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Investigating Runway Incursions in The United States Airports

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INVESTIGATING RUNWAY INCURSIONS IN THE UNITED STATES AIRPORTS

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According to the Federal Aviation Administration (FAA), the number of runway incursions is rising. Over the last two decades, the number of runway incursions at US airports has increased from 987 in 2002 to 25,036 in 2020. Runway incursions are a major threat to aviation safety, causing major delays and financial consequences for airlines, as well as injury or death through incidents such as aircraft collisions. The FAA promotes the implementation of runway safety technology, infrastructure, procedural methods, changing airport layouts, and training practices to reduce the frequency of runway incursions. In this paper, the relationship between airport geometry factors, mitigating technologies, and the number of runway incursions at large hub airports in the United States was investigated using Random Effects Poisson Model for Panel Data analyses.

Airport operations data from the FAA Air Traffic Activity System, runway incursion data from the FAA Aviation Safety Information Analysis and Sharing System from 2002 through 2020, and airport geometry data created using airport geometry features from the FAA airport diagrams were collected. 30 large hub airports with FAA-installed mitigating technologies were investigated. The model identified significant variables that correlate with incursions, based on airport geometry, for large hub airports categories defined by the National Plan of Integrated Airport Systems (NPIAS). The model results indicate that airports with significant number of runway-to-runway intersection points increase runway incursion rates and mitigating technologies ASDE-X and RSWL help reduce the severity A and B incursions. Only four variables, "RWY_RWY, Airport operations, ASDE-X, and RWSL", were found to be significant.

Keywords: Runway Incursions, Airport Geometry, ASDE-X, RWSL, Airport safety, Panel Model.

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ABBREVIATIONS

ASDE-X:	Airport Surface Detection Equipment Model X
ATC:	Air Traffic Control
FAA:	Federal Aviation Administration
ICAO:	International Civil Aviation Organization
NPIAS:	National Plan of Integrated Airport Systems
OE:	Operation Error
OED:	Operational Error/Deviations
OI:	Operational Incident
PD:	Pilot Deviation
RI:	Runway Incursion
RWSL:	Runway Status Light System
RWS:	Runway Incursion Database
RWY:	Runway
RWY/RWY:	Runway to Runway
TWY:	Taxiway
V/PD:	Vehicle and Pedestrian Deviation

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DEDICATION

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

In 2007, the Federal Aviation Administration (FAA) adopted the definition of the International Civil Aviation Organization (ICAO) that runway incursion is " any incident at an airport involving the improper presence of a vehicle, aircraft, or person on a protected surface intended for aircraft landing and taking off. " (Federal Aviation Administration, 2022).

Figure 1 shows how the FAA classifies incursions based on their severity and cause. Severity levels are divided into four categories, with A being the most severe and D being the least severe. (Federal Aviation Administration, 2022).

• **Category A:** An occurrence that was exceedingly serious and narrowly escaped a collision.

• **Category B:** A circumstance where there is a high chance of a collision; to avoid one, a quick corrective action or evasive maneuver may be required.

• **Category C:** An occurrence where there was enough time or space to escape a collision.

• **Category D:** An incident that fits the criteria for a runway incursion but has no immediate safety repercussions as a result of an incorrectly parked car, person, or aircraft on a runway or in a protected location

Runway Incursion Categories

Category D	Category C	Category B	Category A	Accident
Incident that meets the definition of runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and take-off of aircraft but with no immediate safety consequences.	An incident characterized by ample time and/or distance to avoid a collision.	An incident in which separation decreases and there is a significant potential for collision, which may result in a time critical corrective/ evasive response to avoid a collision.	A serious incident in which a collision was narrowly avoided.	An incursion that resulted in a collision

Figure 1. FAA Categories of Runway Incursions (*Source*: FAA, 2022)

The following categories of factors that contribute to runway incursions are used by the FAA and ICAO to categorize them (FAA, 2020):

Operational incident (OI): The decision made by an air traffic controller that causes less space than what is necessary between two or more aircraft, or between an aircraft and an obstruction.

Pilot deviation (PD): A pilot's activity that contravened a Federal Aviation Regulation, such as entering the runway without authorization.

Vehicle/pedestrian deviation (V/PD): Unauthorized entry of vehicles or pedestrians into airport movement areas without the consent of the air traffic controller (ATC).

Reducing runway incursions is one of the FAA's top priorities. For more than a decade, avoiding runway incursions has been on the Federal Aviation Administration's (FAA) "Most Wanted" list of safety improvements. Although the Federal Aviation Administration (FAA) has been interested in reducing runway incursions for many years, recent incidents demonstrate that runway incursions are still an issue. The number of runway incursions has been increasing since 2002, with 26,357 runway incursions occurring between 2002 and 2020. (FAA, 2017). Evidence has indicated that as traffic volume increases, so does the number of runway incursions accidents. The runway incursion rate climbed by more than 43% between 1988 and 1990, while travel volume at towered airports in the US also rose by 4.76% (ALPA, 2007). The RI rate decreased by 30% between 1990 and 1993, a period during which traffic volume decreased by 5.34%. (ALPA, 2007). Although the number of runway incursions that end in accidents is quite low, during the past ten years there has been no discernible decline in the frequency of these incidents. Figure 2 depicts the surge of runway incursions from 2010 to 2018, with an almost 85% increase in overall incursions.

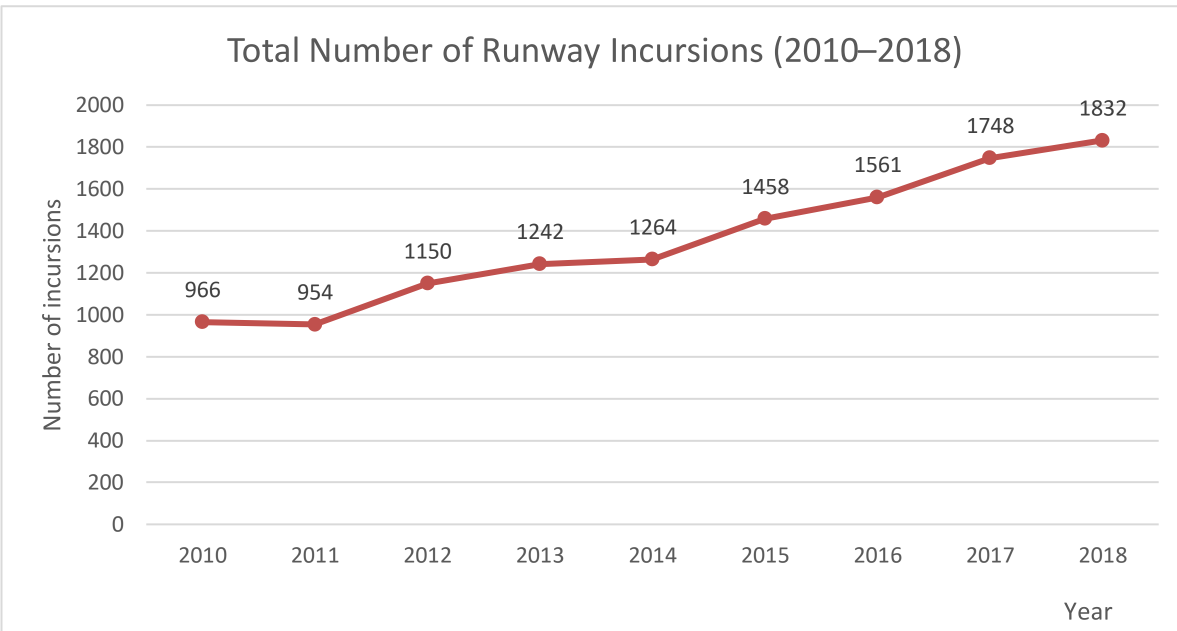

Figure 2. Runway Incursions from 2010 to 2018

Runway incursions have previously resulted in major accidents with considerable casualties. One of the deadliest aviation catastrophes in history was triggered by a runway incursion. Contrary to air traffic control expectations, two Boeing 747s collided in 1997 in Tenerife, Canary Islands, Spain, killing 583 people (National Transportation Safety Board [NTSB], 2007), In 2001, 118 people were killed in Linate, Italy. The severe runway incursions from 1977 to 2022 that caused damage to aircraft, airport properties, and fatalities are summarized in Table 1.

Table 1. An Overview of Significant Runway Incursion Incidents From 1977 to 2020. (*Source*: NTSB 2007)

Year	Runway Incursion Occurrence
1977	In Tenerife, two commercial airplanes collided on the runway, killing 583 people.
1983	In Madrid, Spain, a runway collision involving two commercial aircraft resulted in 100 fatalities.
1990	When a North-West Airlines Boeing 727 and a DC-9 crashed on a foggy runway in Detroit, Michigan, eight persons were killed and 36 were injured.
1990	In Atlanta, Georgia, a small, twin-engine aircraft that had not taxied off the runway collided with a Boeing 727 that was landing and caused one fatality.
1991	A Boeing 737 was landing at Los Angeles International Airport when it crashed with a commuter plane that was waiting on the runway, killing 34 passengers.
1994	In St. Louis, Missouri, the occupants of a tiny twin-engine plane were killed when the plane taxied into the path of a DC-9 landing on the same runway.
1996	14 people were killed when a twin-engine business plane taxied onto a runway at an unattended airport in Quincy, Illinois, as a commuter plane was touching down.
1999	A commercial airliner on takeoff came within 300 feet of another commercial airliner that had taxied onto the runway in four consecutive occurrences (two at Chicago O'Hare, one at Los Angeles, and one at JFK in New York).
1999	Two single-engine private planes collided on a runway near Sarasota, Florida, killing four persons.
2000	In Taiwan, a Singapore Airlines B-747 took off at night during a typhoon on a blocked runway before colliding with construction machinery and causing the deaths of 82 people.
2012	During a touch-and-go attempt, a Cessna 172N Ram killed a person mowing the grass at Tone Airfield.
2014	On takeoff from Moscow Vnukovo Airport, a Dassault Falcon 50 crashed with a snowplow that had strayed onto the runway, killing Total oil company Chairman and CEO Christophe de Margerie.
2020	The Austin-Bergstrom International Airport was invaded by an adult male invader who made his way to runway 17R before being hit and killed by a Boeing 737-7H4 Southwest Airlines Flight 1392 as it touched down at the airport. There were no injuries or fatalities among the 58 individuals on board, but the 737's left engine nacelle incurred significant damage.

It is imperative to study the topic of runway incursions for two main reasons. First, runway incursions have been a consistent problem for the aviation safety industry from the present day to as far back as the 1977 Tenerife disaster (FAA, 2017; Thomas, 2002). Second, it is evident that the aviation industry has been and will continue to be interested in learning more about runway incursions and accumulating as much information as possible. Runway incursion incidence is paramount for scrutinizing system safety and identifying problematic trends. Accordingly, the FAA has implemented mandatory reporting of runway incursion events and stores the resultant data within its Runway Incursion Database (RWS) (FAA, 2020).

To address multi-agency concerns regarding runway incursions, the FAA has invested in a range of technology-based safety measures, including Runway Status Lights (RWSL), Airport Surface Detection Equipment-Model X (ASDE-X), and Airport Surface Surveillance Capability (ASSC). An airport surface traffic management system known as ASDE-X gives air traffic controllers seamless coverage, aircraft identification, and the capacity to spot potential runway conflicts by giving them thorough coverage of activity on the runways and taxiways. A runway safety technology called Airport Surface Surveillance Capability (ASSC) enables controllers and pilots to identify potential aircraft and ground vehicle runway conflicts on the airport's surface as well as on approach and departure pathways within a short distance of the airport. Runway Status Lights (RWSL) are technological lights implanted in the runway and taxiway pavement that give immediate, clear notifications without any input from a controller. The signal automatically changes to red when it is unsafe to enter, cross, or start takeoff due to other traffic, allowing pilots and vehicle operators to stop when runways are hazardous. (FAA, 2007; Office of the Inspector General Department of Transportation [OIG], 2018). This study will concentrate on Runway Status Lights (RWSL) and Airport Surface Surveillance Capability (ASSC) in large airports because the Federal Aviation

Administration (FAA) has heavily installed RWSL and ASDE-X at large hubs while using fewer RWSL at medium hubs and fewer ASSC at small hubs. A system's effectiveness, such as that of ASDE-X, RWSL, and ASSC, can be learned by investigating runway incursions. They can also aid in assessing the return on investment of billions in taxpayer money and in assessing the distribution of safety improvement funding to the best technology, practices, and educational initiatives. (Schönefeld & Moller, 2012; Van Eekeren, Wright, & Cokorilo, 2018).

1.2 Research Objective

The purpose of this study is to investigate runway incursions at airports in the United States. This paper will investigate the relationship between airport geometry and the number of runway incursions per operation at commercial airports in the United States' large hubs. This research will assist the aviation industry in better understanding the relationship between runway geometries, mitigating technologies, and runway incursions, with the goal of potentially reducing runway incursions.

The research questions that guided this study are as follows:

a) Research question 1: Do runway incursion mitigation technologies (ASDE-X and RSWL) installed at the airport contribute to reducing the number of runway incursions at an airport?

b) Research question 2: Do the airport geometry contribute significantly to the number of runway incursions at an airport?

1.3 Outline of the Study

This thesis is comprised of five chapters. The first chapter provides an overview of the problems, the research objectives, and the layout of the study. The second chapter presents a literature review of the existing research on runway incursions in the United States, as well as different types of statistical models. The third chapter describes the methodology and the data collection procedure which includes data extraction and data description. Then the fourth chapter analyzes and discusses the results. Finally, the fifth chapter provides the study conclusions and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

The literature review is conducted from four perspectives in order to establish the context for the proposed research. First, the existing studies related to runway incursion severity will be presented. Secondly, quantitative and qualitative research and articles on different types of contributing factors related to airport geometry will be discussed. Thirdly, previous and recent studies related to runway incursion-mitigating technologies will be discussed. Finally, a summary of the existing studies will be discussed.

2.1 Runway Incursion Severity

Mathew, Major, Hubbard, and Bullock (2017) used statistical methods to conduct a correlational study to examine factors that correlate with runway incursions for different airport categories. They emphasized the importance of their study by citing previous research that identified runway incursions as an ongoing and prevalent threat to aviation safety. They stated that their study updated previous work (Mathew, Major, Hubbard, & Bullock, 2016) by incorporating additional 2015 data, additional literature, and a new variable (The local time when the incursion took place). Their findings effectively demonstrated that factors contributing to runway incursions vary depending on the size of the airport and the severity of the incursions. They proposed that there is no single best solution for preventing runway incursions at all airports; thus, the most appropriate countermeasures should differ depending on the airport category.

Wang, Hubbard, and Zakharov (2018) conducted a qualitative case study with the goal of applying an unconventional process of literature review known as "systematic" to the aviation discipline, as opposed to the more commonly used conventional style of literature review known as "narrative," with the goal of identifying factors that contribute to runway incursions. Wang et al. (2018) supported the need for their study by citing prior research from the FAA, which stated that RI remains a constant challenge and top priority for the administration, citing an average of three runway incursion events per day in the United States. They went on to say that runway incursions have been steadily increasing since 2012, with 6,830 incursions occurring between 2012 and 2016. (FAA, 2017).

2.2 Airport Geometry

According to Ashford, Mumayiz, and Wright (2011), perpendicular taxiways are appropriate for runways with 30 operations per hour or less during peak hours. Taxiway angles should be 45 degrees or less from the runway centerline. Also, for small planes, an angled taxiway 45 degrees from the runway centerline is recommended. 45-degree taxiways were recommended for an exit speed of 40 miles per hour. Thirty-degree taxiways are ideal for high-speed runway exits, with speeds of up to 60 mph. It was concluded that in order to reduce pilot confusion, intersecting taxiways with multiple acute angles should be avoided in taxiway layouts.

Green (2014) published preliminary results from a system-level Bayesian Belief Network model for runway incursion and excursion occurrences such as airport issues, weather issues, operational issues, and communication issues. He considered a variety of system-level issues, including airport issues (such as layout, markings, and lights, as well as closures) and air traffic control issues (e.g., certification, training, and operations).

Wilke et al. (2015) used regression analysis to examine the "airport surface system architecture" and concluded that the geometric characteristics of an airport influence the severity of runway incursions. Wilke et al. (2015) examined the “airport surface system architecture” based on regression analysis and concluded that the geometric characteristics of an airport affect the runway incursion severity. The authors discovered a surprising lack of literature on an analytical framework for assessing runway incursion severity. They presented a structured framework for modeling incursion causal factors, as well as a multiprocess approach consisting of an airport surface system architecture description, term definitions, data requirements, airport characteristics, and statistical analysis. To estimate the impact of airport characteristics on incursion severity, they used the Mann-Whitney U and Kruskal-Wallis tests, as well as logistic regression. The number of runways and taxiway segments, as well as the number of conflict points, were discovered to be the most important factors influencing runway incursion severity. This paper used similar airfield characteristics in modeling incursions, such as runway geometry and the number of taxiways, and follows Wilke et al recommendation .'s to investigate alternative model specifications in future research.

Johnson et al. (2016) confirmed that airfield geometry plays a role in incursions, reporting that airports with runway intersections, taxiways or another runway have a higher incidence of incursions than airports without runway intersections. Although airfield geometry and crossing runways, as well as hotspots, play an important role in runway incursions, the scope of this paper was limited to modeling factors affecting the severity and incident types at airports grouped by airport category.

Mrazova (2014) reported a 21% decrease in incursions between 2011 and 2012. However, the author predicted that this trend would reverse due to rising traffic levels. Given projected increases in global air traffic, runway incursions will continue to be a major safety concern. The author emphasized the significant progress that has been made globally to combat incursions but cautioned that stakeholders must be cautious and focus on reducing the number of incidents as much as possible.

Mathew et al. (2017) used econometrics-based modeling techniques to identify statistically significant factors in data on runway incursions from the Federal Aviation Administration's (FAA) public websites. The model discovered statistically significant variables that correlate with the severity of incursions. According to the model results, operational incidents (OI) are more likely at large hub airports.

Biernbaum and Hagemann (2012) examined 8812 incursions from 2001 to 2010 using a multinomial logit model and discovered that OI incidents were less likely to result in a more severe incursion at the 35 busiest airports but were more likely to result in severe incursions A and B at other airports. This finding demonstrates how incursion characteristics differ depending on airport size. In addition, the authors created cross-tabulations that revealed fascinating relationships between variables in terms of runway incident severity and incident type. They urged future research to include actual estimation of runway incursion frequency models.

Huo and Han (2012) discovered that typical error significantly influences runway incursion by performing multiple regression analyses of incursion results and influencing factors using the least square method. They concluded that the main influencing factors are improper airfield management, runway invasion of people and vehicles, poor coordination in civil and military airports, insufficient personnel training, and a lack of runway incursion consciousness.

Zhang and Yang (2010) investigated the relationship between crash causes, specifically pilot deviation (PD), operational error/deviation (OE/OD), vehicle/pedestrian deviation (V/PD), and event severity. They reported that the key to preventing A and B runway incursions is to improve pedestrian and vehicle driver access to the airfield and the quality of their communication, whereas the key to preventing C and D runway incursions is to train pilots to obey laws and rules.

2.3 Technologies

According to Air Line Pilots Association (ALPA), runway incursion can be reduced by up to 95% with a combination of technologies that improve the flight crew's situation awareness and provide conflict-alerting capability during ground operations.

According to Croft (2015), 35 of the largest U.S. airports were outfitted with Airport Surface Detection Equipment Model X (ASDE- X) and Automatic Dependent Surveillance-Broadcast (ADS-B), which provided controllers with improved situational awareness and resulted in a reduction in the number of Category A and B incursions. Furthermore, these technologies have paved the way for other types of anti-intrusion technologies, such as runway status lights.

Schonefeld and Moller (2012) thoroughly examined runway incursion avoidance and alerting systems. The authors noted incursion trends at the time of publication and predicted that as traffic increased, incursions would likely increase. According to the study, runway incursions are not a problem limited to the United States, as European airports such as Zurich and London Heathrow report a large number of incidents each year. Because incursions are mostly caused by human error, data fusion of sensors, maps, tracks, and movement models at individual airports is the best way to help operations stakeholders avoid mistakes. The study found that when mitigation technologies are properly installed and used, they have the potential to reduce runway incursions by up to 80%. The implementation of the Final Approach Runway Occupancy Signal (FAROS) and RWSL reduced incursions at Dallas-Ft. Worth International Airport by up to 70% (Schonefeld & Moller, 2012).

Schonefeld and Moller (2012) elaborated on the theoretical potential for increased safety via prevention systems. Surveillance, traffic information, tracking, situational evaluation, and human-machine interfaces and signals are all examples of preventative systems. Although some of these preventative methods include modeling or forecasting, the main focus is on practical operational technical solutions. Aside from prevention systems, there are only a few existing models geared toward long-term planning. However, no statistical analysis of existing data was performed. Furthermore, “signal installation is a costly process,” necessitating the installation of “kilometers of cables” in addition to component costs (Schonefeld & Moller, 2012, p. 37). Such systems have high maintenance costs because they must be kept in perfect working order to be effective.

(Ison, 2020) investigated the before and after installations of Runway Status Lights (RWSL) at Los Angeles International Airport in 2012 and Dallas Fort Worth International Airport in 2004. The author compared periods before Runway Status Lights (RWSL) at both airports, he discovered no significant differences in the severity of A, B, and D counts. Severity A, B, and C rates also did not differ significantly. As a result, the author concluded that the Runway Status Lights (RWSL) technology did not contribute to a reduction in runway incursions at either airport.

Bisch, Calabreses, and Donohoe (2016) published a report for the United States Department of Transportation (DOT) that presented the findings of an 11-year runway incursions analysis. The findings, as with most runway incursion investigations, were intended to inform the development and deployment of technologies aimed at preventing or mitigating future runway incursion occurrences. The emphasis was on traffic scenarios, locations, and contributing factors for runway incursions at airports that do not have surface surveillance. Surface surveillance, according to the report, could reduce runway incursions regardless of other contributing factors because it would improve air traffic controller awareness of the location and movement of ground traffic. This would allow air traffic controllers to intervene and implement corrective measures before runway incursions occurred.

Jiang Li et al. (2020) investigated several major technical systems used in the detection of active targets in airport hotspots and discovered that microwave phased-array radar can provide parameters such as target detection distance, angle, speed, and direction. When compared to traditional detection technology systems, microwave phased-array radar offers higher detection accuracy, lower total cost, and easier acceptance. The authors concluded that, as technology advances, phased array radar technology will be able to continuously scan the detection area, accurately detect the distance, angle, speed, and other information of the invading target all day long, and actively track and warn the real target. The detected target information can also be used to provide more accurate detection assistance for moving targets in the airport's hot spot.

Claros, B., Sun, C., & Edara, P. (2017) investigated 65 hub airports in the United States, considering various contributing factors. Annual airport operations, runway geometric configuration, number of taxiways, and weather variables were chosen as predictor variables for the model. Separate negative multinomial models were estimated for each of the three-runway incursion severity categories: total, A-C, and D. The use of the AIMs in conjunction with the empirical Bayes method was demonstrated in a case study of nine ASDE-X airports. Due to a lack of data, the case study's findings were inconclusive. The authors concluded that despite the implementation of ASDE-X technology, 7 of the 9 airports studied did not experience reduced severe runway incursions.

According to Broderick (2008), the FAA is passing up an opportunity to implement a more comprehensive solution to the runway incursion problem as part of the modernization of the National Airspace System. The FAA issued a notice of proposed rulemaking (NPRM) in November 2007 that only requires Automatic Dependent Surveillance-Broadcast (ADS-B) out, which provides basic aircraft information such as location and altitude. By incorporating ADS-B into the FAA mandate, other services, such as a built-in method to transmit surface conflict warnings directly to pilots, would become possible. According to the NTSB, developing such a system would be the most significant thing the FAA could do to improve runway safety.

2.4 Summary

It is clear from the various literature references mentioned above that most previous studies did not focus on severity A and B at large hub airports and those that did investigate only a few-year range. Furthermore, the research on mitigating technologies also only investigated one technology with a small number of airports and a year sample size range. The current study filled a research gap by focusing on runway incursion severity A and B, as well as technological runway incursion mitigation efforts at large hub airports.

CHAPTER 3

METHODOLOGY

3.1 Data Description

The data for the study ranged from 2002 to 2020. The sampling list for this research consists of a group of airports with similar characteristics in the same major airport category as the National Plan of Integrated Airport Systems (NPIAS). The National Plan of Integrated Airport Systems (NPIAS) categorizes commercial service airports (large hub, medium hub, small hub, and non-hub) based on annual passenger enplanements, and those airports are eligible to receive federal grants through the Airport Improvement Program (AIP). There are 30 large hubs out of the 396 primary airports in the National Plan of Integrated Airport Systems (NPIAS). Table 2 shows how FAA categorized airports based on the number of passengers that board an aircraft at an airport.

Table 2. FAA Categories of Airport Activities (*Source*: FAA 2022)

Definition	Criteria	Also referred to as
Commercial Service Publicly owned airports with at least 2,500 annual enplanements and scheduled air carrier service. Primary airports are commercial service airports with more than 10,000 annual enplanements.		
Large Hub	Receives 1 percent or more of the annual U.S. commercial enplanements	Primary
Medium Hub	Receives 0.25 to 1.0 percent of the annual U.S. commercial enplanements	Primary
Small Hub	Receives 0.05 to 0.25 percent of the annual U.S. commercial enplanements	Primary

Large hub airports handle a high volume of commercial traffic, and air traffic controllers play an important role in ensuring safe operations. Countermeasures based on advanced technologies are also most appropriate at large hub airports, where the volume of commercial aircraft and the high cost of even minor delays justifies the significant financial outlay required. Operating characteristics, financial resources, infrastructure, and technology deployment can differ between and within airport categories.

3.2 Data Collection

All information was obtained from the FAA's Operations Network (OPSNET) and Runway Incursions (RWS) databases (FAA, 2022). OPSNET was used to collect system-wide airport tower operations volume data. Counts of runway incursions by severity type were collected from the Runway Incursions (RWS) database (i.e., A, B, C, and D). For sampling purposes, a list of airports from the NPIAS database that met the criteria of commercial service, primary, and large hub was generated. The final list of 30 airports included large hub airports with similar characteristics as a result of similar administration practices and funding sources. This particular set of samples was tested. The airports in the sample had minimal changes in airfield geometry and low-impact construction projects that did not have a significant impact on runway and taxiway operations such as taxiway or runway closure. During the study period from 2002 to 2020 airport diagrams, historical aerial photographs, and available press releases or project reports were used to verify airport changes. Table 3 shows the 30 large airports selected from the NPIAS list used in this study.

Table 3. List of The Large Hub Airports Sample (*Source*: NPIAS 2021–2025)

Airport	ID	Airport	ID
Hartsfield - Jackson Atlanta International	ATL	Los Angeles International	LAX
General Edward Lawrence Logan International	BOS	Laguardia	LGA
Baltimore/Washington International Thurgood Marshall	BWI	Orlando International	MCO
Charlotte/Douglas International	CLT	Chicago Midway International	MDW
Ronald Reagan Washington National	DCA	Miami International	MIA

Denver International	DEN	Minneapolis-St Paul International/Wold-Chamberlain	MSP
Dallas-Fort Worth International	DFW	Chicago O'Hare International	ORD
Detroit Metropolitan Wayne County	DTW	Portland International	PDX
Newark Liberty International	EWR	Philadelphia International	PHL
Fort Lauderdale/Hollywood International	FLL	Phoenix Sky Harbor International	PHX
Daniel K Inouye International	HNL	San Diego International	SAN
Washington Dulles International	IAD	Seattle-Tacoma International	SEA
George Bush Intercontinental/Houston	IAH	San Francisco International	SFO
John F Kennedy International	JFK	Salt Lake City International	SLC
McCarran International	LAS	Tampa International	TPA

3.3 Dependent and Independent Variables

The dependent and independent variables used in this study and the detailed explanations of these variables are provided below in Table 4.

Table 4. Dependent and Independent Variables

Variables	Description
Dependent Variable	
Severity A and B	The total number of runway incursions at Severity levels of A and B per year at an airport. Severity A is a serious incident in which a collision was narrowly avoided. Severity B is an incident in which separation decreases and there is a significant potential for collision, which may result in a time critical corrective/evasive response to avoid a collision.
Independent Variables	

RWY_RWY	Point at which a runway intersects with another runway.
ASDE-X Tech	Runway incursion surface surveillance mitigation technology.
RWSL Tech	Runway Incursion mitigation technology.
Num of RWY	Total number of runways in each airport.
Total RWY Length	Addition of all the runway length.
Acute Angle	Taxiway exit turn that is less than 90 degrees.
Right Angle	Runway and taxiway turn that is 90 degrees.
2 Right Angle or Crossing TWY	Taxiway that crosses or intersect between a runway and a taxiway and are opposite to each other.
Annual Operations	Takeoffs and landings of aircrafts at an airport.
Single RWY	Airport has one runway and is used for both takeoffs and landings.
Parallel RWY	Two or more runways at an airport whose centerlines are parallel.
Mixed Runway	Airport that have both single and parallel runway.
Crossing Runway	Runway that Intersects another runway .

3.3.1 Dependent Variables

The dependent variable for the **random effects Poisson model for panel data** was the total number of runway incursion incidents. at Severity levels A and B per year at an airport. As we mentioned before, severity A and B are the most severe runway incursion levels. The proximity of the severity A, B, C, and D incursion is presented below in Figure 3.

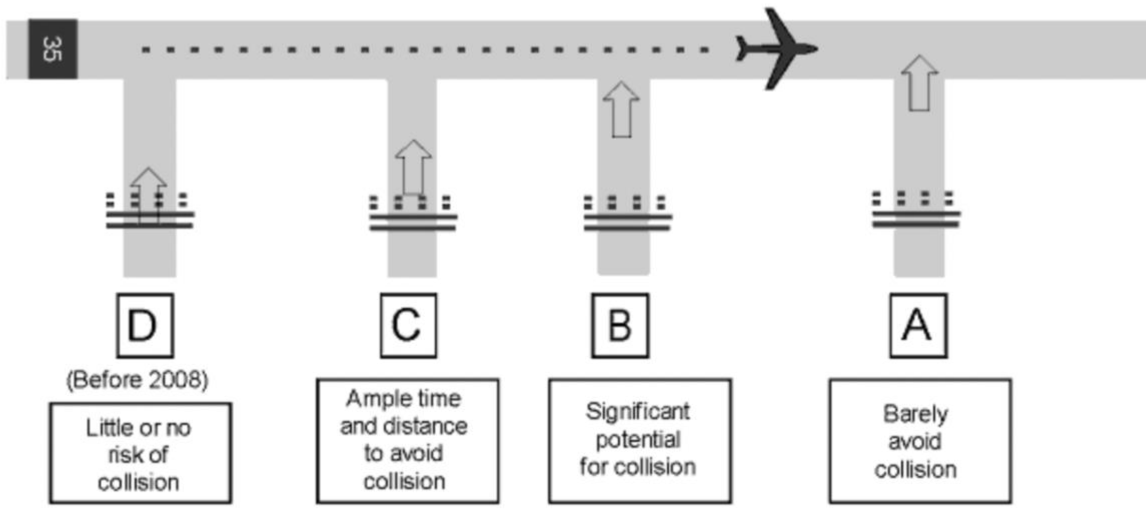

Figure 3. Illustration of Runway Incursion Severities (*Source*: Reducing Runway Incursions, Focus: Pilot Deviations by Federal Aviation Administration, June 2003)

The dependent variables were collected from the FAA Runway Safety Office Runway Incursions (RWS) database. The incident data appear to contain 4,362 records for runway incursion events at 30 large hub airports from January 1, 2002, to December 31, 2020. Data was collected between the years 2002 and 2020. All datasets (2002-2020) were collected in a calendar year from January to December of each year. Before determining the specifications for the final model, runway incursion incidents for the year 2001 (October to December) were excluded from the dataset because it did not cover the entire calendar year.

3.3.2 Independent Variables

The independent variables were selected from three different sections. 1) Operations Network (OPSNET), 2) Airport geometry, and 3) Airport mitigating technologies.

3.3.2.1 Operations Network (OPSNET)

First, the operations data for the calendar year 2002-2020 for the 30 large hub airports were downloaded from the Operations Network (OPSNET) in a CSV file. Due to the fact that the number of annual airport operations is large, it was rescaled to be per 100,000 operations. The air traffic volume data set provided quantitative estimates of the number of landings and takeoffs (combined) that occurred at each airport each year.

3.3.2.2 Airport Geometry

Second, the airport geometry independent data were derived from a visual examination of the features on each airport layout diagram which are grouped into two sections a) runway variables and b) taxiway variables. Figure 4 below is the airport layout of General Edward Lawrence Logan International (BOS), and the example of the airport geometry variables that were collected and utilized in this research.

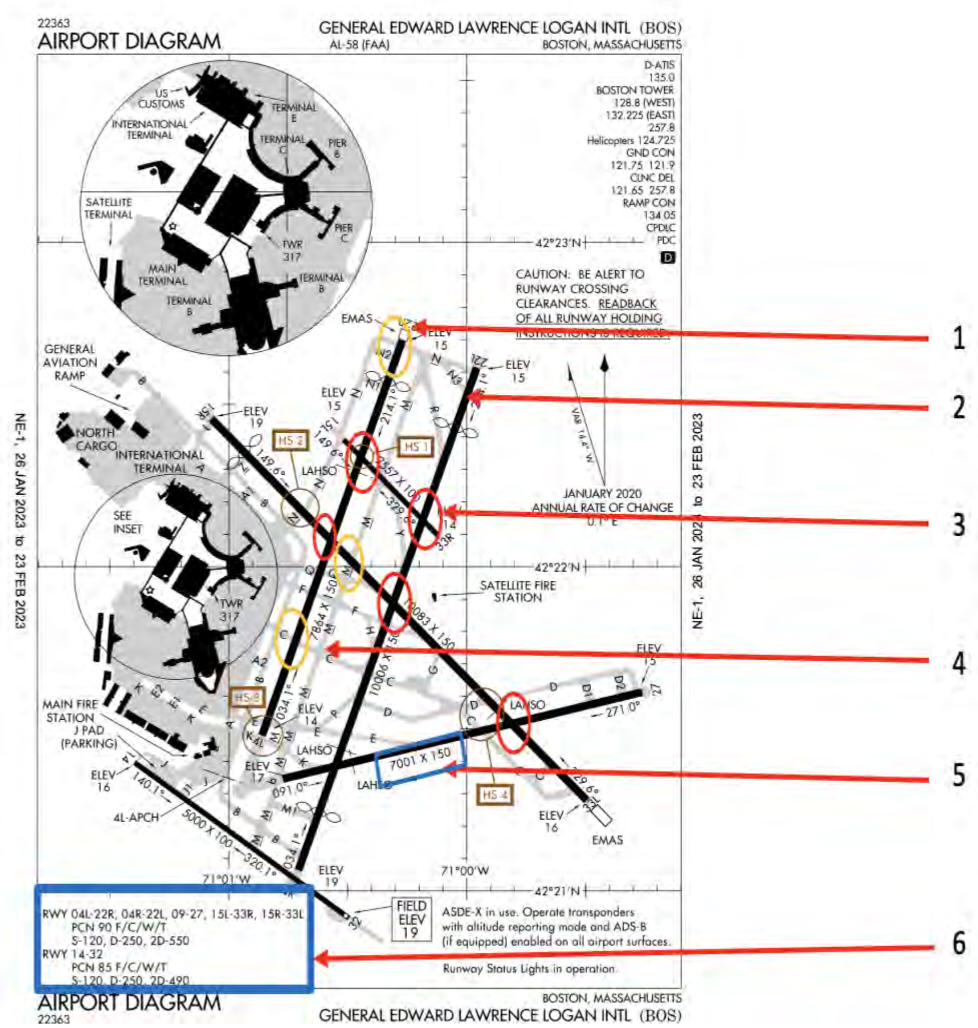

Figure 4. Example of Airport Layout Diagram and The Variables That Were Extracted from The Layout (*Source*: FAA)

The figure below depicts the description of the runway and taxiway variables that were visually collected from Figure 4. All the 30 large hubs airports layout diagrams of this study were collected visually in a similar way.

Numbers	Symbol	Description
1		Runway to the taxiway intersection point. The grey line intersects with the black line.
2		Black lines represent the runways
3		Runway to a runway intersection point Black line intersects with another black line.
4		Gray lines represent the taxiways
5	7001 x 150	Runway length and width
6	RWY 04L-22R,09-27 PCN 90 F/C/W/T S-120, D-250, 2D-	Runways number. Runway number is also always at both end of each runway line.

Figure 5. Example of The Airport Layout Diagram Variables Description

a) Runway Variables

Airports have unique geometric configurations. The runway variables in this study were classified by runway configuration, which includes single, parallel, mixed runway, RWY/RWY, Num of RWY, and Total RWY length. The model's representation of the runway parameters was based on this classification and the corresponding runway lengths at each airport. For instance, a runway-configured airport may have both single and parallel runway configurations; therefore, both categories were considered in the prediction. The number of runways in each category were added up for example in parallel runways, the lengths of both runways are added. A mixed runway configuration is the combination of one or more types, such as single and crossing, single and parallel, or single and parallel and crossing.

Figure 6 is an example of the classification of the types of runways that were visually collected from the airport layout diagram. As mentioned in Table 4, RWY_RWY is the point at which a runway intersects with another runway.

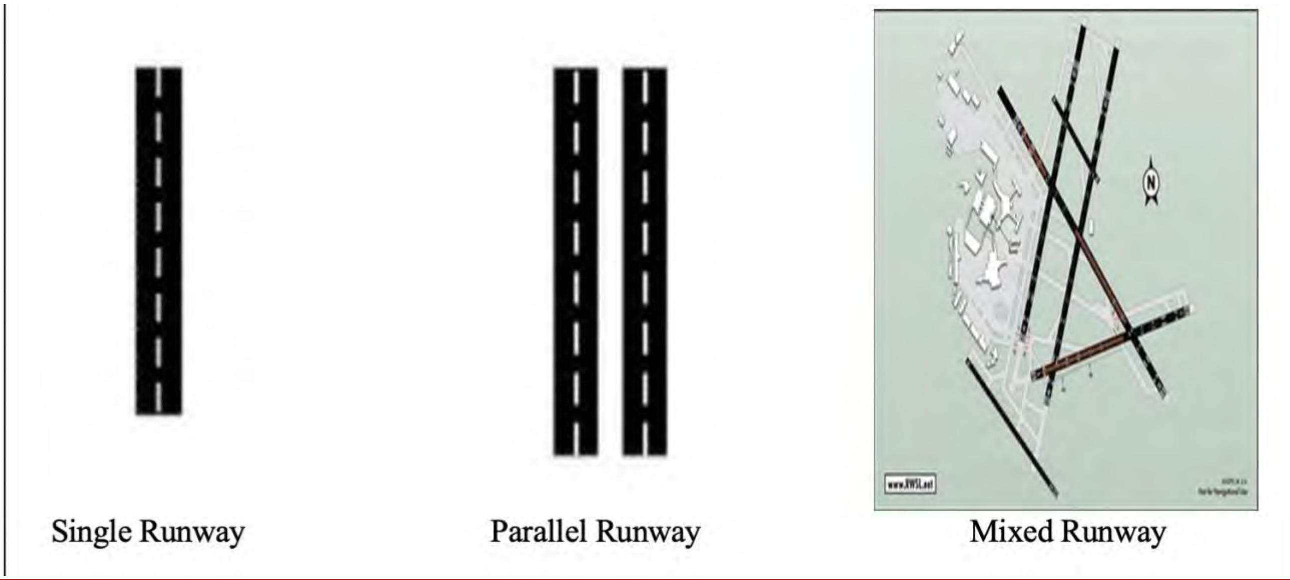

Figure 6. Example of The Airport Runway Geometry Configuration

b) Taxiways Variables

Taxiways are used to control how aircraft land and depart from the runway. The model considered three different types of taxiways variables: right angle, acute angle, also known as a high-speed taxiway, and crossing taxiway or two right angles. Figure 7 shows the example of taxiway-to-runway intersections at the airport that may be associated with the rate of runway incursions.

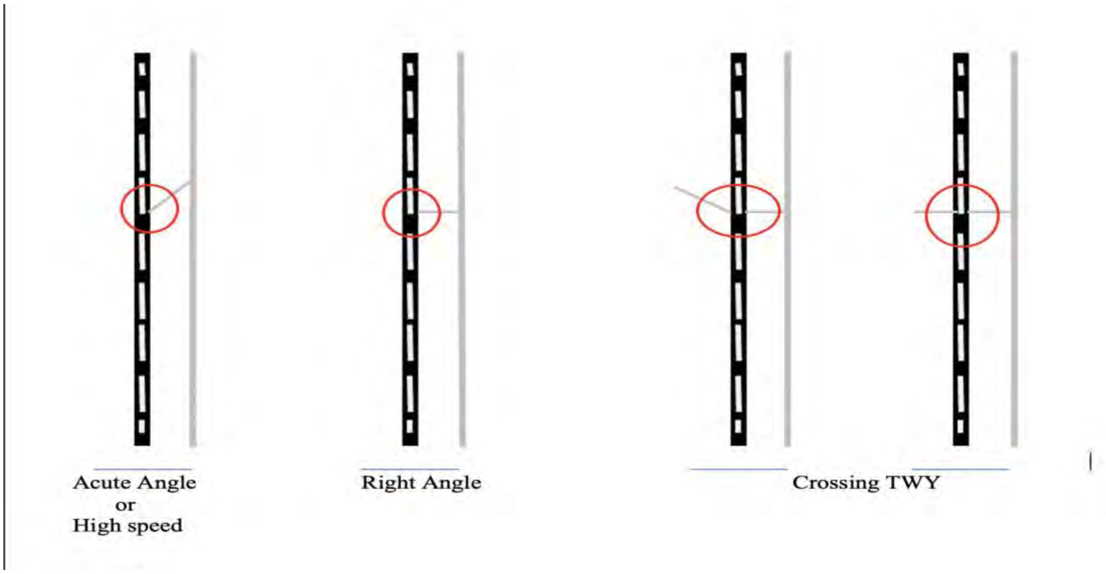

Figure 7. Example of The Taxiway Intersections Used in This Study

<u>3.3.2.3 Airport Runway Incursion Mitigating Technologies</u>

Lastly, the Surface technologies (ASDE-X AND RSWL) initial operating capability date for each airport will be extracted from the FAA report.

Figure 8 shows the image of SAAB SR-3 ASDE-X ground radar a surveillance system that uses radar and satellite technology to track the surface movement of aircraft and vehicles. It was developed to assist in the reduction of critical Category A and B runway incursions.

Figure 8. Air Traffic Control ASDE-X Ground Radar Unit (Source: SAAB)

Figure 9 depicts Runway Status Lights (RWSL) technology embedded in runway and taxiway pavement that alerts pilots and vehicle operators when runways are unsafe. When other traffic makes it unsafe to enter, cross, or begin takeoff, the lights automatically turn red. The lights provide direct, immediate alerts and do not require controller input.

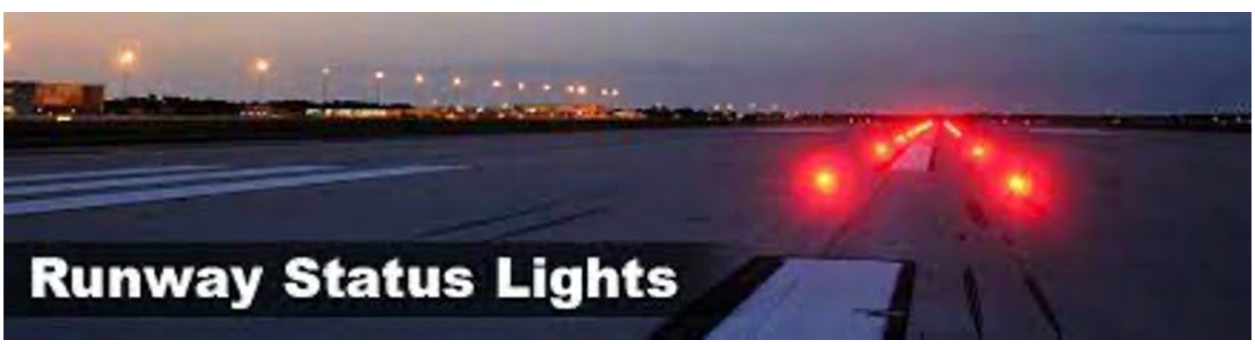

Figure 9. Runway Status Lights Technology (Source: FAA 2022)

3.4 Model Development

In this study, the panel data modeling method is used for analyzing the impacts of various factors on the number of runway incursions at an airport.

Panel data refers to samples of the same cross-sectional units observed at multiple points in time. A panel-data observation has two dimensions: denotes the cross-sectional unit and denotes the time period of the observation. In this study, the data consist of information collected from 30 large hub airports over 19 years. Thus, it is the panel data with 30 cross-sectional units observed during 19 time periods (*N=30* and *T=19*). Therefore, it can be viewed as panel data and the models for panel data can be applied to take into account the heterogeneity in runway incursion frequencies across different airports. Furthermore, since the dependent variable, i.e. the annual runway incursion frequency, is count data, the Poisson regression model for panel data was selected for this study. In general, the Poisson regression model for panel data can be expressed mathematically as follows (Green, 2000):

$$f(Y_{it} = y_{it} \mid X_{it}) = \frac{\exp(-\lambda_{it})\lambda_{it}^{y_{ij}}}{y_{it}!} \qquad (1)$$

where $f(.)$ is the probability mass function (pmf) of , which is assumed to draw from a Poisson distribution with parameter λ_{it}, which is the expectation of . By relating λ_{it} to independent variables by following Equation, the independent variables can be incorporated into the model.

$$Exp(Y_{it}) = \lambda_{it} = \exp(\beta' X_{it} + \gamma Z_i + \varepsilon_{it}) \qquad (2)$$

Where is the dependent variable, i.e. the number of runway incursions at an airport *i* ($i = 1 \cdots 30$) during the year *t* (t=1···19); X_{it} is the vector of independent variables as listed in Table 4; In the panel data model, there are two types of independent variables: 1) the individual-specific variables which are specific to the airport *i* and to be constant over time (during the different years), such as the airport geometric characteristics listed in Table 4; and 2) time-variant variables which will change over time, such as the airport operation; is the individual effect which is specific to the individual airport *i* and to be constant over time; is the error term and are the coefficient vectors for X_{it}.

In general, they are two types of panel data models: the fixed-effects model and the random-effects model. The random-effects model assumes that the individual-specific effects are distributed independently of the independent variables while the fixed effects model allows being correlated with the independent variables. In the random-effects model, is included as a part of the error term, and in the fixed-effects model, is included as an individual specific intercept for the metropolitan area i. The standard fixed-effects model cannot identify the effects of any individual-specific variables because it requires within-group variation for model estimation (Qi et al., 2007). Therefore, in this study, the random-effects model was selected.

CHAPTER 4

RESULTS ANALYSIS

In this chapter, the results of the **Random Effects Poisson Model for Panel data** are presented and discussed. According to the independent variables listed in Table 4, the technologies factors ASDE-X and RSWL are highly correlated. The collinearity problem in a regression model is caused by high correlations between the two independent variables. As a result of the correlation between the independent variables ASDE-X and RWSL technologies, two separate models were run for this study.

Thirteen independent variables were considered in the modeling, and Table 4 provides definitions and values for each one. Independent variables that were found to have low statistical significance (less than 75%) were removed in a sequential variable elimination process. The results of the developed random-effects panel data model are presented in Table 6 and Table 7. According to the modeling results presented in Table 6 and Table 7, there are only four independent variables that are significantly associated with the reduction of runway incursions in the U.S. They are the AirportOperation_100000, RWY_RWY, RWSLTech, and ASDE-XTech and their impacts are discussed below.

Table 5. Results of the Random Effects Poisson Model for Panel Data for RWSL Technology

	Estimate Std	**Error**	**t value**	**Pr(> t)**
(Intercept)	-2.42091	0.44788	-5.405	6.47e-08
AirportOperation_100000	0.09830	0.08018	1.226	0.2202
RWY_RWY	0.12056	0.09002	1.339	0.1805
RWSLTech	-0.76002	0.32653	-2.328	0.0199
sigma	3.02392	1.90586	1.587	0.1126
Sample size	4,362			

Table 6. Results of the Random Effects Poisson Model for Panel Data for ASDE-X Technology

	Estimate Std	Error	t value	Pr(> t)
(Intercept)	-2.43117	0.47353	-5.134	2.83e-07
AirportOperation_100000	0.11426	0.11426	1.385	0.1661
RWY_RWY	0.11884	0.09515	1.249	0.2117
ASDEXTech	-0.38954	0.23128	-1.684	0.0921
sigma	2.45914	1.38745	1.772	0.0763
Sample size	4,362			

4.1 AirportOperation_100000

Table 5 and Table 6 indicate that an increase in airport operations rate tended to increase runway incursions. Mrazova (2014) also found that with the increases in traffic levels at the airport, runway incursions will continue to increase and be a major safety concern. These results are reasonable because every year FAA reports an increase in airport operations for airports in the United States, as well as an increase in runway incursions rate. Furthermore, due to legacy runway and taxiway configurations, the risk of runway incursion has increased in conjunction with increasing traffic volume, particularly for airports designed and built before the jet age.

4.2 RWY_RWY

Table 6 and Table 7 indicate that the total number of runway-to-runway intersecting points was found to be a significant predictor for the increase of runway incursions at the airports. This finding is consistent with the finding of previous studies. Johnson et al. (2016) also confirmed that airfield geometry plays a role in incursions, reporting that airports with runway intersections have a higher incidence of incursions than airports without runway intersections. Wilke et al. (2015) also found that the geometric characteristics of an airport influence the severity of runway incursions. The author confirmed that in the U.S. airfield, the rate of safety occurrences was associated with the number of conflict points, the number of runway-to-runway conflict points, and subcontractors working on the airfield. One major finding of their study was that the severity of safety occurrences was related to both the airport geometry and the causal factors underlying the occurrences.

4.3 RWSL Technology

Table 6 indicates that the severity level of runway incursions decreased significantly with the installation of the Runway Status Light (RWSL). This finding is reasonable because when runways are unsafe, Runway Status Lights (RWSL) technology alerts pilots and vehicle operators. The lights automatically turn red when other traffic makes it unsafe to enter, cross, or begin takeoff. The lights provide immediate, direct alerts and do not require air traffic controller insight. Pilots can also use their best judgment and abort takeoff with the help of the RWSL technology alert when authorized to use an unsafe runway by an air traffic controller. This finding is also consistent with the findings of Schonefeld & Moller (2012) who found that when mitigation technologies are properly installed and used, they have the potential to reduce runway incursions by up to 80%. The author's findings concluded that the RWSL technology at Dallas-Ft. Worth International Airport reduced incursions by up to 70%. In addition, a report to the Department of Transportation (DOT) by Bisch, Calabreses, and Donohoe (2016) stated that surface surveillance could reduce runway incursions regardless of other contributing factors.

4.4 ASDE-X Technology

The results in Table 7 indicated that the use of ASDE-X technology could help reduce Category A and B runway incursions. However, the significant level of ASDE-X technology is relatively low compared to that of RWSL Technology. This finding is different from the findings in the literature review. Claros et al. (2017) reported that despite the use of ASDE-X technology, seven of the nine airports investigated did not see a reduction in severe runway incursions. This study has a relatively small sample airport and year size, and it only compared the incident rates in eight large hubs and one small hub airport between 2008 and 2014.

Comparing the results in Tables 6 and 7, it can be seen that RWSL Technology can reduce more runway incursions than ASDE-X technology. The reason might be because RWSL directly alerts the pilots while ASDE-X alerts air traffic controllers of potential runway conflicts, then the controller notifies the pilots. Runway incursions might still occur if the air traffic controller does not pay proper attention to the ASDE-X display screen, intervene, and implement corrective measures to pilots on time. Also, variables, such as nighttime versus daytime operations, were omitted that could have been useful in isolating ASDE-X influences, as the FAA states that ASDE-X technology is beneficial at night or during adverse weather when visibility is poor.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

In this research, we investigated runway incursions in the United States Large hub airports. A comprehensive set of airport layout, mitigating technologies implementation, runway incursions, and airport operations were collected in the U.S. from 2002 to 2020, and the random effects Poisson models for panel data were developed for use in analyzing the frequency of runway incursion incidents. The modeling results showed that there are 2 variables that have significant impacts on the occurrence of runway incursion incidents with severity levels A or B. The following items are the key findings of the study, along with some corresponding recommendations:

- ASDE-X and RWSL technologies have proven to help reduce runway incursions rate. The Federal Aviation Administration (FAA) should invest and roll out more mitigating technologies to help reduce runway incursions at airports.
- The cramped and complex configurations of runways at airports have been shown to increase runway incursions incidents. Complicated airport design with a significant number of runway-to-runway intersection points should be avoided in future airport design.
- For airports that currently have complex runway configurations with a significant number of runway to runway intersection point it is recommended that airports that currently have complex runway configurations with a significant number of runways to the runway intersection point use mitigating technologies such as runway status light (RWSL) at conflict points to assist pilots of unsafe operations, thereby reducing runway incursions.

Policy Implications

The findings of this study can help FAA and Aviation agencies better understand the relationship between airport geometry, runway incursions, and mitigating technologies. In addition, the local government can also allocate funding and technologies to airports with higher runway incursion rates. Overall, the results of the study can help the FAA and aviation agencies make the right decisions to fully consider technology as one of the solutions for mitigating runway incursions.

Limitations and future study needs

There are several limitations of this study. First, some other unobserved factors like runway incursion type (PD, VPD, and OE/OI), weather, and time of the day may also contribute to the incursion rate and need to be investigated in the future. Second, this study only included the large hub airports, based on enplanements on NPIAS. Third, correlation analysis between the two ASDE-X and RWSL technologies wasn't performed due to insufficient data available. In future research, a larger sample that will include medium and small hub airports in the U.S. could be considered. Also, a correlation analysis between the two technologies will be performed to know which technology is more effective in reducing runway incursion.

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