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Four runway configuration types and their relation to arrival delays

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Approved by Major Professor(s): Kathryne Newton

Approved by: Michael Dyrenfurth 4/8/2015
Head of the Departmental Graduate Program Date

FOUR RUNWAY CONFIGURATION TYPES AND THEIR RELATION TO ARRIVAL DELAYS

A Thesis
Submitted to the Faculty
of
Purdue University
by
Rachel J. Kennedy

In Partial Fulfillment of the
Requirements for the Degree
of
Master of Science

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ABSTRACT

Kennedy, Rachel J. M.S., Purdue University, May 2015. Four Runway Configuration Types and Their Relation to Arrival Delays. Major Professor: Kathryne Newton

Aside from a safe flight, airline passengers expect to arrive to their destination on time. With an abundance of flights in the United States arriving late each day, it has yet to be determined if the airport's layout plays a role. This research looks at four common runway configuration types at hub and non-hub airports to determine if runway configurations affect arrival delays. A two-way ANOVA is conducted comparing the means of the on-time arrival percentage between airports exhibiting each of the four runway configurations as well as hub and non-hub airport status. The results determine if any or none of the runway configurations and hub types have the greatest influence on arrival delays.

CHAPTER 1. INTRODUCTION

Airline passengers expect to arrive to their destination on time, which is why delayed flights account for the largest amount of complaints among travelers (Baranishyn, Cudmore, & Fletcher, 2010). While poor weather conditions are unavoidable and ultimately responsible for most delays, there are multiple other reasons for delayed flights (United States Department of Transportation, 2014b). Acknowledging and posing solutions to non-weather delays is key in increasing customer satisfaction.

The following thesis addresses a gap in the knowledge of aircraft arrival delays and the effect of the configuration of the runways at the arriving airport. The problem at hand and its importance are addressed as well as the basis for beginning research in this area. A research question, assumptions, limitations, and delimitations of the study are provided as well as definitions of key terms relevant to the research.

1.1 Statement of the Problem

Aircraft are considered to have arrived at their final destination once the aircraft has pulled up to the assigned gate and the pilot has set the brakes. Even after touching the ground on time, a plane can still arrive to its gate well past the published arrival time. Arrival times can be delayed by instances on the ground such as queueing to land, stopping to cross active runways, and long taxiing distances. The following thesis describes research conducted to examine the impact of different types of runway configurations at commercial airports in the United States with scheduled passenger service. Data was analyzed to help determine if a specific runway arrangement is contributing to the number and length of arrival delays in commercial flights.

1.2 Significance of the Problem

Delayed flights affect multiple entities. Passengers, aircraft availability, and airport operations are all potentially negatively impacted by arrival delays. Addressing the problem of arrival delays is important in keeping the commercial airline industry running efficiently. Airlines have been padding their Estimated Time of Arrivals (ETAs) since being required to report delay data starting in 1987 (Government Accountability Office, 1990). Even with the buffer time, airlines were still reporting non-weather related delays. Determining if non-weather delays appear more frequently in specific runway arrangements can help determine patterns for future studies in delays and on-time arrivals. Studying the frequency of arrival delays can help determine published arrival times at airports with specific runway arrangements.

1.3 Scope of the Study

Due to the availability of data and reports from the United States Department of Transportation (DOT), the following analysis was restricted to commercial airports in the United States. Commercial airlines that make over one percent of total U.S. domestic passenger revenue are required by the FAA to report the on-time data for only the flights that are carrying passengers (Airline Service Quality Performance Reports, 2004). Focusing on major carrier airlines rather than freight, private charter, or military flights is more relevant to the everyday traveler and normal operations at high-traffic airports.

The most active airports in the United States often have multiple runways. While some airports have opted for numerous non-intersecting runways, others have an intersecting pattern; both patterns allow for less waiting time between multiple take offs and landings. Additionally, there are airports in which only one runway is present. The following research focused on determining a pattern in on-time arrivals at U.S. airports with the three mentioned configuration categories.

1.4 Research Question

This research primarily answered the following question:

- How does airport runway configuration contribute to passenger aircraft arrival delays for the 14 busiest commercial airlines' domestic flights at airports with FAA operated air traffic control towers?

1.5 Assumptions

The following assumptions were made for this research:

- Airlines have correctly reported their monthly on-time data to the FAA.
- The FAA has reported the exact data received from the airlines.
- All runways in multi-runway configurations are used.
- Data is not heavily influenced by international or other non-reportable flights.
- Cancelled flights have no contribution to delay data.

1.6 Limitations

The following limitations are inherent to this project:

- Only flights operated by 14 specific airlines headquartered in the United States were analyzed due to available data.
- Data was only taken from airports in the contiguous United States.
- U.S domestic flights, those that take off and land in the U.S., and their related data were the only type of flights studied.
- The 318 U.S. airports served by regularly scheduled commercial service were the only airports considered for the analysis.
- Airports controlled by Federal Aviation Administration operated air traffic control towers were the only airports studied.
- Runway configurations were determined by visual inspection rather than actual runway usage.

1.7 Delimitations

The delimitations of this study are as follows:

- Cargo, military, and personally chartered flights were not analyzed.
- Joint use civilian/military airports were not studied.
- Departure delays were not examined.
- Potential causes for delays other than runway configuration that are related to an airport’s layout and infrastructure were not investigated.
- Data observed was only for the 2013 calendar year.

- The configuration and layout of taxi-ways within each runway configuration were not established.

1.8 Definitions of Key Terms

Flight— Any non-stop scheduled passenger flight segment with a specific flight number scheduled to be operated pursuant to a published schedule within a specific origin-destination city pair, other than trans-border or foreign air transportation (Airline Service Quality Performance Reports, 2004).

Late Flight (delay)—A flight that arrives at the gate 15 minutes or more after the published arrival time (Airline Service Quality Performance Reports, 2004).

On-time—A flight that is operated less than 15 minutes after the scheduled time shown in the carriers' Computerized Reservations Systems (CRS) (United States Department of Transportation, 2014a).

Push-back Time—The time at which aircraft is given permission to push back from their allocated gate, start their engines, and commence their taxi to the runway (Atkin, De Maere, Burke, & Greenwood, 2013).

Runway—A rectangular area on the airport surface prepared for the takeoff and landing of an aircraft (Horonjeff, 2010).

Runway Configuration—The number and relative orientations of one or more runways on an airfield (Horonjeff, 2010).

Taxi-time—The time between actual pushback and takeoff. The amount of time that the aircraft spends on the airport surface with engines on, and includes the time spent on the taxi-way system and in the runway queues (Simaiakis & Balakrishnan, 2009)

1.9 Summary

The contents of this chapter addressed the significance of conducting research comparing runway configurations and arrival delays. The research question provided a starting point for the study and the assumptions, limitations, and delimitations narrowed the focus of the research that is presented in this thesis.

CHAPTER 2. REVIEW OF THE LITERATURE

In order to study today’s air travel complications, looking back to the development of flight is key to understanding how issues have evolved over time. From the original wooden Wright Flyer to today’s 500 passenger Airbus A380, aircraft have rapidly advanced as the premier mode of fast, long-distance transportation. The following review of literature demonstrates how the airplane and the passenger flight industry came to be transportation necessities. The provided background establishes the need to solve today’s aviation related issues in order to continue building and advancing the industry. Today’s airport conditions and problems are also addressed to have a better understanding of the current state of the industry and why a comparison between delays and runway configuration should be further studied.

2.1 Origins of Flight

Brothers Wilbur and Orville Wright began studying human flight in 1899 (Garber, 1963). They were initially successful in creating gliders but they ultimately had larger ambitions, which included engines and greater pilot control. In Kitty Hawk, North Carolina, on December 17, 1903, Orville piloted the Wright Flyer and took to the air making history. Later Orville wrote:

> The first flight lasted only 12 seconds, a flight very modest compared with that of birds, but it was, nevertheless, the first in the history of the world in which a machine carrying a man had raised itself by its own power into the air in free flight, had sailed forward on a level course without reduction in speed, and had finally landed without being wrecked. The second and third flights were a little longer, and the fourth lasted 59 seconds, covering a distance of 853 feet over the ground against a 20-mile wind (Garber, 1963, p. 467).

In the years following the first flight, other aviators took to building their own aircraft and teaching themselves how to fly. By the beginning of World War I in 1914, only 11 years later, aircraft had advanced to serve the needs of militaries around the world. The aircraft of this time exhibited the ability perform reconnaissance, execute ground attacks, and serve in aerial combat (Kennett, 1999).

The creation of airfields stemmed from the growing presence of aircraft. Aircraft were originally landed on grass or dirt airfields. The airfields and the aircraft themselves wore out from the wear and tear of multiple landings. In 1919 cities started to build airports to meet the demand of the growing military and the aircraft fleet of the United States Post Office (Bednarek, 2001).

2.2 Development of Passenger Flight

The first industry to utilize the concept of air transport was the United States Post Office (Szurovy, 2000). The creation of this service in 1918 eventually lead to the development of passenger flights and the airlines as we know them today. On May 15, 1918 the first scheduled airmail service that connected New York City and Washington

D.C. with a stop in Philadelphia, Pennsylvania was launched. By 1925, under the Kelly Contract Air Mail Act, the Post Office was required to contract its successful airmail practices to private airlines. Airlines were paid per pound of mail carried until 1930 when the Watres-McNary Act was passed. The act mandated that airlines were to be paid for available cargo space for mail regardless of whether mail was actually carried (Szurovy, 2000). The mandate caused airlines to not only invest in larger aircraft to earn more money from mail carriage, but in carrying passengers to offset operating costs. It was at this time that the public quickly became captivated by air travel. The industry and the desire to fly quickly grew.

2.3 Development of Airports

In 1946 the *Federal Airport Act* was signed by President Harry S. Truman (Quilty, 2004). Due to the increase in passenger flights, infrastructure was needed to accommodate the growing industry. New runways and taxiways were constructed with funding from the act. Terminal buildings, although not covered under this act, were also heavily constructed during this time period. The costs were supported through local and private funding (Federal Airport Act of 1946).

A rapidly growing airline industry was cause for the Airport and Airway Development Act of 1970 (Quilty, 2004). The act established a trust fund from taxes on airline fares, freight, and fuel in order to make improvements towards the congestion and delays major airports were experiencing (Airport and Airway Development Act of 1970).

2.4 Air Transportation Today

On October 24, 1978, President Jimmy Carter signed the *Airport Deregulation Act*. The act eliminated government control over airfares and instead relied on the competitive market to drive ticket prices and services (Airline Deregulation Act of 1978). Once signed into law, airfare prices dropped significantly making air travel affordable to more passengers. Between 1979 and 1988 the average airfare per passenger decreased by nine percent (Government Accountability Office, 1996). The affordable price of flying and the addition of nonstop routes helped airlines and airports continue to grow.

2.4.1 Customer Satisfaction

Once flying to a destination became standard practice, expectations of the airlines rose. The United States Department of Transportation (DOT) has reported that flight problems, which include cancellations and delays, are the top complaint among airline passengers. In July 2014, 35% of complaints made to the airlines were regarding delayed and cancelled flights. In July of the previous year, these complaints were at 40% (United States Department of Transportation, 2014a). Research has been conducted to determine what can be done to ease customer dissatisfaction during lengthy tarmac delays. Providing food and beverage service, television programming, comfortable and clean conditions, and cell phone usage made delayed passengers less angry with the airline (Baranishyn, Cudmore, & Fletcher, 2010). During tarmac delays, passengers are protected by the Airline Passenger Bill of Rights Act of 2011. The act ensures that passengers have necessary services when they are experiencing tarmac delays (Airline Passenger Bill of Rights Act of 2011). The act required that airlines submit contingency plans on how they will accommodate passengers experiencing tarmac delays exceeding three hours. While solving the problems of delays as they occur may relax some frustrated passengers, determining and eliminating the problem is necessary in order to reduce the number of delay-related complaints.

2.4.2 Reporting

Since September 1987, the DOT requires all U.S. airlines with more than one percent of total passenger revenues to report their arrival and departure data for non-stop legs on a monthly basis. At that time, 12 total airlines met the requirements to report their data. As of 2013, there are 14 airlines included in the reporting. These airlines are listed in Appendix A.

To make on-time arrival statistics look more favorable, airlines once padded their expected arrival times. Even with these adjustments, airlines were still reporting delays. The extra time allotted for each flight also increased airline operating costs and allowed for fewer flights to be scheduled. This caused the airlines to reevaluate the practice of allocating too much extra time (Government Accountability Office, 1990).

Airlines utilize computer reservation systems (CRS), which provide information about airline schedules, availability, fares, and other services (Alexander & Yoon-Ho, 2004). These systems, which differ by airline, use travel time and historical taxi time for the departing and arriving airports to estimate the published arrival time. The Office of Airline Information, under the Bureau of Transportations Statistics, requires the airlines to report the on-time performance data from their CRS each month (Airline Service Quality Performance Reports). The office compiles the DOT required data into the On-

Time Flight Performance Report. There are 29 different delay related statistics that are required to be reported. These figures range from general information about the flight, such as flight number and route, to the difference in scheduled and actual arrival times. The full list is shown in Appendix B. The airlines are required to report data that involves any airport in the 48 contiguous states but can voluntarily report all domestic data (Airline Service Quality Performance Reports). The 14 airlines required to report have all elected to report all of their domestic data. Assembled reports of the data listed in Appendix B are released monthly to the public through the United States Bureau of Transportation Statistics' website.

2.5 Delays

Carriers must specify the reason for each late arriving flight in the Bureau of Transportation Statistics' (BTS) monthly reports with one of five justifications: Air Carrier, Extreme Weather, National Aviation System (NAS), Late Arriving Aircraft, or Security. The BTS defines the delay types as follows:

- Air Carrier: The cause of the cancellation or delay was due to circumstances within the airlines control (e.g., maintenance or crew problems, aircraft cleaning, baggage loading, fueling, etc.).
- Extreme Weather: Significant meteorological conditions (actual or forecasted) that, in the judgment of the carrier, delays or prevents the operation of a flight such as a tornado, blizzard or hurricane.
- National Aviation System (NAS): Delays and cancelations attributable to the national aviation system that refer to a broad set of conditions, such as non-

extreme weather conditions, airport operations, heavy traffic volume, and air traffic control.

- Late Arriving Aircraft: A previous flight with the same aircraft arrived late, causing the present flight to depart late.
- Security: Delays or cancellations caused by evacuation of a terminal or concourse, re-boarding of aircraft because of security breach, inoperative screening equipment and/or long lines in excess of 29 minutes at screening areas (United States Department of Transportation, 2014b).

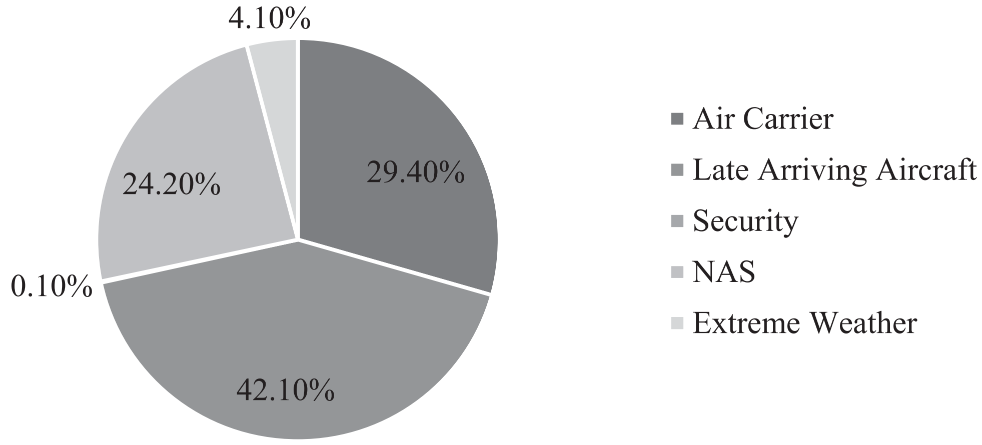


Figure 2.1 Percentage of Delay Types in 2013 (United States Department of Transportation, 2014b)

NAS delays will be further addressed and investigated as taxiing time and runway congestion fall into this delay category. Data obtained from the United States Department of Transportation (2014b), seen in Figure 2.1, shows the percentage of each type of delay in 2013. While the NAS category accounts for roughly 24% of all delays and only 7% of all flights each month, it is the easiest to resolve, as most of its conditions occur routinely rather than by random chance.

2.5.1 Taxiing

The time it takes to taxi from the end of the runway to the arriving gate can cause delays when high aircraft traffic is present. Waiting for aircraft to pass, crossing active runways, and moving long distances all contribute to high taxi times. Research conducted at the Massachusetts Institute of Technology has concluded that taxiing time varies by the time of day. Aircraft at Newark Liberty International Airport (EWR), in the best case, aircraft can take 15 minutes to taxi between gate and runway. On May 16th 2007, between the hours of 9:00 am and 1:00 pm the average taxi time fell near the 15-minute mark. Between the hours of 2:00 pm and 5:00 pm average taxi times reached upwards of 45 minutes (Simaiakis & Balakrishnan, 2009). Long taxi times during peak travel hours of the day pose a threat to achieving an on-time arrival. Even though roughly 72% of flights each month arrive on or before their scheduled arrival time, long taxi times are a factor to consider in the remaining delays. A diagram of EWR, as seen in Figure 2.2, shows that that the terminals and runways are a great distance from one another and that there are an abundance of taxiways. One can conclude that taxiing between the southernmost gate in Terminal A and the north end of runway 22L would take a significant amount of time simply by looking at the layout of the airport. Planes landing on runway 22L would need to yield to planes taking off and landing on runways 22R and 29 as well as planes entering and leaving from other gates. Diagrams of the airport's runways help assume that taxi time at EWR would take 15 minutes, an already high amount of time. Long landing queues in addition to long taxi times at airports of this magnitude most likely contribute to delays. The intersecting pattern of the runways at EWR could potentially be causing even longer taxi times and delays.

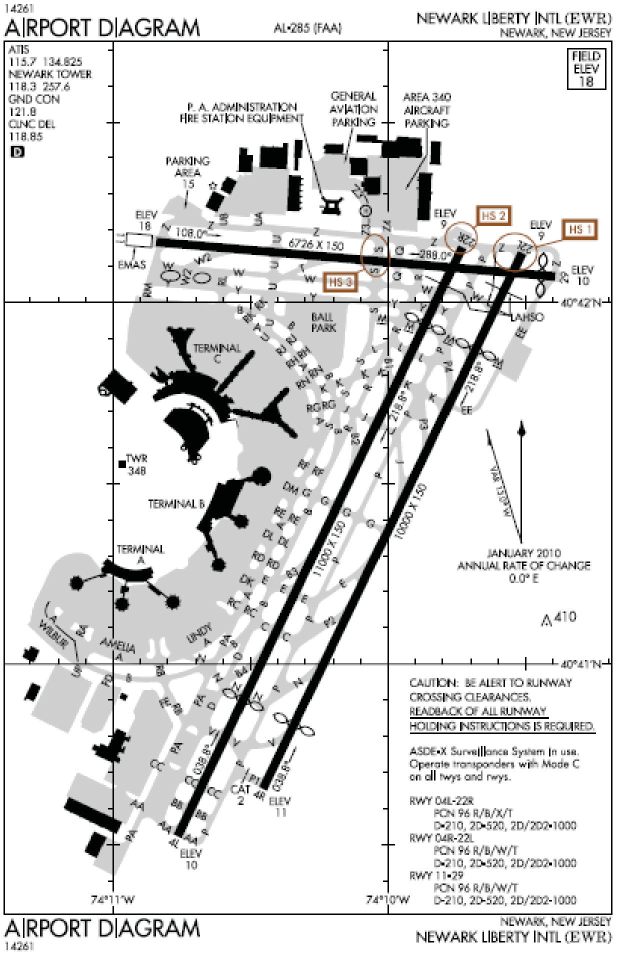


Figure 2.2 Diagram of Newark Liberty International Airport (Federal Aviation Administration, 2014b). Reprinted under public domain.

2.5.2 Queuing

An additional factor of arrival delays is the time spent waiting to land and take off. As only one aircraft can land on a runway at a time, multiple planes arriving to the same destination airport at the same time will have to wait to land. The occurrence is known as queueing. Queues are typically seen as waste in carrier operations and need to be evaluated and eliminated in order to achieve optimal production rates (Sternberg, 2012). Queueing of aircraft to take off and land has been studied by numerous research groups in order to make the process more efficient and less prone to delays. Stiverson and Rathinam (2011) have looked into runway-queue management problems and developed an algorithm to appropriately schedule arriving and departing aircraft to provide an optimal solution to queues causing delays at busy airports.

Queues are most likely to occur at high traffic airports. Airports in large metropolitan areas with multiple runways are more likely to experience frequent queuing. Remote airports with several flights a day are likely to never experience takeoff or landing queues due to minimal air traffic. Queues to arrive and depart are necessary for airports with multiple runways. Planes arriving at intersecting runways cannot land at the same time as they risk colliding at the interesting point of the runways. Their arrivals need to be staggered, which causes one plane to wait while the other lands. Additionally, arriving and departing aircraft both need to be cleared for takeoff/landing in a timely manner when they are occurring on the same runway. Therefore, these aircraft also need to be staggered to avoid incursions. Due to size and configuration, planes queuing at larger airports and airports sharing arriving and departing runways, especially during peak times, are more prone to delays.

2.5.3 Gate Availability

If a flight is delayed due to extreme weather, it will most likely arrive at its destination airport after its scheduled arrival time. If a significant amount of time has passed, a gate may not be available for the passengers to deplane. In such a case, aircraft will go into a holding pen and wait for a gate to become available.

The lack of available gates for late arriving flights is most likely to occur with smaller airlines and for flights that do not originate/terminate at the airline’s hub. Hartsfield Jackson International Airport (ATL) in Atlanta, Georgia is the headquarters of Delta Airlines. The airline occupies an overwhelming majority of the gates at ATL. If a Delta flight arrives substantially late to ATL, the airline has more than enough gates to accommodate the late flight. If a United Airlines flight arrives to ATL well past its scheduled arrival time, there may not be any gates available due to the already limited amount of United Airlines operated gates at that airport. The late flight would have to wait until a gate becomes available, which could be a substantial amount of time. As airport operations are responsible for gate assignments, what initially started as an extreme weather delay can end as an NAS delay.

2.6 Runway Configurations

There are four main types of runway configurations: single, intersecting, parallel, and open-V (Horonjeff, 2010). These terms refer to the orientations of the runways in relation to one another. While some airports may exhibit a variety of different configurations, these four are the base for all configuration designs.

2.6.1 Single

Single runways consist of one lone runway that accommodates both takeoffs and landings. The configuration is often seen in small regional airports that do not have heavy amounts of air traffic. Single runways can handle up to 100 flights per hour in ideal conditions, both inbound and outbound. (Horonjeff, 2010). With a majority of single runways, aircraft take off and arrive in the directions shown in Figure 2.3. The operating process allows for aircraft to land and take off within a short amount of time as aircraft in either direction do not have to wait for the other aircraft to clear the airspace. NAS related delays occurring on single runways are most likely to happen when the airport experiences high traffic.

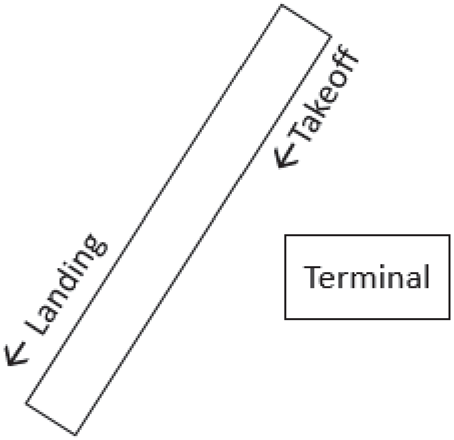


Figure 2.3 Single Runway Configuration

2.6.2 Intersecting

Intersecting runways consist of two or more runways that cross paths and share ground with one another. These runways are often used in locations with strong winds and/or limited expansion space. When wind speeds are not favorable for arriving and departing aircraft, one of the intersecting runways will go unused. The benefit of having intersecting runways is that one will always be available no matter the wind direction and speed. In low wind conditions, both runways can be used but takeoffs and landings need to be heavily monitored to avoid collisions at the intersecting points. Runways that have an intersecting point in the middle have a lower capacity than runways that intersect near either end (Horonjeff, 2010).

Runways that intersect are presumed to experience a higher frequency of NAS delays due to prolonged waiting. Queuing while waiting for the crossing runway to clear can cause long wait times to occur. Waiting to cross one of the runways while taxiing can also factor into delays. A typical takeoff and landing configuration for intersecting runways is seen in Figure 2.4.

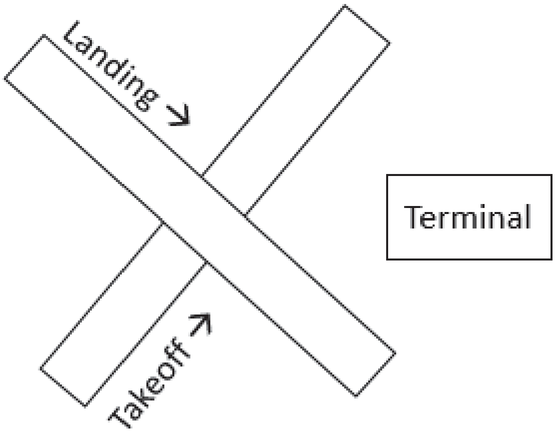


Figure 2.4 Intersecting Runway Configuration

2.6.3 Parallel

Parallel runways are defined as those in which more than one runway is present and situated at the same angle. A basic parallel runway configuration can be seen in

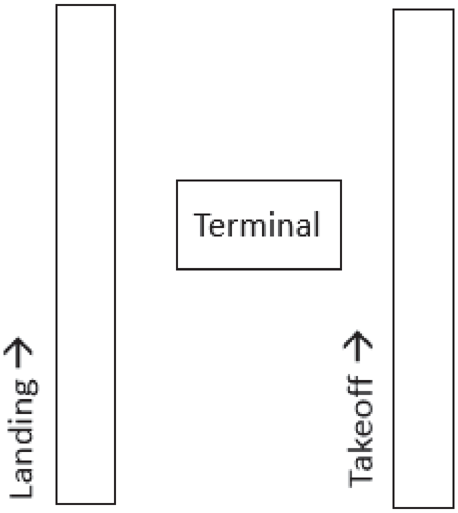
Figure 2.5. The capacity of parallel runways depends on the number of runways in parallel and the spacing between them. The spacing between parallel runways is classified as close, intermediate, or far apart in distance (Horonjeff, 2010). Close parallel is defined as having between 700 and 2500 feet between runways. Due to this proximity, close parallel runways can only be operated one at a time. Runways that are 2500 to 4300 feet apart are called intermediate spaced runways. Each runway can operate at the same time but only if one is used for arrivals and the other is used for departures. If there are more than two runways in parallel, the runways will alternate as arriving and departing runways. For example, consider three runways, named X, Y, and Z, with Y being in the middle. Runway X would operate for arrivals, Y for departures, and Z for arrivals. Parallel runways greater than 4300 feet apart are considered as far apart runways and can operate independently from one another. In this case, runways next to each other can accommodate both aircraft arrivals and departures simultaneously. Each of these spacing mode restrictions apply only to ideal flying conditions. In poor weather situations, most

parallel runways operate as single arriving only or single departing only.

Figure 2.5 Parallel Runway Configuration

The spacing between intermediate and far runways allows enough distance for a perpendicular taxiway between the runways. A taxiway of this sort will increase the capacity of the runways as smaller aircraft may not need the entire runway to land and can exit the runway sooner. While runway capacity would be increased, this would not necessarily be a positive change. More aircraft landing and then taxiing at slow speeds would cause a drastic increase in overall traffic, thus contributing to NAS related delays.

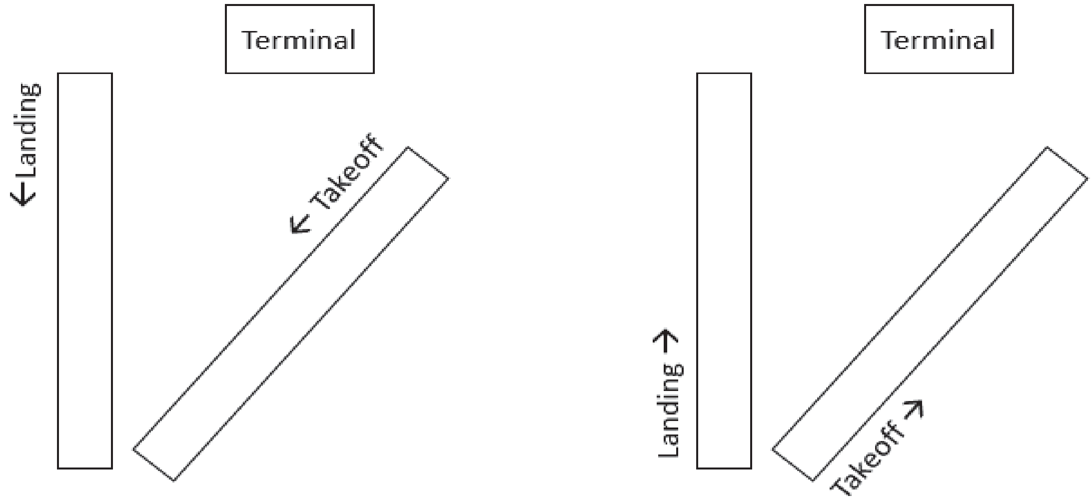
Researchers in the Netherlands have noted queueing issues with closely spaced runways and brainstormed different approaches for aircraft to take. Two approaches were investigated. First, a staggered approach procedure in which aircraft approaching the two runways were offset to allow one runway to be used at a time but also allowed aircraft for the second runway to approach the instant the aircraft on the first runway touched the ground. The second was a steeper approach procedure in which aircraft approaching one



runway came in at a steeper angle than aircraft arriving to the other runway. This gave the aircraft approaching both runways adequate space. Both procedures were simulated on two large airports. Each approach seemed promising in increasing runway arrival capacity and reducing the interference of near-simultaneous landings on closely spaced parallel runways (Janic, 2008).

2.6.4 Open-V

Open-V runways are those that are oriented in different directions that do not intersect (Horonjeff, 2010). If wind speeds were strong enough in one direction, the runway unfavorable to the prevailing wind would be inoperable. The remaining runway would act as if were at a single runway airport. Open-V runways can further be classified in two different ways: converging or diverging. A converging layout is one in which operations move towards the point at which the runways make the V shape. In ideal conditions, this pattern can see as many as 100 inbound and outbound flights per hour. Diverging runways are the opposite as operations start at the end of the V shape and move outwards from each other. The diverging pattern is more efficient as it can see up to 180 flights an hour in ideal conditions (Horonjeff, 2010). NAS delays would minimally occur in the open-V configuration, mostly due to taxiing. Visual comparisons of converging open-V runways and diverging open-V runways are shown in Figure 2.6.



Converging Open-V Runways

Diverging Open-V Runways

Figure 2.6 Open-V Runway Configurations

2.6.5 Restrictions and Considerations

The layout of an airport's runways is often chosen by factors other than available space. Typical weather conditions such as wind and visibility limit the directions and amount of aircraft an airport can accommodate. Runways are only usable when crosswinds do not exceed set limits and tailwinds are not greater than six knots (George Mason University, 2014). Intersecting runways in an "X" shape are often seen at airports that face adverse wind conditions, such as Chicago's Midway airport. The arrangement of runways allows for four different directional landings to accommodate all wind conditions.

Potential noise is also considered when trying to utilize multiple runways and increase system capacity. The largest airports in the United States often border residential and other densely populated areas; therefore keeping noise to a minimum is crucial to reducing complaints. For this reason, many airports are situated on bodies of water. Aircraft at these airports can take off with maximum thrust and not disturb those on the inland side of the airport. Most major airports still have noise restrictions in place. For example, at Boston Logan International Airport (BOS), no runway can be continuously used in one direction for more than four hours in order to reduce the noise nearby residents are exposed to (George Mason University, 2014).

Surrounding infrastructure and geographical features also influence runway configuration design. San Diego’s Lindbergh International Airport (SAN) is the busiest single runway airport in the United States. SAN is located in the heart of the city and has no room to expand due to its proximity to downtown San Diego, residential communities, and the San Diego Bay. In fact, ordinances are in place to limit the height of downtown buildings as a precaution to low approaching aircraft. SAN does not have the space for additional runways and will forever be a single runway airport despite surges in air traffic.

2.6.6 Ideal Configuration

While no single runway configuration is perfect for reducing taxi times, queuing, and delays, there is one airport in the United States with a configuration that could be considered the ideal. Travis Air Force Base in Fairfield, California does not serve commercial airlines, but its runway configuration nearly eliminates taxiing time and taxiing related delays. Figure 2.7 is a pictorial representation of the two runways at the military installation. Arriving aircraft land and briefly taxi to the terminal at the eastern end of the landing runway. Departing aircraft taxi to the westernmost side of the takeoff runway. Taxiing delays are practically eliminated as all taxiing occurs in the same spot right in front of the terminal. If commercial airports adopted this style of configuration, NAS delays would be minimized as a smooth flow of aircraft would be established.

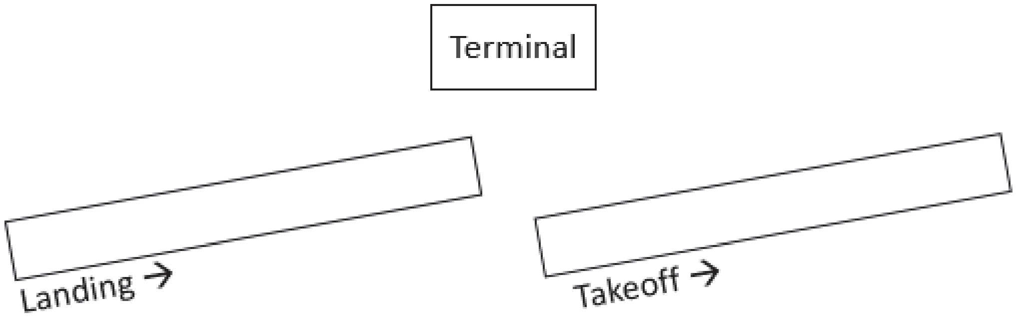


Figure 2.7 Travis Air Force Base Runway Configuration

2.7 Airport Categories

Every year the FAA publishes a detailed list of the number of departing passengers (enplanements), that each airport in the United States accommodated in the previous calendar year. The airports on this list are all primary commercial service airports and are classified by four different hub types as defined in Title 49 Section 47102 of the U.S. Code (2011):

1. Large Hub: 1% or more of annual passenger boardings.
2. Medium Hub: At least 0.25%, but less than 1% of annual passenger boardings.
3. Small Hub: At least 0.05% but less than 0.25% of annual passenger boardings
4. Nonhub: More than 10,000 enplanements but less than 0.05% of annual passenger boardings.

Airports that do not meet any of these requirements are classified as non-primary airports. If the airport has less than 2,500 enplanements in a given year, it is not considered a commercial service airport. An airports’ hub type can change from year to year based on changes in the volume of scheduled commercial passenger service.

2.8 Incursions

Incursions are defined as a scenario in which at least two aircraft occupy or intend to occupy the same geographical space (Singh & Meier, 2004). With runways that intersect and a plethora of taxiways, high traffic airports have the greatest risk of runway incursions. Singh and Meier (2004) stated that incursions can be caused by three factors:

1. Pilot Deviations— Errors committed by the pilot during movement on the airport surface
2. Operational Errors—Wrong clearances issued by the controller
3. Vehicle or Pedestrian Deviations—Causing an incursion on the runway

Incursions and close calls have rapidly increased over the past 20 years with the leading cause being pilot deviations. Incursions most commonly occur with aircraft attempting to taxi across an active runway. This is most likely to occur at airports with intersecting or parallel runways. In the worst case, an actual collision would lead to extreme delays as runways and taxiways would be shut down.

Gaps in communication can occur as air traffic controllers aim to move aircraft as quickly as possible. Controllers and pilots can lose their situational awareness if they are rushed into trying to meet their published arrival time. If airports with intersecting and parallel runways do in fact achieve the largest amount of late arrivals, perhaps altering the arrival times based on runway configurations would help avoid incursions involving poor judgment by pilots and ground controllers.

2.9 Statistical Testing

Comparing data between different runway configurations is best done using known statistical tests. Unlike visually inspecting the data in each category, statistical tests mathematically make comparisons amongst groups of data and provide results in order to draw appropriate conclusions.

2.9.1 Analysis of Variance

An analysis of variance (ANOVA) assesses whether observed differences among sample means of quantitative data are statistically significant by comparing several population means of normally distributed data (Moore & McCabe, 2014). An ANOVA can help determine if the means of several independent samples are significantly different. There are many different types of ANOVA tests, including one-way ANOVAs and two-way ANOVAs.

Both ANOVA tests require that data meets three conditions before the test can be performed (Moore & McCabe, 2014):

1. The data must be normally distributed.
2. The groups of data must have equal variances.
3. The samples must be independent of one another.

Normality is established by using an Anderson-Darling Test and equal variances are determined by constructing multiple comparison intervals for the standard deviation. Both can be run using statistical software packages.

In the event that given data is not normally distributed, a Kruskal-Wallis test is used in place of an ANOVA test. A Kruskal-Wallis test investigates a null hypothesis stating that yields have the same distribution in all groups and an alternative hypothesis that yields are systematically higher in some groups than others (Moore & McCabe, 2014). This test focuses on the rankings of the median of each group rather than the mean which is the focus of an ANOVA test.

2.9.1.1 One-Way ANOVA

A one-way ANOVA is used to test the significance in the means of data that differ by one factor. Only one independent variable and one dependent variable are present in the data set. As with any statistical test, null and alternative hypotheses need to be established. The null hypothesis of an ANOVA states that all means between the desired groups are the same while the alternative hypothesis suggests that the means are not equal. Once data has been collected, summary statistics such as sample size, mean, standard deviation, and variance are determined for each set of data.

To complete the ANOVA, degrees of freedom, sum of squares, and mean square are calculated within and between each group. The F value and the p-value are also calculated in order to make a decision about accepting or rejecting the null hypothesis. Multiple calculations are required to successfully complete an ANOVA. The process of conducting a one-way ANOVA is simplified by using a statistical software package. The output from the chosen program will provide a p-value for the test. If the p-value is less than a predetermined alpha level, typically 0.05, then the null hypothesis will be rejected. If the p-value is greater than the alpha level, the null hypothesis will fail to be rejected.

2.9.1.2 Two-Way ANOVA

In a two-way ANOVA, two independent variables are tested against a dependent variable. There are three different sets of null and alternative hypotheses for this test. The first determines if there is a difference in the effect of the first independent variable, the second determines if there is a difference in the effect of the second independent variable and the third determines if there is any interaction between the two independent variables.

The calculations used to complete the two-way ANOVA are the same as those of the one-way ANOVA, the only difference being the additional calculations for the interaction between the two independent variables. As with the one-way ANOVA, the test is best completed using a statistical software package. The statistical output will provide a p-value for each hypothesis. Each p-value should be compared to the predetermined alpha level and each null hypothesis should be or rejected or fail to be rejected in the same manner as the one-way ANOVA. If any null hypotheses are rejected additional analyses are recommended to clarify the nature of the differences between the means, known as post hoc tests (Moore & McCabe, 2014).

2.10 Summary

Studies on different airport runway configurations and delays that occur on the ground have been researched individually but never together. Statistically finding a correlation between the two can potentially lead to new standards in evaluating runway choices, procedures in flight scheduling, and customer satisfaction. After looking at the prior issues of the aviation industry and passenger flight, reducing delays seems to be a growing concern. Starting in the early 20th century, aviation problems have evolved from developing early aviation technology, to how to carry the most mail, to how to carry the most people. Now that the industry has grasped the movement of people, the next industry-wide issue is getting people where they need to be at the time they are promised. While there are uncontrollable factors to achieving this promise, the factors of NAS that can be changed need to be addressed, analyzed, and statistically studied.

CHAPTER 3. METHODOLOGY

The following chapter outlines a methodology to further acknowledge trends in aircraft arrival delays. An in-depth look at past data helps relate delays to runway configurations. Statistical analyses were conducted on the acquired data to draw conclusions about different runway configurations. The methodology presented was used to answer the research question: How does airport runway configuration contribute to passenger aircraft arrival delays for the 14 busiest commercial airlines' domestic flights at airports with FAA operated air traffic control towers?

3.1 Data Acquisition

The methodology aimed to answer the research question by looking at multiple sources of preexisting data. The Bureau of Transportation Statistics (BTS) within the U.S. Department of Transportation (DOT) houses the Research and Innovative Technology Administration (RITA). RITA provides vast amounts of transportation data to the public via their website (United States Department of Transportation, 2014c). Within the RITA aviation data library there are over 30 databases with air travel data and statistics. The Airline On-Time Performance Data database was accessed to gather pertinent on-time arrival data for this study. The database allows data to be sorted by many different variables. Available categories relevant to this study include: time period, airline, destination airport, arrival performance, flight summaries, and cause of delay. The RITA databases provide data from all airports that are served by U.S. commercial airlines on a regularly scheduled basis. These airports can be served by many airlines and offer flights to multiple destinations, such as Los Angeles International Airport, or feature service from one airline such as Cedar City Regional Airport in Cedar City, Utah, which only provides flights by Delta Airlines to Salt Lake City. Each airport in the study that is required to report on-time data, regardless of size and available services, was investigated to determine the configuration pattern of its runways.

The on-time performance percentages per airport in the Airline On-Time Performance Database can be classified by the origin or destination airport. If a flight was to take off from O'Hare International Airport (ORD) in Chicago and land on time at La Guardia International Airport (LGA) in New York City the statistics under origin airport (ORD) would show for the flight landing on time at LGA. Under the analysis for the destination airport, this flight being on time would fall under the statistics for LGA. Because this study aimed to find trends in aircraft arrivals, the destination statistics were more favorable because they account for aircraft arriving at that airport, regardless of where they originated from. The exact data for this study was taken from the "DestAirportID" analysis and filtered by "*OntimeArrivalPct" as well as by the year 2013. These filters provided the correct statistics and the information for the airports essential for this study. The steps taken to get to the data from the main RITA website to the resulting output are outlined visually in Appendix C.

Airports located in Alaska, Hawaii, and other United States territories were removed from the data. The remaining airports were those only located in the contiguous United States.

3.1.1 FAA Operated Airports

The Federal Aviation Administration provides airport data through their Operations Network, known as OPSNET. OPSNET provides the Air Traffic Activity Data System (ATADS) which contains official NAS air traffic operations data and presents it to the public (Federal Aviation Adminstration, 2009d). The Facility Information report provides a list of all 3308 airport facilitates in the United States. The output of the report defines a classification for each airport which provides detail about the airport's air traffic control systems. Many facilities fall under the Non-FAA Facility category. This category defines airports as a facility which is not under contract to the FAA and has the option of using its own employees or subcontracting air traffic control services (Federal Aviation Administration, 2009a). Any airport that was listed in the RITA database and is listed as a Non-FAA Facility by the ATADS data was removed from the dataset. Removing these airports leaves the dataset with airports that are controlled under the same organization and policies

3.1.2 Joint-Use Airports

There are 23 airports in the United States that are considered Joint-Use Airports. These airports are owned by the Department of Defense and both military and civilian aircraft share use of the airfield (Federal Aviation Administration, 2014c).

As military operations take precedence over commercial flights, any airport listed as Joint-Use by the FAA was removed from the data. The list of all Joint-Use airports in the United States is shown in Appendix D.

3.1.3 Runway Classification

The process seen in Figure 3.1 was used to classify each of the remaining eligible airports taken from the database. Each airport was individually entered into the FAA's Airport Diagram webpage, shown in Appendix E. First, the number of runways the airport has was determined and recorded. The airport was classified as a Single Runway airport if it had only one runway. If the airport had two runways, it was necessary to determine if the runways intersected with one another. The airport was classified as Intersecting Runways if they did intersect and Non-Intersecting Runways if they did not. Different layouts for two runways that are classified as Intersecting Runways are seen, but not limited to, the configurations shown in Figure 3.2. Due to similarities in their configurations and takeoff and landing practices, parallel runways and open-V runways were both classified as Non-Intersecting for the purpose of this study. Potential cases of non-intersecting runways for airports with only two runways are seen in Figure 3.3.

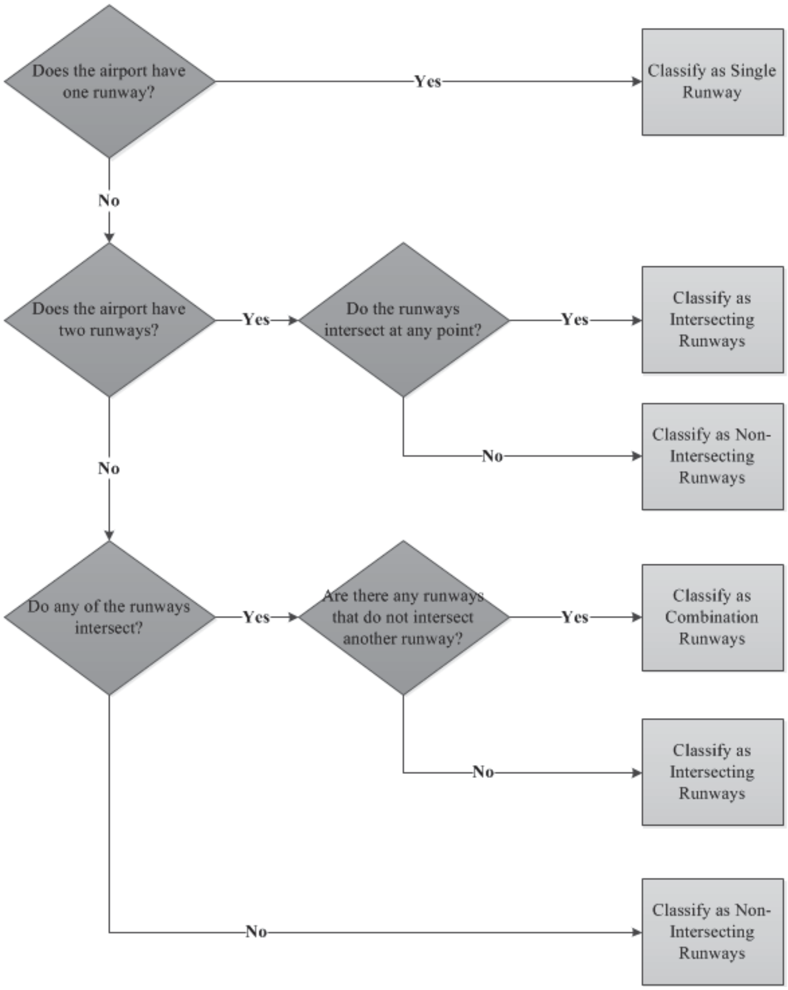


Figure 3.1 Airport Classification Process

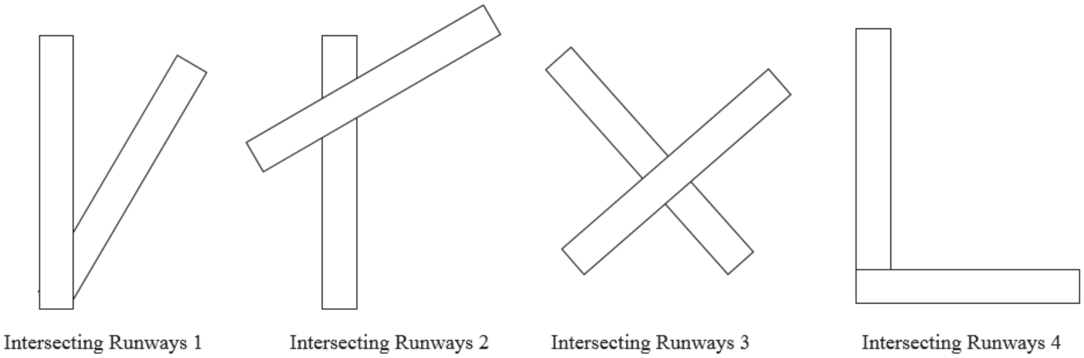


Figure 3.2 Potential Intersecting Runways for Airports with Two Runways

Once it was determined that an airport with more than two runways had intersecting runways, it was then classified as either Intersecting Runways or Combination Runways. To be classified as Intersecting Runways, airports with more than two runways must have all of the runways intersecting with one another. If there were any runways in this scenario that did not touch all other runways, the airport was classified as having Combination Runways. Airports exhibiting both intersecting and non-intersecting runways fell in this category due to the chance of operating under either classification if one or more runways were not operational at any time. Examples of classifications for airports with more than two runways are seen in Figure 3.4.

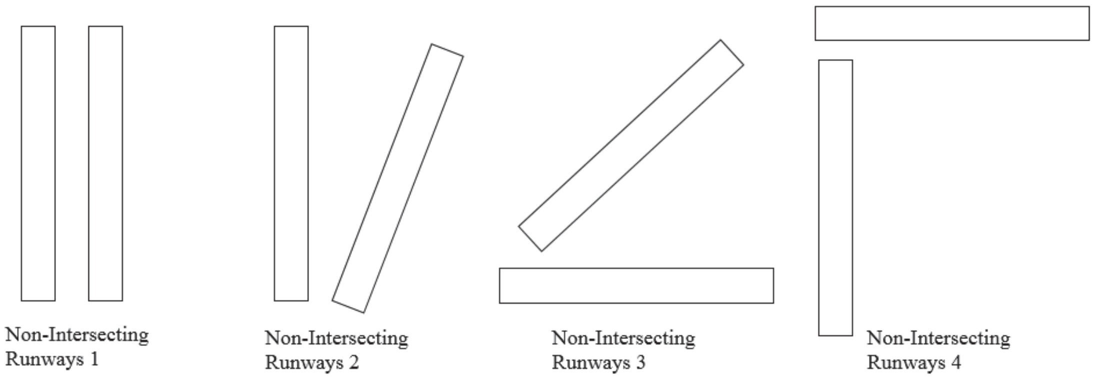


Figure 3.3 Potential Non-Intersecting Runways for Airports with Two Runways

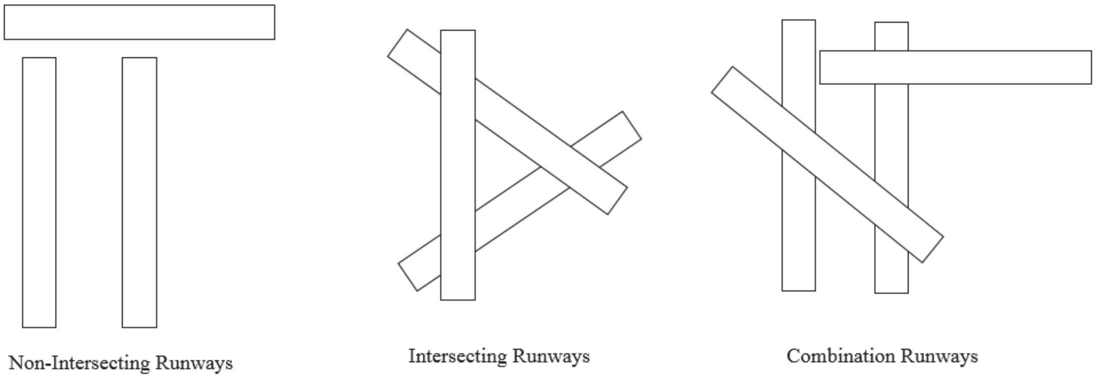


Figure 3.4 Potential Classifications for Airports with More Than Two Runways

3.1.4 Hub Classification

After being classified by runway configuration, each airport was categorized as either Hub or Nonhub based upon where it fell on the enplanement list for the 2013 calendar year. Airports that the FAA had classified as large hub, medium hub, and small hub were combined to signify Hub airports. The airports listed as nonhub remained in the Nonhub category for the study. Further dividing each runway configuration as Hub or Nonhub helped distinguish between arrival delays at airports with different amounts of traffic as Hub airports may be more susceptible to delays due to more passengers and more flights.

After the removal of airports that served less than 10,000 passengers, or non-primary airports, the list of airports was then divided into the final eight configuration groups.

1. Single Runway—Hub
2. Single Runway—Nonhub
3. Intersecting Runway—Hub
4. Intersecting Runway—Nonhub
5. Non-intersecting Runway—Hub
6. Non-intersecting Runway—Nonhub
7. Combination Runway—Hub
8. Combination Runway—Nonhub

3.1.5 Software

Microsoft Excel was utilized to organize the list of airports by runway configuration and hub type. The data types included airport information, percentage of on-time arrivals, enplanements for the 2013 calendar year, and hub status. These data were kept in the worksheet for easy retrieval for later analysis. The statistical software packages SPSS and Minitab were used to conduct tests, analyze the data from the different runway configurations, and plot the data in appropriate graphs.

3.2 Analysis

The data were required to meet all conditions of running an ANOVA before the test was performed. First, the on-time arrival percentage was plotted in a histogram and checked for normality by conducting an Anderson Darling test. Multiple comparison intervals for the standard deviation of each category were constructed to determine if the groups have equal variances. These tests were both conducted in Minitab. Since the data from one airport has no effect on the data from another airport, the airports are independent samples.

After the conditions of normality and equal variances were met, a two-way ANOVA was run in SPSS. The two-way ANOVA tested for significance in the on-time arrival percentage at airports for each runway configuration and their appropriate hub classification. It also determined if the interaction of the two independent variables had any significance. The two-way ANOVA tested the following three hypotheses based on an alpha level of 0.05:

1. H_{01}: $\mu_{single} = \mu_{intersecting} = \mu_{non\text{-}intersecting} = \mu_{combination}$

   $H_{\alpha 1}$: not all μ are equal

2. H_{02}: $\mu_{hub} = \mu_{nonhub}$

   $H_{\alpha 2}$: not all μ are equal

3. H_{03}: There is no significant interaction between configuration and hub classification

   $H_{\alpha 3}$: There is a significant interaction between configuration and hub classification

3.3 Threats

Airports were classified based on their runway configuration as of December 2014. The analyzed data were taken from previous years and in that time runways may have been closed due to construction, weather, operating costs, were not built at that time, or other factors. The best effort was made to determine that the airports are classified in the configuration they exhibited at the time of data collection. Unavoidable inaccuracies in identifying configurations also threatened the validity of the results.

3.4 Summary

This study commenced by retrieving data from the Airline On-Time Performance Database and eliminating Non FAA Facilities and Joint-Use airports. Once the on-time arrival percentage for each of the qualified airports was obtained, the listed airports were classified by one of four runway configurations. Within each configuration the data were further categorized as Hub or Nonhub. After eight categories were developed, two different two-way ANOVAs were run. One for on-time arrival percentage and the other for the taxi-in time statistic.

CHAPTER 4. PRESENTATION OF DATA AND FINDINGS

The following chapter presents the executed methodology that was outlined in Chapter 3. Once the data were obtained, they were classified into appropriate groups and the statistical analyses were performed. The chapter displays descriptive data for all of the classification categories and the output from the statistical test.

4.1 Data Removal and Classification

The initial list of airports, their corresponding location information, and on-time arrival percentage were collected and organized in Microsoft Excel. The column indicating airport location was filtered to display airports located in Alaska, Hawaii, Puerto Rico, the Virgin Islands, and other United States territories. The 32 resulting airports were removed from the data.

The list of all airports from the ATADS Facility Information report were compared to the remaining 286 airports. Any airport listed as a Non-FAA facility was removed from the data. This resulted in another 44 airports being removed from the dataset.

The list of Joint-Use airports was compared to the remaining 242 airports. One airport was removed from the data, leaving 241 airports. Three other RITA reportable airports appeared on the Joint-Use list but were previously eliminated from the data.

Each airport was entered into the FAA's Airport Diagram website and its runways were appropriately classified by a visual inspection of the airport diagram that the FAA had on file on December 3, 2014.

The number of enplanements in 2013 and the airports hub status were recorded per to the List of Commercial Service Airports based on CY2013 Enplanements provided by the FAA. Orlando Sanford International and St Pete-Clearwater International, both Small Hub, Combination Runway airports, appear on the enplanement list but are not a part of the RITA database. While each airport served over 500,000 passengers in 2013, the scheduled passenger services were only provided by Allegiant Air. This low-cost airline, along with Spirit Airlines, makes up less than 1% of scheduled flights in the industry so the two airports were not included in the data even though they experience ample passenger traffic.

Once completed, the data were filtered by number of enplanements in 2013. The airports that did not serve at least 10,000 passengers were removed from the data since they are not considered primary airports. Only one remaining airport experienced less than 10,000 enplanements, leaving 240 airports in the dataset and ready for analysis. The frequency of on-time arrival percentages for these airports was plotted in Minitab and shown in Figure 4.1. The full spreadsheet of data eligible for analysis is displayed in Appendix F and the data of each airport eliminated from the final dataset in displayed in Appendix G.

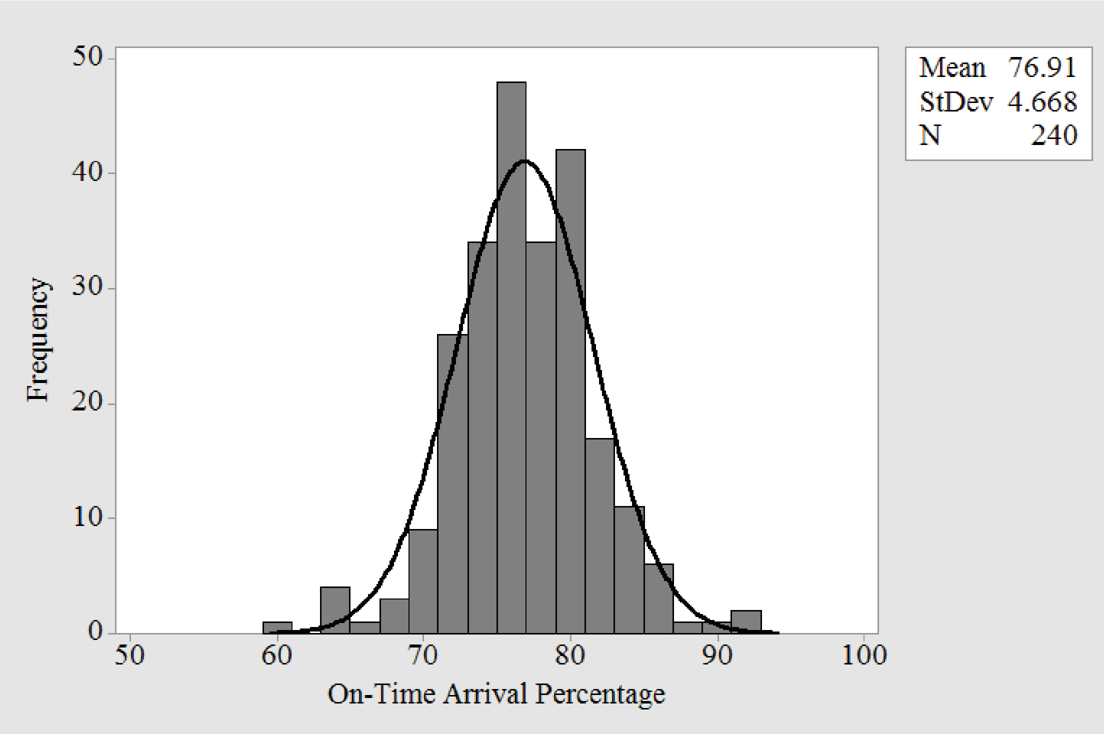


Figure 4.1 Histogram of All On-Time Arrival Percentages

4.2 ANOVA Conditions

In order to meet the first assumption for running a two-way ANOVA an Anderson Darling test was performed in Minitab to determine if the data were normally distributed. The resulting probability plot is shown in Figure 4.2. The test returned as normally distributed, p= 0.057. The majority of on-time arrival percentages fell along the normal distribution line in Figure 4.2, indicating a normal distribution.

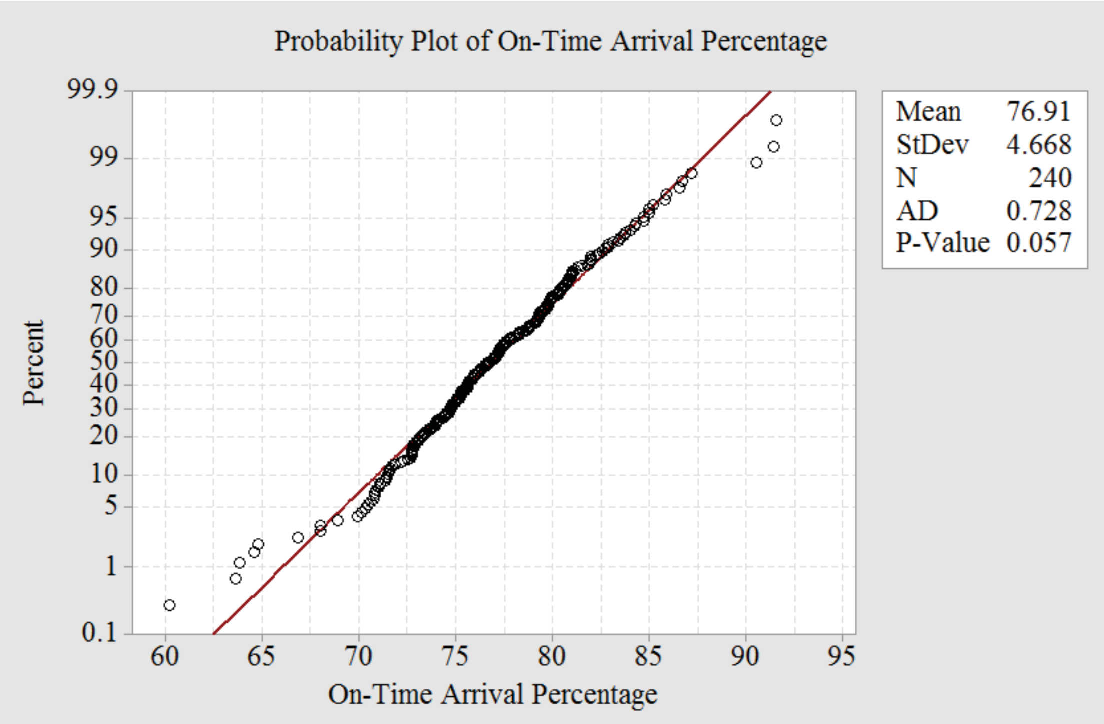


Figure 4.2 Probability Plot of On-Time Arrival Percentages

The final cut of 240 airports was appropriately filtered to establish the number of airports in each of the eight configuration/hub groups. The counts of airports as well as totals for each runway and each hub category are outlined in Table 4.1. The Intersecting Runway configuration had the most airports with 94 while Single Runway airports accounted for the fewest with 24 of the 240 total airports. Within the Hub category, Single Runway airports were far fewer, making up only 7% of the total Hub airports. The three remaining categories accounted for 23%, 33%, and 37% of the airports in the Hub category.

Table 4.1

Final Airport Category Counts

	Hub Type		
Configuration	Hub	Nonhub	Total
Single	8	16	24
Intersecting	27	67	94
Non-Intersecting	39	19	58
Combination	44	20	64
Total	118	122	240

The categories were tested for equal variances by constructing multiple comparison intervals in Minitab. The resulting output of the test is shown in Figure 4.3. The multiple comparisons intervals confirm that the groups of data have equal variances at the 0.05 alpha level, *p*=.058, due to the intervals all overlapping. As mentioned in Chapter 3, the data from one airport has no effect on the data from another airport, therefore, the airports are independent samples. As the conditions for running a two-way ANOVA were all met, the test proceeded.

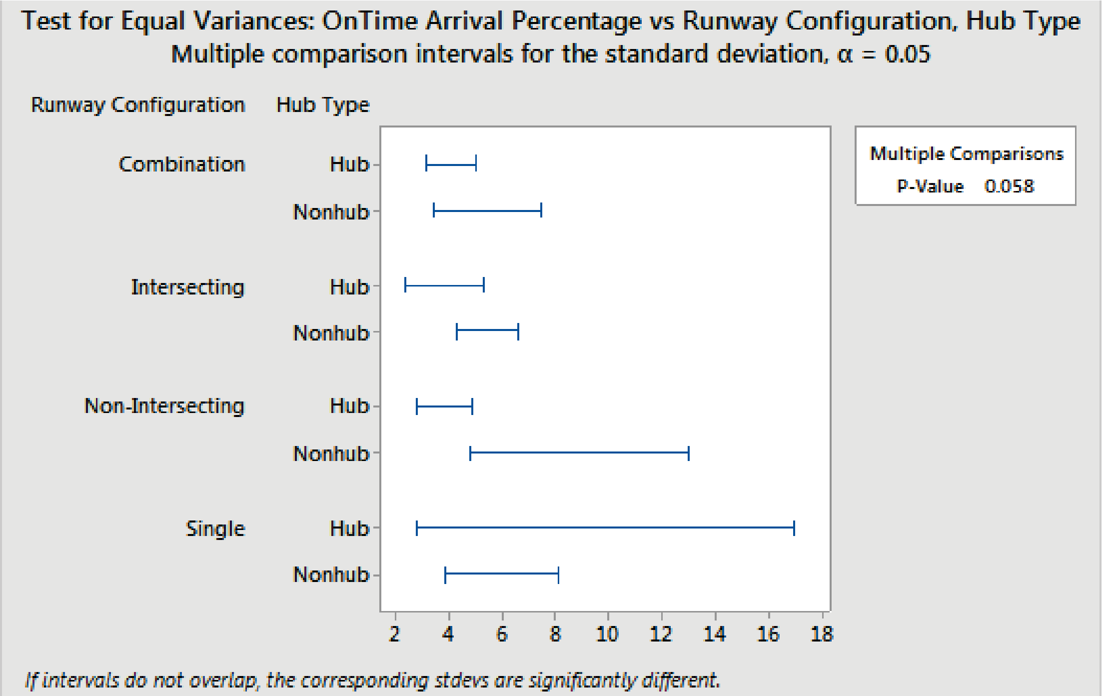


Figure 4.3 Test for Equal Variances

4.3 On-Time Arrival Two-Way ANOVA

After the assumptions were met, the data were transferred into SPSS and a two-way ANOVA was run to test the hypotheses presented in Chapter 3. The descriptive statistics for the test were generated and are seen in Table 4.2.

Table 4.2

Descriptive Statistics for On-Time Arrival Percentage Data

Category	Mean	Std. Deviation	N
Combination			
Hub	76.84	3.751	44
Nonhub	76.35	4.634	20
Intersecting			
Hub	76.31	3.278	27
Nonhub	76.12	5.410	67
Non-Intersecting			
Hub	78.10	3.458	39
Nonhub	78.48	7.212	19
Single			
Hub	80.27	5.359	8
Nonhub	76.47	4.993	16

The marginal means for each runway/hub configuration were plotted in Figure 4.3. The plot shows one line per runway configuration. Any lines that cross one another are seen to have an interaction but need to further be confirmed that the interaction is significant. From the plot, it is assumed that Single Runways and Non-intersecting Runways have significance with one another when compared against hub type. Lines that are near-parallel indicate that there is no significant interaction between them. Because Single Runways were the only configuration type to display a negative slope, it was assumed that the two-way ANOVA would indicate a significant interaction in Single Runways.

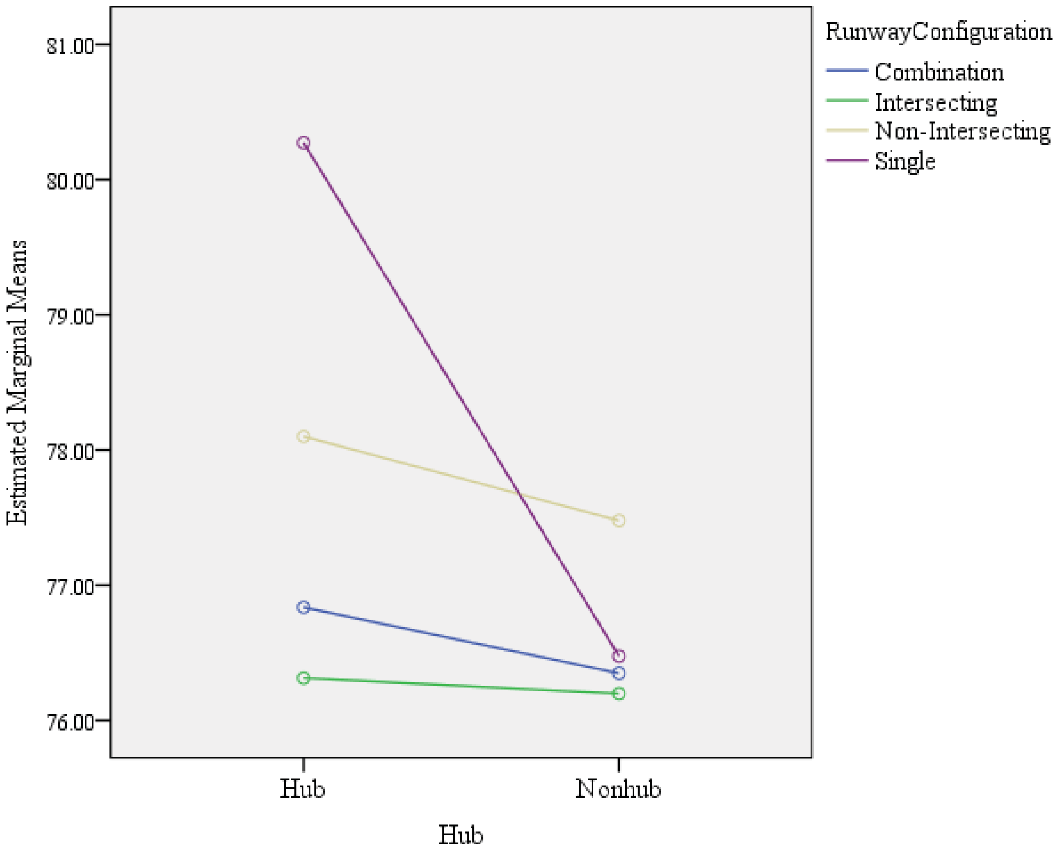


Figure 4.4 Estimated Marginal Means Plot of On-Time Arrival Percentages

The output for the two-way ANOVA that analyzed the on-time arrival percentages is seen in Table 4.3. The test looked for a significance in runway classifications as well as hub types, and then for an interaction between the two.

Table 4.3

Two-Way ANOVA Output for On-Time Arrival

Source	SS	df	MSE	F	*p*-value
Runway Classification	123.367	3	41.122	1.358	0.129
Hub Type	64.624	1	64.624	2.997	0.085
Runway*Hub	58.401	3	19.467	0.093	0.440
Error	5001.880	232	21.560		
Total	1424660.882	240			

The two-way ANOVA resulted with no significant effect of runway configurations on on-time arrival percentage at the 0.05 alpha level, F(3,232)=1.358, *p*=.129. The hub type, F(1,232)=2.997, *p*=.085, and the interaction of hub type and runway classification, F(3,226)=0.093, *p*=.440 were also not significant. Due to no significance at the 0.05 alpha level in any of the three tested sources, no post hoc test was necessary.

4.4 Summary

This chapter presented the results of the conducted analysis. The data were collected and appropriately reduced. The final set of 240 airports was categorized and plotted then the on-time arrival percentage was run in a two-way ANOVA comparing runway configuration and hub/nonhub status. The results of the analysis will be discussed in detail in Chapter 5 and appropriate conclusions will be made.

CHAPTER 5. CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

The following chapter evaluates the output of the test run in Chapter 4. The test results are compared their hypotheses and discussed in order to draw conclusions about the entire dataset and answer the research question: how does airport runway configuration contribute to passenger aircraft arrival delays for the 14 busiest commercial airlines' domestic flights at airports with FAA operated air traffic control towers? Recommendations for further research and analysis are also made.

5.1 On-Time Arrival Two-Way ANOVA Conclusions

The initial two-way ANOVA compared runway classification and hub type against on-time arrival percentages. The analysis tested the following hypotheses:

1. H_{01}: $\mu_{\text{single}} = \mu_{\text{intersecting}} = \mu_{\text{non-intersecting}} = \mu_{\text{combination}}$

   $H_{\alpha 1}$: not all μ are equal

2. H_{02}: $\mu_{\text{hub}} = \mu_{\text{nonhub}}$

   $H_{\alpha 2}$: not all μ are equal

3. H_{03}: There is no significant interaction between configuration and hub classification

   $H_{\alpha 3}$: There is a significant interaction between configuration and hub classification

The first set of null and alternative hypotheses focused on the configuration of the runways, testing if the means between Single Runways, Intersecting Runways, Non-Intersecting Runways, and Combination Runways were all equal or not. The two-way ANOVA, F(3,232)=1.358, *p*=.129, resulted with a p-value greater than the 0.05 alpha level.

The second set of hypotheses were set to determine if the means between Hub and Nonhub airports were equal or not equal. The two-way ANOVA, F(1,232)=2.997, *p*=.085, resulted with a p value greater than the 0.05 alpha level

The third and final set of null and alternative hypotheses tested for a significant interaction between runway configuration and hub type. The two-way ANOVA, F(3,226)=0.093, *p*=.440, also resulted with a p-value greater the alpha level of 0.05.

Table 5.1

Two-Way ANOVA Summary of Results

Source	Significance	Alpha	Null Hypothesis	Status
Runway Classification	0.129	0.05	H_{01}	Fail to Reject
Hub Type	0.085	0.05	H_{02}	Fail to Reject
Runway*Hub	0.440	0.05	H_{03}	Fail to Reject

Because all three tests within the two-way ANOVA resulted in p-values greater than the 0.05 alpha level, each of the three null hypotheses failed to be rejected. The summarized results of the two-way ANOVA are illustrated in Table 5.1. Failing to reject all null hypotheses indicates that the means of runway configuration are equal, the means of hub type are equal, and there is no significant interaction between runway configuration and hub type.

5.2 Answer to Research Question

The analysis performed on the airport data was conducted to answer the research question: how does airport runway configuration contribute to passenger aircraft arrival delays for the 14 busiest commercial airlines' domestic flights at airports with FAA operated air traffic control towers?

By failing to reject all three null hypotheses presented in the two-way ANOVA, there is significant evidence to conclude that runway configuration does not contribute to passenger aircraft arrival delays for the 14 busiest commercial airlines' domestic flights at airports with FAA operated air traffic control towers.

5.3 Recommendations for Future Work

The conclusions drawn in this analysis would be further confirmed if the tests were repeated across multiple years of data. If data from different years resulted in the same trends, then more precise conclusions could be drawn. If the same data for a different year showed different results, further analysis would be necessary in determining why.

Additionally, running the same analysis with data from other countries could determine if the United States' on-time arrivals and runway configurations behave in the same way as the rest of the world.

5.4 Summary

This thesis has concluded that if a new airport were to be built that expected to serve more than 0.05% of annual passenger boardings, no specific runway configuration would amount in more on-time arrivals than any other.

In order to reduce the number of aircraft arrival delays altogether, there is no specific runway configuration that needs to be further studied among these four configurations as they all statistically have equal mean on-time arrival percentages. Delays as a whole would need to be investigated across the industry rather than at airports with specific runway configurations.

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APPENDICES

Appendix A Airlines With At Least One Percent of Scheduled Passenger Service

According to the September 2014 Air Travel Consumer Report (United States Department of Transportation, 2014a), the following airlines account for at least one percent of scheduled passenger service and are therefore required to report their on-time performance statistics on a monthly basis:

1. AirTran Airways
2. Alaska Airlines
3. American Airlines
4. Envoy (formerly American Eagle)
5. Delta Airlines
6. ExpressJet Airlines
7. Frontier Airlines
8. Hawaiian Airlines
9. JetBlue Airways
10. SkyWest Airlines
11. Southwest Airlines
12. United Airlines
13. US Airways
14. Virgin America

As of January 2014, American Airlines and US Airways report their data together and appear as American Airlines. Additionally, AirTran Airways and Southwest airlines began reporting together starting January 2014 and appear as Southwest Airlines. Starting January 2015, Spirit Airlines is required to report their data as they had surpassed one percent of scheduled passenger services in 2014.

Appendix B Required On-Time Performance Statistics

1. Carrier and flight number.
2. Aircraft tail number.
3. Origin and destination airport codes.
4. Published OAG departure and arrival time for each scheduled operation of the flight.
5. CRS scheduled arrival and departure time for each scheduled operation of the flight.
6. Actual departure and arrival time for each operation of the flight.
7. Difference in minutes between OAG and CRS scheduled arrival times.
8. Difference in minutes between OAG and CRS scheduled departure times.
9. Actual wheels-off and wheels-on times for each operation of the flight.
10. Date and day of week of scheduled flight operation.
11. Scheduled elapsed time, according to CRS schedule.
12. Actual elapsed time.
13. Amount of departure delay, if any.
14. Amount of arrival delay, if any.
15. Amount of elapsed time difference, if any.
16. Casual code for cancellation, if any.
17. Minutes of delay attributed to the air carrier delay, if any.
18. Minutes of delay attributed to extreme weather delay, if any.
19. Minutes of delay attributed to the national aviation system, if any.

20. Minutes of delay attributed to security, if any.
21. Minutes of delay attributed to a previous late arriving aircraft, if any.
22. For gate returns, first gate-departure time at origin airport.
23. Total ground time away from gate for all gate/air returns at origin airport, including cancelled flights—actual minutes.
24. Longest time away from gate for gate return or cancelled flight.
25. Three-letter code of airport where diverted flight landed.
26. Wheels-on time at diverted airport.
27. Total time away from gate at diverted airport.
28. Longest period of time away from gate at diverted airport.
29. Wheels-off time at diverted airport (Airline Service Quality Performance Reports, 2004).

Appendix C Retrieval of Data from RITA Database

The following steps and images show how to navigate the RITA website to retrieve the on-time arrival percentage data:

1. Navigate to http://www.transtats.bts.gov/homepage.asp
2. Click on Database Directory under the Resources section.

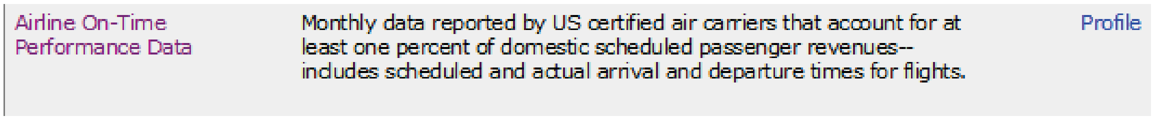
Airline Activity : National Summary (U.S. Flights)

	2013 *	2014 *	Change
Enplaned Passengers (million)	646	662	2.5%
Departures (000)	8,756	8,530	-2.6%
Freight/Mail (million lbs)	19,932	20,305	1.9%
Load Factor (%)	83.5	84.5	1.0 points
Airlines with scheduled service	97	98	1.0%

* 12 months ending December of each year

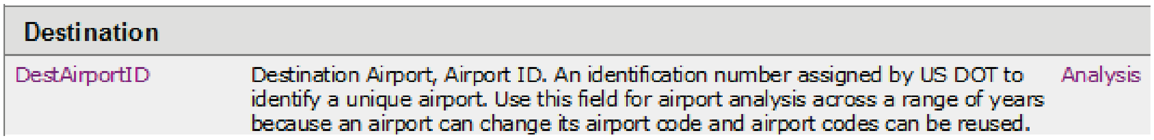
Airlines	Share
Southwest	16.9%

3. Select Airline On-Time Performance Data from the list of databases.



Airline On-Time Performance Data	Monthly data reported by US certified air carriers that account for at least one percent of domestic scheduled passenger revenues--includes scheduled and actual arrival and departure times for flights.	Profile

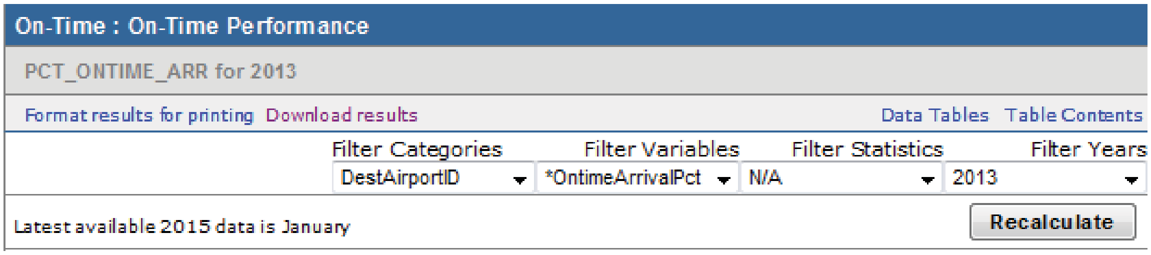
4. Click On-Time Performance.
5. Scroll down to find DestAirportID and select the Analysis link to the right of the description.



Destination

DestAirportID	Destination Airport, Airport ID. An identification number assigned by US DOT to identify a unique airport. Use this field for airport analysis across a range of years because an airport can change its airport code and airport codes can be reused.	Analysis

6. Select the appropriate filters and click recalculate to display the correct data.



On-Time : On-Time Performance

PCT_ONTIME_ARR for 2013

Filter Categories: DestAirportID

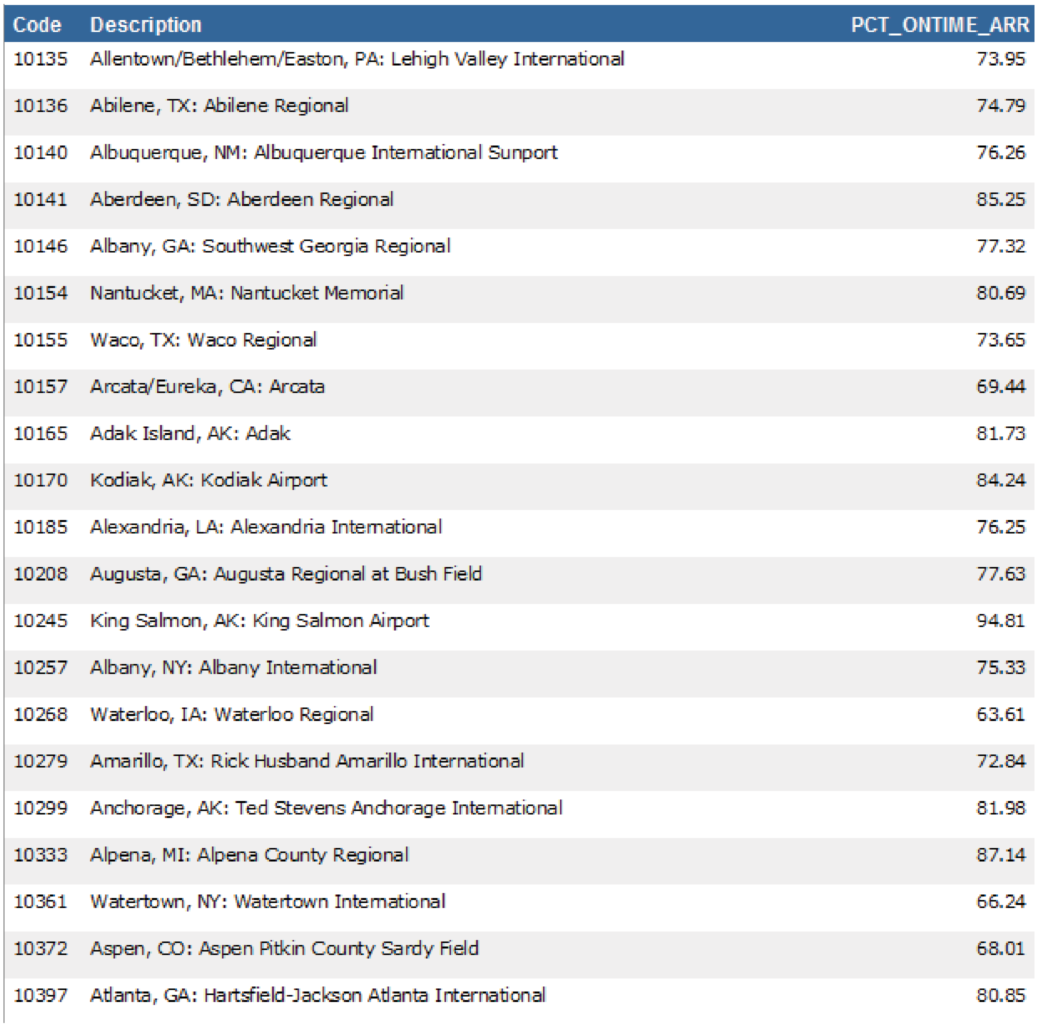
Filter Variables: *OntimeArrivalPct

Filter Statistics: N/A

Filter Years: 2013

Latest available 2015 data is January

7. Retreive the data.



Code	Description	PCT_ONTIME_ARR
10135	Allentown/Bethlehem/Easton, PA: Lehigh Valley International	73.95
10136	Abilene, TX: Abilene Regional	74.79
10140	Albuquerque, NM: Albuquerque International Sunport	76.26
10141	Aberdeen, SD: Aberdeen Regional	85.25
10146	Albany, GA: Southwest Georgia Regional	77.32
10154	Nantucket, MA: Nantucket Memorial	80.69
10155	Waco, TX: Waco Regional	73.65
10157	Arcata/Eureka, CA: Arcata	69.44
10165	Adak Island, AK: Adak	81.73
10170	Kodiak, AK: Kodiak Airport	84.24
10185	Alexandria, LA: Alexandria International	76.25
10208	Augusta, GA: Augusta Regional at Bush Field	77.63
10245	King Salmon, AK: King Salmon Airport	94.81
10257	Albany, NY: Albany International	75.33
10268	Waterloo, IA: Waterloo Regional	63.61
10279	Amarillo, TX: Rick Husband Amarillo International	72.84
10299	Anchorage, AK: Ted Stevens Anchorage International	81.98
10333	Alpena, MI: Alpena County Regional	87.14
10361	Watertown, NY: Watertown International	66.24
10372	Aspen, CO: Aspen Pitkin County Sardy Field	68.01
10397	Atlanta, GA: Hartsfield-Jackson Atlanta International	80.85

Appendix D Joint-Use Airports

The FAA works with the military departments on the joint-use of existing military airports when a civil sponsor wants to use the military airfield (Federal Aviation Administration, 2014c). The military installations, listed by branch, serve both military and civilian aircraft:

Air Force

1. AF Plant 42, Palmdale, CA
2. Barter Island LRRS, Barter Island, AK
3. Charleston AFB, Charleston, SC
4. Dover AFB, Dover DE
5. Eglin AFB, Valparaiso, FL
6. Grissom AFB, Peru, IN
7. Kelly/Lackland AFB, San Antonio, TX
8. March ARB, Riverside, CA
9. Pt. Lay LRRS, Point Lay, AK
10. Scott AFB (Mid America), Belleville, IL
11. Sheppard AFB, Wichita Falls, TX
12. Westover ARB, Chicopee, MA

Army

13. Blackstone AAF (Ft. Pickett), VA
14. Camp Guernsey AAF, Guernsey, WY
15. Dillingham AAF, Waialua, HI
16. Forney AAF (Fort Leonard Wood), MO

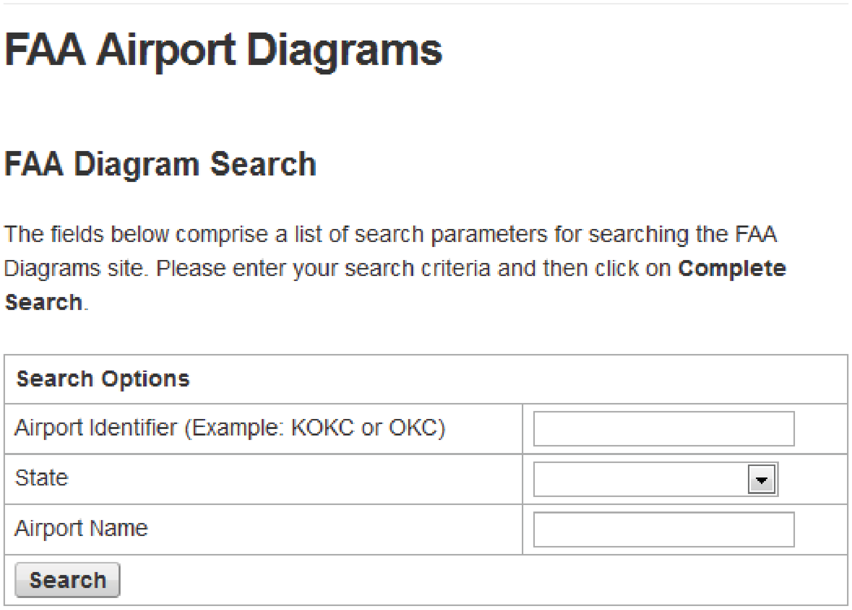
17. Robert Gray AAF, Ft. Hood/Killeen, TX
18. Grayling AAF, (Camp Grayling), MI
19. Libby AAF (Ft. Huachuca), Sierra Vista, AZ
20. Sherman AAF, (Ft. Leavenworth), KS
21. Sparta/Fort McCoy (Sparta), WI
22. Wright AAF (Fort Stewart) Midcoast Rgnl, Ft Steward/Hinesville, GA

Navy

23. MCAS Yuma, Yuma, AZ

Appendix E FAA Airport Diagram Retrieval

The airport diagrams used to classify each airport's runway configurations were taken from the FAA Airport Diagrams Search at the following link: http://www.faa.gov/airports/runway_safety/diagrams/

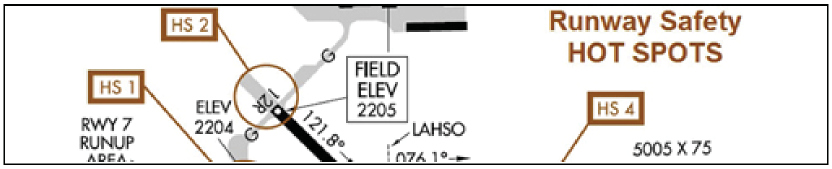


FAA Airport Diagrams

FAA Diagram Search

The fields below comprise a list of search parameters for searching the FAA Diagrams site. Please enter your search criteria and then click on **Complete Search**.

Search Options	
Airport Identifier (Example: KOKC or OKC)	
State	
Airport Name	



The airport identifier was enter for each eligible airport and the resulting diagram was used to classify the runways.

Appendix F Data of Airports Eligible for Analysis

Code	Airport Name	City	State	Runway Classifications	2013 Enplanements	Hub	On-Time Arrival Percentage
ABE	Lehigh Valley International	Allentown	PA	Intersecting	301,969	Nonhub	73.95
ABI	Abilene Regional	Abilene	TX	Non-Intersecting	82,758	Nonhub	74.79
ABQ	Albuquerque International Sunport	Albuquerque	MN	Combination	2,477,960	Hub	76.26
ABY	Southwest Georgia Regional	Albany	GA	Intersecting	31,276	Nonhub	77.32
ACK	Nantucket Memorial	Nantucket	MA	Intersecting	184,618	Nonhub	80.69
ACT	Waco Regional	Waco	TX	Intersecting	62,634	Nonhub	73.65
AEX	Alexandria International	Alexandria	LA	Intersecting	183,899	Nonhub	76.25
AGS	Augusta Regional at Bush Field	Augusta	GA	Intersecting	261,079	Nonhub	77.63
ALB	Albany International	Albany	NY	Intersecting	1,196,753	Hub	75.33
ALO	Waterloo Regional	Waterloo	IA	Intersecting	20,984	Nonhub	63.61
AMA	Rick Husband Amarillo International	Amarillo	TX	Non-Intersecting	370,589	Hub	72.84
ASE	Aspen Pitkin County Sardy Field	Aspen	CO	Single	208,682	Nonhub	68.01
ATL	Hartsfield-Jackson Atlanta International	Atlanta	GA	Non-Intersecting	45,308,685	Hub	80.85
ATW	Outagamie County Regional	Appleton	WI	Intersecting	246,211	Nonhub	73.76
AUS	Austin-Bergstrom International	Austin	TX	Non-Intersecting	4,902,080	Hub	76.59
AVL	Asheville Regional	Asheville	NC	Single	342,731	Nonhub	77.43
AVP	Wilkes Barre Scranton International	Scranton	PA	Intersecting	216,536	Nonhub	71.04

AZO	Kalamazoo/Battle Creek International	Kalamazoo	MI	Combination	129,211	Nonhub	77.34
BBG	Branson Airport	Branson	MO	Single	40,000	Nonhub	79.95
BDL	Bradley International	Hartford	CT	Intersecting	2,681,718	Hub	75.65
BFL	Meadows Field	Bakersfield	CA	Non-Intersecting	143,175	Nonhub	79.78
BGM	Greater Binghamton Airport	Binghamton	NY	Intersecting	95,210	Nonhub	79.29
BGR	Bangor International	Bangor	ME	Single	265,245	Nonhub	70.80
BHM	Birmingham-Shuttlesworth International	Birmingham	AL	Intersecting	1,335,014	Hub	75.10
BIL	Billings Logan International	Billings	MT	Combination	387,368	Hub	83.50
BIS	Bismarck Municipal	Bismarck	ND	Intersecting	238,929	Nonhub	79.81
BLI	Bellingham International	Bellingham	WA	Single	596,142	Hub	91.45
BMI	Central Illinois Regional	Bloomington	IL	Intersecting	211,957	Nonhub	74.04
BNA	Nashville International	Nashville	TN	Combination	5,052,066	Hub	77.07
BOI	Boise Air Terminal	Boise	ID	Non-Intersecting	1,313,741	Hub	79.18
BOS	Logan International	Boston	MA	Combination	14,721,693	Hub	78.29
BPT	Jack Brooks Regional	Beaumont	TX	Intersecting	35,790	Nonhub	70.59
BRO	Brownsville South Padre Island International	Brownsville	TX	Combination	100,793	Nonhub	71.52
BTM	Bert Mooney	Butte	MT	Intersecting	29,490	Nonhub	90.53
BTR	Baton Rouge Metropolitan/Ryan Field	Baton Rouge	LA	Combination	401,035	Hub	74.70
BTV	Burlington International	Burlington	VT	Intersecting	606,721	Hub	73.96
BUF	Buffalo Niagara International	Buffalo	NY	Intersecting	2,568,018	Hub	75.47
BUR	Bob Hope	Burbank	CA	Intersecting	1,919,005	Hub	82.73
BWI	Baltimore/Washington International Thurgood Marshall	Baltimore	MD	Combination	11,134,130	Hub	79.43

BZN	Bozeman Yellowstone International	Bozeman	MT	Intersecting	442,788	Hub	84.70
CAE	Columbia Metropolitan	Columbia	SC	Intersecting	487,180	Hub	72.75
CAK	Akron-Canton Regional	Akron	OH	Intersecting	852,332	Hub	76.33
CHA	Lovell Field	Chattanooga	TN	Intersecting	131,181	Nonhub	77.29
CHO	Charlottesville Albemarle	Charlottesville	VA	Single	231,148	Nonhub	72.71
CIC	Chico Municipal	Chico	CA	Non-Intersecting	16,835	Nonhub	68.01
CID	The Eastern Iowa	Cedar Rapids	IA	Intersecting	520,360	Hub	75.25
CLE	Cleveland-Hopkins International	Cleveland	OH	Non-Intersecting	4,375,822	Hub	76.49
CLL	Easterwood Field	College Station	TX	Intersecting	87,409	Nonhub	77.85
CLT	Charlotte Douglass International	Charlotte	NC	Combination	21,347,428	Hub	80.65
CMH	Port Columbus International	Columbus	OH	Non-Intersecting	3,065,569	Hub	75.82
CMI	University of Illinois/Willard	Champaign	IL	Combination	84,853	Nonhub	64.58
COS	City of Colorado Springs Municipal	Colorado Springs	CO	Non-Intersecting	658,318	Hub	71.84
COU	Columbia Regional	Columbia	MO	Intersecting	45,714	Nonhub	69.94
CPR	Casper/Natrona County Regional	Casper	WY	Intersecting	98,622	Nonhub	79.87
CRQ	McClellan-Palomar	Carlsbad	CA	Single	52,561	Nonhub	80.86
CRW	Yeager	Charleston	WV	Single	250,509	Nonhub	72.55
CSG	Columbus Airport	Columbus	GA	Intersecting	59,675	Nonhub	79.09
CVG	Cincinnati/Northern Kentucky International	Cincinnati	OH	Combination	2,776,377	Hub	80.54
CWA	Central Wisconsin	Mosinee	WI	Intersecting	123,797	Nonhub	71.59
DAB	Daytona Beach International	Daytona Beach	FL	Combination	293,843	Nonhub	84.34
DAL	Dallas Love Field	Dallas	TX	Combination	4,026,085	Hub	78.61

DAY	James M Cox/Dayton International	Dayton	OH	Combination	1,224,841	Hub	75.62
DBQ	Dubuque Regional	Dubuque	IA	Intersecting	33,465	Nonhub	84.71
DCA	Ronald Reagan International	Washington	DC	Intersecting	9,811,796	Hub	78.68
DEN	Denver International	Denver	CO	Non-Intersecting	25,497,348	Hub	76.81
DFW	Dallas/Fort Worth International	Fort Worth	TX	Non-Intersecting	29,018,883	Hub	78.17
DHN	Dothan Regional	Dothan	AL	Intersecting	48,423	Nonhub	80.00
DLH	Duluth International	Duluth	MN	Intersecting	155,455	Nonhub	79.43
DSM	Des Moines International	Des Moines	IA	Intersecting	1,079,189	Hub	72.71
DTW	Detroit Metro Wayne County	Detroit	MI	Combination	15,683,787	Hub	82.86
EAU	Chippewa Valley Regional	Eau Claire	WI	Intersecting	21,677	Nonhub	74.76
ECP	Northwest Florida Beaches International	Panama City	FL	Single	391,893	Hub	77.28
EGE	Eagle County Regional	Eagle	CO	Single	168,535	Nonhub	73.96
ELM	Elmira/Corning Regional	Elmira	NY	Intersecting	129,749	Nonhub	79.29
ELP	El Paso International	El Paso	TX	Non-Intersecting	1,363,258	Hub	75.90
ERI	Erie International/Tom Ridge Field	Erie	PA	Intersecting	109,520	Nonhub	78.79
EUG	Mahlon Sweet Field	Eugene	OR	Non-Intersecting	434,095	Hub	79.24
EVV	Evansville Regional	Evansville	IN	Combination	161,279	Nonhub	75.51
EWN	Coastal Carolina Regional	New Bern	NC	Intersecting	121,479	Nonhub	76.27
EWR	Newark Liberty International	Newark	NJ	Combination	17,514,139	Hub	70.36
EYW	Key West International	Key West	FL	Single	403,021	Hub	84.98
FAR	Hector International	Fargo	ND	Combination	403,786	Hub	73.13
FAT	Fresno Yosemite International	Fresno	CA	Non-	684,849	Hub	79.91

				Intersecting			
FAY	Fayetteville Regional/Grannis Field	Fayetteville	NC	Intersecting	244,345	Nonhub	80.46
FLG	Flagstaff Pulliam	Flagstaff	AZ	Single	58,323	Nonhub	87.18
FLL	Fort Lauderdale-Hollywood International	Fort Lauderdale	FL	Non-Intersecting	11,509,361	Hub	75.31
FNT	Bishop International	Flint	MI	Intersecting	398,132	Hub	80.38
FSD	Joe Foss Field	Sioux Falls	SD	Combination	481,716	Hub	71.40
FSM	Fort Smith Regional	Fort Smith	AR	Intersecting	82,742	Nonhub	77.58
FWA	Fort Wayne International	Fort Wayne	IN	Combination	294,968	Nonhub	75.63
GCC	Gillette Campbell County	Gillette	WY	Intersecting	29,130	Nonhub	76.52
GCK	Garden City Regional	Garden City	KS	Intersecting	24,456	Nonhub	75.69
GEG	Spokane International	Spokane	WA	Intersecting	1,417,731	Hub	79.89
GFK	Grand Forks International	Grand Forks	ND	Combination	148,663	Nonhub	82.26
GGG	East Texas Regional	Longview	TX	Intersecting	20,870	Nonhub	75.28
GJT	Grand Junction Regional	Grand Junction	CO	Intersecting	211,270	Nonhub	79.29
GNV	Gainesville Regional	Gainesville	FL	Non-Intersecting	198,388	Nonhub	80.32
GPT	Gulfport-Biloxi International	Gulfport	MS	Non-Intersecting	369,597	Nonhub	74.98
GRB	Austin Straubel International	Green Bay	WI	Intersecting	293,703	Nonhub	73.92
GRI	Central Nebraska Regional	Grand Island	NE	Non-Intersecting	57,165	Nonhub	74.74
GRR	Gerald R. Ford International	Grand Rapids	MI	Combination	1,123,257	Hub	75.92
GSO	Piedmont Triad International	Greensboro	NC	Combination	860,124	Hub	74.80
GSP	Greenville-Spartanburg International	Greer	SC	Single	917,088	Hub	75.54
GTF	Great Falls International	Great Falls	MT	Combination	182,390	Nonhub	82.38

GTR	Golden Triangle Regional	Columbus	MS	Single	41,140	Nonhub	79.33
HLN	Helena Regional	Helena	MT	Intersecting	97,310	Nonhub	84.03
HOB	Lea County Regional	Hobbs	NM	Intersecting	17,246	Nonhub	66.84
HOU	William P Hobby	Houston	TX	Combination	5,379,782	Hub	78.01
HPN	Westchester County	White Plains	NY	Intersecting	770,550	Hub	73.39
HRL	Valley International	Harlington	TX	Combination	347,829	Nonhub	79.64
HSV	Huntsville International- Carl T Jones Field	Huntsville	AL	Non-Intersecting	505,541	Hub	75.72
IAD	Washington Dulles International	Washington	DC	Non-Intersecting	10,575,366	Hub	77.50
IAH	George Bush Intercontinental/Houston	Houston	TX	Non-Intersecting	18,953,519	Hub	79.78
ICT	Wichita Mid-Continent	Wichita	KS	Combination	736,220	Hub	71.42
IDA	Idaho Falls Regional	Idaho Falls	ID	Non-Intersecting	147,073	Nonhub	84.26
ILG	New Castle	Wilmington	DE	Combination	52,456	Nonhub	75.00
ILM	Wilmington International	Wilmington	NC	Intersecting	397,737	Hub	79.18
IND	Indianapolis International	Indianapolis	IN	Non-Intersecting	3,535,579	Hub	77.53
ISP	Long Island MacArthur	Islip	NY	Combination	662,612	Hub	70.80
ITH	Ithaca Tompkins Regional Airport	Ithaca	NY	Single	103,722	Nonhub	81.02
JAC	Jackson Hole	Jackson	WY	Single	295,719	Nonhub	79.69
JAN	Jackson Medgar Wiley Evers International	Jackson	MS	Non-Intersecting	596,045	Hub	77.22
JAX	Jacksonville International	Jacksonville	FL	Non-Intersecting	2,549,712	Hub	77.28
JFK	John F. Kennedy International	New York	NY	Combination	25,036,855	Hub	75.03
JLN	Joplin Regional	Joplin	MO	Combination	23,329	Nonhub	75.24

LAN	Capital Region International	Lansing	MI	Combination	216,925	Nonhub	73.21
LAS	McCarran International	Las Vegas	NV	Combination	19,923,594	Hub	80.40
LAW	Lawton-Fort Sill Regional	Lawton	OK	Single	55,526	Nonhub	74.54
LAX	Los Angeles International	Los Angeles	CA	Non-Intersecting	32,427,115	Hub	79.63
LBB	Lubbock Preston Smith International	Lubbock	TX	Non-Intersecting	454,408	Hub	75.04
LCH	Lakes Charles Regional	Lake Charles	LA	Non-Intersecting	65,281	Nonhub	81.92
LEX	Blue Grass	Lexington	KY	Non-Intersecting	539,879	Hub	75.59
LFT	Lafayette Regional	Lafayette	LA	Combination	233,498	Nonhub	76.68
LGA	LaGuardia	New York	NY	Intersecting	13,353,365	Hub	72.71
LGB	Long Beach Airport	Long Beach	CA	Combination	1,438,948	Hub	86.56
LIT	Bill and Hillary Clinton Nat Adams Field	Little Rock	AR	Non-Intersecting	1,055,608	Hub	73.64
LMT	Klamath Falls Airport	Klamath Falls	OR	Intersecting	13,443	Nonhub	82.88
LNK	Lincoln Airport	Lincoln	NE	Combination	138,787	Nonhub	71.65
LRD	Laredo Airport	Laredo	TX	Combination	109,773	Nonhub	74.42
LSE	La Crosse Municipal	La Crosse	WI	Intersecting	90,297	Nonhub	81.52
LWS	Lewiston Nez Perce County	Lewiston	ID	Non-Intersecting	62,209	Nonhub	91.58
MAF	Midland International	Midland	TX	Combination	507,061	Hub	74.82
MBS	MBS International	Saginaw	MI	Intersecting	120,689	Nonhub	80.03
MCI	Kansas City International	Kansas City	MO	Combination	4,836,221	Hub	75.95
MCO	Orlando International	Orlando	FL	Non-Intersecting	16,885,160	Hub	79.36
MDT	Harrisburg International	Harrisburg	PA	Single	657,650	Hub	76.66
MDW	Chicago Midway International	Chicago	IL	Combination	9,919,985	Hub	77.15

MEM	Memphis International	Memphis	TN	Non-Intersecting	2,301,481	Hub	81.06
MFE	McAllen Miller International	Mission	TX	Non-Intersecting	335,483	Nonhub	74.43
MFR	Rogue Valley International	Medford	OR	Single	306,450	Nonhub	73.07
MGM	Montgomery Regional	Montgomery	AL	Intersecting	157,958	Nonhub	76.89
MHK	Manhattan Regional	Manhattan	KS	Intersecting	65,683	Nonhub	70.74
MHT	Manchester-Boston Regional	Manchester	NH	Intersecting	1,190,082	Hub	72.81
MIA	Miami International	Miami	FL	Combination	19,422,275	Hub	81.97
MKE	General Mitchell International	Milwaukee	WI	Combination	3,214,617	Hub	77.14
MKG	Muskegon County	Muskegon	MI	Intersecting	18,020	Nonhub	71.60
MLB	Melbourne International	Melbourne	FL	Non-Intersecting	211,702	Nonhub	85.85
MLI	Quad City International	Moline	IL	Intersecting	384,198	Hub	74.10
MLU	Monroe Regional	Monroe	LA	Intersecting	115,757	Nonhub	76.36
MOB	Mobile Regional	Mobile	AL	Non-Intersecting	287,661	Nonhub	75.59
MOD	Modesto City-County-Harry Sham Field	Modesto	CA	Non-Intersecting	11,310	Nonhub	70.11
MOT	Minot International	Minot	ND	Intersecting	220,787	Nonhub	76.74
MRY	Monterey Regional	Monterey	CA	Non-Intersecting	205,383	Nonhub	77.20
MSN	Dane County Regional-Truax Field	Madison	WI	Intersecting	826,019	Hub	73.28
MSO	Missoula International	Missoula	MT	Intersecting	298,253	Nonhub	82.58
MSP	Minneapolis-St Paul International	Minneapolis	MN	Combination	16,282,038	Hub	83.18
MSY	Louis Armstrong New Orleans International	New Orleans	LA	Non-Intersecting	4,577,498	Hub	79.01

MVY	Martha's Vineyard Airport	Martha's Vineyard	MA	Intersecting	56,763	Nonhub	76.92
MYR	Myrtle Beach International	Myrtle Beach	SC	Single	823,294	Hub	77.47
OAK	Metropolitan Oakland International	Oakland	CA	Non-Intersecting	4,771,830	Hub	80.99
OKC	Will Rogers World	Oklahoma City	OK	Combination	1,790,407	Hub	72.76
OMA	Eppley Airfield	Omaha	NE	Combination	1,977,480	Hub	74.90
ONT	Ontario International	Ontario	CA	Non-Intersecting	1,970,538	Hub	80.38
ORD	Chicago O'Hare International	Chicago	IL	Combination	32,278,906	Hub	73.52
ORF	Norfolk International	Norfolk	VA	Intersecting	1,561,225	Hub	76.02
OTH	Southwest Orgon Regional	North Bend	OR	Non-Intersecting	16,864	Nonhub	60.17
PAH	Barkley Regional	Paducah	KY	Intersecting	20,523	Nonhub	74.35
PBI	Palm Beach International	West Palm Beach	FL	Combination	2,848,901	Hub	75.20
PDX	Portland International	Portland	OR	Combination	7,453,098	Hub	81.97
PHF	Newport News/Williamsburg International	Newport News	VA	Intersecting	264,279	Nonhub	77.80
PHL	Philadelphia International	Philadelphia	PA	Combination	14,705,014	Hub	75.96
PHX	Phoenix Sky Harbor International	Phoenix	AZ	Non-Intersecting	19,525,829	Hub	83.79
PIA	General Downing-Peoria International	Peoria	IL	Intersecting	291,147	Nonhub	71.73
PIH	Pocatello Regional	Pocatello	ID	Non-Intersecting	23,775	Nonhub	85.92
PIT	Pittsburgh International	Pittsburgh	PA	Combination	3,813,007	Hub	78.50
PNS	Pensacola International	Pensacola	FL	Intersecting	744,259	Hub	76.96
PSC	Tri Cities	Pasco	WA	Combination	327,419	Nonhub	81.04

PSP	Palm Springs International	Palm Springs	CA	Non-Intersecting	876,428	Hub	81.31
PVD	Theodore Francis Green State	Providence	RI	Intersecting	1,885,232	Hub	76.40
PWM	Portland International Jetport	Portland	ME	Intersecting	837,335	Hub	74.21
RAP	Rapid City Regional	Rapid City	SD	Intersecting	256,052	Nonhub	77.28
RDD	Redding Municipal	Redding	CA	Intersecting	24,875	Nonhub	68.92
RDM	Roberts Field	Bend	OR	Intersecting	236,303	Nonhub	80.94
RDU	Raleigh-Durham International	Raleigh	NC	Non-Intersecting	4,482,973	Hub	77.81
RFD	Chicago/Rockford International	Rockford	IL	Intersecting	109,384	Nonhub	71.08
RIC	Richmond International	Richmond	VA	Combination	1,598,413	Hub	75.71
RNO	Reno/Tahoe International	Reno	NV	Combination	1,672,139	Hub	79.35
ROA	Roanoke Regional/Woodrum Field	Roanoke	VA	Intersecting	310,295	Nonhub	73.43
ROC	Greater Rochester International	Rochester	NY	Combination	1,209,532	Hub	73.09
ROW	Roswell International Air Center	Roswell	NM	Non-Intersecting	32,616	Nonhub	72.98
RST	Rochester International	Rochester	MN	Intersecting	110,104	Nonhub	78.83
RSW	Southwest Florida International	Fort Myers	FL	Single	3,789,386	Hub	79.70
SAF	Santa Fe Municipal	Santa Fe	NM	Intersecting	65,845	Nonhub	73.73
SAN	San Diego International	San Diego	CA	Single	8,876,777	Hub	79.10
SAT	San Antonio International	San Antonio	TX	Combination	4,006,798	Hub	76.99
SAV	Savannah/Hilton Head International	Savannah	GA	Intersecting	798,970	Hub	75.91
SAW	Sawyer International	Marquette	MI	Single	42,335	Nonhub	72.20
SBA	Santa Barbara Municipal	Santa Barbara	CA	Combination	365,036	Nonhub	80.73
SBN	South Bend International	South Bend	IN	Combination	329,403	Nonhub	74.64
SBP	San Luis County Regional	San Luis	CA	Non-	135,844	Nonhub	81.87

		Obispo		Intersecting			
SDF	Louisville International-Standiford Field	Louisville	KY	Combination	1,669,470	Hub	76.10
SEA	Seattle/Tacoma International	Seattle	WA	Non-Intersecting	16,690,295	Hub	83.41
SFO	San Francisco International	San Francisco	CA	Combination	21,706,567	Hub	72.66
SGF	Springfield-Branson National	Springfield	MO	Intersecting	368,752	Nonhub	71.07
SHV	Shreveport Regional	Shreveport	LA	Intersecting	279,897	Nonhub	75.26
SJC	Norman Y. Mineta San Jose International	San Jose	CA	Non-Intersecting	4,317,896	Hub	81.16
SJT	San Angelo Regional/Mathis Field	San Angelo	TX	Combination	62,296	Nonhub	72.95
SLC	Salt Lake City International	Salt Lake City	UT	Non-Intersecting	9,669,234	Hub	85.04
SMF	Sacramento International	Sacramento	CA	Non-Intersecting	4,255,145	Hub	80.75
SMX	Santa Maria Public/Capt. G. Allan Hancock Field	Santa Maria	CA	Intersecting	51,395	Nonhub	86.75
SNA	John Wayne Airport-Orange County	Santa Ana	CA	Non-Intersecting	4,542,376	Hub	83.68
SPI	Abraham Lincoln Capital	Springfield	IL	Intersecting	70,651	Nonhub	74.68
SRQ	Sarasota/Bradenton International	Sarasota	FL	Intersecting	595,423	Hub	82.02
STL	Lambert-St Louis International	St Louis	MO	Combination	6,213,972	Hub	78.30
SUN	Friedman Memorial	Sun Valley	ID	Single	52,393	Nonhub	80.30
SUX	Sioux Gateway/Col. Bud Day Field	Sioux City	IA	Intersecting	25,000	Nonhub	63.81
SWF	Stewart International	Newburgh	NY	Intersecting	163,815	Nonhub	75.31
SYR	Syracuse Hancock International	Syracuse	NY	Intersecting	991,663	Hub	74.54
TLH	Tallahassee Regional	Tallahassee	FL	Non-	336,129	Nonhub	77.58

				Intersecting			
TPA	Tampa International	Tampa	FL	Combination	8,268,207	Hub	78.75
TRI	Tri-Cities Regional TN/VA	Bristol	TN	Intersecting	204,402	Nonhub	78.27
TTN	Trenton Mercer	Trenton	NJ	Intersecting	148,256	Nonhub	64.80
TUL	Tulsa International	Tulsa	OK	Combination	1,323,943	Hub	71.47
TUS	Tucson International	Tucson	AZ	Non-Intersecting	1,570,329	Hub	78.85
TVC	Cherry Capital	Traverse City	MI	Intersecting	189,644	Nonhub	72.30
TWF	Joslin Field-Magic Valley Regional	Twin Falls	ID	Intersecting	28,601	Nonhub	85.19
TXK	Texarkana Regional-Webb Field	Texarkana	AR	Intersecting	32,882	Nonhub	72.81
TYR	Tyler Pounds Regional	Tyler	TX	Combination	85,789	Nonhub	78.20
TYS	McGhee Tyson	Knoxville	TN	Non-Intersecting	833,174	Hub	70.90
XNA	Northwest Arkansas Regional	Fayetteville	AR	Non-Intersecting	558,218	Hub	70.51

Appendix G Airports Removed from the Dataset

Code	Airport Name	City	State	Initial Reason For Elimination
ABR	Aberdeen Regional	Aberdeen	SD	Non-FAA Facility
ACV	Arcata	Arcata	CA	Non-FAA Facility
ADK	Adak	Adak Island	AK	Not in Contiguous U.S.
ADQ	Kodiak Airport	Kodiak	AK	Not in Contiguous U.S.
AKN	King Salmon Airport	King Salmon	AK	Not in Contiguous U.S.
ANC	Ted Stevens Anchorage International	Anchorage	AK	Not in Contiguous U.S.
APN	Alpena County Regional	Alpena	MI	Non-FAA Facility
ART	Watertown International	Watertown	NY	Non-FAA Facility
AZA	Phoenix-Mesa Gateway	Phoenix	AZ	Non-FAA Facility
BET	Bethel Airport	Bethel	AK	Not in Contiguous U.S.
BJI	Bemidji Regional	Bemidji	MN	Non-FAA Facility
BQK	Brunswick Golden Isles	Brunswick	GA	Non-FAA Facility
BQN	Rafael Hernandez	Aguadilla	PR	Not in Contiguous U.S.
BRD	Brainerd Lakes Regional	Brainerd	MN	Non-FAA Facility
BRW	Wiley Post/Will Rogers Memorial	Barrow	AK	Not in Contiguous U.S.
CDC	Cedar City Regional	Cedar City	UT	Non-FAA Facility
CDV	Merle K Mudhole Smith	Cordova	AK	Not in Contiguous U.S.
CEC	Jack McNamara Field	Crescent City	CA	Non-FAA Facility
CHS	Charleston AFB/International	Charleston	SC	Joint-Use
CIU	Chippewa County International	Sault Ste Marie	MI	Non-FAA Facility
CMX	Houghton County Memorial	Hancock	MI	Non-FAA Facility
COD	Yellowstone Regional	Cody	WY	Non-FAA Facility
CRP	Corpus Christi International	Corpus Christi	TX	Non-FAA Facility
DIK	Dickinson-Theodore Roosevelt Regional	Dickinson	ND	Non-FAA Facility

DLG	Dillingham Airport	Dillingham	AK	Not in Contiguous U.S.
DRO	Durango La Plata County	Durango	CO	Non-FAA Facility
DRT	Del Rio International	Del Rio	TX	Non-FAA Facility
EKO	Elko Regional	Elko	NV	Non-FAA Facility
ESC	Delta County	Escanaba	MI	Non-FAA Facility
FAI	Fairbanks International	Fairbanks	AK	Not in Contiguous U.S.
FCA	Glacier Park International	Kalispell	MT	Non-FAA Facility
GRK	Robert Gray AAF	Killeen	TX	Non-FAA Facility
GST	Gustavus Airport	Gustavus	AK	Not in Contiguous U.S.
GUC	Gunnison-Crested Butte Regional	Gunnison	CO	Non-FAA Facility
GUM	Guam International	Guam	TT	Not in Contiguous U.S.
HDN	Yampa Valley	Hayden	CO	Non-FAA Facility
HIB	Range Regional	Hibbing	MN	Non-FAA Facility
HNL	Honolulu International	Honolulu	HI	Not in Contiguous U.S.
IMT	Ford	Iron Mountain	MI	Non-FAA Facility
INL	Falls International	International Falls	MN	Non-FAA Facility
IPL	Imperial County	El Centro	CA	Non-FAA Facility
ISN	Sloulin Field International	Williston	ND	Non-FAA Facility
ITO	Hilo International	Hilo	HI	Not in Contiguous U.S.
IYK	Inyokern Airport	Inyokern	CA	Non-FAA Facility
JNU	Juneau International	Juneau	AK	Not in Contiguous U.S.
KOA	Kona International Airport at Keahole	Kona	HI	Not in Contiguous U.S.
KTN	Ketchikan International	Ketchikan	AK	Not in Contiguous U.S.
LAR	Laramie Regional	Laramie	WY	Non-FAA Facility
LIH	Lihue Airport	Lihue	HI	Not in Contiguous U.S.
MMH	Mammoth Lakes Airport	Mammoth Lakes	CA	Non-FAA Facility
MTJ	Montrose Regional	Montrose	CO	Non-FAA Facility

OAJ	Albert J Ellis	Jacksonville	NC	Non-FAA Facility
OGG	Kahului Airport	Kahului	HI	Not in Contiguous U.S.
OME	Nome Airport	Nome	AK	Not in Contiguous U.S.
ORH	Worcester Regional	Worcester	MA	Less than 10,000 Enplanements
OTZ	Ralph Wien Memorial	Kotzebue	AK	Not in Contiguous U.S.
PLN	Pellston Regional Airport of Emmet County	Pellston	MI	Non-FAA Facility
PPG	Pago Pago International	Pago Pago	TT	Not in Contiguous U.S.
PSE	Mercedita	Ponce	PR	Not in Contiguous U.S.
PSG	Petersburg James A Johnson	Petersburg	AK	Not in Contiguous U.S.
RHI	Rhinelander/Oneida County	Rhinelander	WI	Non-FAA Facility
RKS	Rock Springs Sweetwater County	Rock Springs	WY	Non-FAA Facility
SCC	Deadhorse Airport	Deadhorse	AK	Not in Contiguous U.S.
SCE	University Park	State College	PA	Non-FAA Facility
SGU	St George Municipal	St George	UT	Non-FAA Facility
SHD	Shenandoah Valley Regional Airport	Staunton	VA	Non-FAA Facility
SIT	Sitka Rocky Gutierrez	Sitka	AK	Not in Contiguous U.S.
SJU	Luis Munoz Marin International	San Juan	PR	Not in Contiguous U.S.
SPN	Francisco C Ada Saipan International	Saipan	TT	Not in Contiguous U.S.
SPS	Sheppard AFB/Wichita Falls Municipal	Wichita Falls	TX	Non-FAA Facility
STT	Cyril E King	Charlotte Amalie	VI	Not in Contiguous U.S.
STX	Henry E Rohlsen	Christiansted	VI	Not in Contiguous U.S.
VLD	Valdosta Regional	Valdosta	GA	Non-FAA Facility
VPS	Northwest Florida Regional	Valparaiso	FL	Non-FAA Facility
WRG	Wrangell Airport	Wrangell	AK	Not in Contiguous U.S.
WYS	Yellowstone	West Yellowstone	MT	Non-FAA Facility
YAK	Yakutat Airport	Yakutat	AK	Not in Contiguous U.S.
YUM	Yuma MCAS/Yuma International	Yuma	AZ	Non-FAA Facility