

A CORRELATIONAL STUDY OF THE RELATIONSHIP BETWEEN HUMAN
FACTOR ERRORS AND THE OCCURRENCE OF RUNWAY INCURSIONS

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ABSTRACT

Runway incursions have been a problem since the advent of airports. As air traffic has increased, so have the number of runway incursions. Throughout the years, many research studies have been conducted and systems developed in an attempt to reduce the rate of runway incursions. Despite best efforts, the rate of runway incursions has continued to rise. This research did not attempt to address remedies for runway incursions; instead it attempted to identify the most common causes of runway incursions. With a better understanding of the causes of runway incursions, the Federal Aviation Administration and the aviation community can better utilize their efforts and resources to reduce the persistent safety threat caused by runway incursions.

Introduction

Background of the Problem

Runway incursions are a serious and persistent threat to aviation safety. The number of air traffic operations in the National Airspace System (NAS) is continuing to grow with more than 58 million takeoffs and landings in 2008 (Federal Aviation Administration [FAA], 2009, January). The increase of takeoffs and landings in the NAS increases the chances of runway incursions. In the 1990's, the number of runway incursions were declining but that trend has since reversed and the data now shows a

significant increase. Only a few of these runway incursions have resulted in a catastrophe but this could change as the rate of operations continues to grow unless something is done to reduce the threat.

What is a runway incursion?

A runway incursion is defined by the Federal Aviation Administration (Federal Aviation Administration [FAA], n.d.) 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” (p.1). Runway incursions are further divided into four categories of severity where *category D* is the least severe and *category A* is the most severe.

Category D runway incursions are those that have little or no chance of collision. Pilots have adequate time to consider a variety of options. *Category C* runway incursions occur when pilots have ample time and distance to avoid a potential collision. *Category B* runway incursions have a significant potential for collision. In a *category B* runway incursion, pilots have minimal reaction time to take emergency action to avoid a collision. *Category A* runway incursions are those in which a collision was narrowly avoided by the pilot by using extreme and instantaneous action.

Consequences

On February 1, 1991 at Los Angeles International airport, a USAir Boeing 737 and a Skywest Metroliner collided on runway 24L killing 34 people. The air traffic controller (ATC) cleared the Metroliner to taxi into position and hold at runway 24L intersection 45, half way down the runway. The controller then cleared the Boeing 737 to land on runway 24L, forgetting that the Metroliner was in position and holding. The Metroliner was never cleared for takeoff and the two aircraft collided (NTSB, 1993).

The most studied runway incursion in aviation history to date occurred on March 27, 1977 at Los Rodeos (Tenerife) airport (Ministerio De Transportes Y Comunicaciones, 1977). A KLM Boeing 747 and a PanAm 747 collided on the runway killing 583 people. The KLM 747 was cleared into position and hold to wait for takeoff clearance while the PanAm 747 was back taxiing on the same runway. Dense fog made it impossible for the tower to see the runway or for the two aircraft to see each other. The captain of the KLM 747 started his takeoff prior to receiving clearance from the tower. The two planes collided in the middle of runway 30 (Ministerio De Transportes Y Comunicaciones, 1977).

Statement of the Problem

Although much research has gone into finding solutions for runway incursions, the FAA is no closer to a real solution than it was a decade ago. Despite the FAA's best efforts to reduce runway incursion risks, dangerous runway incursions have continued to increase over the last five years. The purpose of this study was to determine the causes and circumstances associated with runway incursions. This research focused on the

human and environmental elements that are known to increase the probability of runway incursions. Understanding why runway incursions occur is just as important as knowing how they occur. This study attempted to uncover the ‘why’ so that the FAA and the rest of the aviation community can better allocate their finances and manpower in developing effective procedures and technologies to reduce them. The “how” of runway incursions consists of who generated the runway incursion. The FAA tracks these incidents in categories of pilot deviation, operational errors, and vehicle/pedestrian deviations. The “why” that this study focused on is made up of why did the individual involved in the incident become involved. These can include miscommunication, loss of situational awareness, fatigue, distraction, etc.

Significance of the Problem

The NAS handles more than 180,000 takeoffs and landings every day (FAA, 2008). The taxiways, ramps, and gate structures are a complex system of markings, lighting, and signage. Under adverse weather conditions the complexity of this environment increases as the visibility diminishes and visual cues become concealed. With runway incursions averaging about two a day (FAA, 2008), the opportunity for a catastrophic runway incursion is high.

The FAA (2008) determined that 55% of runway incursions are caused by pilot deviation, 29% of runway incursions are caused by operational errors, and that 16% are caused by vehicle and pedestrian deviations. Krause (2003) found that commercial operators accounted for 38% of runway incursions, general aviation accounted for 60%, and military operations accounted for 2% of pilot induced runway incursions.

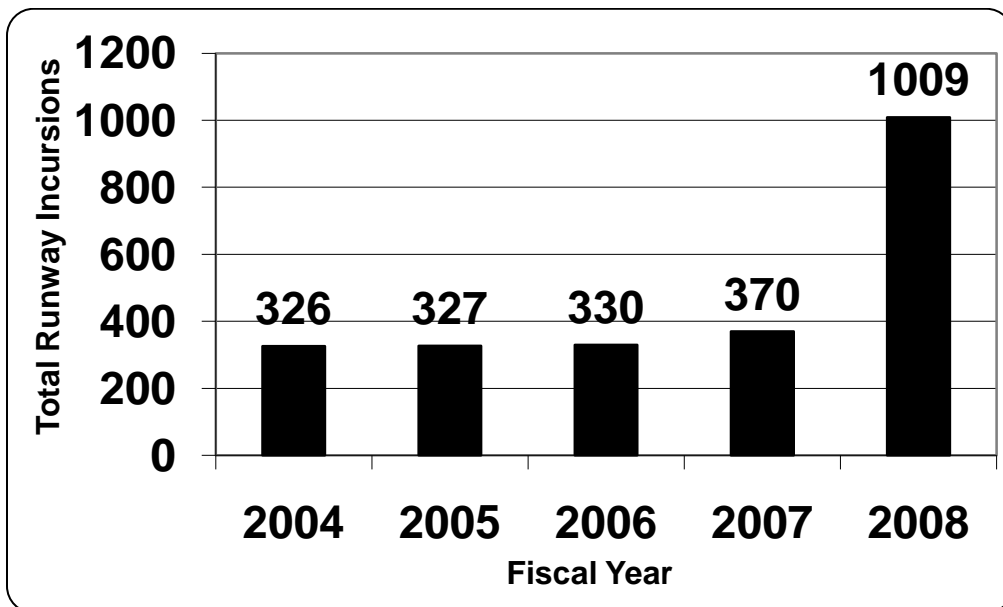


Figure 1. Fiscal Year 2004-2008 runway incursion totals.

Runway incursions were on a slow rise and then spiked in 2008. Figure 1 shows in Fiscal Year (FY) 2004 there were 326 reported runway incursions in the United States, compared to the 1,009 reported runway incursions in FY 2008. [Note. From Runway Safety Statistics [Data file]. Available from Federal Aviation Administration Web site, http://www.faa.gov/airports_airtraffic/airports/runway_safety/data/index.cfm] If this trend is allowed to continue, the possibility of another major catastrophe, like the one in Tenerife, greatly increases within the United States.

Figure 2 presents the categorization of runway incursions by error type; Operational Error (OE), Pilot Deviation (PD), and Vehicle/Pedestrian Deviation (VPD). Figure 3 shows that in recent years pilot deviations have been the main cause of runway incursions, followed by operational errors and vehicle/pedestrian deviations. In FY 2008 pilot deviations accounted for 637 of the 1,009 runway incursions. It is for this reason that continued research into the human causal factors of runway incursions is essential to mitigating runway incursions.

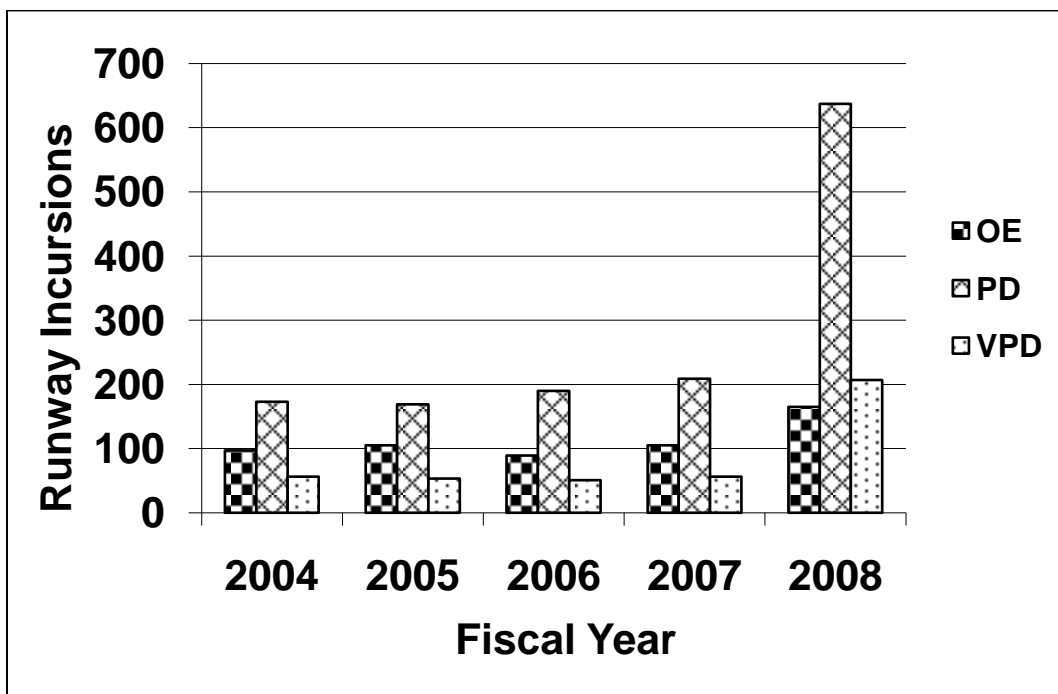


Figure 2. Fiscal Year 2004-2008 runway incursion totals by error type.

Note. From Runway Safety Statistics [Data file]. Available from Federal Aviation Administration Web site, http://www.faa.gov/airports_airtraffic/airports/runway_safety/data/index.cfm

Limitations

There are nearly 20,000 non-towered airports and approximately 500 towered airports in the United States. Runway incursion data is only actively collected at the 500 locations with an operating control tower. Unless the occurrence results in an accident or

the pilot voluntarily reports the event, non-towered runway incursions go unreported to the FAA resulting in a lack of data. Since a majority of general aviation flights fly into and out of non-towered airports, runway incursion data may be biased.

Data for this research was obtained from the Aviation Safety Reporting System (ASRS) and the NTSB reports. Runway incursion reports submitted to the ASRS are voluntary and it cannot be determined how many runway incursions go unreported. Since ASRS reports are written by the individuals involved, they are typically very detailed but can lack an unbiased account of the event. NTSB reports can provide trend information at towered airports but tend to lack the specific details needed to determine root cause.

Review of Relevant Literature and Research

A Brief History

Between 2006 and 2007, the rate of runway incursions increased by 12%. While Dillingham's report (2008) acknowledged the steps the FAA has taken to reduce runway incursion; Dillingham also stated that "the lack of leadership and coordination, technology challenges, lack of data, and human factors-related issues impede further progress" (Dillingham, 2008, p. 2). The Dillingham study revealed that 72% of runway incursions involved general aviation aircraft, but one-third of the most serious runway incursions involved air carriers. This research looked at 20 of the nations towered airports. The results of this study provide insights into the importance of the FAA working together with the aviation community stakeholders to develop a plan for reducing runway incursions.

Dillingham's study provided some insights to the validity of the runway incursion data. The FAA's runway incursion data collection system needs to be expanded to include non-towered airports. Further studies need to be undertaken to determine where the true threat of runway incursions lay so that efforts to reduce them can be properly allocated; even if that means a shift of focus from the air carriers to general aviation. Since smaller air carriers provide service to non-towered airports as well, runway incursion data for non-towered airports are just as necessary as data from towered airports.

Human Factors

The first human factors runway incursion study was conducted by Bellatoni and Kodis in 1978. Since then, many researchers have followed in their footsteps. Cardosi and Yost's study analyzed runway incursion safety data to identify weaknesses of aircraft control from airport control towers and provide possible remedies (2001). The study revealed that the most common ATC errors resulting in runway incursions were (a) forgetting about an aircraft or surface vehicle, (b) forgetting about a clearance that had been issued, (c) communication errors, and (d) lack of coordination between controllers.

During Cardosi and Yost's research, they examined tower operational error and deviation reports, NTSB accident and incident reports, and ASRS reports. Their goal was

to determine what types of errors ATC routinely made, identify the causal factors of these errors, and determine what tower improvements could be made to reduce controller errors. Cardosi and Yost discovered that the most common controller errors were:

- Aircraft observation – actual observation of aircraft – 42%
- Improper use of visual data – taking off – 28%
- Ground operations – taxiing across runway – 22%
- Improper use of visual data – landing – 16%
- Communications error – misunderstanding – 16% (2001, p. 28).

Cardosi and Yost concluded their report with three recommendations for the prevention of runway incursions (a) “improve surveillance and monitoring equipment for controllers, (b) improve means of communication between pilots and controllers, and (c) improve airport markings and signage – particularly more conspicuous hold short markings” (2001, p. 41).

During the last decade, runway incursions have been rising at an alarming rate. While the Inspector General’s 2007 report has cited the FAA’s efforts towards reducing runway incursions, it also confirms that the FAA has been taking a reactive versus proactive approach to initiating prevention measures. This research aimed to provide the FAA with recommendations that could help reduce the system wide issues causing runway incursions. The study revealed that there are several programs being run by the FAA which show great potential but they “need greater accountability at the national level to ensure that runway safety remains a priority” (Office of Inspector General, 2007, p. viii). To the extent that this research was limited to four airports, results of this study provided insights into the importance of the FAA continuing to determine the root causes of runway incursions at those airports.

Boston Logan, Chicago O’Hare, Philadelphia, and Los Angeles International airports were selected for this study because of their higher than average runway incursion rate. The research team analyzed runway incursion data for all four airports during a four year period between FY 2003 and FY 2006. The team conducted interviews of FAA representatives, airport operators, pilots, controllers, and mechanics. The three major findings from this study were (a) the need for better communication, (b) additional training of human factors for air traffic controllers, and (c) the need for greater accountability at the national level.

The continuing increase of flight operations and the increased complexity of the airport environment have increased the amount of time pilots are exposed to situations that make them more vulnerable to human errors. In Knott, Gannon, and Rench’s study (2000), they recognized the technological advances being developed around the world, but caution that “the human machine interface has to be considered in the reorganized working procedures” (p. 29). Knott, Gannon, and Rench’s study aimed to provide the FAA with an overview of the work being done around the globe to decrease the human factor errors involved in runway incursions. The study revealed while all countries are working on the runway incursion problem, the U.S. is leading the way.

Regardless of who is designing the system, it must be remembered that “to achieve that potential of human factors involvement in computer-human interface design, human factors engineers must transition from being isolated specialists to integrated components of the mainstream life-cycle development process” (Knott, Gannon, & Rench, 2000, p. 46). In short, joint studies between countries need to be undertaken to determine how cultural and language barriers affect the chances for runway incursions when crews fly outside of their home country. Organizations such as the International Federation of Airline Pilots’ Associations (IFALPA), U.S. Airline Pilots’ Association (ALPA), and the International Civil Aviation Organization (ICAO) are resources that the global community can use to help in the research and development of new human factor related solutions to runway incursions.

DiFiore and Cardosi (2006) conducted a study to examine what pilots who were involved in runway incursions thought caused them to become involved in the event. Their study concluded that written reports by the pilots involved in a runway incursion are a satisfactory method of determining causal factors. The study revealed that 75% of the reports reviewed occurred in Visual Meteorological Conditions (VMC), 10% were in Instrument Meteorological Conditions (IMC), and 15% of the reports did not state weather conditions at the time of the runway incursion. While self reporting Aviation Safety Reporting System (ASRS) reports present several limiting factors, results of this study provided a rich resource of information on what pilots believe are the causal factors of their runway incursions.

DiFiore and Cardosi (2006) selected 300 ASRS reports, in which 50 were excluded since they did not meet their pre-established criteria. In addition, several reports were of the same event filed by each pilot of the crew. This left DiFiore and Cardosi with 231 different events. The four major recommendations that were deduced from this study were (a) pilots need to reduce the amount of time spent inside the cockpit, (b) ATC needs to ensure their instructions are clear and concise, (c) radio congestion needs to be reduced, and (d) airport markings need to be deliberate and clear to ensure that taxi routes are easy to navigate and hold short lines do not go unnoticed.

Statement of the Hypothesis

To uncover the root causes of runway incursions, it must first be known not only what happened but why did the event happen. This research attempted to discover the root causes of runway incursions at four specific airports so that others may develop educational and technological improvements that focus on the true problem of runway incursions. It was hypothesized that an analysis of NTSB and ASRS reports of runway incursions would reveal a statistically significant relationship between runway incursions and human factor errors. It was further hypothesized that no statistically significant relationship existed between inclement weather and the occurrence of runway incursions.

Research Methodology

Research Model

The primary goal of this quantitative research study was to determine if a positive relationship existed between human factor errors and runway incursion rates. This research also intended to determine if inclement weather played a role in the occurrence of runway incursions. This study utilized the correlational research method.

This study was not designed to determine a causal relationship between the independent variables (human factor errors) and the dependent variable (runway incursions), but rather to attempt to find a correlation between the two. While the correlational method cannot determine true cause, it can determine which possible causes of runway incursions seem to have the greatest influence and can determine the degree of relationship that exists between human factor errors and runway incursions. The correlational method also allowed the researcher to determine whether there was an association between runway incursions and inclement weather.

Sources of Data

This study was conducted using multiple sources of data: ASRS reports, NTSB reports, and current statistical data from the FAA and NTSB websites. This data collection method is encouraged by Yin's (1994) recommendation to use multiple sources of data to connect the hypothesis to the conclusions drawn. A qualitative data collection method was used to help the researcher analyze the human factor errors associated with runway incursions and to generalize the findings to the aviation community.

The first stage of data collection included collecting current runway incursion statistical data from the FAA's website, http://www.faa.gov/airports_airtraffic/airports/runway_safety/data. The FAA has compiled data on the number of runway incursions that occur each quarter and have categorized them into operational errors, pilot deviations, and vehicle/pedestrian deviations. This data provided a historical background of the severity and types of runway incursions that have occurred.

The second stage of data collection included obtaining runway incursion reports from the ASRS and NTSB websites. The database for the ASRS reports was accessed at http://www.asias.faa.gov/pls/portal/portal.wwa_app_module.new_instance?p_moduleid=1581664609. The ASRS is a voluntary incident reporting system established by the FAA and administered by NASA. Pilots, ATC, flight attendants, maintenance personnel, and others involved in aviation operations submit ASRS reports when they are involved in or observe a situation in which they believe aviation safety was compromised. Once NASA has received the report, all identifying information is removed from the report before being entered into the ASRS database. Results from the ASRS search engine are listed by the date the event occurred.

The database for the NTSB reports was accessed at <http://www.nts.gov/ntsb/query.asp>. The NTSB is charged with investigating aviation accidents and incidents that occur within the United States. The NTSB determines the probable cause of the accidents and incidents and develops safety recommendations to prevent similar occurrences. The NTSB database classifies reports either as an accident or incident.

The key words 'Runway incursion' and 'Incursion' were used in the search engine of these two databases to obtain relevant ASRS and NTSB reports. All aircraft types, operations, and locations were selected to be used in the advanced search engine feature of the databases. Reports were randomly selected from reports submitted to the ASRS and NTSB databases between 2005 and 2009.

The Data Collection Device

Data obtained through ASRS and NTSB runway incursion reports were entered into a SPSS spreadsheet. This spreadsheet collected the following data:

- Who was the primary individual in the runway incursion
 - ATC
 - Pilot
- Weather conditions at the time
 - VMC
 - IMC
- Time of day
 - Day
 - Night
- Type of airport
 - Controlled
 - Uncontrolled
- Type of operation
 - FAR Part 135
 - FAR Part 121
 - FAR Part 91
- Crew Size
 - 1 pilot
 - 2 pilots
 - 3 flight crew members
- Contributing factors
 - Miscommunications
 - Frequency congestion
 - Blocked transmissions
 - Airport signage
 - Airport markings
 - Complex taxiways
 - Situational awareness
 - Disruption in routine

- Fatigue
- Distraction
- Rushed
- Non-human factor issues

Explanation of Contributing Factors

It is important to understand what each of the contributing factor categories encompassed so that the reader can fully understand the data collected and the final results. Therefore, this section will provide a detailed description of each of the contributing factor.

1. Miscommunications – includes miscommunications between the pilots and controllers as a result of a communication error, such as a read back error or a misunderstanding of ATC instructions. It also includes miscommunication or lack of communication between controllers in the tower or between pilots in the cockpit. Miscommunications can be caused by the use of improper phraseology, a pilot accepting a clearance that was intended for another aircraft, or similar call signs on the same frequency.
2. Frequency Congestion – occurs as radio traffic increases to the point in which a pilot must wait for a long enough break in radio transmissions to make contact with the controller. Frequency congestion plays a role in the break down of effective communications.
3. Blocked Transmission – occurs when two people attempt to make a radio transmission on the same frequency at the same time. Often the result is a loud squealing sound over the frequency and neither person's message is received. Also included in blocked transmission are transmissions that were not received correctly due to the quality of the radio transmission. Oftentimes, radio transmissions can be weak or contain a lot of static.
4. Airport Signage – includes lack of proper signage and poor positioning of signs and inadequate or missing lights.
5. Airport Markings – includes lack of proper markings, poor quality of painted markings (faded or worn), and poorly placed markings.
6. Complex Taxiways – includes complicated taxiway intersections, complex airport geometry, and airports undergoing extensive airport construction resulting in several closed taxiways making it difficult for crews to navigate the surface area.
7. Situational Awareness – factors associated with the pilot's ability to correctly identify their location on the airport surface. Situational awareness also includes factors associated with controller's ability to correctly identify the location of the aircraft they are giving instructions to and maintain awareness of the big picture.

8. Disruption in Routine – occurs when a change in taxi route is given to a flight crew that is accustomed to a standard taxi route. This includes following another aircraft beyond the point of clearance and pilot expectation of the location of hold-short lines. Disruption in routine also encompasses interruptions in ATC relief briefings.
9. Fatigue – includes mental and physical fatigue issues which can be caused by long duty days or working many days in a row.
10. Distraction – includes distractions from cockpit duties, such as checklist and setting up avionics. Distractions can also include mental distractions from home life issues or even work related issues.
11. Rushed – hastily conducting any portion of the flight, to include preflight, taxi, takeoff, and landing due to schedule pressures, or rushed due to ATC urgency.
12. Non-human Factor Issues – all issues that do not originate from human factors. Such items include mechanical failures and environmental factors (weather, visibility, and surface conditions).

Procedures

This study examined 300 ASRS and NTSB reports of runway incursions submitted between January 2005 and March 2009. It was the researcher's attempt to reduce standard error of the mean by sampling a large quantity of runway incursion reports. By reducing the standard error of the mean, it was more likely that the results of this study would accurately represent the pilot and ATC populations.

The reports selected were those involving either pilot deviations or operational errors. Reports describing vehicle or pedestrian deviations were excluded from this study. Aviation safety reporting system reports from individuals describing runway incursions witnessed but where they were not directly involved were also excluded from this study. Duplicate reports, such as when two pilots of the same crew reported the same runway incursion, were combined into one entry and counted as one report.

Treatment of Data

The spreadsheet or scorecard was used to score each ASRS and NTSB report. This study utilized the student edition of the SPSS 16.0 software to record the results from each score card. The SPSS spreadsheet that was used for recording the data and running the analyses is shown in Appendix B. Table 1 contains the coding information for the spreadsheet. The ASRS and NTSB reports were first nominally scored based on type of operation versus contributing factor. Each contributing factor in a report received a score of one. Since no causal factor was more important than the others, nominal data was the appropriate measurement for scoring and determining which factors were most prevalent in runway incursions. Once all reports had been scored, the data was entered into the SPSS spreadsheet and analyzed.

First, the data in this study was analyzed using the Chi-Square Goodness of Fit. The Chi-Square Goodness of Fit is a statistical test that is able to determine how well a model fits observed data. It allowed the researcher to evaluate how close the observed data were to what was expected. The Chi-Square Goodness of Fit determined if the observed frequencies were different than what was expected.

Second, the data in this study was analyzed using the Chi-Square Test of Independence. The Chi-Square Test of Independence is a statistical method that tests the difference in proportions of two or more groups. This test allowed the researcher to assess whether paired observations on different variables were independent of each other. For this study the Chi-Square Test of Independence was used to determine if there was a difference in causal factors between ATC and pilots and between VMC and IMC conditions.

Third, the data in this study was analyzed using the Pearson Product-Moment Correlation (Pearson r). The Pearson r is a statistical method that tests whether a correlation exists between variables. When a positive correlational relationship is found, the method indicates that as one variable increases, so does the other. When a negative correlational relationship is found, it indicates that as one variable increases, the other variable decreases. The Pearson r was used in this study to test the strength of the relationships between the causal factors and weather.

Table 1 *Runway Incursion Code Book*

Variable	Name	Coding Values
Miscommunications	MC	1 = factor
Frequency Congestion	FC	1 = factor
Blocked Transmission	BT	1 = factor
Airport Signage	AS	1 = factor
Airport Markings	AM	1 = factor
Complex Taxiways	CT	1 = factor
Situational Awareness	SA	1 = factor
Disruption in Routine	DIR	1 = factor
Fatigue	Fatigue	1 = factor
Distraction	Distraction	1 = factor
Rushed	Rushed	1 = factor
Non-Human Factor Issues	NHFI	1 = factor
Type of Operation	Operation	1 = FAR 121 2 = FAR 135 3 = FAR 91
Type of Runway Incursion	RITYPE	1 = Crossing a hold short line 2 = Entering a runway 3 = Crossing a runway 4 = Taxi into position and hold 5 = Takeoff 6 = Landing
Time of Day	DAY/NIGHT	1 = Day 2 = Night

Table 1 continued on next page...

Table 1 continued...

Variable	Name	Coding Values
Crew Size	CREW SIZE	1-3 scale
Type of Airport	AIRPORT	1 = controlled 2= uncontrolled
Weather Conditions	WX	1 = VMC 2 = IMC 3 = Unknown
Individual Involved	INDIVIDUAL	1 = Pilot 2 = ATC

SCORE CARD

Report # _____

<p><u>Type of Operation</u></p> <p><input type="checkbox"/> FAR 121 <input type="checkbox"/> FAR 135 <input type="checkbox"/> FAR 91</p> <p><u>Weather</u></p> <p><input type="checkbox"/> VMC <input type="checkbox"/> IMC <input type="checkbox"/> Unknown</p> <p><u>Crew Size</u></p> <p><input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3</p> <p><u>Type of Runway Incursion</u></p> <p><input type="checkbox"/> Crossing a hold short line <input type="checkbox"/> Entering a runway <input type="checkbox"/> Crossing a runway <input type="checkbox"/> Taxi into position and hold <input type="checkbox"/> Takeoff <input type="checkbox"/> Landing</p>	<p><u>Time of Day</u></p> <p><input type="checkbox"/> Day <input type="checkbox"/> Night</p> <p><u>Type of Airport</u></p> <p><input type="checkbox"/> Controlled <input type="checkbox"/> Uncontrolled</p> <p><u>Primary Individual Involved</u></p> <p><input type="checkbox"/> Pilot <input type="checkbox"/> ATC</p> <p><u>Contributing Factors</u></p> <p><input type="checkbox"/> Miscommunication <input type="checkbox"/> Frequency Congestion <input type="checkbox"/> Blocked Transmissions <input type="checkbox"/> Airport Signage <input type="checkbox"/> Airport Markings <input type="checkbox"/> Complex Taxiways <input type="checkbox"/> Situational Awareness <input type="checkbox"/> Disruption in Routine <input type="checkbox"/> Fatigue <input type="checkbox"/> Distraction <input type="checkbox"/> Rushed <input type="checkbox"/> Non-Human Factor Issues</p>
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Figure 3. Score card to be used for scoring ASRS and NTSB reports.

Results

Three hundred ASRS and NTSB runway incursion reports were sampled in order to determine if a pattern existed, providing illumination into some of the causes of runway incursions. The first step was to scan the reports and determine if they met the study criteria. Of the 300 ASRS and NTSB runway incursion reports sampled, 24 reports were excluded because they failed to meet the study criteria. Eleven reports were excluded since they were reports filed by a person who observed a runway incursion but was not involved. Three runway incursion reports were excluded from this study because not enough data was provided to make a determination of the causal factors. These reports simply stated that a runway incursion occurred but did not provide specific details. Seven reports were excluded because they reported close calls that did not result in an actual runway incursion but could have. This study strictly focused on occurrences that resulted in an actual runway incursion. Finally, three reports were excluded because the runway incursions were caused by an airport vehicle. Of the remaining reports, four were filed by pilots and co-pilots describing the same incident. The information from these duplicate reports were combined producing 274 unique events.

An evaluation of the 274 unique events revealed that 253 reports filed involved aircraft operated under FAR Part 121 (124 reports) and FAR Part 91 (129 reports), and 21 reports involved aircraft operating under FAR Part 135. The majority of these runway incursions occurred with aircraft containing two pilots (64%). Thirty-five percent of the runway incursions occurred with a single pilot and only 1% of the runway incursions occurred in aircraft having three person crews. Eighty-eight percent of the sampled runway incursions occurred in VMC while only 5% occurred in IMC. Seven percent of the reports did not identify the weather conditions at the time of the incident. Pilot deviations accounted for 83.9% (230) of the runway incursions while 16.1% (44) of the runway incursions were caused by ATC operational errors.

The runway incursions described in the ASRS and NTSB reports were categorized into six different categories; crossing a hold short line, crossing a runway, entering a runway, taxiing into position and hold, takeoff, and landing. As can be seen in Figure 3, the majority of runway incursions involved only crossing the hold short line (36.1%) but not actually penetrating the runway environment. Incidents involving aircraft crossing a runway occurred in 23.7% of the incidents, and incidents involving an aircraft entering a runway accounted for 19.7% of the runway incursions studied. An additional 9.9% of the reports described takeoff runway incursions in which either the pilot took off without an ATC clearance or ATC mistakenly cleared an aircraft to takeoff. Taxiing into position and hold only accounted for 6.2% of the studied runway incursions and 4.4% involved landing.

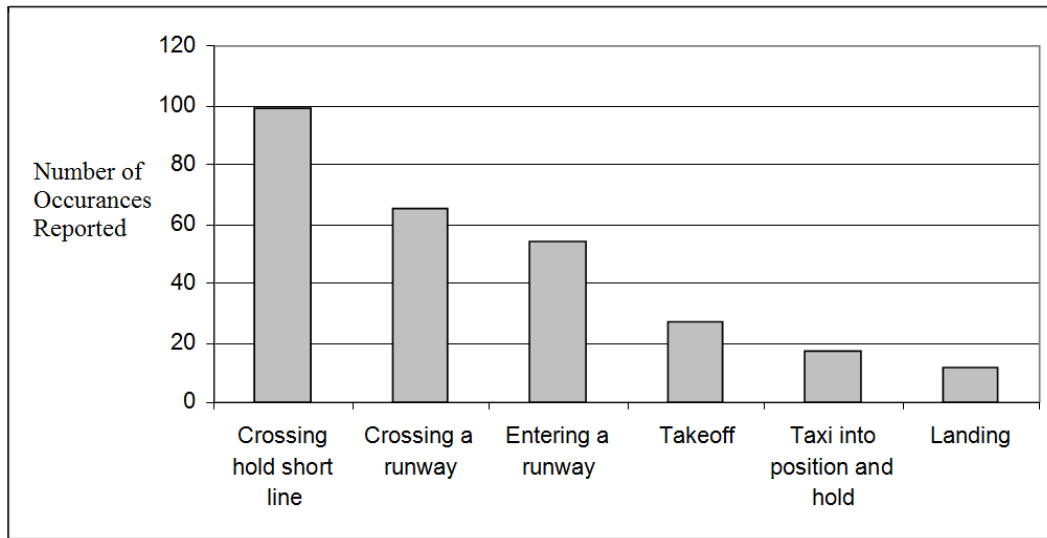


Figure 4. Distribution of runway incursion types.

Human Factors

A Chi-Square analysis was conducted to evaluate the hypothesis that an analysis of NTSB and ASRS reports of runway incursions would reveal a statistically significant relationship between runway incursions and human factor errors. The results of the chi-square analysis support the hypothesis that there is a significant statistical relationship between human factor errors and runway incursions.

The author thought that the studied reports would show an even distribution among the runway incursion factors. Examination of the Chi-Square Goodness of Fit test ($\alpha = .05$) indicated a statistically significant difference in the actual results versus what was expected. The actual results of human factor runway incursion causes varied significantly from the expected results of an even distribution ($\chi^2(274) = 311.452, p < .01$).

Figure 5 shows that situational awareness was the most frequently reported runway incursion factor, cited in 34% of all the reports examined. Miscommunication was the second most common factor, cited in 27% of all reports. Distraction was cited in 16% of the runway incursions studied. The least cited factors included frequency congestion (0.7%), disruption in routine (1.8%), and blocked transmissions (2.2%).

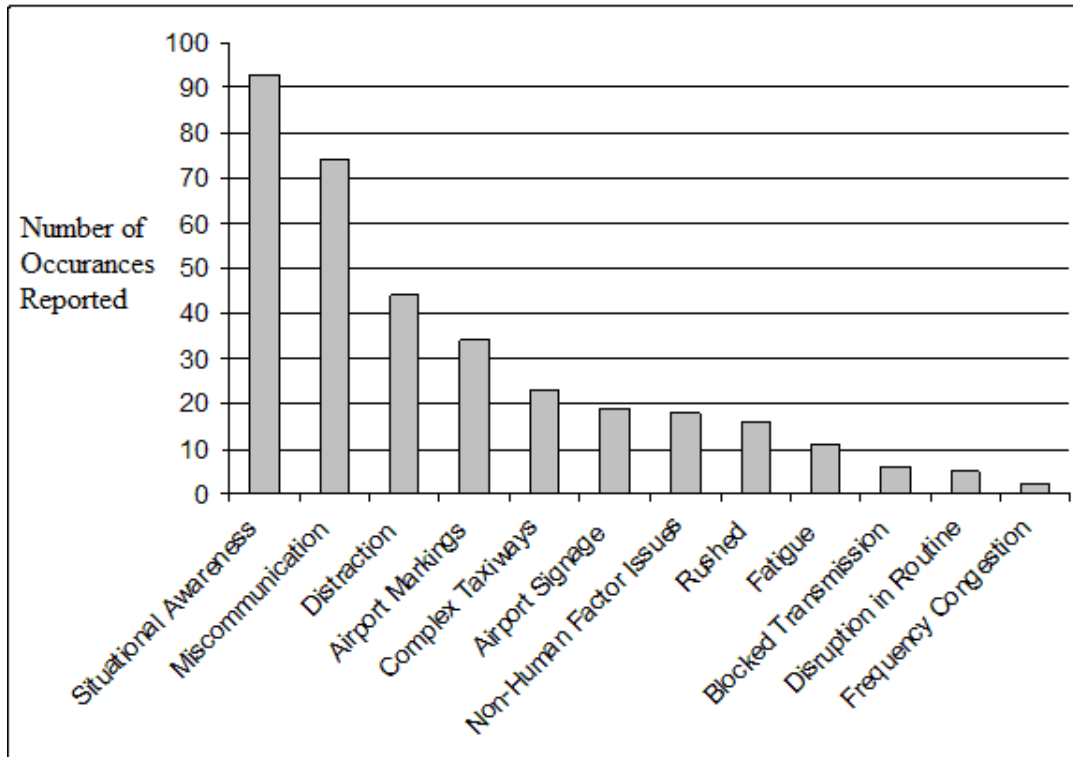


Figure 5. Runway incursion factors cited by ASRS and NTSB reporters.

Inclement Weather

A Chi-Square Test of Independence was conducted to evaluate if there was a difference in causal factors between ATC and pilots and between VMC and IMC. Results indicated very little difference of the primary causal factors between ATC and pilots. Situational awareness was the most common causal factor for both pilots and ATC followed closely by miscommunication.

The results of the Chi-Square Test of Independence conducted for pilots and ATC indicated there is a statistically significant relationship between:

1. Situational awareness and pilot and ATC errors - ($\chi^2(93) = 23.891, p < .01$)
2. Airport markings and pilot errors - ($\chi^2(34) = 7.426, p < .01$)
3. Complex taxiways and pilot errors- ($\chi^2(23) = 4.803, p < .05$)

Results indicated that in all runway incursion factors the majority of runway incursions occurred in VMC. The results of the Chi-Square Test of Independence conducted for VMC and IMC indicated there was a statistically significant relationship between weather (IMC) and non-human factor issues ($\chi^2(17) = 10.920, p < .01$) and weather and fatigue ($\chi^2(11) = 8.350, p < .05$).

A Pearson r was conducted to evaluate the hypothesis; no statistically significant relationship exists between inclement weather and the chances of runway incursions. Examination of the Pearson r ($\alpha = .05$) indicated no statistically significant relationship between VMC or IMC weather conditions and any of the runway incursion causal factors.

Table 2 *VMC Pearson r Test Results*

Causal Factor	Pearson r Value	p value
Miscommunication	r(274) = -.068	p>.05
Frequency Congestions	r(274) = .031	p>.05
Blocked Transmission	r(274) = .053	p>.05
Airport Signage	r(274) = .052	p>.05
Airport Markings	r(274) = .099	p>.05
Complex Taxiways	r(274) = .067	p>.05
Situational Awareness	r(274) = .061	p>.05
Disruption in Routine	r(274) = .049	p>.05
Fatigue	r(274) = -.103	p>.05
Distraction	r(274) = .062	p>.05
Rushed	r(274) = .040	p>.05
Non-Human Factor Issues	r(274) = -.195	p<.01

Table 3 *IMC Pearson r Test Results*

Causal Factor	Pearson r Value	p value
Miscommunication	r(274) = .058	p>.05
Frequency Congestions	r(274) = -.019	p>.05
Blocked Transmission	r(274) = -.033	p>.05
Airport Signage	r(274) = .007	p>.05
Airport Markings	r(274) = -.084	p>.05
Complex Taxiways	r(274) = -.006	p>.05
Situational Awareness	r(274) = -.015	p>.05
Disruption in Routine	r(274) = -.030	p>.05
Fatigue	r(274) = -.046	p>.05
Distraction	r(274) = -.051	p>.05
Rushed	r(274) = -.056	p>.05
Non-Human Factor Issues	r(274) = .156	P=.01

Therefore, the hypothesis that no statistically significant relationship exists between inclement weather and the chances of runway incursions was accepted. Consequently, inclement weather does not affect the occurrence rate of runway incursions.

Discussion

The results of this study supported the original hypotheses: that an analysis of NTSB and ASRS runway incursion reports would reveal a statistically significant relationship between runway incursions and human factor errors and that no statistically significant relationship existed between inclement weather and the chance of runway incursions. The occurrence of a runway incursion due to human factor issues was 90% higher than the occurrence of a runway incursion due to non-human factor issues. Also, it was observed that inclement weather conditions did not play a factor in the occurrence of runway incursions. Results showed that 88.7% of the runway incursions studied occurred in VMC while only 4.7% occurred in IMC. Even though 6.6% of the reports studied did not identify the type of weather at the time of the incursion, it was concluded that inclement weather does not affect the occurrence rate of runway incursions.

Effects of Human Factor Errors

The acceptance of the first hypothesis, an analysis of NTSB and ASRS reports of runway incursions revealed a statistically significant relationship between runway incursions and human factor errors. This was in line with intuitive thought that the most fallible component in the aviation industry is the human element. Of the human factor elements examined, the most common error that led to a runway incursion by both pilots and ATC was due to a loss of situational awareness followed closely by miscommunication. This loss of situational awareness occurred when pilots failed to realize their actual location on the airport. In other words, they believed they were in one place when in reality they were some place entirely different. In most of these cases, at least one pilot had an airport diagram out.

An airport diagram is a pictorial layout of the airports surface environment; a map of the runways, taxiways, and ramp areas. Often times the confusion started with the pilot losing track of where they were on the airport diagram. In some cases, the initial confusion occurred as a pilot taxied out of the ramp area and into the taxiway structure. Many ramps are wide open areas that have several taxiways joining it. When a pilot initially started to taxi on the wrong taxiway, it leads the pilot to believe they are somewhere they are not. It is typically not until the pilot arrived at an intersection that they realized something was wrong. Unfortunately, the intersection was often at an intersection between a taxiway and runway, which resulted in the pilot incorrectly turning onto a runway that was believed to be a taxiway.

Loss of pilot situational awareness also occurred when the airport had significant construction projects. The closed taxiways and/or runways caused pilots to become disorientated with their taxi route. This was partially due to construction equipment blocking the taxiway and runway signs. Construction also interfered with the pilot's "before landing briefing" of how they were going to exit the runway and their initial plan

to get to the ramp. If the taxiway the pilot planned to use to exit the runway after landing was unavailable and the tower gave them instructions to use a different taxiway, it increased the pilot's chance of missing the exit taxiway.

The loss of situational awareness in ATC occurred when the controller lost the "big picture". Not only do controllers need to know where the current aircraft they are giving instructions to was located but they also must know where all the other aircraft under their control were located and where they were headed. Many operational errors occurred when a controller cleared an aircraft to cross a runway while another aircraft was conducting a takeoff or landing roll. Other operational errors included clearing two aircraft to takeoff on intersecting runways, clearing an aircraft to takeoff believing the landing aircraft on an intersecting runway had already passed through the intersection, and clearing an aircraft into 'position and hold' at an intersection that a departing aircraft had not yet passed. These events occurred when the controller lost track of where each aircraft was located and what instructions they had provided.

Miscommunication was found to be the second most common factor that resulted in runway incursions. At airports without an operating air traffic control tower 40% of all runway incursions were due to miscommunication. These pilot deviations were caused when pilots did not communicate proper position reports on the Common Traffic Advisory Frequency (CTAF) to other pilots flying in that area. The failure to communicate with other pilots in the area created a situation in which a pilot on the ground may not have known that another aircraft was on an approach to the same runway. Another common miscommunication caused runway incursion issue was due to pilots who were not monitoring the CTAF and positioned their aircraft on the runway when another pilot was on short final. Since these pilots did not monitor the CTAF, they did not have the valuable information of the location of other aircraft. The most significant problem in these cases occurred at airports with intersecting runways. One aircraft communicated on the CTAF its landing sequence while another aircraft was not listening to the communications took off on the intersecting runway.

At controlled airports the lack of communication was not as much of a factor as it was at uncontrolled airports. The major problems in communications at controlled airports were due to miscommunication. The main problems observed were: occurrences when ATC did not properly coordinate aircraft movement amongst the different controller positions, miscommunication between two pilots about their assigned runway and taxi clearances but neither pilot called ATC for clarification, pilots who missed part of the clearance and did not ask ATC to repeat the instructions, pilots who did not hear instructions given to them during taxi, and pilots who misunderstood what ATC wanted them to do or ATC misunderstanding what the pilots wanted to do.

Effects of Weather

The most interesting finding in this study was the acceptance of the second hypothesis where no statistically significant relationship existed between inclement weather and the occurrence of runway incursions. The results in this study showed that inclement weather was not a factor in runway incursions. Eighty-eight (88%) percent of

the runway incursions studied occurred during VMC. It would be intuitive to assume that as the weather became worse runway incursions would be more likely due to reduced visibility and an increased workload on the pilots and controllers. However, the findings were contrary to this belief suggesting that as weather decreased pilots and controllers exercised a higher level of vigilance.

Conclusions

In St. Louis, Missouri on November 22, 1994 an MD-82 was on its takeoff roll on runway 30R when it collided with a Cessna 441. The Cessna pilot had received a clearance to back taxi into position and hold on Runway 31. The pilot taxied into position on runway 30R at intersection R instead of taxing into position on runway 31. The MD-82 collided with the Cessna 441; killing both people on board the Cessna and causing several minor injuries to passengers on board the MD-82 (Aviation Safety Network, 1994).

It is accidents like this one that emphasize the need to determine the causes of runway incursions and what can be done to prevent them. One of the primary goals of this study was to ascertain if there was a positive correlation between human factor errors and runway incursions. This study also evaluated the effects of human factor errors and weather on the occurrence of runway incursions. Through this analysis, the major contributing factors to the rise in runway incursions caused by pilots and air traffic controllers have been identified as human factor errors.

After analyzing nearly 300 randomly selected ASRS and NTSB runway incursion reports, it was revealed that the major contributing human factor to the occurrence of runway incursions was the loss of situational awareness in pilots and controllers. The results show the aviation community needs to focus their efforts to reduce runway incursions that could result in catastrophic accidents in a way that aids pilots and controllers in maintaining their situational awareness. In the past, the FAA focused on expensive technological improvements to airports and aircraft to reduce runway incursions. These much needed improvements helped slow the increase in runway incursion rates over the years but to reverse the trend and reduce runway incursion rates the aviation industry needs to focus on the one element that has been overlooked; the human. Improvements need to be made to the pilots and controllers ability to maintain situational awareness. ATC and pilots also need to be encouraged to stop and ask for assistance when they lose their situational awareness and possibly receive training in the recognition of the loss of situational awareness.

This research also explored how weather impacted the occurrence of runway incursions. Results found that when the weather conditions became adverse there was no increase in the number of runway incursions. In fact, it was determined that most of the runway incursions occurred in VMC. Further studies are required to determine the differences between VMC and IMC operations that result in the improvement of pilot and ATC performance, and the reduction of runway incursions.

Recommendations

Following this study, several recommendations have become apparent. The majority of these recommendations focus on the human element instead of possible technological advancements. Not only are human element related improvements less expensive than technological improvements but they could be quicker and easier to implement. Instead of having to dig up concrete to install new devices or retrofit aircraft with new equipment, human improvements may include an educational workshop or implementation of new procedures.

There are several things that pilots can do to aid in maintaining their situational awareness. Pilots can set themselves up for a safe and successful taxi by:

1. Reviewing the airport diagram for hotspots and determine the location of construction areas before they even start the engines.
2. After receiving a taxi clearance pilots should make certain they understand the directions and review the route on the airport diagram before beginning the taxi. If the pilot becomes unclear of any part of the instruction, they should ask ATC for clarification before moving.
3. Pilots should minimize the amount of time they spend focused on items in the cockpit. They can achieve minimum heads down time by tuning all needed frequencies, setting up all navigational equipment, and having all required charts out before they call for taxi. If something changes that need to be re-entered, the pilot should postpone making these changes until they have come to a complete stop, perhaps in a run-up area or while holding short.
4. If at any time the pilot loses their situational awareness, they should immediately stop the aircraft, unless the pilot is certain they are on a runway, and ask ATC for assistance. This can be accomplished by asking for a progressive taxi. Stopping and asking for help will require education and encouragement since many pilots are hesitant to admit when they are disoriented.

Many steps can be taken to help eliminate operational errors from occurring due to the loss of situational awareness. First, the tower should be properly staffed at all times. Until ATC facilities are properly staffed, controllers will be required to engage in additional duties not related to their assigned duty position. This situation forces the controller to handle tasks that are not part of their original duty assignment, increasing their workload and distracting them from their primary task. Under these circumstances it is easy for a controller to lose situational awareness and initiate a sequence of events leading up to a runway incursion.

Second, as of June 10, 2009, X model Airport Surface Detection Equipment (ASDE-X) has been successfully integrated into 19 of the 35 major U.S. airports. By fall of 2010, the remaining 16 airports will have ASDE-X incorporated into their operating environment (FAA, 2009). ASDE-X provides ATC a map of the airport overlaid on a

radar screen which displays the movement of all aircraft and transponder equipped airport vehicles. ASDE-X drastically aids in increasing the controllers' situational awareness. Therefore, it is recommended that not only do the nation's 35 busiest airports be equipped with ASDE-X but all towered airports should be equipped.

This study was able to correlate runway incursions to human factor errors. Through this research study it has been identified that the loss of situational awareness is the largest contributing human factor to the occurrence of runway incursions. However, further study needs to be conducted to determine how situational awareness is lost and why does the loss of situational awareness occur. To implement changes that would have a positive impact on the reduction of the loss of situational awareness that leads to runway incursions, the factors effecting situational awareness must be understood.

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