Specific Tasks

Table 3-3: Research Objectives and Tasks

Research Objective 1: Evaluate human causal elements that impact safety on the Air Operations Area.
Task 1 – Evaluate the runway incursion incidents for 2014-2015 in the U.S. by region.
Task 2 – Determine specific region, state, and airports to evaluate runway incursion rates and human causal elements.
Task 3 – Investigate the NASA’s Aviation Safety Reporting System database using ASIAS for selected airports for runway incursions events from 2014 – 2015 and identify top 5 most common human causal elements. .
Task 4 – Determine which of the human causal elements have the most impact on runway incursion rates.

Research Objective 2: Determine system architecture configuration for maximum reliability. Develop runway incursion detection module. Perform an operational demonstration with selected personnel.
Task 5 – Establish a baseline and configuration method and set up accurate metrics for experiment.
Task 6 – Determine and procure all equipment needed to develop incursion detection module.
Task 7 – Identify persons of contact at airport and confirm their understanding of the project and agree on project boundaries.
Task 8 – Conduct site visits
Task 9 – Identify two major “hotspots” at airport to implement testing of technology.
Task 10 – Install the system and test a prototype to ensure workability of system.
Task 11 – Conduct reliability experiments.
Task 12 – Perform an operational demonstration with selected personnel and use feedback for updates.
Task 13 – Redefine prototype and improve design to develop final product.
Research Objective 3: Perform economic analysis and evaluate the financial impacts with other solutions. Evaluate the impacts of different automated technologies. Determine the best automated technology to use. Determine legal aspect of runway incursion in terms of liability.
Task 14 – Calculate NPV for Runway Incursion Prevention System and other solutions.
Task 15 – Investigate various case law surrounding serious runway incursion incidents.

The overall objective is to investigate a framework that can reduce runway incursion occurrences by evaluating the influence of human causal elements, evaluating the impact of automated systems that can be tested on a device, investigating economic justification, and provide some legal information surrounding the topic of liability of an occurrence. The research objectives associated with the specific task and methods are as below.

Research Objective 1: Evaluate human causal elements that contribute to runway incursions on the Air Operations Area at an airport.

Task 1 – Evaluate the runway incursion incidents for 2014-2015 in the U.S. by region.

The first step for task 1 of this research was to examine the statistics for the regional runway incursion totals for 2014 – 2015 on the FAA Runway Safety website. Upon doing this, the observed data was categorized into a table by runway incursion totals by incident type for each region. It is of interest to know whether or not these runway incursions are dependent or independent of location. We want to know this to verify that the data distributions of the runway incursion totals by region that we have observed are not by chance. Intuitively, we would think that runway incursion rates would be dependent on region. To verify this, we used Chi-Squared Test of Independence to test the probability of independence. The two-way Chi-Squared test and hypothesis testing parameters for this are below.

$$E_{i,j} = \frac{i_T \times j_T}{N}$$

$$\chi^2 = \sum_{i=1}^{n} \sum_{j=1}^{k} \frac{(O_{i,j} - E_{i,j})^2}{E_{i,j}}$$

where:

$O_{i,j}$ = Observed value for cell i,j

$E_{i,j}$ = Expected value for cell i,j

n = number of rows for incident type

k = number of columns for a region

Null hypothesis:

H_o: Incursion incident and Region are independent

Alternative Hypothesis:

H_a: Incursion incident and Region are not independent

Decision Rule: Reject H_o if p-value is less than 0.05 significance level

Task 2 – Determine specific region, state and airports to evaluate runway incursion rates and human causal elements.

After we determined whether or not the runway incursion data is dependent or independent of location, we chose to look at the runway incursion rates in the Southwest

(ASW) region in the state of Texas. This location was chosen because the research is being done in this region. However, this can be expanded to any region. We researched all airports in the state of Texas for the purpose of identifying the top airports in Texas which accounted for most of the runway incursion incidents. Once this was determined, we performed another Chi-Squared test of independence to determine of runway incursion incidents are dependent or independent of an airport. Again, intuitively, we would assume that these runway incursion rates would be dependent on an airport. However, we perform this statistical test to verify this relationship. The two-way Chi-Squared test and hypothesis testing parameters for this are below.

$$\chi^2 = \sum_{i=1}^{n}\sum_{j=1}^{k} \frac{(O_{i,j} - E_{i,j})^2}{E_{i,j}}$$

where:

$O_{i,j}$ = Observed value for cell i,j

$E_{i,j}$ = Expected value for cell i,j

n = number of rows for incident type

k = number of columns for airport

Null hypothesis:

H_o: Incursion incident and Airport are independent

Alternative Hypothesis:

H_a: Incursion incident and Airport are not independent

Decision Rule: Reject H_o if p-value is less than 0.05 significance level

Task 3 – Investigate the NASA's Aviation Safety Reporting System database using ASIAS for selected airports for runway incursions events from 2014 – 2015 and identify top 5 most common human causal elements.

Next, the task was to go to the ASIAS website and search the NASA's Aviation Reporting System (ASRS) database for all the runway incursion incidents reported for the top 5 airports in Texas that account for most of the runway incursion events in Texas. Within the ASIAS database, ASRS allows the individual to sort runway incursion incidents by airport and a range of dates. Each report has its ASRS access number, as well as, event date, contributing factors of the event (human causal elements), environmental conditions, and a narrative of the reported incident per the individuals involved in the event. For each airport, all reports in the range of January 1, 2014 – December 31, 2015, was examined. The output for the report examination was the contributing factor in terms of the human causal element or elements that played a role in the incursion event. At that juncture, these human causal elements were arranged in an excel file by the airport, ASRS access number, and the primary and secondary contributing factors for the event. Once in the excel file, the human causal elements were arranged by the sort and filter function in order to analyze the data and count which were the top five elements for the 5 airports. After this, this data was arranged into a table sorted by airport and top 5 human causal elements in efforts to perform statistical analysis on the data. In order to analyze the data, we utilized a complete block design with airports being the blocking factor h and the human causal elements being the treatments τ. The linear model formulation for the complete block design is below.

$$Y_{hi} = \mu_{..} + \theta_h + \tau_i + \varepsilon_{hi}, \varepsilon_{hi} \sim N(0, \sigma^2),$$

$for\ h = 1, \dots, b; \quad i = 1, \dots, v,$

Where:

Y_{hi} = is the random variable response representing the measurement on treatment i observed in block h, and ε_{hi} is the associated random error.

$\mu_{..}$ = is the overall mean.

θ_h = is the blocking factor on the response.

τ_i = is the treatment effect on the response.

H_o: $\tau_1 = \tau_2 = \tau_3 = \tau_4 = \tau_5$

H_a: At least two of the τ_i differ

Decision Rule: Reject H_o if $\frac{msT}{msE} > F_{v-1,bv-v-v+1,\propto}$

It is a reasonable assumption to make that the blocks and the treatments do not interact.

We used ANOVA analysis to analyze the data.

Task 4 – Determine which of the human causal elements have the most impact on runway incursion rates.

From the output of our general linear model, we determined which of these human causal elements had the most impact on the runway incursion rates.

Research Objective 2: Determine system architecture configuration for maximum reliability. Develop runway incursion detection module. Perform an operational demonstration with selected personnel.

Task 5 – Establish a baseline and configuration method and set up accurate metrics for the experiment.

For our task 5, we wanted to establish our baseline and configurations by conducting two experiments. The first experiment tested our theoretical reliability of the runway incursion detection system considered two different configurations for the antennas that will give us maximum readability for the automated devices to collect data. The second experiment was to test our outside environment in terms of the noise level in dB at our respective areas close to where a runway incursion can occur. Our methodology for our experiments to test the reliability and the noise factor followed the format below.

A. Experiment Procedure

For our experiments we worked with both University of Texas at Arlington RAID Labs to conduct our simulation of the reliability of the device and with the Federal

Aviation Administration air traffic controllers, air traffic management, and technical operations technicians to collect the noise levels out on the Air Operation Area surrounding the sites where the proposed system will be integrated. The following steps below was our experiment procedure that we followed:

1. **Problem Definition**

In this section, we defined our problem definition for the experiment and conducted site visits and spoke to various personnel regarding the input variables of the simulation model, the output variables and which factors that are of interest.

2. **Model Definition**

The model definition was based on the factors including their levels for our experiment. For the reliability experiment, we looked at three factors: antenna configuration with two levels: configuration 1 and configuration 2, distance with three levels: 5ft, 15ft, and 25ft, and device location with three levels: pocket, armband, and waist. For the noise factor experiment, we looked at two factors: sites with two levels: site 1 and site 2, and day with seven levels: Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and Sunday. The model is a multivariate response linear model. The experimental design was decided in this section.

3. **Run the experiments.**

After the model definition and experimental design, the experiments were conducted.

4. **Statistical Analysis**

The analysis started with the preliminary analysis of the model assumptions. From there, we conducted the ANOVA. Lastly, we investigated the analysis of effects of the model.

5. Results and conclusions.

After the analysis, the final linear model and the results of the experiment was analyzed.

Task 6 – Determine all equipment needed to develop incursion detection module.

This task allowed us to look into everything that would be necessary to develop the runway incursion detection module, as well as, what it would take to procure the necessary parts.

Task 7 – Identify persons of contact at the airport and confirm their understanding of the project and agree on project boundaries.

Next, it was necessary for us to contact the appropriate individuals in the FAA who worked at the Dallas/Fort Worth airport. The personnel of we contacted were air traffic tower control management, air traffic controllers, and system specialist technicians.

Task 8 – Conduct site visits

Once we made the appropriate contacts, we scheduled times we can meet and talk to various personnel about the project, as well as, conduct specific site visits on the AOA where we collected the noise level data.

Task 9 – Identify two major “hotspots” at the airport to implement testing of technology.

Through informal interviews with air traffic management, air traffic tower controllers, and system specialist technicians, it was determined where the most potential risk for a runway incursion would take place and need to be heightened attention to air traffic controllers and drivers on the AOA, in this case, the system technicians that have equipment that needs to be worked on throughout the AOA.

Task 10 – Install the system and test a prototype to ensure workability of the system.

Theoretically, we wanted to install the system on the AOA at the hotspots, but due to regulations from the Dallas/Fort Worth Airport, before installing any new technology it has to go through the proper chain of command and then get approved by

Dallas/Fort Worth Airport officials, which is a very lengthy process. So, we ran a simulated reliability experiment with the device at the University of Texas at Arlington RAIDS lab. However, we were approved to get the dB noise levels on the AOA for the respective hotspots and surrounding area.

Task 11 – Conduct the experiments

The experiment procedure for experiment one and experiment two is below.

Experiment Procedure: 1

Problem Definition:

For the first experiment, we wanted to test the reliability of the device to be able to accurately and effectively have the proper read reliability for the automated devices once in the interrogator zone of the system. We wanted to know at what distance, antenna configuration, and at what position of the device would give us a maximum response. The system's reliability was established by read rate and signal strength.

Model Definition:

I. Experiment 1: System Reliability

A. Factors

1. Factor 1: Antenna configuration with 2 levels (configuration 1, configuration2)
2. Factor 2: Distance with 3 levels (5 ft, 15 ft, 25 ft)
3. Factor 3: Position of the device with 3 levels (pocket, arm and waist)

B. Response Variables

1. Read rate
2. Signal Strength

Run the experiment:

We employed a three full factorial design with r = 3 replications

The design layout was as follows:

3 Factor Complete Factorial Experiment Layout with 3 Replications

Factor 1 = Antenna Configuration – Two levels: Configuration 1 = 1, Configuration 2 = 2
Factor 2 = Distance – Three levels: 5ft = 1, 15ft = 2, 25ft = 3
Factor 3 = Tag Location – Three levels: Pocket = 1, Armband = 2, Waist = 3

Table 3-4: Experiment 1 Coded Layout

N	Factor 1	Factor 2	Factor 3
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	1	1	1
20	1	1	2
21	1	1	3
22	1	2	1
23	1	2	2
24	1	2	3
25	1	3	1
26	1	3	2
27	1	3	3
28	2	1	1
29	2	1	2
30	2	1	3
31	2	2	1
32	2	2	2
33	2	2	3
34	2	3	1
35	2	3	2
36	2	3	3
37	1	1	1
38	1	1	2

39	1	1	3
40	1	2	1
41	1	2	2
42	1	2	3
43	1	3	1
44	1	3	2
45	1	3	3
46	2	1	1
47	2	1	2
48	2	1	3
49	2	2	1
50	2	2	2
51	2	2	3
52	2	3	1
53	2	3	2
54	2	3	3

Randomization of the experiment was performed using Minitab. The randomized data collection table is provided in the Appendices.

The linear model formulation is as follows:

$$Y_{ijkt} = \mu_{\dots} + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijkt}$$

for i = 1,…, a, j=1, …., b, k=1, …., c, and t=1, ….., r.

Where ε_{ijkt} are iid N(0,σ^2), and “Z” is the number of response variables.

Y_{ijkt} = t-th response observed for trt (i,j,k).

$\mu_{\dots}$ = is the overall mean.

α_i = is the effect on the response due to the fact that ith level of factor 1.

β_j = is the effect on the response due to the fact that jth level of factor 2.

γ_k = is the effect on the response due to the fact that kth level of factor 3.

$(\alpha\beta)_{ij}$ = is the interaction effect in ith and jth of factors 1 and 2.

$(\alpha\gamma)_{ik}$ = is the interaction effect in the ith and kth of factors 1 and 3.

$(\beta\gamma)_{jk}$ = is the interaction effect in the jth and kth of factors 2 and 3.

$(\alpha\beta\gamma)_{ijk}$ = is the interaction effect in ith, jth and kth of factors 1, 2 and 3.

Statistical Analysis:

The statistical analysis was conducted using Minitab.

Results and Conclusions:

The results and conclusion of this experiment is talked about in chapter 4 and 5.

Experiment Procedure: 2

Problem Definition:

For experiment 2, we tested the outside noise level at two sites of the FAA technician and where the proposed system will be installed. We wanted to investigate the dB noise level because we wanted to know at what level is acceptable for the person carrying the device should be so that they may hear it effectively.

Model Definition:

II. Experiment 2: Environment Noise Level

A. Factors

1. Factor 1: Site with 2 levels (site 1, site 2)
2. Factor 2: Days with 7 levels (Mon, Tue, Wed, Thurs, Fri, Sat, Sun)

B. Response Variable

1. dB level

Run the experiment:

We employed a two full factorial design with r = 2 replications

The design layout is below:

2 Factor Complete Factorial Experiment Layout with 2 Replications

Factor 1 = Sites - two levels - Site 1 = 1, Site 2 = 2
Factor 2 = Days - seven levels – Mon = 1, Tue = 2, Wed = 3, Thur = 4, Fri = 5, Sat = 6, Sun = 7

Table 3-5: Experiment 2 Coded Layout

N	Factor 1	Factor 2
1	1	1
2	1	2
3	1	3
4	1	4
5	1	5
6	1	6
7	1	7
8	2	1
9	2	2
10	2	3
11	2	4
12	2	5
13	2	6
14	2	7
15	1	1
16	1	2
17	1	3
18	1	4
19	1	5
20	1	6
21	1	7
22	2	1
23	2	2
24	2	3
25	2	4
26	2	5
27	2	6
28	2	7

Randomization of the experiment was performed using Minitab. The randomized data collection table is provided in the Appendices.

The linear model formulation is as follows:

$$Y_{ijt} = \mu_{..} + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijt}$$

for i = 1,…, a, j=1, …., b, k=1, …., c, and t=1, ….., r.

Where ε_{ijt} are iid N(0,σ^2),

Y_{ijt} = t-th response observed for trt (i,j).

$\mu_{..}$ = is the overall mean.

α_i = is the effect on the response due to the ith level of factor 1.

β_j = is the effect on the response due to the jth level of factor 2.

$(\alpha\beta)_{ij}$ = is the interaction effect in ith and jth of factors 1 and 2.

Statistical Analysis:

The statistical analysis was conducted using SAS and Minitab.

Results and Conclusions:

The results and conclusion of this experiment is talked about in chapter 4 and 5.

Task 12 – Perform an operational demonstration with selected personnel and use feedback for updates.

This task is now a future task once we are able to win a grant and get approved through the proper channels to carry this research full-scale and apply it at an airport.

Task 13 – Redefine prototype and the improve design to develop the final product.

This task is now a future task once we are able to win a grant and get approved through the proper channels to carry this research full-scale and apply it at an airport.

Research Objective 3: Perform economic analysis and evaluate the financial impacts with other solutions. Evaluate the impacts of different automated technologies. Determine the best automated technology to use. Determine legal aspect of runway incursion in terms of liability.

Task 14 – Calculate NPV for Runway Incursion Prevention System and other solutions.

Though the main concern of this dissertation was to investigate our runway incursion prevention system, this task had us to look into the cost and net present value (NPV) of employing such a system. Furthermore, we wanted to investigate other solutions that would achieve the similar goals as our system. Moreover, we wanted to see the cost of these other solutions and compare them to our system cost to confirm the economic viability of choosing such a solution.

Task 15 – Investigate various case law surrounding serious runway incursion incidents.

For this task, we researched various books and journals to see what the outcome in terms of liability was when a serious accident took place.

The ***overall objective of this research*** is to investigate a framework that leverages a RFID integrated with Zigbee location system (RTLS) & human causal factors, data analytics & legal repository of information surrounding a runway incursion incident, and employee training & a decision support system. In the first stage of the framework, we want to define and correlate the human causal elements and investigate what role they play on runway incursion rates. Also in the first stage of the framework, we will develop a working prototype that can reside on a device and provide audible, visual, and vibrating alerts to the employee that alerts them of their location when they are approaching a hazardous zone or are in one. In the second stage of the framework, we want to provide data analytics and legal information repository surrounding the issue of runway incursions in terms of liability when a severe incursion takes place. We ***hypothesize*** that there is a statistically significant relationship between human causal elements and runway incursions rates. We also ***hypothesize*** that the prototype is capable of alerting FAA technicians when they enter into protected areas that require authorization that present safety and security hazards in a reliable way.

3.4 Equipment and Location

The equipment and software used for our experiment was as follows:

- Xerafy RFID tag
- Impinj Speedway Revolution UHF Reader
- 2 Alien AFR 8696 – C Antennas
- Impinj computer software
- dB Volume Meter App

- ANOVA in Minitab and SAS

The location for our experiments was the University of Texas at Arlington RAID labs and the Dallas/Fort Worth Airport on the airport operation area. Data analysis for the experiments occurred at the University of Texas at Arlington using Minitab and SAS.

Chapter 4

Results

This chapter discusses the results obtained from the analysis performed on the data from the research objectives using excel, SAS, and Minitab.

4.1 Research Question 1 Results

Research Objective #1: Evaluate human causal elements that contribute to runway incursions on the Air Operations Area at an airport.

From our 1st task, we wanted to evaluate the runway incursion data for all of the regions in the U.S. by incident type. For this, we used a chi-square test of independence to see if our runway incursion incidents are dependent or independent of region. The observed data is in table 4-1 and the expected data is in table 4-2 below.

Table 4-1: Observed Incursion Incident vs Region

FY	AAL	ACE	AEA	AGL	ANE	ANM	ASO	ASW	AWP	Total

2014 -2015	Alaska	Central	Eastern	Great Lakes	New England	Northwest Mountain	Southern	Southwest	Western Pacific	
OI	16	15	113	80	24	46	103	51	131	579
PD	64	30	137	183	33	146	315	237	500	1645
V/PD	30	10	52	66	9	43	69	85	122	486
Total	110	55	302	329	66	235	487	373	753	2710

Table 4-2: Expected Incursion Incident vs Region

FY 2014 -2015	AAL Alaska	ACE Central	AEA Eastern	AGL Great Lakes	ANE New England	ANM Northwest Mountain	ASO Southern	ASW Southwest	AWP Western Pacific	Total
OI	23	12	65	80	14	50	104	80	161	579
PD	67	33	183	183	40	143	296	226	457	1645
V/PD	20	10	52	54	12	42	87	67	135	486
Total	110	55	302	329	66	235	487	373	753	2710

H_o: Incident type and Region are independent

H_a: Incident type and Region are not independent

Chi-Sq = 101.902, DF = 16, **P-Value = 0.000**

Conclusion: Reject the null hypothesis and conclude that there is a relationship between incident type and region.

Since we have a p-value of practically zero and a high chi-square statistic, it is safe to say that runway incursion incidents are dependent on the region. This conclusion was somewhat intuitive, however, we proved our assumption by performing the Chi-square test. Subsequently, incidents are dependent on a specific region. Next, we chose the ASO Southern region, airports in Texas, in particular, to further evaluate our research question. Of the 117 airports in Texas, we looked at the top 5 airports that accounted for 51% of the total runway incursion rates for the state of Texas. Based on the statistics from the FAA Runway Safety Office, the top 5 airports were Dallas/Fort Worth (DFW), Dallas Love Field (DAL), George Bush Intercontinental (IAH), David Wayne Hooks Memorial (DWH), and Hobby Airport (HOU). For this, we used a chi-square test of independence to see if our runway incursion incidents are dependent or independent of the airport. The observed data is in table 4-3 and the expected data is in table 4-4 below.

Table 4-3: Observed Incursion Incident vs. TX Airport

FY 2014-2015	Dallas/Fort Worth DFW	Dallas Love Field DAL	George Bush Intercontinental IAH	David Wayne Hooks Memorial DWH	Hobby Airport HOU	Total
OI	19	0	11	2	3	35
PD	15	26	6	38	14	99
V/PD	8	7	3	17	5	40
Total	42	33	20	57	22	174

Table 4-4: Expected Incursion Incident vs. TX Airport

FY 2014-2015	Dallas/Fort Worth	Dallas Love Field	George Bush Intercontinental	David Wayne Hooks Memorial	Hobby Airport	Total

	DFW	DAL	IAH	DWH	HOU	
OI	8	7	4	12	4	35
PD	24	19	11	32	13	99
V/PD	10	7	5	13	5	40
Total	42	33	20	57	22	174

H_o: Incident type and Airports are independent

H_a: Incident type and Airports are not independent

Chi-Sq = 52.001, DF = 8, **P-Value = 0.000**

2 cells with expected count less than 5.

Conclusion: Reject the null hypothesis and conclude that there is an association between incident type and airports.

Since we have a p-value of practically zero, it is safe to say that runway incursion incidents are dependent on the particular airport as well. Again, this conclusion was somewhat intuitive based on our previous determination of location by region, however, we statistically proved our assumption by performing the Chi-square test. Subsequently, incidents are dependent on a specific region. Again, since we are located in Texas, and we know statistically that incursion incidents are dependent on the airport, we further investigated our research question using these top 5 airports in Texas. Table 4-5 describes the distribution of incursion incidents that were attributed to these top human causal elements for these 5 airports. Our data was analyzed using a complete block design with airports as the blocking factor.

Table 4-5: Runway Incursion Events Contributed to Human Causal Element per Airport

Airport 2014-2015	Distraction	Workload	Situational Awareness	Miscommunication	Confusion
DFW	5	27	36	10	12
DAL	3	10	19	6	5
IAH	3	16	29	9	9
DWH	1	1	4	2	1
HOU	1	2	8	1	3

Table 4-6: Descriptive Statistics for Human Causal Elements

Human Causal Element	N	Mean Rates	Standard Deviation Rate
Distraction = 1	5	2.6	1.6733201
Workload = 2	5	11.2	10.7563934
Situational Awareness = 3	5	19.2	13.5535973
Miscommunication = 4	5	5.6	4.0373258
Confusion = 5	5	6	4.4721360

Table 4-7: Factor Information for Complete Block Design

Factor	Levels	Values
Human Causal Element (HCE)	5	1, 2, 3, 4, 5
Airport	5	1, 2, 3, 4, 5

Table 4-8: ANOVA Results for Complete Block Design Model

Source	DF	SS	MS	F-Value	p-Value
Model	8	1784.880000	223.110000	8.48	0.0002
Error	16	420.960000	26.310000		
Corrected Total	24	2205.840000			

Table 4-9: ANOVA Results Type I SS

Source	DF	Type I SS	MS	F-Value	p-Value
Human Causal Element (HCE)	4	851.8400000	212.9600000	8.09	0.0009
Airport	4	933.0400000	233.2600000	8.87	0.0006

Table 4-10: ANOVA Results Type III SS

Source	DF	Type III SS	MS	F-Value	p-Value
Human Causal Element (HCE)	4	851.8400000	212.9600000	8.09	0.0009
Airport	4	933.0400000	233.2600000	8.87	0.0006

Based on our ANOVA results, we have a calculated F-value ratio of 8.09. Since our table value of $F_{4,16}$ is 5.85, we would reject the null hypothesis and conclude that at least two of the treatments, human causal elements, differ and have a different effect on the response, incursion incident rate. Furthermore, we can support our findings by examining our p-value. Since we have a p – value of 0.0009, we can also reject the null since our level of significance of 0.05 is larger.

Table 4-11: Model Summary

R-Square	Coefficient of Variation	Root MSE	Rates Mean
80.91%	57.50367	5.129327	8.92000

Also, examining good our r-square we can see that our data fits our model respectable well.

Figure 4-1 show the box plot of the distribution of runway incursion rates by each human causal element. Again, distraction =1, workload = 2, situational awareness = 3, miscommunication = 4, and confusion = 5. The box plot shows the mean and the quartiles for each human causal element. We see that the means for the incursion rates due to situational awareness and workload is very different from the other human causal elements.

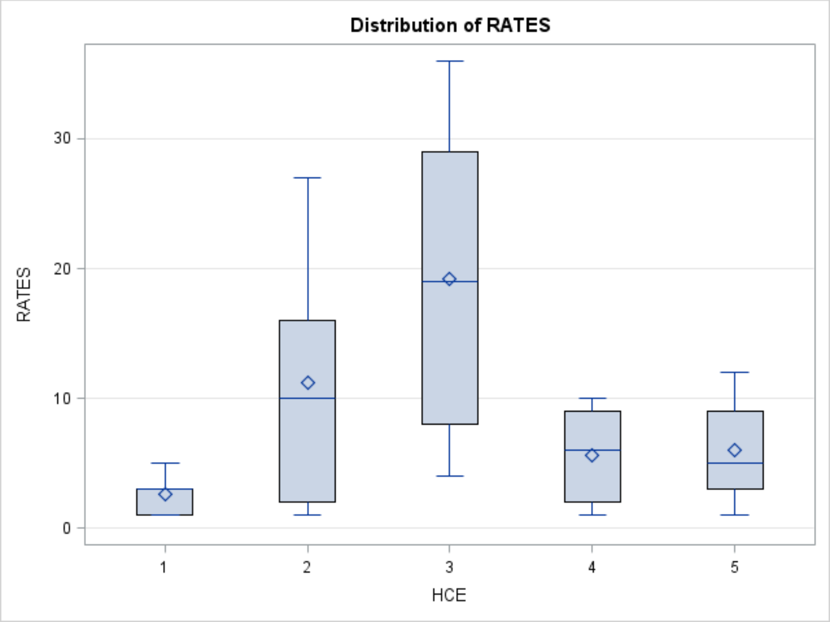


Figure 4-1: Box Plot Distribution of Runway Incursion Rates by Human Causal Element

Table 4-12: Least Squares Means Adjustment for Multiple Comparisons: Tukey

Human Causal Elements	Rates LS Mean	LS Mean Number
Distraction = 1	2.6	1
Workload = 2	11.2	2
Situational Awareness = 3	19.2	3
Miscommunication = 4	5.6	4
Confusion = 5	6	5

Table 4-13: Least Square Means for Effect Human Causal Elements

i/j	1	2	3	4	5
1		0.1073	0.0008	0.8832	0.8295
2	0.1073		0.1481	0.4466	0.5164
3	0.0008	0.1481		0.0054	0.0069
4	0.8832	0.4466	0.0054		0.9999
5	0.8295	0.5164	0.0069	0.9999	

Note* LS Mean (i) = LS Mean (j), and dependent variable is Rates

Table 4-14: LS Mean with 95% Confident Limits

Human Causal Elements	Rates LS Mean	95% Confidence Limits
Distraction = 1	2.600000	(-2.262861, 7.462861)
Workload = 2	11.200000	**(6.337139, 16.062861)**
Situational Awareness = 3	19.200000	**(14.337139, 24.062861)**
Miscommunication = 4	5.600000	**(0.737139, 10.462861)**
Confusion = 5	6.000000	**(1.137139, 10.862861)**

Table 4-15: Tukey's Simultaneous 95% Confidence Limits

i	j	Difference Between Means	Simultaneous 95% Confidence Limits for LS Mean (i) – LS Mean (j)
1	2	-8.6	(-18.538775, 1.338775)
1	3	-16.6	(-26.538775, -6.661225)
1	4	-3.0	**(-12.938775, -12.938775)**
1	5	-3.4	**(-13.338775, -13.338775)**
2	3	-8.0	(-17.938775, 1.938775)
2	4	5.6	(-4.338775, 15.538775)
2	5	5.2	(-4.738775, 15.138775)
3	4	13.6	**(3.661225, 23.538775)**
3	5	13.2	**(3.261225, 23.138775)**
4	5	-0.4	(-10.338775, 9.538775)

After examination of the Tukey’s simultaneous 95% confidence limits, we see that pairs 1 and 4, 1 and 5, 3 and 4, 3 and 5 do not contain zero in their confidence interval. This means that these pairs have statistically different means. The other pairs are considered similar. Furthermore, since all observations follow the same pattern in figure 4-2, it confirms our initial assumption that there is no interaction between the block and the treatments. The interaction plots for rates is below in figure 4-2.

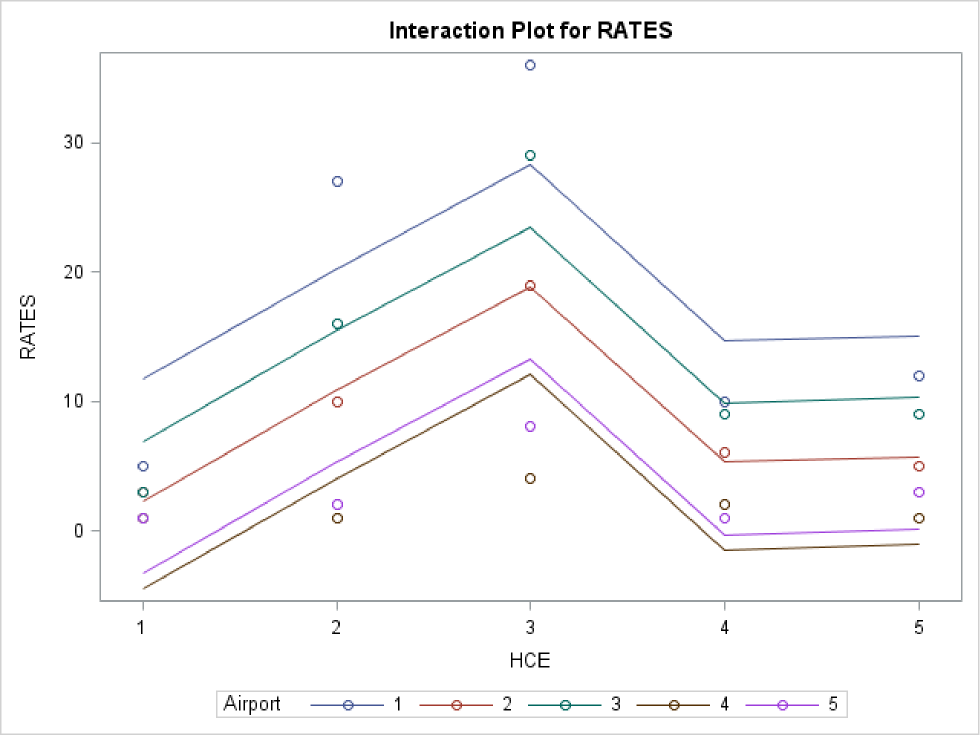


Figure 4-2: Interaction Plot for Human Causal Elements and Airports

4.2 Research Question 2 Results

Research Objective #2: Develop runway incursion detection module and perform an operational demonstration with selected personnel. Determine system architecture configuration for maximum reliability.

Experiment 1: System Reliability

Because of budget limitations and airport regulations of installing actual equipment on AOA, tests were done based on reliability testing of the device in terms of read rate and signal strength.

Table 4-16: Experiment 1 Output Table with Decoded Factors and Responses

Factor 1 Antenna Configuration	**Factor 2** Distance (ft)	**Factor 3** Tag Location	**Response 1** Signal Strength (dBm)	**Response 2** Read Rate (Reads/sec)
Configuration 1	5	Pocket	-62	2.5
Configuration 1	5	Armband	-57	2.2
Configuration 1	5	Waist	-58	1.3
Configuration 1	15	Pocket	-63	2.8
Configuration 1	15	Armband	-60	3.1
Configuration 1	15	Waist	-65	3.2
Configuration 1	25	Pocket	-67	2.6
Configuration 1	25	Armband	-64	2.9
Configuration 1	25	Waist	-68	2.1
Configuration 2	5	Pocket	-59	3.3
Configuration 2	5	Armband	-57	3.2
Configuration 2	5	Waist	-58	1.5
Configuration 2	15	Pocket	-61	2.0
Configuration 2	15	Armband	-60	2.7
Configuration 2	15	Waist	-63	2.2
Configuration 2	25	Pocket	-65	1.3
Configuration 2	25	Armband	-62	1.5
Configuration 2	25	Waist	-63	0.9
Configuration 1	5	Pocket	-60	2.6
Configuration 1	5	Armband	-55	2.1
Configuration 1	5	Waist	-59	1.7
Configuration 1	15	Pocket	-62	2.4
Configuration 1	15	Armband	-61	3.0
Configuration 1	15	Waist	-68	2.9
Configuration 1	25	Pocket	-66	2.3
Configuration 1	25	Armband	-63	2.8
Configuration 1	25	Waist	-69	2.0
Configuration 2	5	Pocket	-57	3.0
Configuration 2	5	Armband	-55	3.6
Configuration 2	5	Waist	-59	2.0
Configuration 2	15	Pocket	-60	2.1
Configuration 2	15	Armband	-62	2.9
Configuration 2	15	Waist	-65	2.3
Configuration 2	25	Pocket	-66	1.5
Configuration 2	25	Armband	-61	1.9
Configuration 2	25	Waist	-65	1.3
Configuration 1	5	Pocket	-63	2.7
Configuration 1	5	Armband	-58	2.9
Configuration 1	5	Waist	-59	1.8
Configuration 1	15	Pocket	-64	2.9
Configuration 1	15	Armband	-59	3.0
Configuration 1	15	Waist	-66	2.0
Configuration 1	25	Pocket	-67	2.4

Configuration 1	25	Armband	-63	2.8
Configuration 1	25	Waist	-69	1.3
Configuration 2	5	Pocket	-57	3.6
Configuration 2	5	Armband	-55	3.7
Configuration 2	5	Waist	-56	2.3
Configuration 2	15	Pocket	-60	2.4
Configuration 2	15	Armband	-59	2.7
Configuration 2	15	Waist	-62	2.2
Configuration 2	25	Pocket	-64	1.7
Configuration 2	25	Armband	-61	1.9
Configuration 2	25	Waist	-64	1.2

Table 4-17: Factor Information with Levels for Experiment 1

Factor	Type	Levels	Values
Antenna Configuration (Ant Conf)	Fixed	2	1, 2
Distance	Fixed	3	1, 2, 3
Device Position (Dev Pos)	Fixed	3	1, 2, 3

Table 4-18: ANOVA Results for Full Model RSSI vs Antenna Configuration, Distance, and Device Position

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
Ant Conf	1	64.463	64.463	64.463	51.19	0.000
Distance	2	428.037	428.037	214.019	169.96	0.000
Dev Pos	2	127.148	127.148	63.574	50.49	0.000
Ant Conf*Distance	**2**	**2.481**	**2.481**	**1.241**	**0.99**	**0.383**
Ant Conf*Dev Pos	2	11.370	11.370	5.685	4.51	0.018
Distance*Dev Conf	4	34.963	34.963	8.741	6.94	0.000
Ant Conf*Dist*Dev Pos	4	15.852	15.852	3.963	3.15	0.026
Error	36	45.333	45.333	1.259		
Total	53	729.648				

Based on our results we see that all of our main effects are significant. However, we have the interaction effect of antenna configuration and distance that is not significant. In this case, this term would be dropped from the model and we would re-run our linear model.

Table 4-19: Model Summary

S	R-Square	Adjusted R-Square
1.12217	93.79%	90.85%

Table 4-19 identifies our R-square for the model. Since we have a very high R-square, its means that our model defines our data very well, meaning that our factors explain 93.79% variation in the response. The standard error is used to describe how well the model describes the response. The lower our standard error, the better our model describes our response. Our model has a standard error of 1.12, which is particularly low. However, just because we have a low standard error does not mean that our model has not violated any assumptions. We must still check the four assumptions of the linear model which are:

1.) The residuals are normally distributed
2.) The residuals are independent
3.) The residuals have a mean of zero
4.) The residuals have constant variance

Figure 4-3 is our normal probability chart. Our normal probability chart verifies our assumption that our residuals are normally distributed. The plot of the residuals should approximately follow a straight line. Based on our results, we may have a few outliers, however, the residuals appears to follow the straight line leading us to believe that the normality of the residual assumption is not violated.

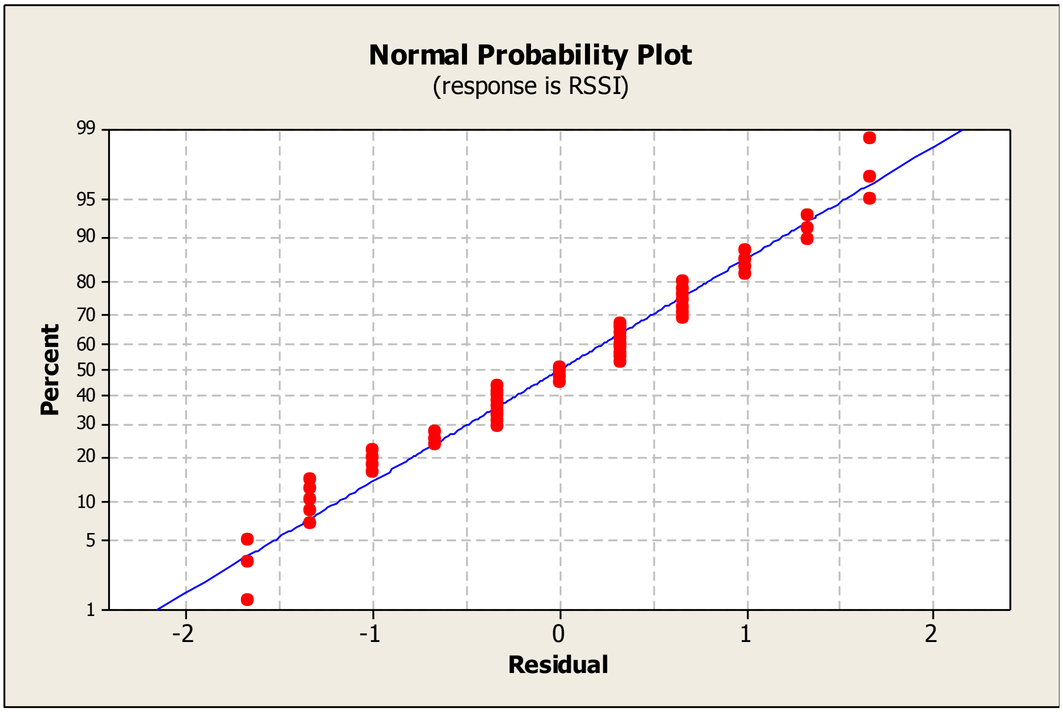


Figure 4-3: Normal Probability Plot (RSSI)

Figure 4-4 is a graph of our fitted values versus our residuals. This plot verifies our assumption of having constant variance of our residuals and that our residuals are randomly distributed. From our figure 4-4, it appears that our residuals are randomly distributed, hence we have not violated our constant variance assumption.

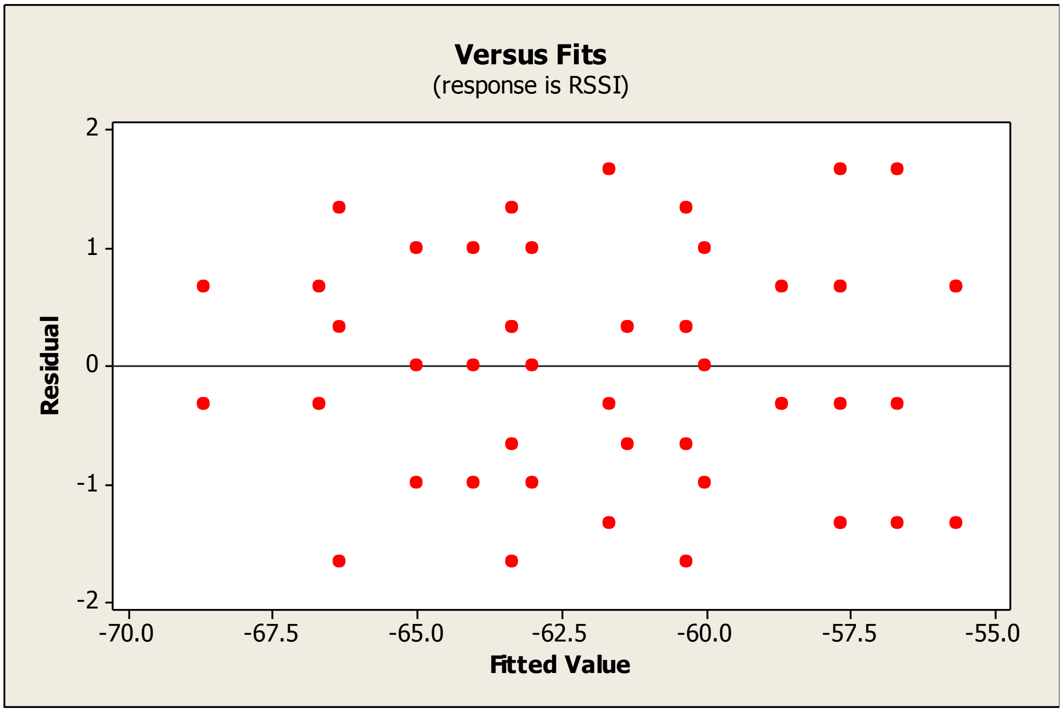


Figure 4-4: Fitted Value vs Residuals Plot (RSSI)

Figure 4-5 displays our observation order versus our residual plot. The purpose of this plot is to verify the assumption that our residuals are independent of one another. If our residuals are independent, then this plot will show no trend in the data points when plotted by time order. Based on our observation order vs residual plot, it shows some random jaggedness which indicates the residuals are independent, thus the assumption is not violated.

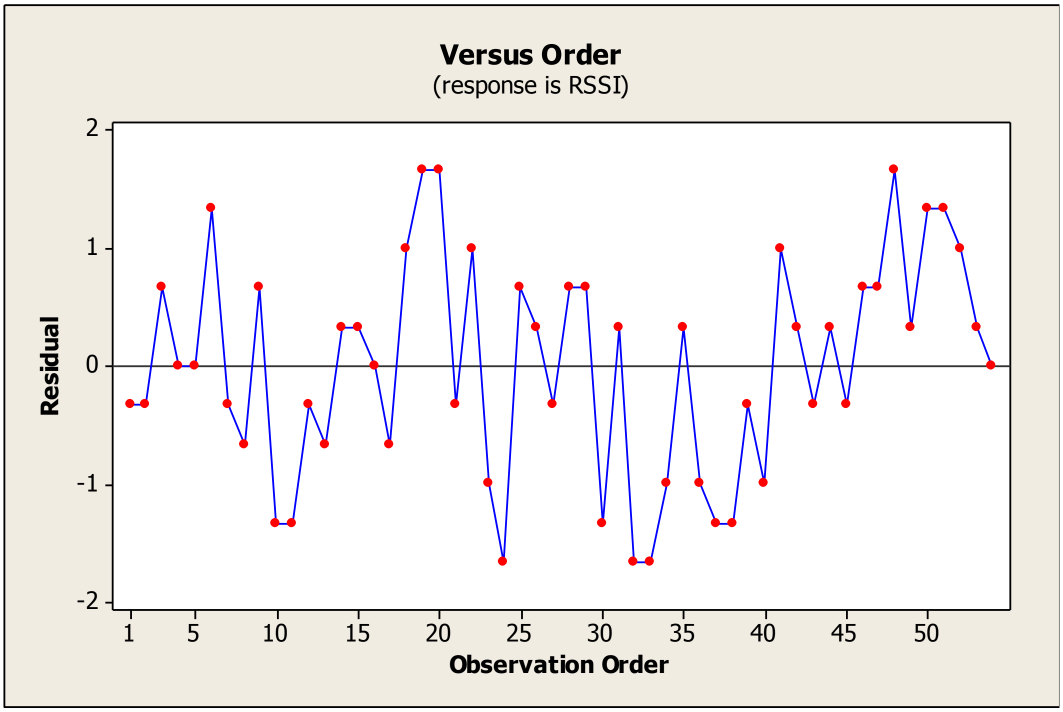


Figure 4-5: Observation Order vs Residual Plot (RSSI)

Figure 4-6 shows the data means for the main effects for the model for each level tested.

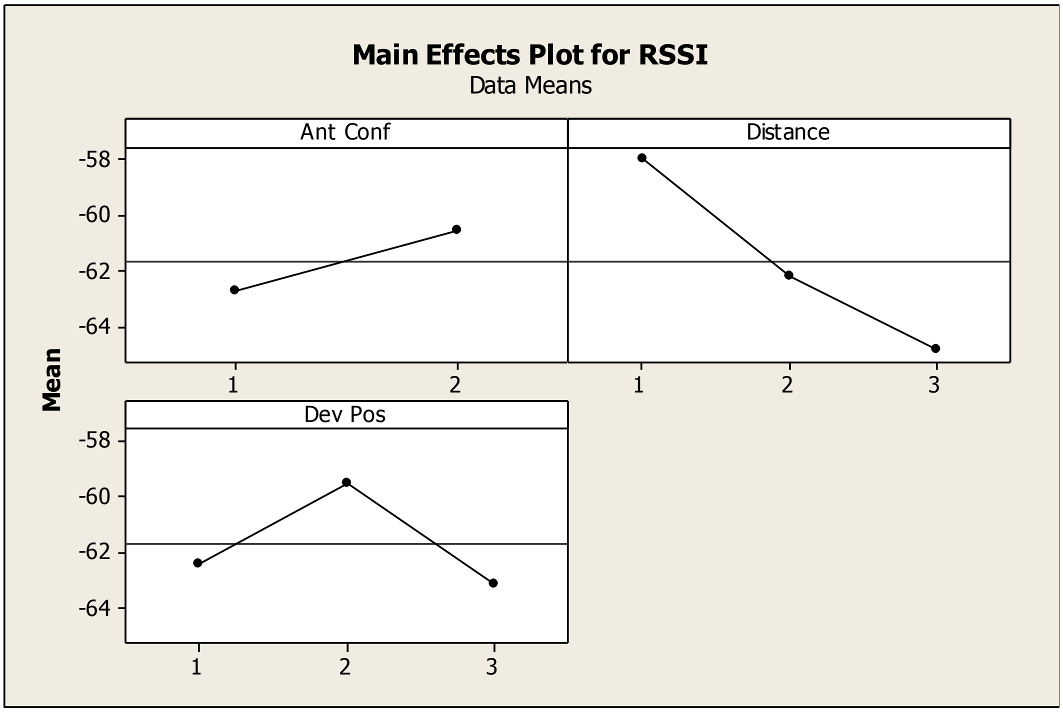


Figure 4-6: Main Effects Plot for RSSI

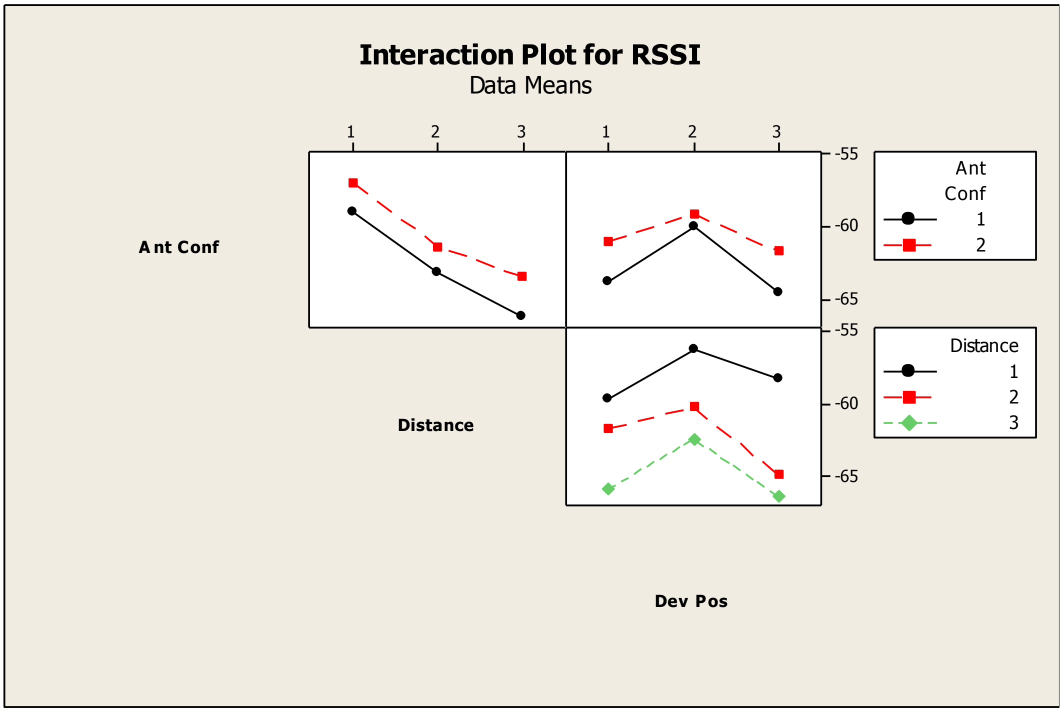


Figure 4-7: Interaction Plot for RSSI

Table 4-20: ANOVA Results for Full Model Read Rate vs Antenna Configuration, Distance, and Device Position

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
Ant Conf	1	0.5400	0.5400	0.5400	6.61	0.014
Distance	2	5.3511	5.3511	2.6756	32.76	0.000
Dev Pos	2	6.2433	6.2433	3.1217	38.22	0.000
Ant Conf*Distance	2	6.0933	6.0933	3.0467	37.31	0.000
Ant Conf*Dev Pos	**2**	**0.1011**	**0.1011**	**0.0506**	**0.62**	**0.544**
Distance*Dev Conf	4	2.2822	2.2822	0.5706	6.99	0.000
Ant Conf*Dist*Dev Pos	**4**	**0.5222**	**0.5222**	**0.1306**	**1.60**	**0.196**
Error	36	2.9400	2.9400	0.0817		
Total	53	24.0733	24.0733			

Again, based on our results from our ANOVA, we see that all of our main effects are significant. However, the interaction effect between antenna configuration and device position is not significant. Also, the interaction effect between antenna configuration, distance, and device position is not significant. Henceforth, these terms can be dropped from the model and we can re-run our ANONA.

Table 4-21: Model Summary

S	R-Square	R-Square Adjusted
0.285774	87.79%	82.02%

Table 4-21 identifies our standard error, R-square, and adjusted R-Square for the model. Since we have a very high R-square, its means that our model defines our data very well, meaning that our factors explain 87.79% variation in the response of read rate. The standard error is used to describe how well the model describes the response. The lower our standard error, the better our model describes our response. Our model has a standard error of 0.285774, which is extremely low. However, just because we have a low standard error does not mean that our model has not violated any assumptions. We must still check the four assumptions of the linear model which are:

1.) The residuals are normally distributed
2.) The residuals are independent
3.) The residuals have a mean of zero
4.) The residuals have constant variance

Figure 4-8 below is our normal probability plot for read rate residuals. Based on our results, we see that we may have a few outliers. Our pattern may indicate that we have a nonnormality issue. To verify this we would need to conduct a normality test. If our normality assumption is violated, then our results from our model may not be reliable.

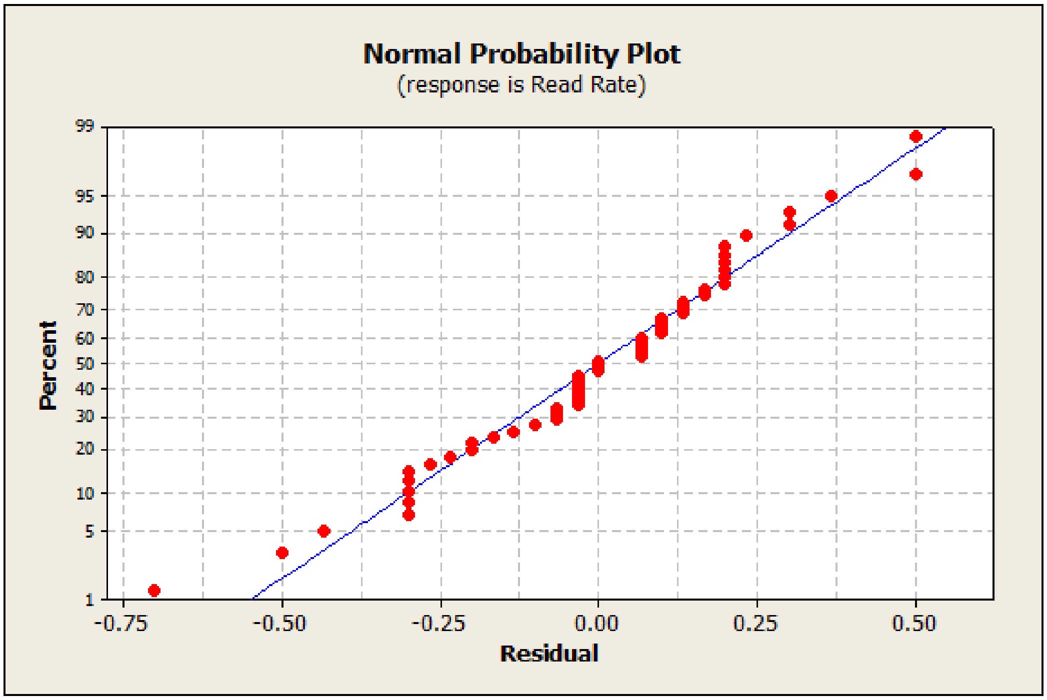


Figure 4-8: Normal Probability Plot (Read Rate)

Figure 4-9 is a plot of our fitted value versus our read rate. Again, this plot checks our assumption of constant variance in the residuals and that the residuals are randomly distributed. Based on our results, this assumption does not appear to be violated.

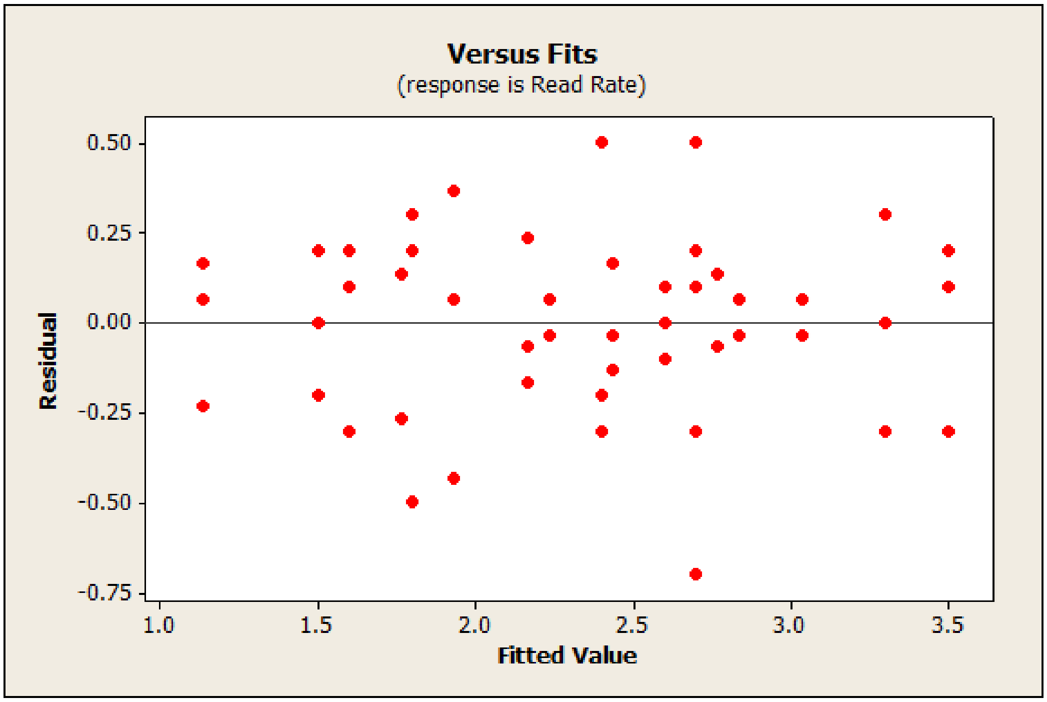


Figure 4-9: Fitted Value vs Residuals (Read Rate)

Figure 4-10 plots the observation order versus the residual. Again, this plot checks our assumption of the independence of the residuals by plotting them in time order. When this is done, there should be no trend in the data. Based on our results, it appears that this assumption has not been violated.

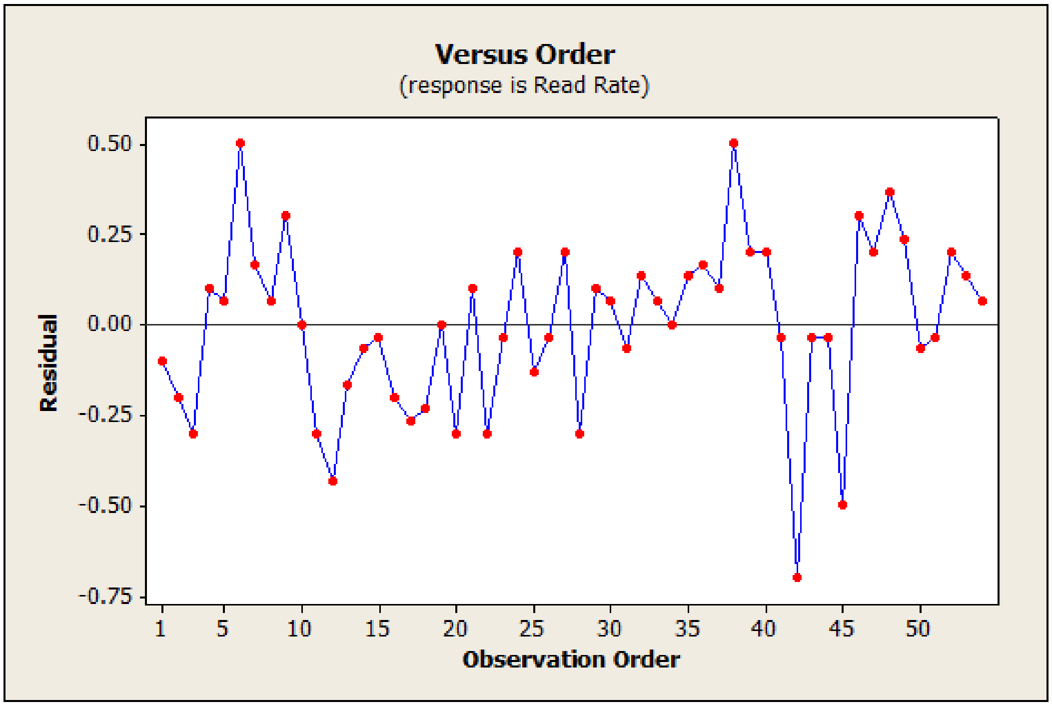


Figure 4-10: Observation Order vs Residual (Read Rate)

Figure 4-11 plots the data means of the main effects for read rate.

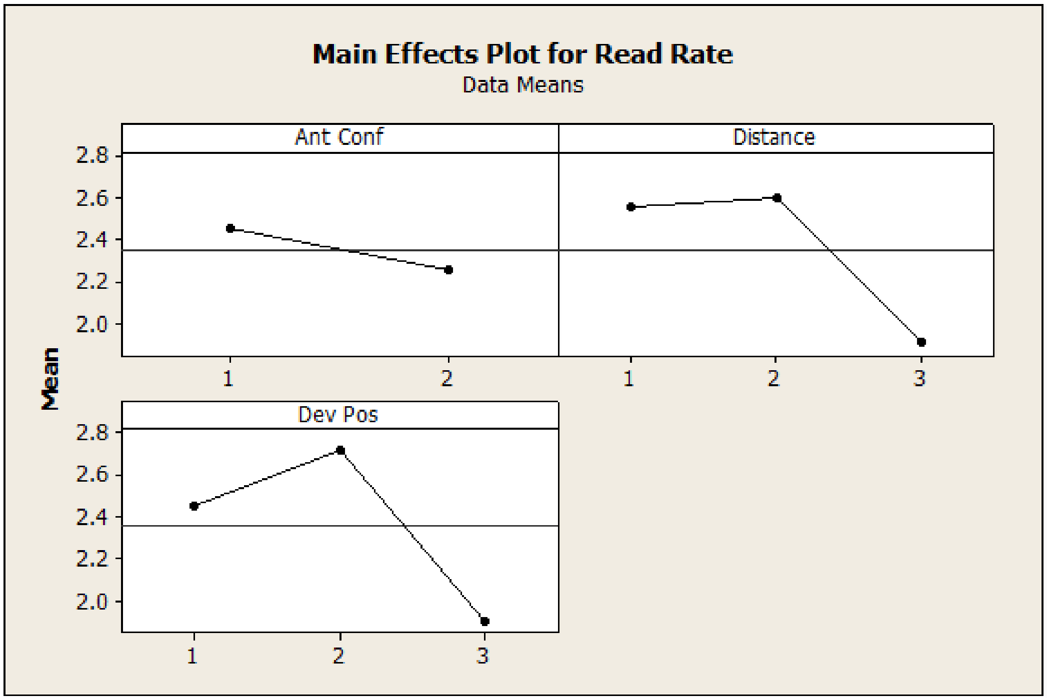


Figure 4-11: Main Effect Plot for Read Rate

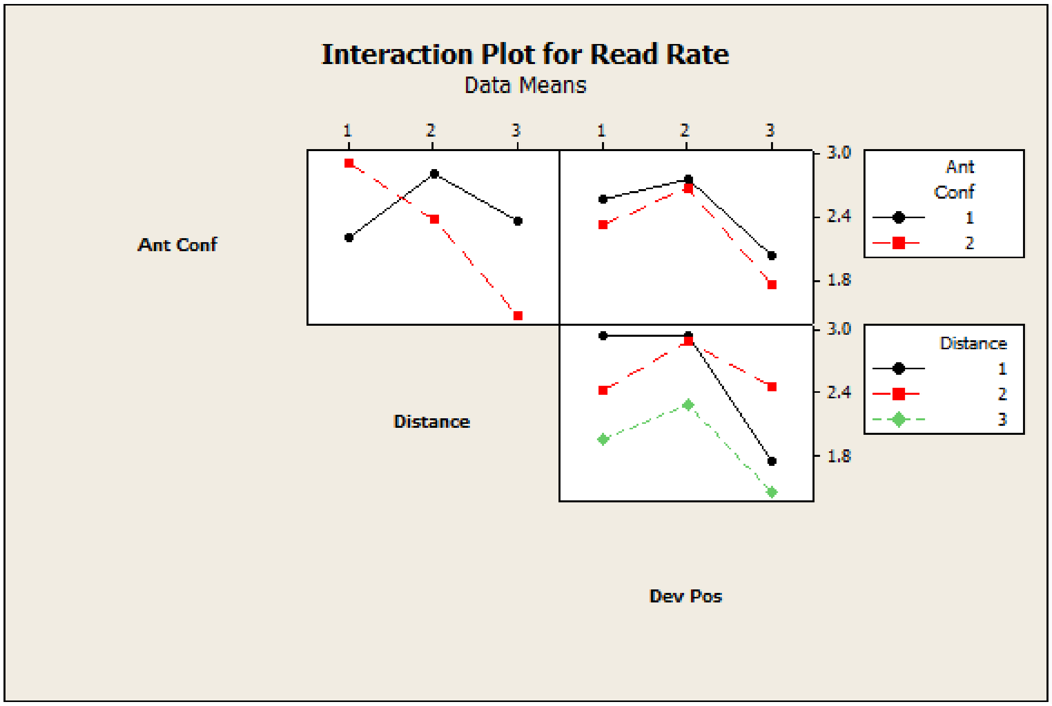


Figure 4-12: Interaction Plot for Read Rate

Experiment 2: Environment Noise levels

Table 4-22: Experiment 2 Output Table with decoded Factors and Response

Factor 1 Site	**Factor 2** Day	**Response Average** (dB)
Site 1	Monday	57.6
Site 1	Tuesday	53.4
Site 1	Wednesday	55.4
Site 1	Thursday	52.9
Site 1	Friday	54.3
Site 1	Saturday	56.6
Site 1	Sunday	52.3
Site 2	Monday	61.2
Site 2	Tuesday	58.3
Site 2	Wednesday	54.3
Site 2	Thursday	55.9
Site 2	Friday	53.9
Site 2	Saturday	58.7

Site 2	Sunday	60.2
Site 1	Monday	53.4
Site 1	Tuesday	54.9
Site 1	Wednesday	52.6
Site 1	Thursday	56.2
Site 1	Friday	55.3
Site 1	Saturday	56.9
Site 1	Sunday	53.2
Site 2	Monday	56.8
Site 2	Tuesday	59.3
Site 2	Wednesday	61.3
Site 2	Thursday	58.9
Site 2	Friday	57.6
Site 2	Saturday	57.9
Site 2	Sunday	59.4

Source	DF	SS	MS	F-Value	P-Value
Model	13	124.2560714	9.5581593	2.00	**0.1059**
Error	14	66.9250000	4.7803571		
Corrected Total	27	191.1810714			

Based on our ANOVA table, we see that our overall model is not significant.

R-Sqaure	Coeff Var	Root MSE	Y Mean
0.649999	3.877828	2.186403	56.38214

Also, are r-square is telling us that our data does not fit the model very well and that the factors only explain about 65% of the variation in the response.

Source	DF	Type I SS	MS	F-Value	P-Value
Site	1	84.70321429	84.70321429	17.72	0.0009
Days	6	14.81357143	2.46892857	0.52	0.7865
Site*Days	6	24.73928571	4.12321429	0.86	0.5451

Source	DF	Type III SS	MS	F-Value	P-Value
Site	1	84.70321429	84.70321429	17.72	0.0009
Days	6	14.81357143	2.46892857	0.52	0.7865
Site*Days	6	24.73928571	4.12321429	0.86	0.5451

Upon further review, we see that our factor of site is significant. We can drop the model of our variables for days and the interaction between site and days and re-run the model with just the factor of site. Then we can determine what effect of site does to the environment noise level.

4.3 Research Objective 3 Results

Research Objective #3: Perform economic analysis and evaluate the financial impacts with other solutions. Research and analyze various case law surrounding liability of airport for negligence or unsafe airport conditions related to accidents

The results of performing the economic analysis started by first examining the cost of procuring the equipment needed to implement the technology. A summary tables of the cost of the three scenarios are provided in the tables below.

Scenario 1: RFID Cost

Equipment	Cost	Quantity	Total
Xerafy Bric RFID Tag	$29	4	$116
Impinj Speedway Revolution UHF RFID Reader	$2,385	2	$4,770
Alien AFR 8696-C RFID Antenna	$186	4	$744
Impinj Software	$480	1	$480
Host Computer	$1,600	1	$1,600
Implementation Cost	$31,680	3 months	$31,680
Hotspot site	$39,390	1 Site	$39,390
Total		3 Sites	$118,170

Scenario 2: RFID with ZigBee Cost

Equipment	Cost	Quantity	Total
Xerafy Bric RFID Tag	$29	4	$116
Impinj Speedway Revolution UHF RFID Reader	$2,385	2	$4770
Alien AFR 8696-C RFID Antenna	$186	4	$744
Impinj Software	$480	1	$480
Host Computer	$1,600	1	$1600
2.4 GHz ZigBee Development Kit	$900	1	$900

Implementation Cost	$31,680	3 months	$31,680
Hotspot site	$40,290	1 Sites	$40,290
Total		3 Sites	$120,870

Scenario 3: GPS Cost

Equipment	Cost	Quantity	Total
Personnel Tracking Unit Battery Powered GPS Tracker with charging station	$247	4	$988
Vehicle Tracking Unit 12-24v Powered GPS Tracker	$318	4	$1,272
RF Base 8 Channel Transceiver Unit with Ethernet (XML and RS-232)	$1,490	2	$2,980
vGateway Middleware Server	$2,496	2	$4,992
vMonitor Sofware	$3,800	1	$3,800
10.4 LCD Compact Display Unit with touchscreen	$600	4	$2,400
Data Repeater Unit	$140	2	$280
Implementation Cost	$31,680	3 months	$31,680
Hotspot site	$48,392	1 Sites	$48,392
Total		3 Sites	$145,176

We calculated the net present value with:

$$NPV = FV/(1+r)^n$$

We used a discount rate of 10% because that is the general discount rate used by companies. In order to simplify our calculation, we used a present worth calculation of the cash flow, or in our case, the negative cash flow each year from the yearly maintenance cost. Our cash flow consisted of the initial investment added to the yearly maintenance cost multiplied by our present worth factor with a discount rate of 10% and a five year project.

Decision Criteria	RFID	RFID & ZigBee	GPS
Net present value	**$452,700.06**	$464,672.00	$556,039.59

Chapter 5

Conclusions and Discussions

5.1 Conclusions

The overall research objective was to determine the influence of human causal elements, investigate the impact of automated technology that can be tested on a device to reduce runway incursions, perform some economic analysis on various automated technology solutions, and investigate some legal case law surrounding the topic of liability of an occurrence. The research questions were based on our overall of objective for the research. We investigated two research questions:

Is there a statistically significant relationship between human causal elements and runway incursions?

Can automated technologies platform be utilized to reduce the occurrence of a runway incursion?

We examined our research questions by investigating three research objectives and testing hypotheses based on our research questions. The three research questions and hypotheses we investigated were:

> ***Research Objective #1:*** Evaluate human causal elements that impact safety on the Air Operations Area.

Null Hypothesis

H_o: There is not a significant relationship between human causal elements and runway incursion rates.

Alternative Hypothesis

H_a: There is a significant relationship between human causal elements and runway incursion rates.

Decision Rule: Reject H_o if the p-value from the main effect is less than the 0.05 significance level.

Research Objective #2*: Determine system architecture configuration for maximum reliability. Develop a runway incursion detection module. Perform an operational demonstration with selected personnel and use feedback for updates.*

Null Hypothesis

H_o: Automated technology system is not reliable to reduce runway incursion incidents

Alternative Hypothesis

H_a: Automated technology system is reliable to reduce runway incursion incidents

Decision Rule: Reject H_o if main effects for linear model of statistical reliability show p-value less than the 0.05 significance level.

Research Objective #3*: Perform economic analysis and evaluate the financial impacts with other solutions. Determine best automated technology to use. Investigate legal aspect of runway incursion in terms of liability.*

Scenario 1 was the most cost effective, however scenario 2 will be better choice for maximum reliability. We also learned that Texas has abrogated sovereign immunity for airports which means that if a serious accident were to occur, airports in Texas would be liable for any damages or compensation for bodily injury or damage of property.

Our conclusions from our hypotheses test are below.

Test	H_0	F-Value	Test	Result
Human Causal Elements	There is not a significant difference between human causal elements on incursion rates	8.48	5.85	Reject H_0
Signal Strength		51.19	4.45	Reject H_0
	Automated technology system is not reliable to reduce runway incursion incidents	169.96	3.59	
		50.49	3.59	
Read Rate		6.61	4.45	Reject H_0
		32.76	3.59	
		38.22	3.59	
Environment Noise Level Material	There is not a significant difference between the sites and days on noise level	2.00	2.57	Fail to Reject H_0

Our tests were taken at an alpha level of 0.05. Understanding the various reasons **"Why"** these incidents take place by investigating human causal elements and what role they play into an incursion.

Understanding the **"How"** a runway incursion event in terms of who created the runway incursion whether its:

- Pilot Deviation
- Operational Incident
- Vehicle/Pedestrian Deviation

Investigated the legal ramifications **"When"** a runway incursion takes place, and at its extreme, when loss of life occurs. The significance of this research is to prevent runway incursions and increase awareness and safety in the aviation industry while furthering knowledge and understanding on a broad front of emerging technologies.

5.2 Limitations

One main limitation of this dissertation was the lack of budget to procure all of the necessary parts to develop module. This was circumvented by using existing parts that we had in the RFID research labs. Other limitations include the fact that this research will require corporation with airport and airport workers during testing phase without impacting operations. Also, another limitation is ASRS reports are subjected to the person interpreting them. Furthermore, all accidents may not be reported to the ASRS.

5.3 Contributions to the Body of Knowledge

This research has contributed to the body of knowledge by showing how RFID can help the aviation sector. It is envisioned by investigating the framework within this research will push forth innovation and safety across airports nationally and internationally. Furthermore, this research contributes to the engineering economy field by allowing us to look at this emerging technology and evaluate different options on the most economically viable. Lastly, this research allows us to follow a framework that will aid in the development and implementation of automated technology.

5.4 Future Work

This research can be expanding upon in various ways. One way I would like to expand this research is to add another independent variable to study, run a factorial ANOVA and test relationships and see if any interaction is present. Other variables include:

Time of Day

Weather Conditions

Also, I want to continue to explore the framework and use the data from this dissertation to create data analytics and start a legal repository database for a specific airport.

5.5 Related Coursework

I have taken numerous courses at the University of Texas at Arlington that have contributed to this dissertation. The first is IE 5300 RFID and Logistics. From this course, the main topic of RFID played heavily into the research as this automated technology was the basis of the detection device. A second class is IE 6308 Design of Experiments. From this course, it assisted me in setting up and conducting my experiments. Furthermore, it really helped me with my statistical analysis. IE 5339 and IE 5346 helped with determining how to implement new technology as well as determining various problems related to the reliability and testing of these new technologies. IE 5304 Engineering Economy helped with justifying different options of selecting a project that is economically viable.

Appendix A

Human Causal Element Data Collection per Airport

ASRS Rep Nbr	Event Primary	Event Contributing	Airport
1318602	situate aware		DFW
1322198	confusion		DFW
1306991	confusion		DFW
1307525	situate aware		DFW
1308304	other		DFW
1308342	workload	confusion	DFW
1308918	situate aware		DFW
1312889	situate aware	confusion	DFW
1313001	situate aware	miscommunicate	DFW
1300243	situate aware		DFW
1300748	workload	distraction	DFW
1301720	situate aware	confusion	DFW
1304801	situate aware		DFW
1292925	distraction		DFW
1293168	situate aware	miscommunicate	DFW
1293864	situate aware		DFW
1297464	confusion	miscommunicate	DFW
1284259	time pressure	situate aware	DFW
1284304	time pressure	situate aware	DFW
1285669	other		DFW
1286504	other		DFW
1286573	workload		DFW
1289683	workload	other	DFW
1276702	other		DFW
1276955	situate aware		DFW
1279745	workload	workload	DFW
1282589	training		DFW
1283584	situate aware	situate aware	DFW
1283699	other		DFW
1268324	workload	workload	DFW
1269078	situate aware		DFW
1271231	situate aware		DFW
1271446	situate aware		DFW
1271867	situate aware	situate aware	DFW
1272529	workload	workload	DFW
1273805	workload	workload	DFW
1273854	other		DFW

1274489	other		DFW
1259252	time pressure		DFW
1266437	other		DFW
1266438	human-mach		DFW
1254520	situate aware		DFW
1254923	workload		DFW
1256687	miscommunicate		DFW
1258312	workload		DFW
1258349	other		DFW
1245605	workload		DFW
1245641	distraction		DFW
1246187	other		DFW
1246454	situate aware		DFW
1246791	other		DFW
1247457	confusion		DFW
1247464	confusion		DFW
1247781	situate aware		DFW
1249434	situate aware		DFW
1241381	other		DFW
1229708	workload	workload	DFW
1231304	situate aware	situate aware	DFW
1232738	situate aware		DFW
1235321	workload	workload	DFW
1236080	situate aware	situate aware	DFW
1238005	situate aware		DFW
1227038		situate aware	DFW
1228645	workload		DFW
1214992	other		DFW
1215270	other		DFW
1215488	workload		DFW
1216908	situate aware		DFW
1218429	situate aware		DFW
1219495	workload		DFW
1221365	miscommunicate		DFW
1207796	situate aware		DFW
1209253	miscommunicate		DFW
1211415	other		DFW
1211416	human-mach	confusion	DFW

1214122	workload		DFW
1205119	other		DFW
1205132	situate aware		DFW
1206526	situate aware	situate aware	DFW
1207473	troubleshooting		DFW
1202663	workload		DFW
1186006	other		DFW
1187848	workload		DFW
1191087	situate aware		DFW
1176977	distraction		DFW
1177750	other		DFW
1181206	training		DFW
1182315	confusion		DFW
1168197	other		DFW
1166840	time pressure		DFW
1167352	other		DFW
1167363	workload		DFW
1167442	training		DFW
1167841	distraction		DFW
1158665	workload		DFW
1141859	miscommunicate		DFW

2014-2015				
#	**ASRS Acesn Nbr**	**Event Primary**	**Event Contrib**	**Airport**
1	1153171	Workload		DAL
2	1162104	Confusion		DAL
3	1163517	Distraction	Distraction	DAL
4	1164386	Workload	Workload	DAL
5	1172499	Workload		DAL
6	1183922	Confusion		DAL
7	1193541	Situational Awareness		DAL
8	1195640	Situational Awareness		DAL
9	1205167	Other / Unknown		DAL
10	1205170	Workload		DAL
11	1205219	Situational Awareness		DAL
12	1215138	Situational Awareness		DAL

13	1217141	Situational Awareness		DAL
14	1218110	Human Machine Interface		DAL
15	1218188	Human Machine Interface		DAL
16	1227401	Training / Qualification		DAL
17	1229437	Situational Awareness		DAL
18	1230564	Distraction		DAL
19	1234287	Workload	Workload	DAL
20	1234930	Situational Awareness		DAL
21	1238465	Situational Awareness	Communication Breakdown	DAL
22	1243605	Confusion		DAL
23	1245486	Confusion	Confusion	DAL
24	1246382	Situational Awareness		DAL
25	1268232	Workload		DAL
26	1268639	Other / Unknown		DAL
27	1274296	Situational Awareness		DAL
28	1281127	Workload		DAL
29	1283070	Situational Awareness		DAL
30	1291622	Training / Qualification	Workload	DAL
31	1291630	Human Machine Interface		DAL
32	1294257	Situational Awareness		DAL
33	1297343	Situational Awareness		DAL
34	1299971	Situational Awareness		DAL
35	1300884	Situational Awareness	Situational Awareness	DAL
36	1308700	Situational Awareness		DAL
37	1309262	Situational Awareness		DAL
38	1310746	Situational Awareness		DAL
39	1319541	Training / Qualification		DAL
1	1145172	Troubleshooting		IAH
2	1149118	Situational Awareness		IAH
3	1170897	Confusion	Confusion	IAH
4	1176567	Situational Awareness		IAH
5	1177592	Workload	Workload	IAH
6	1177609	Workload		IAH
7	1177884	Workload		IAH
8	1177967	Human Machine Interface		IAH
9	1177972	Confusion		IAH

10	1177994	Training / Qualification		IAH
11	1178017	Human Machine Interface		IAH
12	1178276	Time Pressure	Time Pressure	IAH
13	1179710	Human Machine Interface		IAH
14	1180935	Confusion		IAH
15	1183317	Distraction		IAH
16	1184912	Workload		IAH
17	1185220	Human Machine Interface		IAH
18	1185233	Training / Qualification		IAH
19	1186944	Time Pressure	Workload	IAH
20	1187998	Distraction	Distraction	IAH
21	1188003	Situational Awareness		IAH
22	1188720	Situational Awareness		IAH
23	1192434	Human Machine Interface		IAH
24	1196111	Training / Qualification		IAH
25	1196904	Human Machine Interface		IAH
26	1199064	Time Pressure		IAH
27	1200599	Human Machine Interface		IAH
28	1201653	Workload		IAH
29	1201665	Training / Qualification		IAH
30	1203381	Situational Awareness	Communication Breakdown	IAH
31	1204865	Time Pressure		IAH
32	1205460	Situational Awareness		IAH
33	1205918	Workload		IAH
34	1210787	Situational Awareness		IAH
35	1210930	Situational Awareness		IAH
36	1212230	Training / Qualification		IAH
37	1215426	Situational Awareness	Situational Awareness	IAH
38	1219374	Confusion		IAH
39	1222500	Other / Unknown		IAH
40	1224652	Confusion		IAH
41	1226218	Training / Qualification		IAH
42	1228204	Situational Awareness	Situational Awareness	IAH
43	1237574	Situational Awareness		IAH
44	1237636	Human Machine Interface	Human Machine Interface	IAH

45	1239359	Situational Awareness		IAH
46	1240349	Communication Breakdown	Situational Awareness	IAH
47	1242132	Fatigue		IAH
48	1242670	Training / Qualification		IAH
49	1244495	Training / Qualification		IAH
50	1244717	Time Pressure		IAH
51	1245533	Other / Unknown		IAH
52	1246649	Communication Breakdown		IAH
53	1247669	Other / Unknown		IAH
54	1259251	Workload		IAH
55	1259761	Workload		IAH
56	1260500	Situational Awareness		IAH
57	1263786	Fatigue		IAH
58	1264970	Confusion		IAH
59	1265502	Workload	Workload	IAH
60	1266526	Situational Awareness		IAH
61	1269051	Human Machine Interface		IAH
62	1269969	Training / Qualification		IAH
63	1271194	Human Machine Interface		IAH
64	1275667	Workload	Workload	IAH
65	1277581	Training / Qualification		IAH
66	1277678	Situational Awareness		IAH
67	1278319	Situational Awareness		IAH
68	1278868	Communication Breakdown		IAH
69	1281161	Communication Breakdown		IAH
70	1284590	Time Pressure		IAH
71	1287754	Situational Awareness	Situational Awareness	IAH
72	1289395	Situational Awareness	Workload	IAH
73	1291626	Confusion	Troubleshooting	IAH
74	1293693	Situational Awareness	Situational Awareness	IAH
75	1294251	Situational Awareness		IAH
76	1297245	Situational Awareness		IAH
77	1301946	Situational Awareness		IAH
78	1309867	Confusion	Situational Awareness	IAH
79	1309869	Workload		IAH
80	1311541	Situational Awareness		IAH

1	1181991	Situational Awareness		DWH
2	1197457	Communication Breakdown	Confusion	DWH
3	1204727	Training / Workload		DWH
4	1249539	Situational Awareness		DWH
5	1254273	Distraction		DWH
6	1259320	Situational Awareness		DWH
7	1274130	Communication Breakdown		DWH
8	1310021	Situational Awareness		DWH
1	1142978	Confusion		HOU
2	1147335	Training / workload		HOU
3	1175261	Situational Awareness	Training / Qualification	HOU
4	1176618	Workload		HOU
5	1185701	Physiological / Other		HOU
6	1206403	Situational Awareness		HOU
7	1211917	Situational Awareness		HOU
8	1227427	Physiological / confusion		HOU
9	1228435	Other / Unknown		HOU
10	1238470	Situational Awareness		HOU
11	1244548	Troubleshooting		HOU
12	1256817	Human Machine Interface/Distraction		HOU
13	1282383	Training / Qualification		HOU
14	1305477	Situational Awareness	Situational Awareness	HOU
15	1312818	Confusion		HOU
16	1312861	Communication Breakdown		HOU
17	1315699	Situational Awareness	Situational Awareness	HOU

Appendix B

Randomized Data for Experiment 1 System Reliability

RunOrder	Randomized Order
1	40
2	51
3	20
4	4
5	39
6	3
7	15
8	14
9	30
10	18
11	6
12	1
13	7
14	16
15	41
16	22
17	12
18	19
19	46
20	24
21	32
22	53
23	13
24	2
25	29
26	33
27	9
28	26
29	42
30	17
31	38
32	43
33	37
34	36
35	49
36	54
37	35

38	52
39	31
40	8
41	27
42	50
43	21
44	47
45	45
46	5
47	10
48	34
49	44
50	11
51	48
52	23
53	25
54	28

References

Abdulla, R., & Ismail, D. W. (2011, February 18). *Extend Active RFID with a Zigbee Network*. Retrieved from Microwaves & RF: http://mwrf.com/systems/extend-active-rfid-zigbee-network

Airline Pilots Association, International. (2007). *Runway Incursions: A Call to Action.* Retrieved from Alpa White Paper: http://www3.alpa.org/portals/alpa/runwaysafety/runwayincursionwhitepaper.pdf

Aviation Safety Reporting System. (2016). *ASRS Database Online*. Retrieved from Aviation Safety Reporting System: http://asrs.arc.nasa.gov/search/database.html

Buyya, R., & Vahid, A. D. (May 2016). *Internet of Things: Principles and Paradigms.* Elsevier Science.

Cambell, R., & Bagshaw, M. (2002). *Human Performance and Limitations in Aviation.* Malden: Blackwell Science Ltd.

Clampitt, H. G., & Jones, E. C. (2006). *The RFID Certification Textbook.* PWD Group.

Cornell Univeristy Law School. (2016). *Legal Infromation Institute*. Retrieved from Cornell University Law School: https://www.law.cornell.edu/wex/aviation

Digi International Inc. (2016). *ZigBee Wireless Standard*. Retrieved from DIGI: http://www.digi.com/resources/standards-and-technologies/rfmodems/zigbee-wireless-standard

Federal Aviation Administration. (2011). *AMT Handbook Addendum Human Factors.* Retrieved from Federal Aviation Administration: https://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/media/AMT_Handbook_Addendum_Human_Factors.pdf

Federal Aviation Administration. (2016). *National Runway Safety Plan 2015-2017.* Washington D.C.: ATO Safety and Technical Training.

Federal Aviation Administration. (June 2015). *National Runway Safety Report 2013 - 2014.* Washington D.C.

Groover, M. P. (2007). *Work Systems and the Methods, Measurment, and Management of Work.* Uppper Saddle River: Prentice Hall.

Jones, E. C., & Chung, C. A. (2011). *RFID and Auto-ID in Planning and Logistics A Practical Guide for Military UID Applications.* Boca Raton: CRC Press.

Larsen, P. B., Sweeny, J. C., & Gillick, J. E. (2006). *Aviation Law: Cases, Laws and Related Sources.* New York: Transnational Publisher's Inc.

Mullen, J., & Singh, H. S. (2015, December 17). *Air India employee dies after being sucked into plane engine at airport*. Retrieved from CNN:

http://www.cnn.com/2015/12/17/asia/air-india-engineer-sucked-into-plane-engine/

Ranieri, A. (2016). *Aiport Surface Detection Equipment Model X Safe Airport Traffic under all Weather Conditions.* Retrieved from SAAB Solutions: http://saab.com/security/air-traffic-management/air-traffic-management/asde-x/

Rouse, M. (2016). *Definition of ICT*. Retrieved from Tech Target: http://searchcio.techtarget.com/definition/ICT-information-and-communications-technology-or-technologies

Sadler, K. (2015, September 22). *Funding for U.S. airports at risk from runway incursions*. Retrieved from International Airport Review: http://www.internationalairportreview.com/20526/airport-news/funding-for-u-s-airports-at-risk-from-runway-incursions/

Transportation, U. D. (2015, April 21). *Runway Safety*. Retrieved from Federal Aviation Administration: http://www.faa.gov/airports/runway_safety/news/runway_incursions/

U.S. Department of Transportation FAA. (2016, May). *Runway Safety Hot Spots List*. Retrieved from Federal Aviation Administration: http://www.faa.gov/airports/runway_safety/hotspots/hotspots_list/

United States Department of Transportation. (January 2015). *The Economic Impact on Civil Aviation on the U.S. Economy.* Washighton D.C.: Federal Aviation Administration Communications.

United States Government and Accountability Office. (2007). *Aviation Runway and Ramp Safety Sustained Efforts to Address Leadership, Technology, and Other Challenges Needed to Reduce Accidents and Incidents.* Washington D.C.: United States Government and Accountability Office.

Wikipedia Foundation Inc. (2016, August 12). *Aviation Law*. Retrieved from Wikipedia The Free Encylopedia: https://en.wikipedia.org/wiki/Aviation_law

Wikipedia Foundation Inc. (2016). *Internet of Things*. Retrieved from Wikipedia The Free Encyclopedia: https://en.wikipedia.org/wiki/Internet_of_things

Wysocky, K. (2014, October). *Miami International Improves Runway Incurison Detection with Mulit-Tech System.* Retrieved from Airport Improvement: http://www.airportimprovement.com/article/miami-intl-improves-runway-incursion-detection-multi-tech-system

Biographical Information

Samuel I. Okate is working with the Federal Aviation Administration at the D/FW Airport as a System Specialist Engineer for 11 years. He earned his M.S. in Systems Engineering from University Texas at Arlington in December of 2010. He also earned his B.S. in Electrical/Electronics Engineering from the University of North Texas in August of 2004. Samuel is an Adjunct Professor at Dallas Baptist University where he teaches a MANA 6302 Quantitative Analysis, which is a graduate course. He is from Arlington and has lived there his entire life. Samuel is really enthusiastic about learning new things and meeting new people