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Evaluating Flight Delay Benefits From The NextGen Program

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To my parents, Leslie and Mark, thank you for all your help and support all of these years. Without both of you this thesis would have never been possible.

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ABSTRACT

Sperduto, Brian M. M.S.A.A.M., Purdue University, May 2014. Evaluating Flight Delay Benefits from the NextGen Program. Major Professor: Dr. Mary E. Johnson.

This research proposes a method to simulate the flight delay effects of the NextGen program against an actual flight schedule. With the advent of the NextGen program and the substantial cost associated with the program, this research studies the impact the NextGen program may have on flight delays, an area critical to air carrier operations. This research is based on historical results from the summer of 2013 flight schedule to study the impact of a simulated NextGen implementation. The research studied aircraft on a given day looking specifically at the propagation effects of a flight delay and how it would change the total delay for a day. This study was conducted used a delay reduction distribution applied to historical flight delays attributed to the National Airspace System category. The research found a significant reduction in median flight delays per aircraft per day between the simulation results and historical delay. The delay reduction distribution was sampled to estimate the reduction for each segment in the flights for an aircraft's day. Therefore, only reductions of delay or no changes to delay are possible in this study.

CHAPTER 1. INTRODUCTION

In the United States, over six percent of flights are delayed due to capacity restrictions in the U.S. airspace system (Bureau of Transportation Statistics, 2013a). These capacity restrictions are the second highest cause for delays reported in the U.S. (Bureau of Transportation Statistics, 2013a). The Federal Aviation Administration's response to this problem is the NextGen program. The purpose of this study is to model the flight delay effects that may be obtained from the full implementation of the NextGen program.

1.1 Statement of the Problem

According to a study by the Federal Aviation Administration's NEXTOR center of excellence, the total cost of delays for the United States in 2007 was $31.2 billion dollars (Ball et al., 2010). This cost is a combination of lost productivity by both passengers and airlines, and direct costs related to delayed flights. The NextGen program is a proposed program provided by the FAA with a goal to alleviate some of these issues. A study conducted by the FAA estimated a $38 billion dollar benefit from implementation of NextGen through the year 2020 (Federal Aviation Administration, 2013). In addition, the FAA anticipates an overall reduction in delays by 41% versus the current system remaining in place (Federal Aviation Administration, 2013, p. 4).

1.2 Significance of the Problem

In the United States, a passenger has a one in five chance of having their flight delayed beyond the 15 minute window that is considered "on-time" (Bureau of Transportation Statistics, 2013a). To combat delays and other inefficiencies in the system, air carriers pad their flight schedules by adding time to flight arrival time. The additional padding still leaves over 20% of flights delayed. The Bureau of Transportation Statistics reports delays in five different categories, "Air Carrier Delay," "Weather Delay," "National Airspace System Delay," "Aircraft Arriving Late," and "Security Delay" (2013b). A flight can be delayed for any combination of the causes but one of the largest, "National Airspace System," is directly attributed to the national airspace system and its inefficiencies.

One of the Federal Aviation Administration's approach to reduce these delays is the NextGen program. The NextGen program at its core is designed to improve the efficiency of the national airspace system and through this reduce flight delays (Federal Aviation Administration, 2013). The FAA indicates that the NextGen program will provide a cumulative net benefit of $38 billion dollars if this plan goes forward as scheduled.

1.3 Scope

This study investigated the anticipated effects of the NextGen program on the flight schedule, and through this passenger flight delays. This was accomplished by simulating various flight schedules and applying changes to these schedules to simulate

NextGen's effects. Through this simulation, the researcher gained insight into the system-wide implications of the program.

This study analyzed a sample of flight records for U.S. commercial passenger flights conducted during the 2013 summer schedule. This sample was selected to minimize the effects of external factors related to the various seasonal schedules. This study looked at a random sample 1,400 of flights conducted by U.S. Air Carriers between May 28, 2013 and September 3, 2013. This sample consisted of flights conducted wholly within United States airspace using standard air traffic control facilities, excluding flights conducted in oceanic airspace. The parameters for this study were based off the 2013 FAA implementation plan of its NextGen program.

The primary data source for the information used in this study is the Bureau of Transportation Statistic's On-time performance database (2013b). This database contains data from 16 U.S. air carriers. The database provides parameters related to flight schedules, delay types and aircraft identities, and other parameters not needed in this study. This database has been used in industry for over 10 years.

The air carriers involved in this study are the 16 U.S. Air Carriers contained in the On-time performance database. This study only focused on the effects on the NextGen program on mitigating delays. This study did not look at delays caused by weather, mechanical or any other factors outside the control of the air traffic control system. These other delay causes, while being cited as a cause in over 15% of total flights, will be minimally effected by the changes brought on by NextGen and thus outside of the scope of this study (Bureau of Transportation Statistics, 2013a). Any flight that has been cancelled will also be excluded from this study; this study will only look at flights which are able to be conducted.

1.4 Research Question

What is the effect that the anticipated reduction of National Airspace System flight delays attributed to the NextGen program has on overall flight delays?

1.5 Assumptions

The assumptions for this study are:

- All data provided is complete and accurate.
- Flights depart as soon as allowable and are not held.
- Any delay categorized as "National Airspace System" will be mitigated under the NextGen program.
- Delays are attributed to the most accurate cause in the data used.
- Delays attributed to "National Airspace System" are the only delays affected by the NextGen program.
- The delay reduction distribution is accurate
- All changes to delay time due to the NextGen program are either none or a reduction, an increase in delay time are not possible.

1.6 Limitations

The limitations for this study are:

- Data is limited to those available for the 16 air carriers reported in the On-time performance database available from the Bureau of Transportation Statistics.
- Analysis is only conducted on flights taking place completely within the contiguous 48 states in the U.S.
- Flexibility within the schedule to adjust aircraft assignments is not considered.

1.7 Delimitations

The delimitations for this study are:

- Scope is limited to flights that depart between May 28, 2013 and September 3, 2013 in the On-time performance database from the Bureau of Transportation Statistics.

1.8 Definitions

Delay - "Delays are incurred when any action is taken by a controller that prevents an aircraft from proceeding normally to its destination for an interval of 15 minutes or more. This includes actions to delay departing, enroute, or arriving aircraft as well as actions taken to delay aircraft at departing airports due to conditions en route or at destination airports." (Bureau of Transportation Statistics, 2013c).

Oceanic Airspace – "Airspace over the oceans of the world, considered international airspace, where oceanic separation and procedures per the International Civil Aviation Organization are applied. Responsibility for the provisions of air traffic control service in this airspace is delegated to various countries, based generally upon geographic proximity and the availability of the required resources." (Bureau of Transportation Statistics, 2013c).

1.9 Summary

This chapter introduced the problem, its scope, limitations, delimitations, assumptions and appropriate key terms. Chapter 2 covers existing research done in this area, and Chapter 3 discusses the methods to be used in this study.

CHAPTER 2. LITERATURE REVIEW

Research into the area of flight delays has been conducted for many years. Since the growth of commercial aviation, research has been conducted in a variety including flight delays. With the development of the Federal Aviation Administration's NextGen program, studies have been conducted on the areas affected by this program.

This chapter provides an overview of research conducted from 2003-2013 in the areas of flight delays, cost estimation of flight delays, and the NextGen program. The chapter begins with an overview of the NextGen program. It then transitions to an overview of the problems with flight delays and some of the attempts to model these behaviors. Lastly this chapter will provide some attempts to estimate costs related to these delays.

2.1 Approach to This Review

The approach to this review is to provide an overview of the works previously published in these areas and provide a basis to tie these related concepts together. The goal of this review is to provide varying methodologies to show the different manners by which research has been conducted on these subjects. The author's goal is that this review shows a numerous methods for conducting this research.

2.2 NextGen

The Federal Aviation Administration's NextGen program is one of the largest and most ambitious programs ever attempted in the aviation industry. This section attempts to provide an overview of the program, highlights of the benefits as stated by the FAA, and some critical analysis of the program. While not a complete overview of all research on the topic, this section will overview what is expected to come from this program.

One of the core technologies being implemented under the FAA's NextGen program is Automated Dependent Surveillance Broadcast or ADS-B (Federal Aviation Administration, 2013). According to the FAA, this technology will be able to "receive positioning data form GPS satellites, process them and transmit the aircraft's position to the ground" (Federal Aviation Administration, 2013, p. 13). This technology will shift the air traffic control system from a radar based system to an aircraft based broadcast system. Overall, this technology is intended to improve the efficiency of air traffic controllers.

The ADS-B system is broken up into two components, "in" and "out". The "out" system has been under mandate from an 2010 FAA rule making. This system is the transmission component of the ADS-B system. This rule requires that most aircraft in U.S. airspace be equipped with sufficient equipment to satisfy the ADS-B requirement (*Automatic Dependent Surveillance- Broadcast (ADS–B) Out equipment and use*, 2010). When fully implemented by 2020, this requirement should enable one of the major NextGen technologies to be fully utilized.

Another part of the ADS-B system is ADS-B In. This system allows the aircraft's avionics package to see other aircraft with much more information than in current systems (Federal Aviation Administration, 2013). The additional information of speed and aircraft type would be an improvement over the existing systems for detecting traffic according to the FAA. In addition, the U.S. congress has mandated the FAA to create a rule requiring ADS-B In for "aircraft operating in capacity constrained airspace, at capacity constrained airports or in any other airspace deemed appropriate by the administrator" (Federal Aviation Administration, 2013, p. 14).

The infrastructure designed to receive and process these signals is currently in the process of being deployed under the name En route Automation Modernization (ERAM). As of January 2013, a total of 13 of the 20 U.S. air traffic control centers have at least basic ERAM capability, with three additional planned for the first quarter of 2013. The FAA plans on having the ERAM system expanded to support all NextGen capabilities once all centers have been equipped.

One of the core issues with implementing the ADS-B technology is incentivizing operators to implement the technology in their own aircraft. While there may be requirements to have the technology available in most aircraft, operators may not opt to add the technology until near the final deadline. To combat this, the FAA indicates they are working on plans to provide incentives to implement the technology early (Federal Aviation Administration, 2013). According to the FAA, "a "critical mass" capability level is needed before benefits can be attained" (Federal Aviation Administration, 2013, p. 14). The FAA's efforts to attain this "critical mass" revolve around a variety of incentives to operators in an effort to spur conversion.

One of these incentives is the proposed "AirPASS" program. The concept behind the program is to grant operators who implemented NextGen technologies priority handling into airports, above aircraft that have not yet invested in the technology. Another concept being explored is the FAA granting loan guarantees for the purchase and implementation of this technology. While this concept has met with legal resistance, the current FAA Implementation Plan indicates they are currently exploring the concept further (Federal Aviation Administration, 2013).

In 2012 the FAA conducted a business case analysis looking at the benefits of NextGen. This case study was based off the 2012 Implementation Plan's cost numbers. The study's core benefit estimation was based off delay avoidance, which includes both direct airline costs and passenger lost time costs (Federal Aviation Administration, 2012). The business case comes up with a total benefit of $106 billion through the year 2030 from the program's implementation. This is in comparison to the $37 billion estimated cost associated with the program. The benefits include $77 billion in avoided delay benefits and $29 billion in miscellaneous costs such as safety improvements, FAA cost savings, etc.

The costs associated with this program may be substantial, but the net present value analysis estimates a net benefit of $23 billion by 2030 from the program. This substantial benefit does include a passenger's lost time as a benefit toward implementing NextGen. In addition, the overall benefits were calculated based off the exact minutes beyond scheduled arrival time on every flight. The Department of Transportation does not consider a flight delayed unless it is more than 15 minutes later than its originally scheduled time (Bureau of Transportation Statistics, 2013c). The additional precision of the delay calculations does differentiate this methodology from more traditional methods used within the industry. This aside, the business case analysis does build a very strong case for implementation of the program.

One of the main methods of increasing efficiency within the air traffic control system is the use of trajectory based operations. A study by Calderon-Meza and Sherry (2010) looked at the benefits stakeholders may see from this change. Their study set out to simulate the use of these new routings based off real traffic and attempt to see what these efficiencies would be. This shift would involve using more direct routings based off a straight great circle routing, rather than the current system based on airway navigation. To conduct this simulation they used a program called Future ATM Concept Evaluation Tool or FACET. The inputs for the simulation were 65,173 flights based off real traffic from a previous day.

The results of this study indicated that the there was a statistically significant reduction in distance flown. Distance flown is directly related to fuel burn, which is a primary cost driver of any flight. Environmental impacts may also be observed since fuel burned is related to pollution generated by the aircraft's engines. Another parameter looked at was Monitored Alert Parameter, which is a measure of the saturation level of a particular sector of airspace. The results actually saw a drop in the percentage of minutes where a sector was above the saturation point. This is significant since MAP is an indicator of the system's ability to handle this traffic load. Another metric was the number of conflicts detected, which dropped by 41.6% from normal operations. This is important since more conflicts are related to a higher likelihood of issues arising. The results did see an increase in the ground delays generated from the new routings but this could be due to scheduling under the new routings. Since the schedule was originally optimized for different en route times, it may be possible that this increase could be mitigated by reshuffling the schedule. This study provides some intriguing results which can be built upon in the future. This study assumed all aircraft had converted to the new routing structure; future research likely needs to explore a mixed routing system involving both direct and traditional airway routings (Calderon-Meza & Sherry, 2010).

A study conducted by Sherry looked at passenger itineraries as a factor in the overall NextGen system (Sherry, 2011). One of the core assumptions of NextGen is that "when flight on-time performance improves, passenger trip delay statistics will improve too" (Sherry, 2011, p. 8). This assumption may not always hold true in actual passenger itineraries. Due to the nature of the hub and spoke system airlines operate, passengers may require one, two, sometimes three flights all to arrive within tolerances in order for their itinerary to be complete. When you couple all these factors together, there is a lot that must go right for a passenger to arrive on time. Due to this situation Sherry raises some valid questions about this core assumption of NextGen, which needs to be answered in order to fully understand its implications.

This section overviewed the NextGen program and reviewed select research done to estimate its implications. NextGen has a staggering cost associated with it, and it is important fully grasp what the long term implications of the program are. The Federal Aviation Administration's case for NextGen is very strong, and with the right partners within industry it may be fully realized.

2.3 Delay Propagation

One of the main issues you see in the airline scheduling environment is the propagation of delays between flights. This can happen because airlines place minimal time between flights, and their goal is to maximize the utilization of their aircraft. This section outlines some works in this area and some attempts to model this phenomenon.

Churchill, Lovell and Ball (2010) discussed the implications of this phenomenon in one of their studies. They discussed a few different methodologies used to model this issue. One of the methodologies widely used is to "apply a microscopic analytic model and then to aggregate the results" (Churchill et al., 2010, p. 105). This method involves looking at the delays after the fact and tracing the flights throughout the system. This method can sometimes require proprietary data, which may be difficult to obtain. This concept has been built on over time to look at the various phases of flight and where the delay actually occurs rather than just looking at the delay at the conclusion of flight. Another method that has been used is a simulation based method where researchers use this specific data and then simulation changes on the data to observe the results. This area may be promising but, according to this paper, has not yet been widely used. The last major method is using an aggregate statistical approach to the modeling rather than mimicking an individual operation. This method looks less at the specific flights and more at the system as a whole and using these aggregate numbers to make inferences. Overall, all three methods have promise although the simulation based method seems most appropriate for this study.

One of the main methods airlines use to combat delay propagation is the addition of buffers in schedules (Wu, 2005). Wu conducted a study looking at the buffers in place at the time and attempted to calculate what the ideal buffer time would be. In a perfect system the schedule would matchup with the outcome through the system. Unfortunately, the system is imperfect and what is the ideal schedule cannot occur. In an effort to combat this issue airlines will pad their schedules with additional time between flights. This padding is inherently inefficient, but is a necessity to ensure on time performance. By adding this padding, airlines give themselves time to recover between flights and the ability to combat the effects of delay propagation. By padding the schedules, minor delays end up being absorbed into the schedule, while major delays reduce over time assuming no further delays occur.

Wu’s study created a new method of calculating these buffer times based off previous flight data. The method was designed to absorb most minor delays while reducing some more major delays. Overall the concept works and would generally be more ideal than a best guess type method previously employed. While this study was published in 2005, schedule buffers are commonplace today, so much so that they likely need to be reduced in order to obtain higher efficiencies than currently seen.

Liu, Cao, and Ma (2008) conducted a study looking at delay propagation at one unspecified Chinese airport. Their method was based on proprietary data provided by an unknown carrier specific to an unknown airport. This method attempted to model the propagation on the basis of a Bayesian network. Their model was initialized using approximately 180,000 records at this airport. Using this initialization the researchers modeled the movement of flights through this airport and how the delays affect the system. A difference mentioned is most researchers in China are concerned about the departure delay. This is counter to the method used in the U.S. where researchers primarily look at the delay on arrival. This difference is due to the assumption that a flight that arrives late will generally depart. In most situations the turnaround process has been optimized to the point where significant gains in time are unlikely. The researchers, study may be difficult to replicate since it requires a large amount of proprietary data and the cooperation of those involved. This research does provide a solid basis from which to build and reapply to different situations.

Wang, Schaefer and Wojcik (2003) conducted a study looking at delay's impact at three different U.S. airports. Their study specifically looked at weather as a factor by separating delays into various groups. Since airports have a higher capacity in better weather conditions, a delay occurring on a clear day will not have the same impact as a delay occurring on a cloudy, low ceilings day. The researchers also mentioned the concept of a delay multiplier in that a delay occurring earlier in the day has a much bigger impact than a delay occurring later in the day. Generally, airline schedules start at zero in the mornings and build throughout the day. In those situations a large delay occurring on the first flight will balloon throughout the day and may cause an impact in operations throughout the day. In some cases the impact of an early morning fog could have major implications for a carrier's operations throughout the day. As a result of this airlines generally track their morning on time launch rates to see if they have been set up for a successful day.

Wang, Schaefer and Wojcik (2003) approached this problem in a mathematical way, looking at individual flights as part of the system. Overall, their methodology is different in that they were looking at both fixed and random factors influencing operations. In turn, this allows for a more thorough look at the factors influencing delay propagation and how it might be studied in further detail.

Laskey, Xu and Chen (2012) conducted a study looking at delay propagation, looking specifically at propagation on the Chicago O'Hare and Atlanta Hartfield routing. This is different because most other studies have looked at system wide delays or wide groupings of airports, not just one specific pairing. The researchers used a Bayesian network as their method to model the effects. Their model looked at the summer schedule during the year of 2004, which is likely a different atmosphere than what one would see in the industry today. Their research added evidence to the concept of airlines adding padding to their schedules. The results showed that the average enroute time versus what was scheduled to be -12 minutes. This is an indication of the padding added to flight schedules by individual airlines. With this additional padding airlines are able to absorb the additional delays, which could come from system or capacity issues. Another finding was the probability of having a delay of more than 15 minutes was 47%. This is significant since the Department of Transportation defines a delay as any flight more than fifteen minutes later than scheduled arrival time (Bureau of Transportation Statistics, 2013c). Even with an added buffer time, 47% of flights met the delay criteria (Laskey et al., 2012). This study provided another model on how to look at these factors on a more micro level.

Overall, delay propagation is one of the core issues behind how delays work in the aviation system. When delays compound throughout the day, a small delay in the morning turns into a much larger delay in the afternoon. There have been a number of attempts to model delay propagation with a number of different methodologies. Overall it matters how delays move through the system to help to mitigate them further and understand how they progress. This summarizes a number of different works that have been done and a variety of different concepts.

2.4 Cost of Delays

One of the largest challenges that airlines run into is putting a price on what a delay costs them. There are a number of different methods using “soft” costs and some using “hard” costs but all are attempting to get to the same point, what is it costing us? This section summarizes a series of works attempting to determine the real costs of these delays.

One of the more recent major works done in this area was done by Cook, Tanner, and Anderson (2004), looking at the cost of delays for European airlines. The researcher’s study looked specifically at the cost per minute of delays on the ground as well as in the air. The scope was narrowed to mainly include unforeseen delays, excluding delays that were preplanned and mitigated using techniques such as schedule padding. The study determined the cost of delays to be €72 euros ($59 in 2004) per minute. This cost included some “soft” costs, specifically a cost per minute of passenger’s time. This study is built upon by later works, which attempted to replicate the study using U.S. parameters. This sets a basis for the methodology to be further refined by other authors. The numbers used are dated, since the study was done in 2004, but with some adjusting the results likely still apply today.

Ferguson, Kara, Hoffman and Sherry (2013) built upon the works of Cook, Tanner and Anderson (2004) by recreating the European model with American parameters and aircraft. One of the main goals of this study was to update the European model with U.S. parameters and also extend the fleet mix of the study to better represent U.S. traffic. Their study was based off U.S. airlines departing from 19 different U.S. airports in the month of July 2007. This study uses more current parameters than the European model but is six years old at the time of writing this thesis. As airlines shift towards consolidation and the mass retiring of older aircraft, these cost models may change year to year. As with the European model the padding added to the schedule is not considered in this study. Given the available data the researchers conducted a thorough analysis. To conduct additional work more detailed and challenging to obtain information would be required. The researchers split the delay groups into four primary categories, gate delays, taxi out delays, air delays and taxi in delays. There is significant variation between the costs per group so this differentiation is imperative. Using the researchers case study, the costs ranged from $3.57 to $47.13 between the phases (Ferguson et al., 2013). Overall they found that the European model can be adapted to the U.S. market and their approach did follow similar trends with the U.S. results. The researchers indicated additional research should be conducted to validate their results against changing market parameters.

A follow up study conducted by Kara, Ferguson, Hoffman and Sherry (2010) looked at the sensitivity of Ferguson, Kara, Hoffman and Sherry's (2013) previous work to changes in the airline industry. This study looked specifically at the sensitivity of the model to changes in fuel price, fuel burn rate, and crew costs. Their work is significant given that most major costs airlines observe are volatile, and subject to significant change during the course of a year. Given the recent push toward more fuel efficient aircraft by carriers, this study is significant to analyze the effects of these changes.

The researchers found by varying the cost of fuel up to 200% could result in an increase in delay cost by 50%. This is explained by fuel being a significant portion of an airline’s overall operating costs. In addition, the researchers found that smaller regional aircraft are less sensitive to delay costs than larger aircraft. Given carrier’s behavior has been to use these smaller aircraft, evidence has been provided toward their continued use. The researcher’s results additionally showed delay costs are most sensitive to changes in fuel prices, while least sensitive to changes in crew costs.

A report published by Airlines for America (2013), a U.S. airline industry trade group, found that in 2012 $7.2 billion dollars in costs were attributed to system delays by U.S. airlines. This report indicates the overall cost per minute of a delay to be $78.17. Their report used similar parameters as the Ferguson (2013) study but obtained widely different results. These discrepancies indicate the widely varying which may be obtained through analysis of this subject area.

Zou and Hansen (2012) created an alternative methodology for estimating delay costs based on aggregate statistics rather than as stated by the researchers “involve assumptions that are rarely acknowledged or justified” (p. 1033). The researchers additionally raised the point that the schedule buffer that exists in most flight schedules has largely been ignored by existing research. The researcher’s attempt is to close some of these holes, while providing a more accurate picture of delay costs. Their research also pointed out the varying estimates of system wide delays through a variety of methods, which varied from $1.8 billion to $23.4 billion (Zou & Hansen, 2012). The model the researchers developed looks at the problem in a new way. The challenge in evaluating models such as these is validation. Due to the nature of the problem there have been a variety approaches generated, none of which have been completely proven correct.

The concept of estimating delay costs is subject to debate. There is no economical way to track costs to such a micro level that you would be able to validate any models. Due to this there will be variations in how to approach the model. As of writing, it is not possible to say which is correct and which is not. Future research may lead to this answer.

2.5 Summary

The advent of the NextGen program creates a challenging problem in the aviation industry. There is a cost associated with the NextGen program and its full implementation. There is literature on the subject of NextGen and a case has been made as to why it needs to be implemented. From the perspective of delays, one could see how large of a role they play in the day to day operations of any airline. There have been methods established to put a cost to these delays and methods to determine how they propagate through the system. The question remains, how would NextGen's proposed implementation affect an actual flight schedule, a question which this author endeavors to answer.

CHAPTER 3. METHODOLOGY

The purpose of this research is to simulate the potential flight delay reductions attributed to the NextGen program's implementation. This research project simulated the delay reductions utilizing a distribution and calculate an overall net benefit from this program based on delay reduction. The results of this simulation were compared to the total delays in the overall population. The delay reduction estimates came from a simulation conducted on a sample of flights from the original schedule.

3.1 Overview of Methodology

This study was conducted by analyzing the delay reduction patterns with and without the NextGen program's simulated reduction applied. The study began by conducting a random sampling of flights occurring during the summer of 2013. A case was defined as an aircraft's complete flight schedule on a given day. Each case was built using that particular aircraft's schedule for the selected day. The case was then processed through a custom-designed simulator with an appropriate delay reduction applied. The final sum of minutes delayed were recorded. A non-parametric sign test was conducted comparing the simulation median flight delay minutes versus the summer 2013 median flight delay minutes. The test was evaluated at a significance level of $\alpha = 0.05$.

3.2 Sampling

The sampling methodology for this study used a simple random sampling model. The population is defined as all flights occurring between (inclusive) Memorial Day (May 27) and Labor Day (Sept 2) in 2013. This population is refined to only include flights operated by one of the 16 air carriers reporting data to the Bureau of Transportation Statistics (2013b). The sample was built using randomly selected dates and aircraft tail numbers existing in the population. The sampled dates were randomly drawn from all available dates in the population. The aircraft tail numbers were randomly selected from all tail numbers existing in the full flight records database. Should a date/aircraft tail number combination not exist in the flight records, it was excluded and the next random combination utilized until the desired sample size is reached. An example of aircraft tail numbers and dates are shown in Table 3.1.

Table 3.1 Example Date/Aircraft Tail Number Combinations

Date	Tail No.
7/1/2013	N906FJ
6/25/2013	N360NB
7/10/2013	N586UA
8/10/2013	N238WN
5/31/2013	N172US

Each case was constructed on a basis of each sampled aircraft tail number and date pairing. From one sample, using the aircraft tail number, the flight schedule for that aircraft, for that day was determined. Noted was each flight’s actual and scheduled out, in, on, and off time. Included in Figure 3.1 is a sample flight schedule for an aircraft on July 22, 2013.

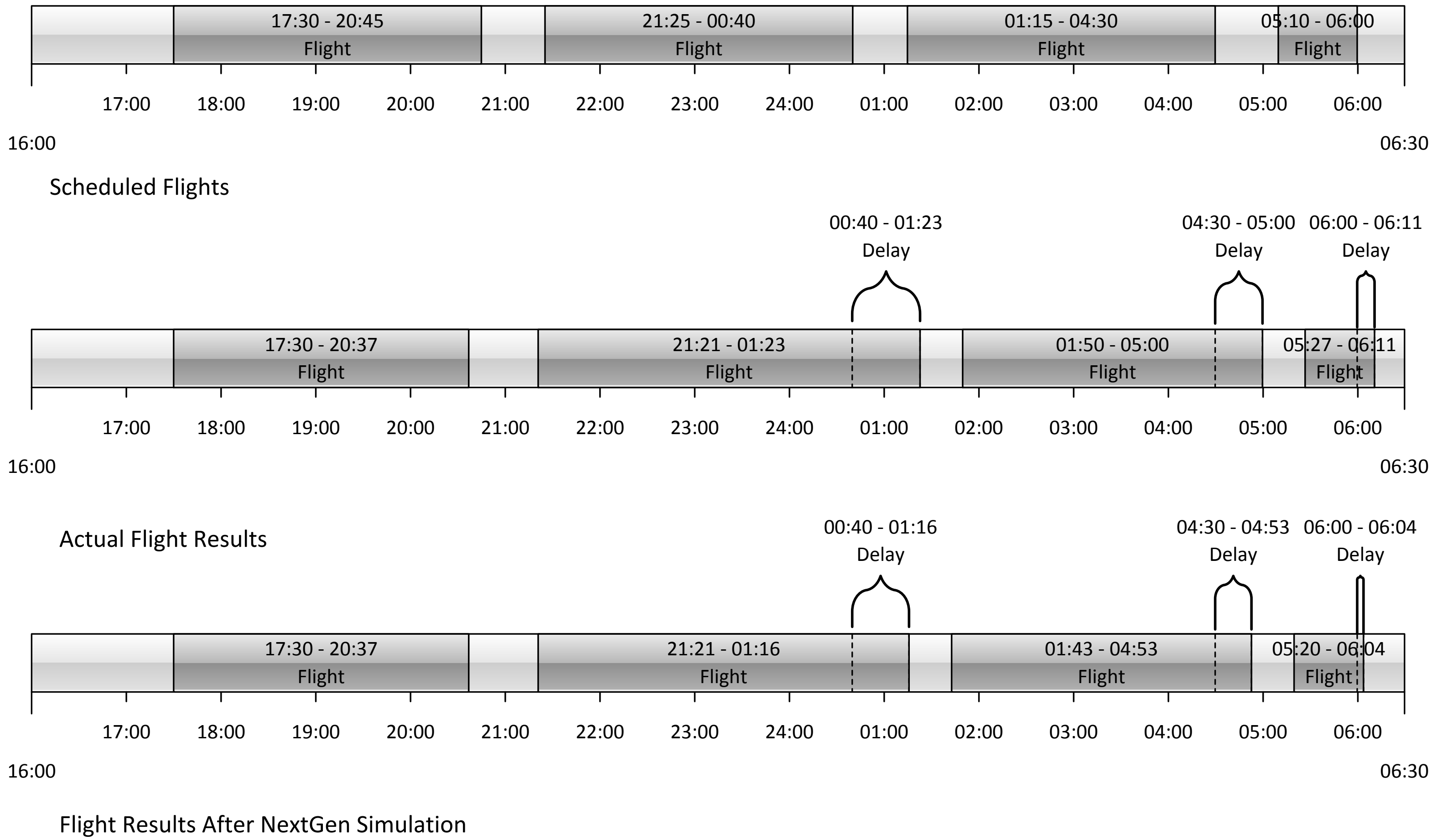

Figure 3.1 Example Flight Schedule With Actual Delays and Simulated NextGen Effects

The original, scheduled flights for a specific aircraft tail number have been diagrammed on the top timeline. On the middle timeline are the actual times from the flight including the actual time of departure, actual time of arrival and any delays associated with this schedule. The bottom timeline is the simulated flight schedule showing anticipated NextGen effects. Any National Airspace System delays have been reduced using the delay reduction distribution and the adjusted arrival times have propagated through the schedule. In Figure 3.1, National Airspace System delays are reduced, but not eliminated.

3.3 Simulation

A simulation was conducted using the input data to calculate the total flight delays with and without the NextGen delay reductions. The simulation was constructed by the author for the purposes of this study. A process map with decision tree overviewing the simulation has been included in Figure 3.2. The simulation began with the first flight of the day. The simulator evaluated the flight on the basis of the difference between scheduled arrival time and actual arrival time. If the actual arrival time is later than the scheduled arrival time, the difference between the two times was calculated. This difference was termed a delay. If this delay had been attributed to “National Airspace System” in the inputs, then this delay time was altered. The alteration was on the basis of a random number generated from a uniform distribution that ranged from 0% to 41%. A “simulated actual arrival time” was calculated by taking the scheduled arrival time and adding the altered delay time to obtain a new actual arrival time. The turnaround time was calculated by taking the next flight in sequence’s actual departure time and subtracting from it the actual arrival from the previous flight without any alteration. This turnaround time was used to calculate a simulated departure time of the next flight in the sequence by adding the simulated arrival time of the previous flight to the turnaround time previously calculated. This new departure time took into account the delay reduction calculation which was attributed to the NextGen Program. The next step was to calculate the flight time of the second and subsequent flights in the sequence. This calculation was done by taking the actual arrival time of this flight and subtracting the actual departure time of this flight. This number was used to calculate a new arrival time for this flight.

The second and subsequent flight's simulation begins by calculating a simulated arrival time for this flight. This calculation was done by taking the previously calculated simulated departure time and adding to it the flight time which was just calculated. This new arrival time was compared against the scheduled arrival time to calculate a new delay factor for this flight. The procedure then repeated itself picking up from the previously stated directions at the point where the delay is conditionally altered on the basis of if the delay was attributed to "National Airspace System." The simulation repeated this sequence until all flights for this case had been simulated. The total number delayed minutes was calculated for the case by summing the calculated minutes delayed without the alteration being applied to that flight; but including any propagated benefits from previous flights. This total number of delay minutes was recorded for later comparison.

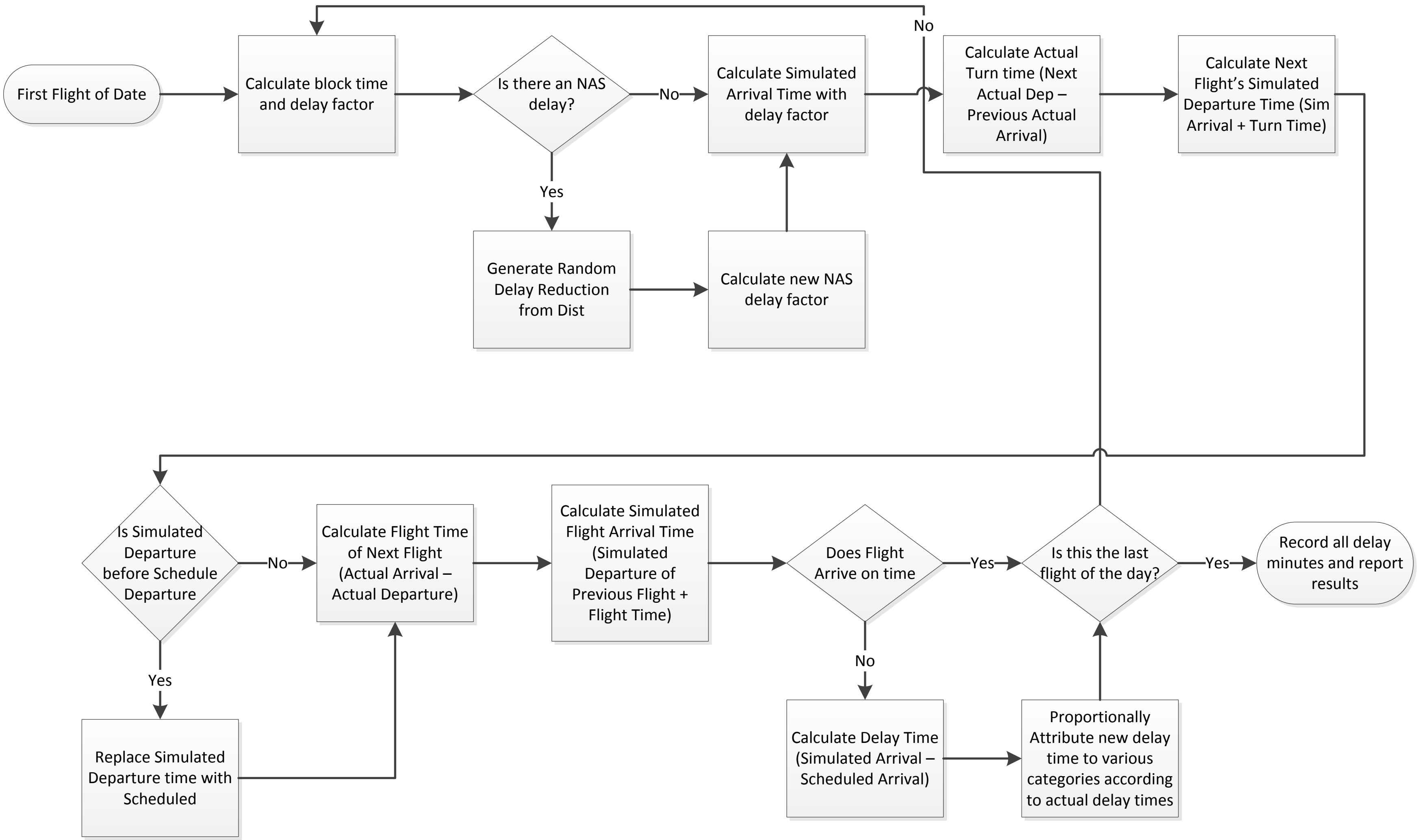

Figure 3.2 Simulator Process Map

3.4 Statistical Analysis

The recorded simulation results were compared on the basis of a single-tailed non-parametric Sign test. The comparison was between the median flight delay for the overall population versus the true median flight delay in the sample with the applied NextGen reduction. Examples of two aircraft tail number and date combinations results has been included in Table 3.2. The baseline scenario has the delay without any modification from the simulation. The NextGen scenario is the result of the simulation. The simulation results were evaluated using a critical α of 0.05.

H_o: There is no significant difference between the true medians of delay minutes with NextGen and overall delay minutes with no alterations.

H_a: There is a significant difference between the true medians of delay minutes with the NextGen program and delay minutes without any alteration.

Table 3.2 Sample Results

Tail No. / Date	NextGen Scenario (delay minutes)	Base Scenario (delay minutes)
N500XX / 7-21-13	85	90
N600XX / 7-28-13	123	123

3.5 Post Analysis

In the post analysis of this study, a total cost estimate was calculated for both scenarios as it relates to air carrier delays. The primary source of data for this analysis was the study conducted by Ferguson, Kara, Hoffman, and Sherry (2013). The Ferguson study was conducted in 2007 using data from July of 2007.

This study's analysis looked at two results, the sum total of delay minutes under simulated NextGen, and the baseline values calculated without the simulated NextGen. The value used for cost was the average cost of delay per minute, $11.71, which was found under the base cost scenario of the Ferguson study (2013, p. 319). The next step in this study was then to adjust the values to account for the effects of inflation over the six year period between 2007 and 2013 using the Bureau of Labor Statistics Consumer Price Index inflation calculator (2013). The results of this analysis was then compared and reported in Chapter 4. In addition to the Ferguson study, the Airlines for American (2013) cost parameters were also used for a separate analysis. The calculation methodology was the same as used with the Ferguson study, but in place of the Ferguson cost per minute is the Airlines for America cost per minute. The results of this analysis have also been reported in Chapter 4.

3.6 Summary

The methodology in this study is designed to determine if there is a significant difference between National Airspace System delays with the attributed NextGen benefits and a baseline value. The study was conducted using a simulation approach on the basis of real data from the BTS On-time performance database conducted using the summer schedule of 2013. Chapter 4 presents for the results for this study.

CHAPTER 4. RESULTS AND FINDINGS

This chapter provides the results and quantitative analysis of the simulation described in Chapter 3.

4.1 Population

The population of this study includes all flights conducted during the summer of 2013 schedule (May 27 – September 2) found in the Bureau of Transportation Statistics On-Time performance database (2013b). In this study, an individual case has been defined as all the flights a unique aircraft conducted on a specific day. A case may include one or many flights by one unique aircraft tail number on a given day.

The population was found to contain 356,356 possible cases meeting the criteria. The graphical summary of this data has been included in Figure A.1 in the Appendix. The mean number of delay minutes for a case was found to be 67.67 minutes with a standard deviation of 117.79 minutes. An Anderson-Darling Normality test was conducted on the data to determine distribution normality. The results rejected the normality assumption with $p \leq 0.005$ compared to a critical alpha of 0.05. The median value was found to be 20.0 minutes with a minimum value of 0.0 minutes and a maximum value of 1966.0 minutes. The inner quartile range of the data was 77.0 minutes.

The sampling methodology started with randomly selecting date and aircraft tail number combinations. There were 100 dates in the range of May 27th through September 3rd. There were 4,718 unique aircraft tail numbers. A random number generator was used to identify aircraft tail number and date combinations. If an aircraft tail number/date combination did not exist in the data set it was excluded and the next random combination was used until the desired sample size of 1,400 was reached.

4.2 Sample

The sample consisted of 1,400 randomly selected combinations of aircraft tail number and date. The graphical summary of the sample delay data has been included in the Appendix in Figure A.2. The resulting sample had a mean of delay minutes of 57.87. The standard deviation of the sample was 103.25. An Anderson-Darling test of normality indicated a $p \leq 0.005$, rejecting the normality assumption with confidence at a critical alpha of 0.05. The median number of delay minutes was 16.48 ranging from 0.00 to 925.15 minutes. The inner quartile range was 63.41 minutes.

4.3 Statistical Analysis

The statistical test selected for this analysis was a Sign Test for Median. This non-parametric test was selected because of the non-normal nature of the data sets precluding a t-test, and the hypothesis being one-sided. The test was setup in a one-sided manner detecting only a change in the sample median less than the test median. The hypotheses for the test are as follows:

H_o: There is no significant difference between the true medians of delay minutes with NextGen and overall delay minutes with no alterations.

H_a: There is a significant reduction between the true medians of delay minutes with the NextGen program and delay minutes without any alteration.

The results of the test found a p value of 0.0025, thus rejecting the null hypothesis at an $\alpha = 0.05$. The test results have been included in Figure 4.1 below.

Sign test of median = 20.00 versus < 20.00

	N	Below	Equal	Above	P	Median
C2	1400	752	2	646	0.0025	16.48

Figure 4.1 One-Way Sign Test Results

4.4 Post Analysis

Post analysis was conducted to estimate cost savings should the simulation results have been what occurred during the summer of 2013 versus the actual results. The sample output found a total delay minutes of 81,011 over 1,400 aircraft tail number and date combinations. This value was proportionally adjusted to account for the 356,356 combinations in the overall population. The calculations found an estimated 20,620,685 minutes of delay on the basis of the sample output of the simulation. These delay minutes were then subtracted from the total population delay minutes of 24,114,235 to find a difference of 3,493,550 minutes of delay time. The cost savings were calculated using the A4A (2013) and Ferguson (2013) cost per delay minute models to provide example estimates. The actual savings is unknown, other delay cost models may provide different answers. Each cost per delay minute model was adjusted for inflation using the Bureau of Labor Statistics inflation calculator for their respective years (2013). The results using both pricing models have been included in Table 4.1.

Table 4.1 Illustration of Cost Savings Using Two Different Cost Values

	Ferguson Model[a]	A4A Model[b]
Cost Per Minute	$13.16[c]	$79.32[c]
Minutes of Reduced Delay	3,493,550	3,493,550
Total Cost Savings	$45,975,117	$277,108,383

Note. Results provided are not generalizable. Results are only valid with the delay reduction distribution in the paper.
[a]Ferguson cost per minute $11.71 (2013, p. 319) [b]A4A cost per minute $78.17 (2013, p. 1) [c]Inflation Adjusted using Bureau of Labor Statistics Calculator (2013)

4.5 Summary

The results of this study found there was a significant change in delay minutes from the simulation results versus the overall population where the sample originated. The difference between the sample and the population medians was found to be 3.52 minutes per aircraft-day combination. The post analysis indicated a total cost savings over the 100 days of the summer schedule of between $46 and $277 million dollars. The results of the study rejected the null hypothesis and found there is a statistically significant difference between median total delay minutes for the simulated changes associated with the NextGen program versus the baseline.

The results are dependent on the specific delay reduction distribution used and are not generalizable. The method used in this study may be applied for future studies when the delay reduction distribution is based on more information than available in this study.

CHAPTER 5. DISCUSSION & RECOMMENDATIONS

This section draws conclusions from the results of this study. Additionally, the author provides interpretation of the results and his recommendations for future study.

5.1 Conclusions

The results of this study found a statistically significant difference between median flight delay minutes with a simulated reduction applied versus the true population median. The results using this distribution found a 17.6% reduction in the median delay time with the simulated NextGen affects applied. The selected distribution of delay reduction was based on the NextGen implementation plan (Federal Aviation Administration, 2013, p. 4). The change in the overall total amount of delay time for a flight and not tied to a specific delay category.

The findings of this study indicate that a change in the National Airspace System component of overall delay had a significant effect on the median flight delay time. This change in median delay time can be attributed to the propagation effects of flight delays. As the initial delay time was reduced earlier in the schedule it began to be absorbed by the schedule later in the day. Modeling this effect was one of the objectives of this study so as to observe how a change in one component of flight delay time effects the larger category.

The Federal Aviation Administration asserted that the NextGen program would reduce flight delays by 41% (2013, p. 4). Not surprisingly, the results of this research did not find a 41% change in overall delay time. This finding is attributed to the way this author chose to model the 41% change in flight delays. Based upon the information available, the author of this study modeled this change in flight delay time on a basis of a uniform distribution ranging from 0% to 41%. While FAA claimed that the NextGen program would reduce flight delays by 41%, there was no additional information provided as to what this 41% change represented or the variation to be expected. The author's decision to model this change as only effecting the National Airspace System component of flight delays does impact the results. Should this study be reproduced using a changed set of component of flight delays, different results would be expected. Additionally, changes to the distribution model of this 41% change in flight delays would have a significant effect on the results. Without additional clarification as to the meaning of this 41% change in flight delays from the FAA, the way by which this change is represented can be interoperated many ways.

Overall, the conclusion of this study found there was a significant change in median flight delay time with the modeled effects of the NextGen program applied, using the methodology and data of this study. The magnitude of this change was lower than the FAA's 41% change attributed to the NextGen program's implementation due to the selected delay reduction distribution. The author attributes this difference to the modeling techniques used in this study and the limited information available to the author when the study was designed. Should additional information become available, a different result from the model would be expected. Therefore, the specific results are not generalizable. The delay amounts and dollar estimates are shown for illustration purposes only.

5.2 Recommendations

The recommendations from this study focus on reproducing this study using different models for the NextGen effects. This study used a specific uniform distribution of the reduction in delay time attributed to NextGen by the FAA. A different distribution different of delay reduction would result in different results. This section highlights some of these different methods by which to model NextGen effects.

The delay reduction distribution selected for this study was a uniform distribution ranging between 0% and 41%. There are numerous ways to model the delay reduction. A Normal distribution with an average set at 41% would produce results different from this study; as would other probability distributions that could be constructed from the available information. A sensitivity analysis of this model should be conducted to determine the susceptibility to changes in the delay reduction model.

The selected schedule is another area that could alter results. This study was confined to a summer schedule. Expanding the study to include the full year schedule and replicating the results against using expanded population would product results over the various seasons. The summer schedule is the most dense schedule run by airlines with the highest flights per day. Expanding the study to less dense schedules are expected to generate different results. Replicating this study year over year may yield different results. This study looked at one summer in one year; trends may exist in the market causing changes in the summer schedule each year not captured in a single year's results.

This study provided a proposed model of how to simulate NextGen related benefits on an existing flight schedule and previous results. This study provided results from the simulation using the summer 2013 schedule. Further study should be conducted using different methods of modeling NextGen's benefits, and using different schedules. This study has proposed one method of evaluating the results of a simulated implementation of NextGen additional work should be done to further expand upon this method.

5.3 Summary

This study proposed a methodology to evaluate NextGen's benefits using real flight schedules and actual flight times. The conclusion is that there is a substantial change in overall flight delays when a simulated reduction is applied to the National Airspace System category of delays. The author proposed areas for future research. Replicating this study against a larger, more varied schedule will better account for changes throughout the year where schedules may be of varying density. A sensitivity analysis of the impact of delay reduction distributions is an area for future work.

The Federal Aviation Administration's NextGen program is a large change in the US aviation industry. The NextGen program will substantially alter how the air traffic control system works every day. This program will require substantial investment from not just the FAA but also aircraft owners and operators to ensure all parties are able to take full advantage of the NextGen program. Previous research has attempted to quantify the benefits associated with this program and have proposed a number of different methods of analyzing this problem. This study proposed a method to analyze flight delay reductions with a simulated NextGen program against an actual flight schedule. In this method, flight delays cannot be increased but may only be either decreased or remain the same. By building upon this research and similar research, researchers a better understanding of the NextGen program's overall impact is possible. The NextGen program will drastically alter the current aviation system, this study provided a method to study these changes.

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APPENDIX

APPENDIX

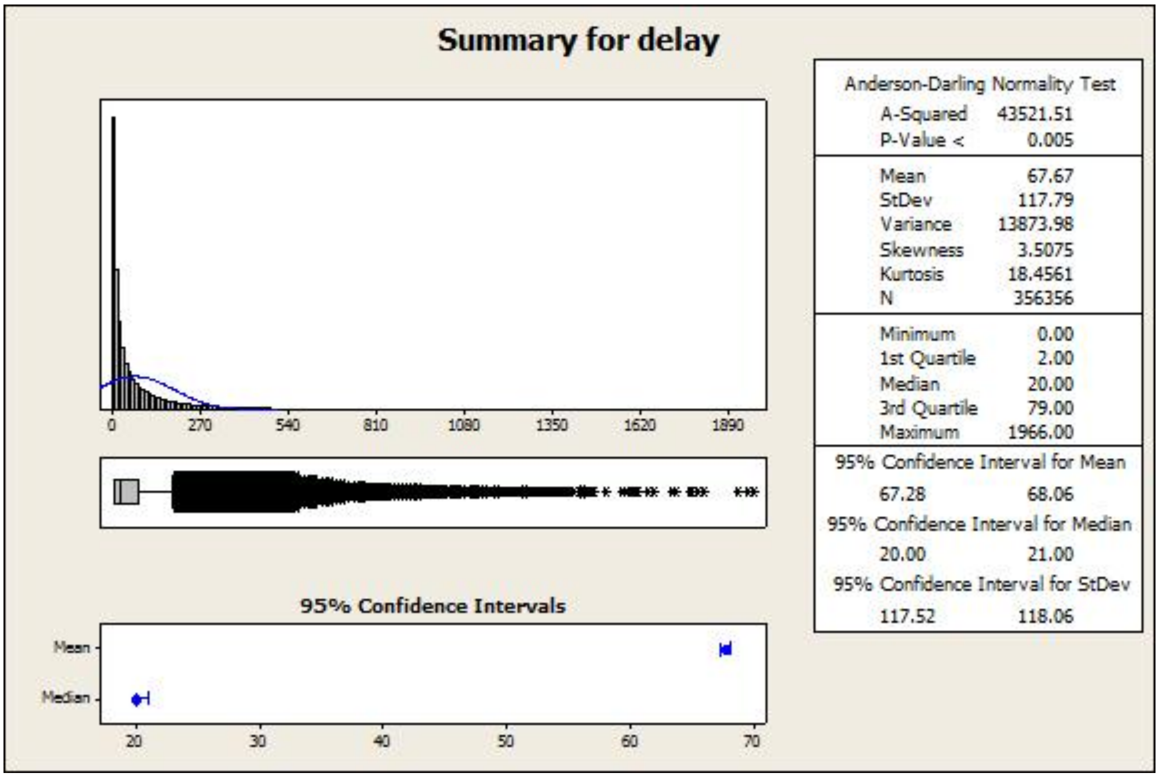

Figure A.1 True Population Graphical Summary (minutes delayed)

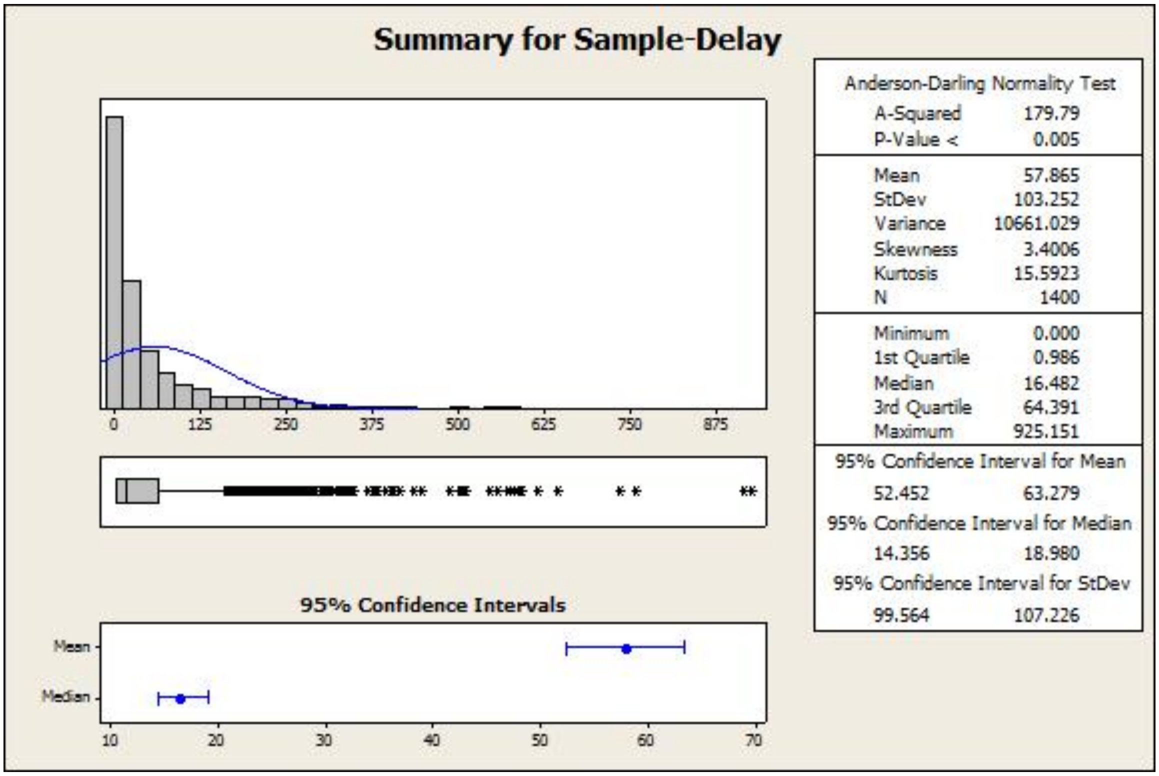

Figure A.2 Simulations Results Graphical Summary (minutes delayed)

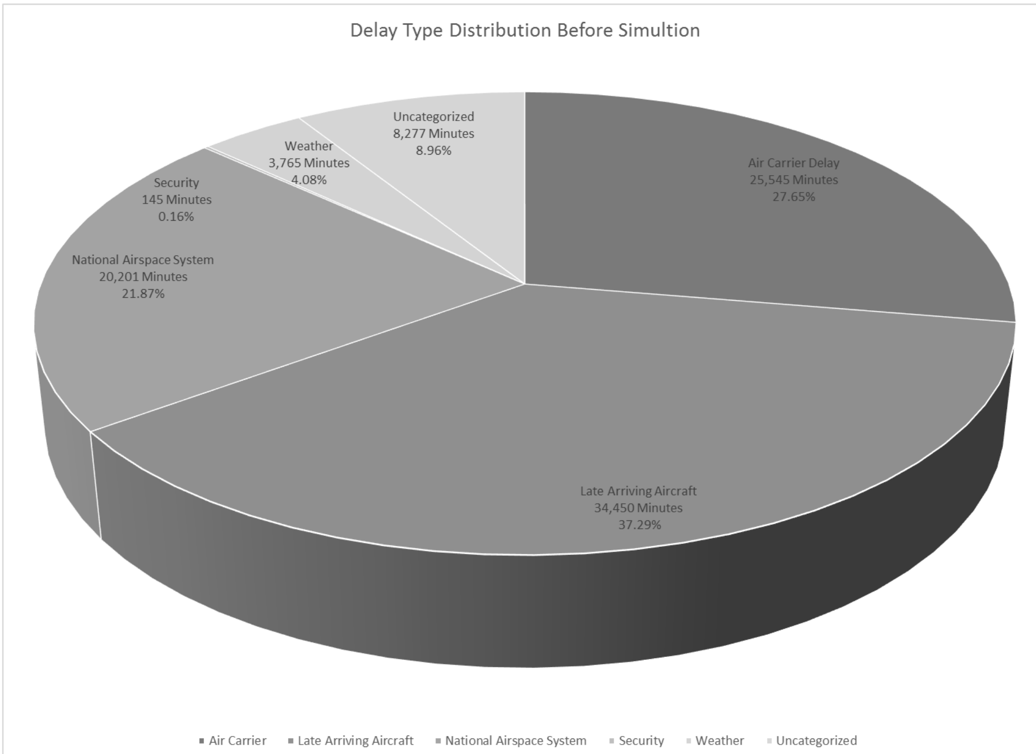

Figure A.3 Delay Type Distribution Before Simulation

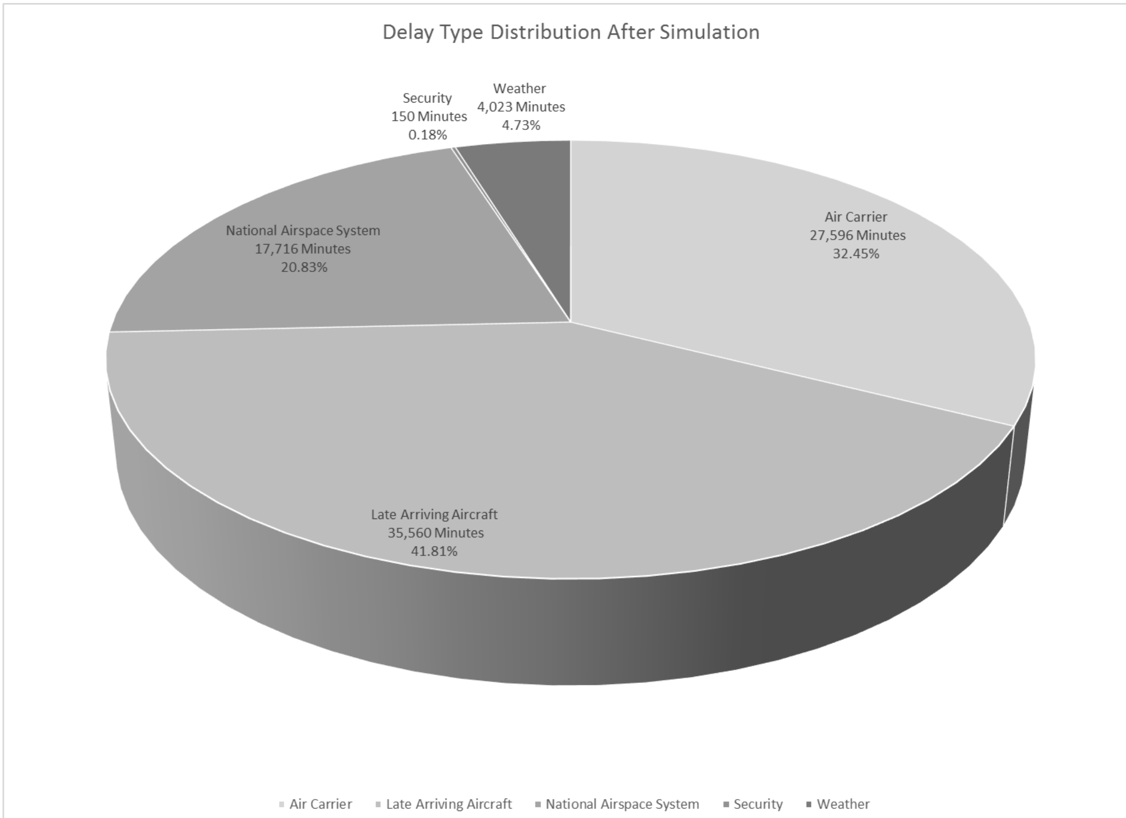

Figure A.4 Delay Type Distribution After Simulation