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Evaluating NAS Delay Impacts from Orbital Launch Operations at Cape Canaveral and Optimizing Launch Windows

Tanner Jordin Furr

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by

Tanner Jordin Furr

Bachelor of Science
Business
University of West Florida
2013

Master of Science
Aeronautics and Space Studies
Embry-Riddle Aeronautical University
2016

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We the undersigned committee
hereby approve the attached dissertation

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Tanner Jordin Furr

John E. Deaton, Ph.D. Professor and Interim Dean College of Aeronautics Major Advisor	Deborah S. Carstens, Ph.D. Professor College of Aeronautics
Alexander R. Vamosi, Ph.D. Associate Professor College of Business	Meredith Carroll, Ph.D. Professor College of Aeronautics

ABSTRACT

TITLE: Evaluating NAS Delay Impacts from Orbital Launch Operations at Cape Canaveral and Optimizing Launch Windows.

AUTHOR: Tanner Jordin Furr

MAJOR ADVISOR: John Deaton, Ph.D.

The purpose of this study was to determine if there was an impact of Part 121 arrival delays into Orlando International Airport (MCO) due to orbital space launch operations at Cape Canaveral. U.S. Government archival data spanning ten months and over 22,000 flights was accessed and categorized into three research questions by day of week, time of day, and whether or not an orbital space launch occurred during the established time frame. Inferential analysis using the one-way ANOVA (RQ1) and two-way ANOVA (RQ2 and RQ3) was conducted and found no significant differences in average Part 121 arrival delays into MCO due to orbital space launch operations at Cape Canaveral. The study concluded that there is at present no delay impact of statistical or practical significance on MCO from orbital space launch operations at Cape Canaveral that could be detected by the study at hand. While the findings of the current study will certainly stand for a time, in the rapidly changing environments of both Part 121 aviation and orbital space launch operations, it would be wise to monitor this issue on a regular basis.

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Dedication

For all of my teachers, especially my greatest one; my Dad.

Chapter 1

Introduction

Purpose of Study

The purpose of this study was to examine the effects of orbital space launch activity at Cape Canaveral on Part 121 arrival delays into Orlando International Airport (MCO). This allowed for direct measurement of any delay impact that orbital launches from Cape Canaveral are currently having on arriving Part 121 traffic into MCO. Within the context of this study, an orbital space launch was defined as any occurrence, or recorded attempt, to send a payload from the surface of the Earth to beyond the Karman Line that involved the activation of a Temporary Flight Restriction (TFR), Restricted Area, or other National Airspace System (NAS) traffic mitigation-related airspace. An arrival delay was defined as the difference between scheduled arrival time and actual arrival time, as measured in minutes. Optimal efficiency was defined as the condition which allows the maximum amount of orbital space launches per week with minimal delay impact on Part 121 operations.

Background and Rationale

There is an ever-increasing number of orbital launch operations originating from the Cape Canaveral Spaceport. This is reflected by quantifiable year-over-year data, and also by an ever increasing number of commercial launch vendors establishing operations either on or near the Cape Canaveral footprint. According to the Federal Aviation Administration (FAA) Office of Commercial Space Operations, in 2009, only one such launch occurred, while in 2019 there were 39 (Federal Aviation Administration (A), 2021). Further illustrating the exponentially-increasing rate of launches is the fact that in just the first three months of 2021, 32 orbital launches have already occurred (2021). According to Cukurtepe and Akgun (2009), the availability of orbital launch windows is also rapidly declining as the desire to launch increases. Cukurtepe and Akgun made a strong case for developing and implementing space traffic management techniques to increase efficiency and optimize launch systems (2009). Over ten years have passed since that study, and still very little attention has been given to this area of aviation.

Just nearby, and directly at odds with the exponentially-growing orbital space launch operations is Orlando International Airport (MCO), which itself is experiencing large annual increases in Part 121 commercial flight activity, in terms of both arrival/departure rates as well as by number of total annual passengers screened by MCO TSA (Bureau of Transportation Statistics, 2020). MCO is considered a core NAS airport by the FAA due to its status as a major hub for several Part 121 carriers and function as a Class B airspace corridor in central Florida (Federal Aviation Administration, 2016).

With both the orbital launch rates from Cape Canaveral, and the Part 121 operations at MCO growing exponentially over time, an airspace conflict is likely inevitable. What is worse, the cracks of such an imminent conflict have already begun to show. In 2019 a single orbital test flight of a SpaceX Falcon Heavy launch vehicle from Cape Canaveral resulted in hundreds of Part 121 flights in and out of Florida being delayed and/or cancelled (Grush, 2019). Any orbital launch attempt from Cape Canaveral requires the activation of certain TFR’s and other airspace surrounding the range safety area around Cape Canaveral (Garceau, 2017). This airspace overlaps the primary arrival corridors into several major Florida airports, including MCO (2017). Thus, any time an orbital launch attempt occurs at Cape Canaveral, special protective airspace is activated that blocks many of the NAS arrival and departure corridors into MCO (2017). This means that air traffic controllers must send aircraft around these airspace blockages, manually vectoring them onto unoptimized arrival routes (2017). This specific process was described well by Garceau (2017) who also illustrated that the reroute most commonly used by controllers requires air traffic to be sent to the opposite side of the Florida peninsula. This action will almost inevitably lead to the activation of a ground delay program for arriving traffic into MCO. This process also leads to thousands of extra miles traveled by Part 121 aircraft during orbital space launches, meaning the waste of an unknown amount of fuel at a direct cost to individual air carriers, the expulsion of tons of additional unnecessary carbon emissions, and perhaps thousands of delayed passengers (Grush, 2019).

The FAA has clearly identified that an airspace issue of some degree has already begun to occur between these two modes of transportation. The President of the Commercial Spaceflight Federation, Eric Stallmer, testified to the United States Senate in 2019 that the FAA’s tools and systems for separating orbital launch traffic and Part 121 air carrier traffic are severely unoptimized and outdated (Grush, 2019). Further, the Air Line Pilots Association (ALPA), the labor union representing many Part 121 air carrier pilots in the United States, produced a formal white paper in the same year that came to the same conclusions (Air Line Pilots Association, 2019). ALPA also stated within their analysis, that the conflict between orbital space launch traffic and Part 121 traffic was rapidly approaching criticality (2019).

The calls for scientific analysis of this practical aviation problem became so loud, in fact, that the FAA began work on at least one program that year that was meant to attempt to reduce the impact of orbital launches from Cape Canaveral on the National Airspace System (NAS). Called the Space Data Integrator, or SDI, the tool is a piece of software meant for use by air traffic controllers to reduce the conflict between orbital space launch activity and NAS traffic by reducing launch range safety areas (Ngai, 2020). As of October 2021, the SDI has only been partially fielded, and is lacking government funding to at least some degree (2020).

A conflict between the desire to conduct orbital launch operations from Cape Canaveral and the desire to conduct Part 121 air carrier operations in and around MCO is likely already occurring, and the situation could be rapidly approaching a resource tug-of-war between the two transportation models for airspace. The simplest solution that could immediately reduce any NAS delay impact occurring from orbital space launches at Cape Canaveral was to ensure that the most efficient orbital launch slot assignment sequence is being utilized. However, before such a slot assignment sequence could be designed, there were two critical variables that needed evaluation. First, the current impact of orbital space launches on airspace neighboring Cape Canaveral required measurement. Second, a determination as to which orbital launch slots are more favorable for reducing NAS delays needed to be made.

It was critical that this problem be solved now, before major delays to either Part 121 traffic or orbital launch operations began to occur regularly. The referenced works above clearly signified that a conflict of unknown severity already existed between these two models of transportation. For that reason, this practical aviation problem needed to be scientifically addressed in the very near term.

Definition of Terms

1. *Cape Canaveral* was defined as the orbital space launch facilities in and surrounding the National Aeronautics and Space Administration (NASA) properties located in Cape Canaveral, Florida, including the Kennedy Space Center and associated Launch Pads 39A and 39B.
2. *Orbital Space Launch* was defined as any occurrence, or recorded attempt, to send a payload from the surface of the Earth to beyond the Karman Line

that involves the activation of a TFR, Restricted Area, or other National Airspace System traffic mitigation-related airspace.

3. *The Karman Line* is generally considered to be the boundary between Earth and space, the Karman Line lies at an altitude of 62 miles, or 100 kilometers (National Environmental Satellite Data and Information Service, 2016).
4. *Part 121 Traffic* was defined as commercial airline traffic considered to be regularly scheduled by the FAA under FAR Part 121 (Federal Aviation Administration (B), 2021).
5. *Arrival Delay* was defined as any difference, expressed in minutes, between a scheduled Part 121 arrival time and the actual arrival time. This is also referred to as a-zero.
6. *Launch Window* was defined as any period of time in which an orbital space launch is designated to occur.
7. *Temporary Flight Restriction (TFR)* was defined as an aera of airspace restricted to transit due to a hazard (Federal Aviation Administration (A), 2021).
8. *Restricted Area* was defined as areas of special airspace that are subject to traffic restrictions (Federal Aviation Administration (A), 2021).
9. *Airspace* was defined as a broad term meant to describe geometric areas of the sky, both controlled and uncontrolled.

10. *National Airspace System (NAS)* was defined as the airspace, navigation systems, and facilities of the United States (Federal Aviation Administration (A), 2020).

Research Questions and Hypotheses

Research Questions

The overall research question that guided this study was “What is the effect of orbital space launches at Cape Canaveral on Part 121 arrival delays into MCO?” This overall research question was supported by the following sub-questions:

1. What was the difference in average Part 121 arrival delay lengths between days that orbital launches from Cape Canaveral occurred and non-launch days?
2. What was the difference in average Part 121 arrival delay lengths between days that orbital launches from Cape Canaveral occurred and non-launch days with respect to day of week?
3. What was the difference in average Part 121 arrival delay lengths between days that orbital launches from Cape Canaveral occurred and non-launch days with respect to time of day?

Research Hypotheses

Hypothesis 1: Part 121 arrival delays will be significantly higher on days in which an orbital space launch occurred from Cape Canaveral.

Hypothesis 2: Part 121 arrival delays will be significantly higher on specific days of the week that orbital launches from Cape Canaveral occur when compared to other days of the week that launches occurred.

Hypothesis 3: Part 121 arrival delays will be significantly higher during specific times of day that orbital launches from Cape Canaveral occur when compared to other times of day that launches occurred.

Preliminary Description of Variables

1. RQ1 utilized arrival delay in minutes as its continuous dependent variable, and the dichotomous value of launch or no launch as its single independent variable. Further description of the dependent and independent variables for RQ1 are located in Chapter 3, below.
2. RQ2 utilized arrival delay in minutes as its continuous dependent variable. RQ2 used two categorical independent variables: the dichotomous value of launch or no launch, and the seven-level value of day of week. Further description of the dependent and independent variables for RQ2 are located in Chapter 3, below.
3. RQ3 utilized arrival delay in minutes as its continuous dependent variable. RQ3 used two categorical independent variables: the dichotomous value of launch or no launch, and the six-level value of time of day. Further description of the dependent and independent variables for RQ3 are located in Chapter 3, below.

Study Design

The research methodology that was used for this analysis is quantitative, associational research. The selected research design was ex post facto, effects type. Quantitative research was the appropriate methodology to be used in this analysis due to the need for all preliminary research questions to be addressed using statistical analysis. A qualitative approach would fail to address any of the preliminary research questions properly, therefore the use of either a qualitative or a mixed-methods approach could be wholly excluded from consideration here. Likewise, associational research was appropriate due to the lack of any intervention within this study, thus excluding experimental research, and the direct need for inferential statistics to be used to address the research questions, thus excluding descriptive research from consideration from use within this study.

The ex post facto design was necessary due to the fact that group differences were being measured, with each group and its corresponding dependent variable data being pre-existing. The use of a correlational design, associational research's other arm, was inappropriate because the study did not examine a relationship within a single group. The effects-type sub design was appropriate due to the fact that the group membership variable was located on the independent variable group for all research questions.

Significance of Study

The significance of this study was that it produced a practical process for solving a practical aviation industry problem. The specific problem in this case was a lack of understanding regarding the current specific delay impact of commercial space launches from Cape Canaveral on Part 121 traffic. The preliminary literature analysis yielded that many already suspect that a conflict between these two modes of transportation is already occurring, yet none had postulated specifics regarding the degree of said conflict. Likewise, if there is a severe problem currently occurring, what needs to be done about it? This study addressed these matters by producing a practical process for industry adoption.

The practical process that was generated by this study is an orbital launch window sequence that was developed using data produced by answering RQ1, RQ2 and RQ3. This sequencing model will be directly useful to aviation practitioners in several sub-fields, such as air traffic control, space traffic control, Part 121 airline scheduling, orbital launch window design, and major airport operations. This model will enable maximum efficiency to be utilized by both modes of transportation using presently existing air traffic control systems, thus providing a means for larger amounts of both modes to exist with minimal conflict to each other.

Study Limitations and Delimitations

Limitations

1. *Missing or Incomplete Archival Data.* Any data that is missing, omitted, or otherwise has been lost was not subject to my control. The use of official U.S. government data sources, and data triangulation, should have minimized the study's exposure to this limitation.
2. *Airline Reporting Practices.* This study assumed that all U.S. Department of Transportation reporting requirements had been properly met by all Part 121 air carriers from which delay data is to be drawn. Likewise, if any individual air carrier employees responsible for reporting said figures misunderstood a reporting requirement, misidentified a reportable event, or simply caused a human error in their reporting, that was beyond the researcher's control.
3. *Real-time air carrier actions taken to mitigate delays.* It is possible that as orbital launch-related Part 121 re-routes and delays began to take place across the Florida peninsula that individual air carriers took action to minimize or mitigate the effects of such delays. This possibility was beyond the researcher's ability to control.
4. *Skill of individual air traffic controllers during reroutes.* Once orbital launch activities begin at Cape Canaveral, ATC re-routes are required for Part 121 traffic arriving into MCO. Many of these re-routings are manually

conducted by air traffic controllers, and therefore, the individual differences in aptitude for this task between controllers could cause an asymmetric influence in the actual arrival delay figures from different days and time periods. This was beyond the researcher's capability to control.

5. *Time length of orbital launch windows.* The time length for which an orbital launch window is approved for can vary from instantaneous, to several hours in duration. The variance in time length of each launch window was beyond the researcher's ability to control.
6. *Effects of Covid-19 on Air Travel.* The volume of Part 121 flights fluctuated following the March 2020 outbreak of Covid-19 and was not within the control of the researcher.

Delimitations

1. *Decision to utilize selected archival data sources.* The research questions presented by this study were best addressed using ex post facto analysis, and therefore using existing data was a necessity. Appropriate U.S. government archives were selected for use in this study due to the high probability that their contained data would have a high degree of integrity. The selection of these data archives should have maximized the population generalizability of the study's results.
2. *Decision to examine MCO arrivals rather than arrivals and departures.* In order to properly measure the issue of orbital launch delays on Part 121

traffic, the scope of study had to be narrow enough to allow for precise results. Further, literature tells us that there is a spherical relationship present between Part 121 arrival and departure delays that would have affected the accuracy of the results of any statistical test that used both metrics as dependent variables. This concept is expanded upon below, in Chapter 2. Although outside of the scope of this study, this topic could make for an interesting subject of follow-on research.

3. *Decision to examine MCO and not Miami International (MIA) or other south Florida airports.* MCO was selected as the subject airport for this study due to its closer proximity to Cape Canaveral's range safety areas compared to MIA and other south Florida airports. It was considered that a comparison could be made between delay impacts at MCO and those at MIA, however, after review, it was determined that this concept was outside the scope of this project and better left for future academic research. It could also be argued that the significantly smaller Melbourne Airport (MLB) is more geographically closer to Cape Canaveral and may therefore suffer from a more significant Part 121 delay impact due to this fact. While this could be true, due to the very limited amount of daily Part 121 arrivals into MLB, that hypothesis would be nearly impossible to evaluate statistically at this time due to both the small available sample of MLB's 121 arrivals and likewise the resultant low power of any findings. The ecological

generalizability of the results may have been affected by this to some degree, however, the use of a single location for study controlled for the potential effects of a location threat to internal validity.

4. *Decision not to use pre-COVID-19 Part 121 archival data.* This study was focused on producing a slot-assignment model that would be practically useful to future generations of professionals, as well as the current one. The depression in Part 121 flying caused by Covid-19 was temporary, and in the previous twelve months the rate of orbital space launches occurring from Cape Canaveral has been exponentially increasing. Therefore, it was ideal to collect data from the most recently-available archival records.
5. *Decision to use the one-way ANOVA rather than independent-means t-test in RQ1.* As explained in Chapter 3, this study was already going to be checking the data for compliance with the assumptions of the ANOVA for addressing RQ2 and RQ3. Therefore, it was simpler to also use the ANOVA to address RQ1, given that the one-way ANOVA theoretically produced identical results to the independent-means t-test in the context of this study. This should not have affected the generalizability of the study's results.
6. *Decision to exclude delays coded due to weather from sample data.* As detailed in Chapters 2 and 3, each Part 121 delay analyzed by this study had been coded by the Department of Transportation by delay cause. Given that

MCO is located in central Florida and therefore is prone to tropical weather patterns, no delays that were coded as due to weather were used as sample data in this study. This action prevented the possible effects of weather as a confounding variable on the study's findings.

Foreword on Literature Review

The preliminary information identified in the background section of Chapter 1 yielded that a known conflict may already exist between Part 121 arrival delays into MCO and orbital space launches from Cape Canaveral. Given that the primary purpose of this study was to examine and measure the effects of orbital space launch activity at Cape Canaveral on Part 121 arrival delays into MCO, it was appropriate to move forward with a formal review of the available academic literature concerning this subject.

Chapter 2

Review of Related Literature

Introduction

The existing literature regarding the research problem at hand, like the problem itself, is interdisciplinary in its foundations. The following review examined a variety of studies meant to address, expand, or examine the processes and procedures regarding the optimization of both air traffic and orbital space traffic. In some contexts, studies will have examined these two modes of transportation separately, and in other contexts, the intent of said studies will have been to mitigate operational friction between the two.

As illustrated below, there is no shortage of simulation work that has been done to model the effects of orbital space launches on NAS traffic, however, no significant work had been conducted that made an assessment of the current NAS delay conflict from orbital space launches by measuring actual Part-121 delay data. Key to understanding the current state of research surrounding the impact of orbital space launches on NAS delays is comprehension of three sub-domains: The underlying dynamics of NAS delays, existing work on the relationship between NAS delays and space launch activity, and core concepts surrounding spaceport design and space traffic control systems.

Review of Past Research Studies

The Dynamics of NAS Delays

A significant body of scientific work exists on the general subject of Part 121 delays, their underlying causes, and preventative measures. Lemetti et al. (2019) produced a correlational study which measured the European equivalent of Part 121 arrival delays into the Stockholm International Airport and determined the practical implications of said delays. Lemetti et al. operationally defined practical impact from arrival delays as fuel consumed, miles flown, and emissions produced. Lemetti et al. had a primary research objective of identifying potential relationships between the multi-level categorical independent variable of time, and a continuous dependent variable of length of delay. In their findings, Lemetti et al. successfully identified that in certain delay events, daily fuel burns for arriving aircraft were up to 6% higher than average. Lemetti et al. recommended follow-on work be conducted in the areas of weather-based arrival delays, and other factors. It could be inferred from the wording of their recommendations for future research that Lemetti et al. would likely endorse research into the effect of any factors that could cause Part 121 arrival delays, including the effects of orbital space launches.

Lemetti et al. was conducted in the vicinity of Stockholm International Airport, which is a European hub airport that is not significantly different from Orlando International Airport in operational capacity or airspace design. Likewise, the fuel burn computational equations used in Lemetti et al. account for fluctuations in density altitude, temperature, and other performance-effecting factors that would affect fuel burn, which indicates that the same equations could be used in future similar or replication studies. For that reason, it is likely that the results of Lemetti et al. could be ecologically generalized to nearly any major hub airport, including Orlando International (MCO). Lemetti et al. did provide significant mathematical operational definitions for their computations of excess fuel burns caused by ATC delays, and in these formulaic definitions is the true value of their study. However, Lemetti et al. failed to provide specific statistical results from any inferential analysis that they may have conducted in their work. To elaborate, Lemetti et al. did originally aim to determine if there was a relationship between certain factors and air carrier delays, however, upon reading their findings, there were no inferential tests (such as a Pearson's r, or perhaps multiple regression and correlation) conducted. Lemetti et al.'s approach could be improved upon using the study's existing research question and variables, if only multiple regression and correlation were used, and appropriate results were reported in their findings. It is unclear whether this omission by the authors was due to their own decision as a study delimitation or that of a publisher-driven content limitation.

In the context of the study at hand, while Lemetti et al. did not directly aim to measure the effects of orbital space launches on arrival delays into Stockholm International Airport (nor is there a spaceport of note in the immediate vicinity of Stockholm), their lack of analysis in this area certainly affords the opportunity for further research into that category of delays. Likewise, their operational definitions of delay impact informed decisions regarding delimitations on this subject within the study at hand.

A more empirically-consequential quantitative work on the subject of air carrier disruptions and delays is found in Lonzius and Lange (2017). The primary research question of Lonzius and Lange can be inferred as “Is there a difference in delay rates between air carriers that use hub and spoke networks, and those that do not?” Lonzius and Lange conducted a study that utilized an ex post facto cause-type design that examined the differences in arrival delays across different Part 121 U.S. air carriers. Lonzius and Lange chose to use average annual arrival delay as their continuous dependent variable, and the twelve continuous variables of arrivals delayed from scheduled time, direct hub connectivity, indirect hub connectivity, routings with swap opportunities, load factor, delayed flights on arrival, percentage of slot controlled airports, percentage of congested airports, weather-related delay, peak time flights, and concentration (2017, p. 106).

Lonzius and Lange provided appropriate descriptive statistics concerning their sample of *N* = 196,412 flights and utilized multiple regression and correlation as the statistical test for their inferential analysis (2017). The source of Lonzius and Lange’s sample data were various official U.S. Government archives, primarily the Bureau of Transportation Statistics (2017). It is notable that Lonzius and Lange recognized the aforementioned spherical relationship between arrival and departure delays and opted to use arrival delays as their dependent variable (2017, p. 102); a delimitation which the authors supported with evidence from their own literature review. Lonzius and Lange used convenience sampling to collect their archival data from the years 2006 – 2013, including statistics from American Airlines, Alaska Airlines, JetBlue Airways, Delta Air Lines, ExpressJet Airlines, Frontier Airlines, AirTran, Hawaiian Airlines, SkyWest Airlines, United Airlines, US Air, Southwest Airlines, and Mesa Airlines (2015, p. 102-103).

Lonzius and Lange found that Part 121 air carriers who utilized direct hub network routing were less prone to delays compared to those carriers that used indirect routing, $R^2 = .21$, $F(1{,}366, 196{,}412) = 6.71$, $p < .01$ (2017, p. 107). Referencing these results, Lonzius and Lange concluded that air carriers should use direct hub routing strategies when conducting network planning combined with robust planning techniques (2017).

Upon review of the sampling strategy it is immediately apparent that there was a major threat to internal validity present in this study by way of the mortality threat. It is interesting to identify a mortality threat in this unusual context, however, it is nonetheless present. Because the authors collected data from 2006 – 2013, an objectively large timespan for a study of this nature, some carriers that existed in 2006 at the beginning of the surveyed time period were either defunct, merged, or otherwise non-existent by the end of the surveyed time period in 2013. For example, in that timeframe AirTran was eventually purchased by Southwest

Air and US Air merged with American Airlines. It is possible that the independence assumption of the multiple regression and correlation test was affected by this relationship, however, that detail would ultimately fall on how the delay data utilized by the study was reported and recorded during the years in which these mergers occurred; something the authors failed to identify or explore. A simple example of this possible threat is the data collected by the authors for 2011, the year in which Southwest Airlines bought AirTran: It is conceivable that the database kept Southwest and AirTran’s respective delay statistics as separate records until the day of the actual merger, and then began recording them as one. However, it is also possible that the database records for 2011 unintentionally reported AirTran’s delay data under both AirTran and Southwest Airlines for some time period in 2011. In this latter case, the independence assumption of multiple regression and correlation would have been violated, and it is probable that a non-parametric test would have been more appropriate.

Even in the absence of this unchecked threat to internal validity, the use of multiple regression and correlation within this study by Lonzius and Lange is somewhat questionable, given that the intent of the study was to examine group differences between different data sets (2017). That is not to say that their use of multiple regression and correlation failed to produce appropriate results, however, their use of multiple regression and correlation in this manner required the authors to code multiple dummy variables, such as weather effect, in order to force the computation to work. However, upon examination of the independent variables used by the authors it is clear that by using these variables categorically rather than in a continuous format, the factorial ANOVA could have been utilized.

Lonzius and Lange (2017) provided further support to the study at hand for using arrival delays in minutes, rather than both departure and arrival delays, as a dependent variable. Lonzius and Lange also provided insight into the inner mechanics of Part 121 NAS delays and factors that can exacerbate them. This finding was relevant to the study at hand in that findings produced by the current study required filtration for exogenous variables, one of which could have been an airline's underlying network structure and its ability to recover from or exacerbate from induced delays due to said network structure.

When measuring the impact of orbital space launch operations on Part 121 delays it is possible to operationally define "impact" by multiple metrics. Lemetti et al. (2019), above, demonstrated a cost-based evaluation model that estimated aircraft fuel burns per additional mile flown. Likewise, Lonzius and Lange (2017) operationally defined impact as arrival delay in minutes from scheduled (a-zero). From Lemetti et al. (2019) we can also derive metrics that would operationally define flight delay impact in terms of both additional milage flown, and furthermore, additional emissions produced. This is notwithstanding the sometimes-used technique of measuring arrival delays in terms of minutes different than scheduled by greater than 15 minutes, referred to as "a-15," or the more obvious operational definition that utilizes the number of passengers inconvenienced. Beygi et al. (2007) was composed prior to Lemetti et al. (2009) yet it provides additional insight into the dynamics of air carrier delays. Beygi et al. was a quantitative analysis that was published with nearly all of its empirical results hidden due to non-disclosure agreements with the air carriers that participated in the study. However, the delay propagation model that was produced by Beygi is still of value in itself, even if the statistical methods used to construct it have been redacted. Figure 2.1, below, illustrates the basics of how an airline delay can impact additional flights that follow it in schedule.

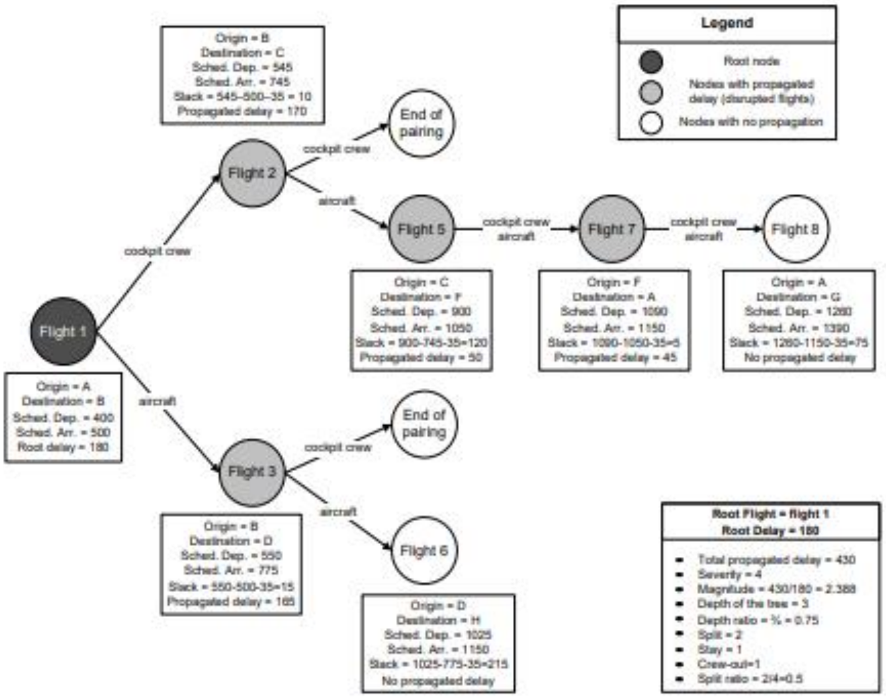

Figure 2.1. Airline Delay Propagation Tree

Note. Taken from (Beygi et al., 2007, p. 3).

Simply put, given that an air carrier had access to a finite number of aircraft in a given time period, it is possible that if an aircraft has an arrival delay, that the next flight scheduled to be operated by that aircraft (and separately by that flight crew) will be impacted by a rolling delay (Beygi et al., 2007). In statistical terminology, we would call this a spherical relationship between arrival delays and departure delays. This sphericity in delay data is relevant to the quantitative methodology of this study and will be built upon further in Chapter 3. It is unfortunate that data redaction made critical analysis of the rest of Beygi et al. practically impossible.

While the measurement metric of an airline delay is important, it is equally important to survey work that has explored the drivers of airline delays. As mentioned above, very little work of scholarly quality has been produced that aimed to measure the effects of orbital space launches on Part 121 delays, however, there was additional work available that compared and/or evaluated the core drivers of Part 121 delays. Bradford and Scheraga (2020) conducted such an analysis relatively recently using a quantitative methodology and an ex post facto effects-type design.

Bradford and Scheraga used the Chi Square goodness-of-fit test to make group comparisons of average delays across different categorical values of delay cause. Bradford and Scheraga used delay data in minutes as their continuous dependent variable, and the categorical value of delay cause as their independent variable. The independent variable categories were weather, non-weather NAS delays, air carrier, and security (2020, p. 1). Bradford and Scheraga used a sample size of $N = 12{,}692{,}341$ flights spread across thirteen years, that were collected from official United States Government archive sources. In their findings, Bradford and Scheraga reported that 49.1% of Part 121 delays found in their sample were due to the air carrier itself, either due to maintenance, crew, or late arriving aircraft (2020). Note that Bradford and Scheraga disregarded the aforementioned sphericity effect of airline delay propagation identified by Beygi, et al. (2007) in their data analysis. Bradford and Scheraga also reported that 34.24% of the delays found within their sample were due to weather, and 16.33% were due to non-weather NAS delays (2020). Based off of the operational definitions provided by Bradford and Scheraga, it is clear that any delays caused by orbital space launch activity would have been coded into the “non-weather NAS delay” independent variable. Overall, the value of the descriptive statistics data produced by Bradford and Scheraga were good, however, they failed to provide some critical information regarding their inferential analysis using the Chi-Square.

Bradford and Scheraga used their descriptive data to then compare actual delay rates against those predicted by four separate models using the Chi-Square Goodness of Fit test. However, while Bradford and Scheraga did report that three of the four Chi-Square tests had findings that were statistically insignificant, they did not provide the actual Chi-Square values, their critical values, or their *p*-values. The single exception is their statistically significant finding of X^2 (1, N = 12,692,341) = 11.34, $p < .01$ for model two’s predictive delay trend compared to the observed delay trend (Bradford & Scheraga, 2020). For this reason, the information from Bradford and Scheraga that was most useful to the study at hand was their descriptive statistics. Bradford and Scheraga used archival data from official U.S. Government sources, and it can therefore be inferred that the integrity of said database, and thus the integrity of their sample data, was good.

Bradford and Scheraga’s research could have been improved in several ways. It is clear that Bradford and Scheraga used convenience sampling and collected all available data from the selected years. In place of this, Bradford and Scheraga could have computed an a-priori sample size calculation and used that as a reference point for sample size. It is also possible that had random sampling been utilized from the existing pool of data, that said sample would have been viable for a parametric omnibus test such as a factorial ANOVA. The easiest improvement that could be made to Bradford and Scheraga (2020) would have been the full disclosure of the statistics related to their inferential analysis. The key takeaway from Bradford and Scheraga is that 34.24% of Part 121 delays from 2006 - 2019 were coded as weather-related, and 16.33% were coded as non-weather NAS (2020). This informs a conclusion that some unknown percentage of the 16.33% non-weather NAS delay statistic was due to orbital space launch activity, although it is impossible to quantify exactly what proportion of the 16.33% was related to this factor without further information from either the authors or the underlying database that was used.

Of the above-surveyed works, many were applicable to the study at hand but stopped short of exploring the effects of space launch activity on NAS traffic. Srivastava et al. (2018) produced a quantitative work of a similar variety that did not specifically research NAS delays due to orbital space launches, but rather, conducted a correlational study on the relationship between closing random airspace segments and NAS delays (2018). In this regard, findings from Srivastava et al. could be ecologically generalized in the context of a work that concerns NAS delays due to airspace closures for *any* reason, including space launch activity. In fact, Srivastava et al. specifically stated within their abstract that airspace closures due to space launch activity were one of many phenomenon that the work aimed to explore further (2018, p. 1).

Srivastava et al. (2018) used a predictive correlational design that made use of archival flight and airspace route data from 2011 - 2016. Srivastava et al. had a primary research goal to identify if there was a relationship between NAS airspace closures and flight delays, and a secondary goal of extracting a regression equation that could be used to predict the future delay impacts of closing certain NAS airspace sectors. These NAS test sectors were divided into certain geographical areas and designated North-West, Center, West, East, and Florida (Srivastava, et al., 2018). Figure 2.2 illustrates the geographic boundaries covered by each NAS test sector.

Figure 2.2. Illustration of Test Sectors Utilized

Note. Taken from (Srivastava et al., 2018, p. 18). Boundaries are depicted in Red.

While Srivastava et al. failed to adequately operationally define their measure of flight delay, and likewise failed to demonstrate proper descriptive information regarding their sample, they did produce one finding of interest: For random airspace closures in the Florida NAS region, their regression equation was able to forecast future delay impact of airspace closures in Florida with an accuracy of $R^2 = .949$ (Srivastava et al., 2018, p. 15).

Srivastava et al. concluded that the increasing activity from orbital space launches, and other sources, was adding strain to the NAS via flight delays (2018, p. 27) . Srivastava et al. recommended that further work on “what if” analysis regarding NAS airspace closures be conducted so that NAS traffic delays could be minimized or mitigated. In the context of the study at hand, this final recommendation for future work could be extrapolated to yield that the authors would likely concur that future research to prevent NAS delays due to airspace closures caused by space launch activity would be appropriate.

Existing Work on NAS Delays Due to Space Launch Activity

Tinoco et al. (2018) produced a content analysis that simulated the general effects of commercial space operations from both Cape Canaveral and Jacksonville Cecil Spaceport on aircraft delays. Tinoco et al. conducted their simulation by modeling the flight path of certain orbital launch vehicles from both of the aforementioned launch points and produced a predictive trend for future cumulative delays on the NAS. The delay impact forecasts that Tinoco et al. produced did factor expected increasing year over year trends in both NAS traffic density and space launch operations projected by the FAA. Of course, these trends were predictive in nature. While the work of Tinoco et al. was not totally in vain, it was very topical in its analysis of the issue at hand (the delay impact of orbital space launches on NAS traffic) in that no inferential analysis was conducted. Using the modeling technique described above, Tinoco et al. found that by 2027 the orbital launches from Cape Canaveral would result in approximately 2000 minutes of delay impact in the NAS networks immediately surrounding Cape Canaveral (2018, p. 17).

While Tinoco et al.'s projections on the whole demonstrate an impending conflict between orbital launch operations and NAS traffic in central Florida, their work fails to produce the type of inferential analysis that academic rigor generally calls for. Tinoco et al. produced an excellent literature review and appear to have used reasonable FAA traffic forecast data for their simulations. However, Tinoco et al. also modeled the effects of orbital space launch activity from Jacksonville Cecil Airport/Spaceport (2018). The decision to model this effect could have been exploratory in nature, however, whatever the case of their intentions, as of 2021 there is no orbital launch activity occurring from Jacksonville Cecil Airport/Spaceport, nor has consideration been given to hosting operations from Virgin Galactic as their model simulates. Tinoco et al. also failed to operationally define “delay” in the context of their results. For example, it is unclear if the 2000 minutes of Part 121 arrival delays were exclusively into MCO, or an aggregate of all air traffic in central Florida divided evenly between all airports within a certain radius of Cape Canaveral. Tinoco et al. committed a critical flaw in their findings by failing to explain this key information. It is important to note, however, that even if Tinoco et al. had properly defined the key information related to their findings, their work is still ultimately a simulation rather than a measurement of the current impact of space operations on the NAS in Florida.

With regard to Tinoco et al. (2018), a follow-on work that also simulated the effects of orbital space launches from Cape Canaveral on Part 121 NAS traffic was produced in 2020. Tinoco et al. (2020) is a superior work to its aforementioned predecessor. Tinoco et al. (2020) produces a proper operational definition of NAS delay and determines a simulated average delay during a particular orbital space launch from Cape Canaveral to be 5 minutes per flight spread across 21 affected Part 121 flights (2020, p. 25). The core issue with Tinoco et al. (2020) is the same issue that is found within the enormous volume of available works related to this subject including Bojorquez and Chen (2019), Tompa et al. (2015), the quantitative component of Srivastava et al. (2015), ad nauseum. These works all utilized a content analysis methodology that made use of a simulation model to predict the impact of orbital launch operations on Part 121 NAS traffic. None of the aforementioned sub-category of papers examined the issue at hand using actual Part 121 delay data from orbital launch events, though such data is readily accessible from official FAA archives. This is a shortfall that in all likelihood can be corrected in future work within this domain.

While it is apparent that no significant purely quantitative work has been conducted to measure the observed effects of space launch activity on Part 121 delays, Srivastava et al. (2015) represents a mixed-methods work that is relevant to this topic. Srivastava et al. is fundamentally a two-part study; it could likely have even been published as two separate documents if the authors desired such. The first half of Srivastava et al. is a quantitative content analysis that used various models to produce descriptive statistics on the effect of future space launches on NAS traffic (2015). In this regard, Srivastava made no evolution beyond previous works of this nature already surveyed in this review and therefore it was not of relevance. However, the second (and far more relevant) half of Srivastava et al. was a qualitative case study on the effects of an actual orbital space launch from Cape Canaveral on NAS traffic (2015). The single orbital space launch that Srivastava chose to conduct their case study on was the launch of NASA's Orion Exploration Flight Test (EFT-1) mission from Cape Canaveral, which occurred on December 5th, 2014, at 1205 GMT (Srivastava et al., 2015, p. 7).

Srivastava et al. observed that 88 NAS flights were delayed by the Orion EFT-1 launch, and that the average flight was rerouted 4.34 NM (2015, p. 10). Srivastava et al. likewise made the decision to also observe the number of NAS flights delayed on previous days during aborted launch attempts. This delimitation by the authors allows for comparisons of delay rates to be observed anecdotally between launch windows that occurred during different days of the week, and during different time periods. The histogram illustrated in Figure 2.3 reflects the variance in number of NAS fights delayed during the various launch windows of Orion EFT-1.

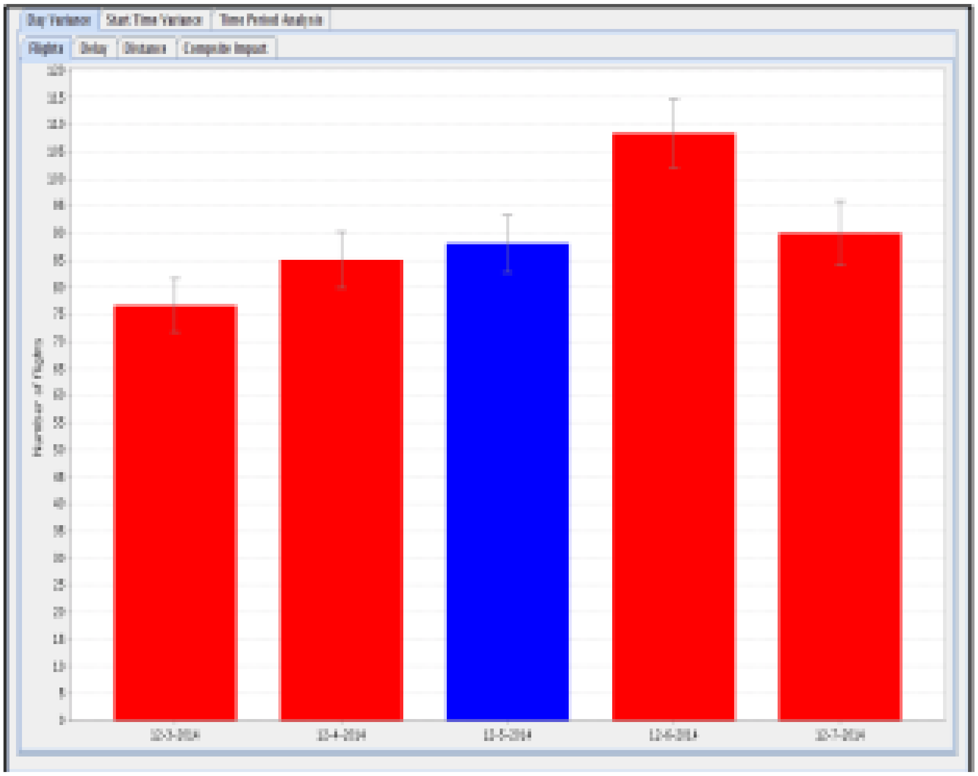

Figure 2.3. Daily Launch Window Delay Variance

Note. Taken from (Srivastava et al., 2015, p. 11). The y-axis depicts number of flights delayed on a given date, and the x-axis depicts different launch window dates. There is no relevant difference between the red and blue bars.

Srivastava et al. produced a detailed case study with moderate descriptive adequacy. The rating of moderate is assigned due to the omission of some key operational definitions by the authors, such as what their specific definition of "NAS flights." The term NAS flights could be interpreted as Part 121 flights, or alternatively as any flight on an IFR flight plan, or even further as any aircraft in controlled airspace, and it is unclear exactly how this term was used by the authors. Further, the qualitative component of the study does appear to conform to the dependability standard of rigor, given that the observations made could be repeated in future work given the contents of Srivastava et al.'s descriptions.

The qualitative component of Srivastava et al. was extremely relevant to the study at hand given that its authors elected to observe the effects of the Orion EFT-1 launch on NAS traffic. Specifically, the finding of Srivastava et al. illustrated above in Figure 3 indicates that at least in the case of the Orion EFT-1 launch, there was observable variance in the number of NAS delays caused depending on the day and time of a given launch window. The observation of a single launch event was ultimately anecdotal; however, it gives credibility to the research hypotheses of the present study that there will be variance in the number of NAS delays caused by a space launch event due to day of week and time of day in which a launch window occurred.

Spaceport Design and Space Traffic Control

It is plausible that one of the most fundamental sources of airspace conflicts between orbital launch traffic and NAS Part 121 traffic is due to pre-existing geographical proximities between major airports and officially designated spaceports. These airspace conflicts are ultimately what result in measurable Part 121 NAS delays. In that regard, limited work (if any) has been done to mitigate the potential for said conflicts through spaceport integration design. Chang and Chen (2021) provided a compelling qualitative overview of the state of competing spaceport design as part of their primary research goal to identify candidate spaceports in Taiwan. However, their work served as a qualitative content analysis, and no quantitative work was completed. Some of the different designs identified by Chang and Chen were the integrated combined air and spaceport (such as Jacksonville Cecil Field in the United States), neighboring spaceports (such as Cape Canaveral/Kennedy Space Center as compared to Orlando International Airport), and the speculative offshore launch concept that has been proposed by SpaceX (2021).

While coded categories generated from the qualitative overview of varying spaceport integration designs could be of value, significantly more value would be derived from an ex post facto study that made group comparisons between the different designs across a common dependent variable. A work of this design and methodology was sought for inclusion within this review, however, none could be located. The most similar work of this nature that could be located was Colvin and Alonso (2015).

Colvin and Alonso (2015) produced quantitative work on space traffic control techniques via an effects type ex post facto study that had an overall research goal of assessing NAS delay differences between different types of safety envelopes. Multiple continuous dependent variables were used by Colvin and Alonso, including delay in minutes, additional distance traveled, number of flights rerouted, and additional fuel burned. Colvin and Alonso used a dichotomous categorical independent variable in all statistical computations of traditional versus compact launch safety window. The sample used by Colvin and Alonso was a group of $N = 90$ Part 121 flights that were collected from an unknown archival data source and overlaid onto certain simulated launch profiles (2015). It is fair to assume that the sample data Colvin and Alonso used was taken from either an official U.S. Government archival source such as the Department of Transportation Bureau of Transportation Statistics, or a non-governmental source such as Flight Aware. In either case, the integrity of the sample data is objectively high, given that neither of these aforementioned archival data sources, be they governmental or not, display flight data that is not directly correlated to a live flight.

Colvin and Alonso overlaid their sample flights over a model of various launch vehicle profiles to forecast delays (2015). Colvin and Alonso found that there was a significant difference in Part 121 delays when using a traditional launch safety envelope over a compact envelope (2015, p. 8). Colvin and Alonso produced a set of 95% confidence intervals to illustrate interval estimates of the additional delay effect caused by the use of traditional launch safety envelopes, of which, the largest difference was $\mu = 1.633$, 95% CI [1.350, 1.916] (2015, p. 8). In this key finding of Colvin and Alonso the dependent variable was number of flights rerouted, which could be interpreted to mean that using a traditional launch safety envelope rather than the more modern compact envelope could result in up to two additional Part 121 flights per hour being rerouted. Colvin and Alonso ultimately concluded that by using a combination of predictive software and compact launch envelopes, NAS safety could be preserved while nearly all delays due to space launch activity could be mitigated (2015, p. 13). It is important to note that Colvin and Alonso reference a program called SU-FARM in their original print's conclusions, although as of 2021 there has been no adoption of this software by the FAA.

The immediate weakness observed in Colvin and Alonso's work is their use of a space launch model overlay rather than actual data from days in which space launches occur. For example, rather than overlay their sample Part 121 flights onto a template of launches that used both traditional and compact launch envelopes Colvin and Alonso could have used actual observations on days in which space launch activity occurred. Given that this work was produced in 2015, well before SpaceX and others significantly entered the orbital launch industry, it is absolutely conceivable that there was simply an insufficient amount of orbital space launches for the authors to produce such a work. As of 2021, it appears that there are more than enough annual orbital space launches for a similar study using actual archival data from days in which an orbital space launch occurred to be used.

Kaltenhauser et al. (2017) conducted a qualitative case study on the state of various initiatives to integrate commercial space launch activity into Europe's equivalent of the NAS using an inductive analysis approach. A key focus of Kaltenhauser et al. was the exploration of different launch platforms and their interaction with airspace restrictions (2017). To that end, Kaltenhauser analyzed conventional land or sea-based orbital space launches, air-launched orbital rockets, deorbiting vehicles, and sub-orbital point to point travel (2017, p. 245). Kaltenhauser also explored the potential uses of digital information processes to increase efficiency (operationally defined as reducing European NAS arrival delays in minutes) during launch events (2015). Figure 2.4 illustrates a simplified illustration of the airspace conflict caused by a space vehicle reentry event.

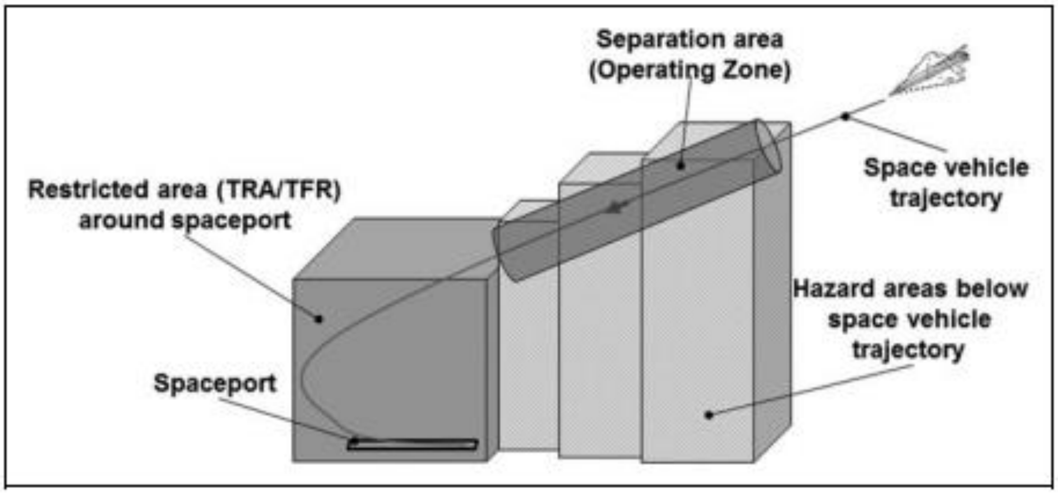

Figure 2.4. Illustration of the Airspace Conflict Generated by Deorbiting Spacecraft

Note. Taken from (Kaltenhauser, et al., 2015, p. 246).

Kaltenhauser et al. ultimately recommended that one of the digital process that their case study surveyed, System Wide Information Management (SWIM), be implemented into a real-time space launch delay mitigation process that they produced as a result of their study. This process is illustrated by Figure 2.5.

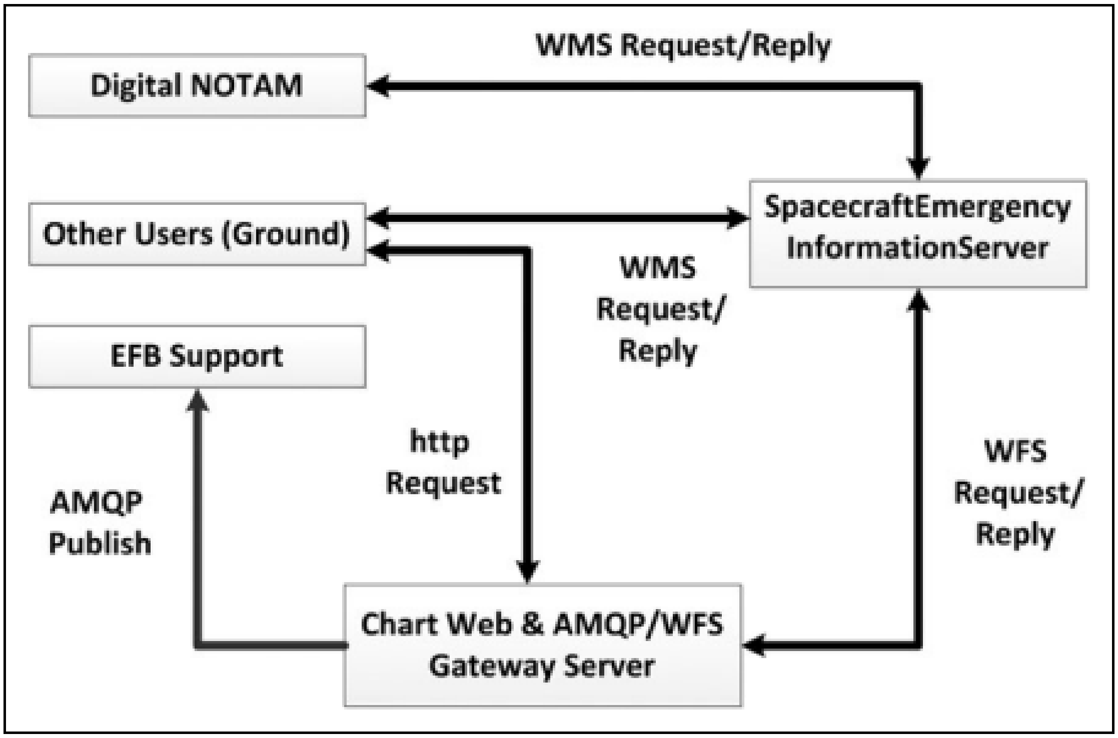

Figure 2.5. Real-Time Launch Delay Prevention Process

Note. Taken from (Kaltenhauser et al., 2017, p. 248).

The key concern of Kaltenhauser et al. is the question of the transferability of its results to the U.S. space launch industry and NAS. When a question of whether or not the transferability qualitative standard of rigor has been met arises, what is really being asked concerns the descriptive adequacy of the study in question. In the case of Kaltenhauser et al., the descriptive adequacy of their work was apparent in their thick description. This is further evidenced by the process which they produced shown in Figure 2.5, which could easily be templated into the American NAS for use. Kaltenhauser et al. did suffer from a lack of in-person interviews, particularly in their sections which detailed European ATC systems and the interaction of individual controllers with said systems. Had Kaltenhauser et al. conducted a limited number of interviews with actual European controllers, not only could a coding process have been used to further develop their process, but member-checks could have been used to validate said process for practicality.

Kaltenhauser et al. was relevant to the study at hand as it identifies key processes that could potentially cause or mitigate airspace conflicts during space launch activities. It is possible that if the study at hand observed significant Part 121 delays occurring at MCO due to orbital space launches at Cape Canaveral, that said delays could be minor enough to be managed with software such as SWIM, or a prominent U.S. equivalent currently in development such as the aforementioned SDI program from Chapter 1 of this study. Finally, although Kaltenhauser et al. was published in 2015, their selection of launch systems to explore proves to be far ahead of its time. For example, Kaltenhauser et al. explored inter-atmospheric launch systems and sea-based orbital launches, neither of which were in serious development in 2015 however, both of which are currently being seriously proposed by companies in the U.S. space launch industry.

Summary and Study Implications

Coalescing the content of the reviewed-works above and extracting core concepts relevant to the design of the study at hand was critical for ensuring the quality of the study at hand’s design. Recalling the introductory section of this chapter, it was identified that the most appropriate method to use for examination of existing research into the complex relationship between orbital space launch activity and Part 121 NAS delays was to break that overall knowledge domain into three supporting sub-domains: Works involving the underlying dynamics of NAS delays, existing work on the relationship between NAS delays and space launch activity, and core concepts surrounding spaceport design and space traffic control systems. Now that a comprehensive review of literature within these sub-domains has been completed, what were the core take-aways with regard to the study at hand?

Returning to the works of both Lemetti et al. (2019) and Lonzius and Lange (2017), a critical take away from both studies was the decisions by both of their respective authors in how to operationally define a flight delay. This decision represents a key delimitation in both studies, and likewise, the quality of their results informed what is a key delimitation within the study at hand.

It is also critical to include Beygi et al. (2007) into this conversation, which while objectively an earlier work in the context of time, was also superior in design and the practical value of its findings compared to Lemetti et al. (2019). It is unfortunate that the publicly-available version of Beygi et al. was heavily redacted due to non-disclosure agreements with the air carriers involved in their work; this may be a consequence of using source data from air carriers and informed that decision in the context of the study at hand. Referencing Figure 1, Beygi et al. ultimately designed a delay propagation model that illustrated the spherical relationship between arrival and departure delays, demonstrating that due to a finite number of aircraft and crew, an arrival delay can propagate into several additional departure delays in a waterfall effect.

The concept of a causal relationship between arrival and departure delays in Part 121 operations is critical to understand for designing research methodologies in this domain, as it may or may not be desirable for a study to have multiple dependent variables that are affecting each other. In most cases, including the study at hand, this effect was not desirable. Bradford and Scheraga (2020) reported relevant findings that 34.24% of the Part 121 delays found within their sample were due to weather, and 16.33% were due to non-weather NAS delays, however, because Bradford and Scheraga discarded the spherical effect between their dependent variables identified by Beygi et al.'s (2007) work, it is possible that these findings were inaccurate. Using this information, the study at hand chose to respect the spherical relationship between Part 121 arrival and departure delays identified in the existing literature and opted to utilize arrival delays as its single dependent variable.

While there were no locatable works that measured the actual relationship between space launch activity and Part 121 NAS delays, there were several studies that came close to this topic. Srivastava et al. (2018) explored NAS delays due to random airspace closures, with the intent of forecast the delay effects of airspace closures due to multiple reasons including space launch activity. Srivastava et al.

(2015) conducted a likewise tangentially-related work, who's qualitative component shed insight on the effects of the launch of the Orion EFT-1 mission from Cape Canaveral on Part 121 flights in the Florida peninsula. While no inferential analysis on this subject was pursued by Srivastava et al. (2015), their work did capture an anecdotal observation that was not an original objective of their work but is critically informative to the study at hand: Due to multiple delays of the EFT-1 launch, its launch windows covered multiple days and time periods and as shown by Srivastava et al. (2015) in Figure 3 of the above review, there was an observed variance in the number of flight delays between the different launch windows. This variance, confirmation of its existence and its exact measurement using inferential analyses were all research goals of the study at hand.

Further content analysis-type work on this subject by Tinoco et al. (2018) and Tinoco et al. (2020) was informative on the general subject of the relationship between orbital space launches and NAS delays, however, their usefulness to the study at hand ended there due to fundamental design issues with their respective works. As stated previously, this design issue was the same problem that was found within the enormous volume of available works related to this subject including Bojorquez and Chen (2019), Tompa et al. (2015) and the quantitative component of Srivastava et al. (2015). These works all utilized a content analysis methodology that made use of a simulation model to predict the impact of orbital launch operations on Part 121 NAS traffic. None of the aforementioned sub-category of papers examined the issue at hand using actual Part 121 delay data from orbital launch events, though such data is readily accessible from official FAA archives. Whether actual data was insufficient in quality during the conduct of these studies, or their authors simply overlooked using actual delay data as a possibility, this is a shortfall that was corrected by the study at hand.

In understanding the comprehensive body of works surrounding the research problem at hand, it was also important to explore the possibility of extraneous factors such as design, systems, and geography that could be inflaming airspace conflicts between orbital space launches and Part 121 NAS delays. This was an important consideration because if the study at hand identified a significant relationship between Part 121 arrival delays into MCO and orbital space launches from Cape Canaveral, such findings would have to be vetted for the effects of extraneous variables.

Chang and Chen (2021) explored categorical factors that could be used to objectively rate the quality of a spaceport’s location. Likewise, Colvin and Alonso (2015) quantitatively explored how using different launch safety envelopes during orbital space launches could variably effect NAS delay impacts. Lonzius and Lange (2017) further explored the propensity of an air carrier’s network and operational system designs to either inflame or reduce an NAS arrival delay. Finally, relevant to this subject was the work of Kaltenhauser et al. (2017), that continued in this same vein to explore the impact of communication software on mitigating or inflaming NAS delays due to space launch activity. All of these previous works informed the study at hand because they demonstrated objective and/or quantitative measurements of factors that are considered extraneous variables to the study at hand.

Chapter 3

Methodology

Population and Sample

Population

The target population of this study was all Part 121 arrival delays into MCO caused by orbital space launches from Cape Canaveral, and the accessible population was all Part 121 arrival delays into MCO caused by orbital launches from Cape Canaveral, as recorded by the United States Department of Transportation Aviation Statistics Database.

According to the official archival records of the U.S. Government held within the Department of Transportation Bureau of Transportation Statistics, between July of 2020 and July of 2021 (the most recent twelve month span of data currently available) MCO experienced a total of N = 116,637 arriving Part 121 flights from eleven unique U.S. air carriers: Endeavor Air (9E), American Airlines (AA), Alaska Airlines (AS), JetBlue Airways (B6), Delta Air Lines (DL), Frontier Airlines (F9), Hawaiian Airlines (HA), Spirit Airlines (NK), United Airlines (UA), Southwest Airlines (WN) and Republic Airlines (YX), (Bureau of Transportation Statistics (B), 2021). This archive did not track arrival information for foreign carriers during the established time period, nor did it collect arrival data on non-Part 121 carriers such as Part 135 domestic charter operators. This delay tracking archival source is referred to as Transtats Tool-B in lower sections of this chapter.

Of the MCO *N* = 116,637 Part 121 arrivals within the time period identified above, *N* = 19,116 were officially coded as delayed (2021). Transtats Tool-B coded delays into sub-categories by general cause and provided both the percentage and raw number of affected flights that were in a particular delay category. These categories were weather (62.14%), Volume (27.74%), Equipment (0.93%), Closed Runway (4.59%), and Other (4.59%) (2021). As identified in the literature review within Chapter 2 of this study, any delay due to orbital space launch activity would have been coded as "Other," the proportion of which yields a possible population of up to *N* = 5,354 MCO Part 121 arriving flight delays due to such a cause during the established time period. It was impossible to derive exactly what proportion of the "other" sub-population of delays was due to space launch activity. Likewise, it was also possible that delayed flights due to space launch activity were mis-coded into the "Volume" category. Figure 6 illustrates a breakdown of MCO Part 121 arrival delays by cause that occurred between July 2020 and July 2021.

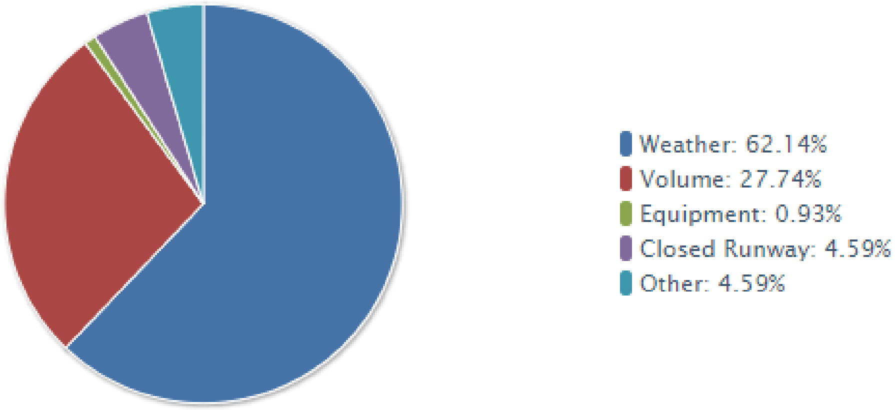

Figure 3.1. *MCO NAS Delays by Cause, July 2020 – July 2021*

Note. Completed with data from (Bureau of Transportation Statistics (B), 2021).

[a]Percentages are of the total flight population of *N* = 116,637 flights.

A key issue with the tracking capability of Transtats Tool-B was that it only appeared to collect data on Part 121 flights which were delayed greater than 15 minutes from scheduled arrival time. Recall from Chapter 2 of this study that this operational definition is referred to as A-15. The issue with tracking A-15 was that much information regarding flights that were delayed from their scheduled arrival time, however, were delayed less than 15 minutes do not appear in the statistics tracked by Transtats Tool-B. A superior tracker would have allowed for records to be collected on arrival delays different than scheduled arrival time in greater than zero minutes (A zero). Fortunately, such a tracker could be located.

The Transtats Carrier On-Time Performance Database, which will be referred to as Transtats Tool-A from hence forth, allowed for massive customization with regard to data retrieval. Transtats Tool-A allowed not only for A-zero delays to be tracked, but also for other categorical items of importance to this study to be tracked as well, such as day of week that a delay occurred, and exact time of day. Each delay listed in Transtats Tool-A was also attached to a specific flight number, easily allowing for the validation of any particular data point within its archives.

Sample

All dependent variable data was collected via official United States Government archives in order to ensure the integrity and validity of any data used. Specifically, Transtats Tool-A was used for collection of Part 121 arrival delay data into MCO. The sampling strategy for this analysis was random. Random sampling was appropriate given the large volume of data available from Transtats Tool-A relative to the required sample sizes of each research question. In order to allow for adequate sample data to be collected, the most recently-available ten months of data from Transtats Tool-A at time of study commencement was drawn, and sub-samples for each research question were drawn using a random number generator. Only delays coded as due to “Volume,” “Other,” or uncoded by Transtats Tool-A were used as sample data for this study.

Power Analysis

A-priori minimum sample size calculations were performed using G*Power version 3.1 for each research question, and the following information was produced:

1. The minimum sample size calculation for the One-Way ANOVA to be performed to evaluate RQ1 was found to be *n* = 128. In order to arrive at this computation, a medium effect size of .25 was assumed, a power of .8 was input as desired, and an alpha of *a* = .05 was listed. The specific results of this computation are listed within Appendix A.
2. The minimum sample size calculation for the 2 x 7 Factorial ANOVA to be performed to evaluate RQ2 was found to be *n* = 158. In order to arrive at this computation, a medium effect size of .25 was assumed, a power of .8 was input as desired, and an alpha of a = .05 was listed. The specific results of this computation are listed within Appendix A.
3. The minimum sample size calculation for the 2 x 6 Factorial ANOVA to be performed to evaluate RQ3 was found to be *n* = 158. In order to arrive at this computation, a medium effect size of .25 was assumed, a power of .8 was input as desired, and an alpha of a = .05 was listed. The specific results of this computation are listed within Appendix A.

Instrumentation

Instrument Validity and Reliability/Data Integrity

No data collection instrument, such as a survey, was utilized by this study. In order to ensure the integrity of all data sources used, only official United States government databases were used to collect dependent variable data. Dependent variable data was synthesized from data obtained using Transtats Tool-A.

In the case of independent variable data, specific past orbital launch dates were readily available from the Federal Aviation Administration (FAA), however, specific launch times proved challenging to collect from this source. Therefore, unless an alternate official government source of this information was found, no less than two non-government database sources were used to collect specific Cape Canaveral orbital launch times, with the two sources being compared to each other for accuracy of reported launch time data. In the event that there was a discrepancy between the two non-government sources of specific launch time, such that the boundary of two time categories was straddled, a third tie-breaker source was used to determine the exact time of the launch in question. If the consultation of the third source still failed to clarify what categorical level of time period the launch in question belongs in, then said launch was removed from consideration under this analysis.

Weather as a Confounder

There was potential for severe weather delays to impact a study located in central Florida. While it is conceivable that any weather-related delay strong enough to cause arrival delays into MCO would also result in cancellation of an orbital space launch at nearby Cape Canaveral, any delay generated during the active launch window of said launch attempt would have been of interest to this study. Fortunately, Transtats Tool-A codified delay reason by cause, and any delay coded as due to weather was removed from consideration of this study. For tracking purposes, the amount of data points removed due to this conflict was reported as Appendix C.

Procedures

Research Methodology

The research methodology to be used for this analysis was quantitative, associational research. The selected research sub-design was ex post facto, effects type. Quantitative research was the appropriate methodology to be used in this analysis due to the need for all preliminary research questions to be addressed using inferential statistical analysis. A qualitative approach would have failed to address any of the preliminary research questions properly, therefore the use of either a qualitative or a mixed-methods approach could be wholly excluded from consideration here. Likewise, associational research was appropriate due to the lack of any intervention within this study, thus excluding experimental research from consideration. Further, the direct need for inferential statistics to be used to address the research questions excluded the possibility of using descriptive research.

The ex post facto design was necessary due to the fact that group differences were being measured, with each group and its corresponding dependent variable data being pre-existing. The use of a correlational design, associational research's other arm, was inappropriate because this study was not examining a relationship within a single group. The effects-type sub design was appropriate due to the fact that the group membership variable was located on the independent variable group for all research questions.

Human Subjects Research

No human subjects or personal identifying data were used in this analysis. Only US government archival data lacking any reference to individuals was analyzed. Thus, the Florida Tech IRB was consulted on this study, however, this study fell under the "exempt" category.

Description of Independent and Dependent Variables

Dependent Variable. The dependent variable that was used within all three research questions was the continuous value of average arrival delay in minutes different than scheduled (a-zero) of Part 121 air carrier traffic into MCO. In the cases of RQ1 and RQ2, the average delay figure was measured across the time parameter of a full day. In the case of RQ3, the average delay figure was measured across the time parameter of the respective time period being compared by the respective independent variable value. For example, within RQ3 a time period of 0000 – 0359 local MCO time was compared, thus, the average arrival delay value was the average calculated delay that occurred between 0000 – 0359.

Independent Variable. There are multiple independent variables that were used within this study. The independent variable that acted as the row variable for all three RQs was the dichotomous categorical value of launch or no launch. If an orbital space launch, as operationally defined within Chapter 1 of this study, occurred on a particular day or during a particular time period, then a value of "launch" was assigned. If no such orbital launch occurred during the time period being compared than a value of "no launch" was assigned.

The secondary independent variables varied between individual RQs, and are explained in detail below:

1. RQ1 did not utilize a secondary independent variable.
2. RQ2 utilized a column independent variable referred to as "day of week." Day of week was defined as the seven-level categorical value of Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, or Saturday.
3. RQ3 utilized a column independent variable referred to as "time of day." Time of day was defined as the six-level categorical value of four hour time period measured from 0000-0000 local MCO/Cape Canaveral time (Eastern Time). The six levels of time of day were

0000 – 0359 (Period 1), 0400 – 0759 (Period 2), 0800 – 1159 (Period 3), 1200 – 1559 (Period 4), 1600 – 1959 (Period 5), and 2000 – 2359 (Period 6).

Study Implementation

Initial dependent variable sample data was drawn from Transtats Tool-A via electronic download. The web address for the access portal to Transtats Tool-A is https://www.transtats.bts.gov/DL_SelectFields.asp?gnoyr_VQ=FGK&QO _fu146_anzr=b0-gvzr. The data from Transtats Tool-A defaulted into an excel spreadsheet format that contained both the information desired for use within this study and also undesired pieces of information such as carrier code, and arrival delays into airports other than MCO. Only delays coded as “Volume,” “Other,” or uncoded were used as sample data. Given that data was available on a month-to-month basis, ten downloads (one per month of desired data) were made. Original and unaltered copies of these spreadsheets were retained and will be stored by the researcher for no less than 24 months following the conclusion and defense of the study’s results.

Once all downloads had been completed and original copies of said downloads preserved for future reference, data were condensed by removing extraneous and unsought data entries from each spreadsheet. Data from each month was then reviewed, both separately and combined, using appropriate descriptive statistics in a manner detailed below in the descriptive statistics section of this chapter.

Independent variable data regarding launch dates and times were obtained primarily from the FAA's launch license portal at https://www.faa.gov/data _research/commercial_space_data/launches/?type=Licensed. This information was broken down in a separate spreadsheet page into sub-categories on days of the week and time period in which each respective launch occurred. Appropriate descriptive products were then produced, which are detailed in the Descriptive Statistics section of this chapter. Once all appropriate data synthesis and descriptive analysis had been completed, inferential analysis of each research question began. All inferential computations were be made using SPSS Version 28.

RQ1 was evaluated using the one-way ANOVA. In the event that the collected data did not meet the assumptions for the one-way ANOVA, the non-parametric Kruskal-Wallis Test would have been used instead. RQ1 had a continuous dependent variable, average Part 121 arrival delay in minutes, and a dichotomous categorical independent variable, the categories of launch or no launch. If for some reason neither the One-Way ANOVA nor the Kruskal Wallis Test were found appropriate, the independent-means t-test would also have been appropriate to evaluate RQ1 inferentially.

RQ2 was evaluated using the two-way factorial ANOVA. In the event that the collected data did not meet the assumptions for the two-way ANOVA, the non-parametric Kruskal-Wallis Test was to be used in series by factor instead. RQ2 had a continuous dependent variable, average Part 121 arrival delay in minutes, and two multi-level categorical independent variables: the dichotomous category of launch or no launch, and the seven-level category of day of week.

RQ3 was evaluated using the two-way factorial ANOVA. In the event that the collected data did not meet the assumptions for the two-way ANOVA, the non-parametric Kruskal-Wallis Test would have been used in series by factor instead. RQ3 had a continuous dependent variable, average Part 121 arrival delay in minutes, and two multi-level categorical independent variables: the dichotomous category of launch or no launch, and the six-level category of time of day.

Upon completion of inferential computations, data was analyzed by the researcher into written and graphical findings. The findings of RQ1, RQ2 and RQ3 will be used to generate an ideal sequence model for orbital launch slot assignments by both day of week and time period that allows for both maximum annual space launches and minimal delay impact to Part 121 arrivals into MCO. Discussion of the findings was compared and contrasted to the findings of existing literature surveyed in Chapter 2 of this study, and written conclusions followed based off of this action. Finally, recommendations for industry practice and future academic research into this area were made.

Threats to Internal Validity

1. *Location:* The ex post facto design is typically vulnerable to the location threat; however, the researcher controlled for this threat by choosing to analyze data from only a single location. Likewise, all dependent variable data was downloaded from a single archival source. Therefore, the effects of the location threat with regard to this study were controlled for.
2. *Instrument:* The ex post facto design is also typically vulnerable to the instrument threat. In this case, no instrument was used for data collection, therefore this threat was no factor.
3. *Mortality:* Despite the use of official U.S. Government archival records, there was a two-fold mortality threat present in this study: The threat of data loss due to poor handling by the record's custodians prior to download by the researcher, and the threat of data loss due to poor handling by the researcher following the initial data download. The threat of data loss due to poor handling by its custodians was outside of the researcher's control and was accepted and listed as a limitation of the study. The risk of data loss due to poor handling by the researcher during data coalescence and synthesis was controlled for by saving backup copies of all work done (including original spreadsheet downloads), and only electronic calculators or similar programs were used to conduct all mathematic calculations. To the extent possible, the mortality threat to this study was controlled for.

4. *History:* There was a significant history threat present to this study and that is the effect of Covid-19 on passenger air travel in the United States. While passenger travel, and thus the number of Part 121 flights, did dramatically decline starting in March of 2020, at present day the TSA reports that the number of passengers screened on some days is already exceeding peak 2019 levels (Transportation Security Administration, 2021). While the effects of Covid resulted in a relatively reduced accessible population, it is highly doubtful that Covid could be used to explain any observed effect between Part 121 arrival delays into MCO and orbital space launches at Cape Canaveral. Therefore, the researcher accepted the possible effects of the history threat and will list the potential effects of Covid on the number of Part 121 flights as a study limitation.

Treatment Verification and Fidelity

This analysis utilized an ex post facto design. Therefore, there was no researcher-manipulated independent variable. Likewise, the ex post facto design prevented any causal relationship from being established between the independent variable and dependent variable. In layman's terms: there was no treatment being examined by this research, and therefore this topic was not a factor.

Data Analysis

Descriptive Statistics

Initially collected data was used for descriptive analysis both separately and in combined formats. Mean, median, mode and variance sample summary data was computed and reported in both written and tabular form as appropriate for dependent variable data. Tables 1 and 2 below illustrate some examples of the descriptive products that were produced by this analysis; however, more were also added as appropriate. Mode data was computed for independent variable data. Table 3, below, illustrates what this descriptive product looks like.

Table 3.1

Summary of MCO A0 and A15 Delays by Air Carrier

	Delay Type					
	A-Zero		**A-15**		**Overall**	
Air Carrier	***N***	**%**	***N***	**%**	***N***	**%**
Endeavor Air						
American Airlines						
Delta Air Lines						
Hawaiian Airlines						
Southwest Airlines						
United Airlines						
Republic Airways						
Spirit Airlines						
Frontier Airways						
JetBlue Airways						
Alaska Airlines						
Total						

Note. N = X.

Table 3.2

Summary of Part 121 Arrival Delays by Cause

Status	***N***	**%**
Weather		
Volume		
Other		
Equipment		
Closure		
Total		

Note. N = X.

Table 3.3

Orbital Space Launches by Day of Week and Time of Day

	Time of Day[a]					
	1	**2**	**3**	**4**	**5**	**6**
Day of Week						
Monday						
Tuesday						
Wednesday						
Thursday						
Friday						
Saturday						
Sunday						
Total						

Note. N = X.

Inferential Statistics

All appropriate assumption tests were completed and either verified or nullified prior to the commencement of any inferential statistical tests. Evidence of the sample data’s compliance with the various assumptions of each RQ’s respective inferential statistical test was attached as Appendix B or otherwise detailed in Chapter 4. All alpha values, degrees of freedom, and F-statistics were provided as summary data. Likewise, the results of all post hoc tests, including pairwise comparisons (if appropriate), power, and effect size were provided.

RQ1 was evaluated using the one-way ANOVA. In the event that the collected data did not meet the assumptions for the one-way ANOVA, the non-parametric Kruskal-Wallis Test would have been used instead. The test statistic used was the F-statistic. This inferential statistical method is appropriate due to the fact that group differences are being compared for statistical significance. RQ1 had a continuous dependent variable, average Part 121 arrival delay in minutes, and a dichotomous categorical independent variable, the categories of launch or no launch. If for some reason neither the One-Way ANOVA nor the Kruskal Wallis Test were found appropriate, the independent-means t-test would also have been appropriate to evaluate RQ1 inferentially.

> *Research Hypothesis*: There was a significant difference in average Part 121 flight delays into MCO between days that an orbital space launch occurred, and days that one did not.
>
> *Null Hypothesis*: There was no difference in average Part 121 flight delays into MCO between days that an orbital space launch occurred, and days that one did not.
>
> H_o: $\mu 1 = \mu 2$

H_1: $\mu 1 \neq \mu 2$

RQ2 was evaluated using the two-way factorial ANOVA. In the event that the collected data did not meet the assumptions for the two-way ANOVA, the non-parametric Kruskal-Wallis Test would have used in series instead by factor. The test statistic used was the F-statistic. This inferential statistical method was appropriate due to the fact that group differences were being compared for statistical significance across multiple factors. Further, this RQ had a continuous dependent variable, average Part 121 arrival delay in minutes, and two multi-level categorical independent variables: the category of launch or no launch, and the seven-level category of day of week. An example of what this ANOVA design looked like is illustrated in Figure 3.2.

Research Hypothesis: There was a significant difference in average Part 121 flight delays into MCO between days that an orbital space launch occurred, and days that one did not, with respect to day of week.

Null Hypothesis, First Main Effect: There was no significant difference on Part 121 arrival delays into MCO based on whether or not an orbital space launch occurred at Cape Canaveral.

Null Hypothesis, Second Main Effect: There was no significant difference on Part 121 arrival delays into MCO with respect to the Day of Week in which a delay occurred.

Null Hypothesis, Interaction Effect: There was no significant interaction effect between whether an orbital space launch occurred at Cape Canaveral, and the Day of Week in which a launch occurred, in terms of Part 121 arrival delays into MCO.

H_{o1}: $\mu 1 = \mu 2$

H_{o2}: $\mu 1 = \mu 2 = \mu 3 \ldots = \mu 7$

H_{o3}: No interaction was present.

2 x 7 Design		Launch or No Launch?	
		Launch	No Launch
Day of Week	Monday	21.92	25.75
	Tuesday	21.92	20.59
	Wednesday	36.25	26.92
	Thursday	23.08	30.5
	Friday	54.75	10.42
	Saturday	20.84	9.42
	Sunday	17.92	45.95

Figure 3.2. *2 x 7 Factorial ANOVA Design*

Note. All values in minutes.

RQ3 was evaluated using the two-way ANOVA. In the event that the collected data did not meet the assumptions for the two-way ANOVA, the non-parametric Kruskal-Wallis Test would have been used instead. The test statistic was the F-statistic. This inferential statistical method was appropriate due to the fact that group differences were being compared for statistical significance. Further, this RQ had a continuous dependent variable, average Part 121 arrival delay in minutes, and two multi-level categorical independent variables: the category of launch or no launch, and the six-level category of time of day. Time of day for this RQ was partitioned into six, four-hour long periods. An example of what this ANOVA design looked like is illustrated in Figure 3.3.

> *Research Hypothesis*: There was a significant difference in average Part 121 flight delays into MCO between days that an orbital space launch occurred, and days that one did not, with respect to time of day.
>
> *Null Hypothesis, First Main Effect*: There was no significant difference on Part 121 arrival delays into MCO based on whether or not an orbital space launch occurred at Cape Canaveral.
>
> *Null Hypothesis, Second Main Effect*: There was no significant difference on Part 121 arrival delays into MCO with respect to the Time of Day in which a delay occurred.
>
> *Null Hypothesis, Interaction Effect*: There was no significant interaction effect between whether an orbital space launch occurred at Cape Canaveral, and the Time of Day in which a launch occurred, in terms of Part 121 arrival delays into MCO.

H_{o1}: $\mu 1 = \mu 2$

H_{o2}: $\mu 1 = \mu 2 = \mu 3 \ldots = \mu 6$

H_{o3}: No interaction was present.

2 x 6 Design		Launch or No Launch?	
		Launch	No Launch
Time of Day	1	32.93	43.72
	2	17	16.07
	3	9.22	21.29
	4	10	14.5
	5	13.22	38.36
	6	39.14	14.93

Figure 3.3. *2 x 6 Factorial ANOVA Design*

Note. All values in minutes.

Foreword on Results Section

Using the details outlined in Chapter 3, available data was drawn, organized, and evaluated both descriptively and inferentially. The details of this process and the proceeding analysis are listed below as Chapter 4.

Chapter 4

Results

Descriptive Statistics of Sample Data

Independent Variable

The primary independent variable for all research questions within this study was the categorized value of days and times that orbital space launches occurred. According to the official archival sources outlined in Chapter 3, $N = 33$ orbital space launches occurred from Cape Canaveral during the ten month time period established by the study. When categorized by day of week and time of day in which said orbital space launches occurred, a mode of Mo = Thursday and Sunday were found when considering the category of Day of Week for launches, and a mode of Mo = Period 4 (1200-1559) was identified when considering the category of Time of Day. This information is illustrated below, in Table 4.1.

While not directly connected to the research questions at hand, it is of note that of the $n = 33$ launches that were recorded and used by this study, the SpaceX Falcon 9 rocket accounted for the vehicle used in 30 of these launches (90.9%), the United Launch Alliance (ULA) Atlas 5 accounted for 2 launches (6.06%), and the ULA Delta 4 Heavy accounted for just a single launch (3.03%). Figure 4.1 serves to give some idea on which operator/vehicle is responsible for the lion's share of recent orbital space launch operations from Cape Canaveral.

Table 4.1

Orbital Space Launches by Day of Week and Time of Day

	Time of Day						
	1	**2**	**3**	**4**	**5**	**6**	**Total**
Day of Week							
Monday	0	0	0	0	0	1	1
Tuesday	0	1	0	2	0	1	4
Wednesday	0	1	1	3	0	1	6
Thursday	3	0	1	2	1	2	9
Friday	0	1	0	0	1	0	2
Saturday	0	0	2	0	1	0	3
Sunday	2	1	3	1	1	0	9
Total	5	4	7	8	4	5	33

Note. N = 33 launches.

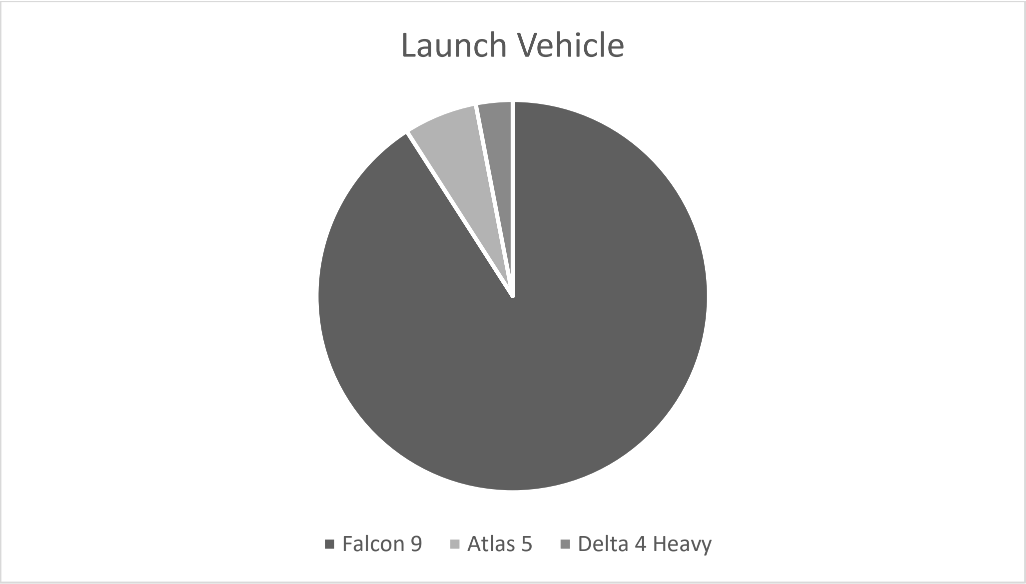

Figure 4.1. *Breakdown of Launch Vehicles Used During Measured Time Period*

Note. N = 33 total observed launch events.

Dependent Variable

Overall

The dependent variable used across all three primary research questions in this study was the value of flight delay in minutes. From the study's established time period of September 2020 to June 2021 (inclusive), a total of N = 22,783 usable arrival delays were recorded by Transtats Tool A. In order to arrive at this sample of usable delays some data entries that were incomplete, such as those marked as delayed but with no recorded time value for said delay, were culled from the sample. Likewise, delays in which the majority of the time was coded as caused by security, late arriving aircraft at origin, or due to weather were also removed from the sample. As a result of these endeavors, 324 delays were removed from the sample due to being coded as caused by weather, 63 were removed due to being coded as caused by security, 3,659 were removed due to being coded as caused by late arrival of aircraft at the flight's point of departure, and 1,195 were removed due to a lack of recorded delay value (missing a-zero). Thus, a total of 5,241 delays were removed from the sample per the guidelines established in Chapter 3, leaving a total sample of N = 22,783 flights available for analysis. A month-by-month tabulation of the number of flights deleted in each category is listed below, as Appendix C. Further, a database of all specific delays that were used and deleted has been retained by the author per the guidance outlined in Chapter 3.

A-priori sample size calculations for all three primary research questions yielded appropriate sample sizes of less than $N = 200$ delays (See Appendix A), while the available sample from Transtats Tool-A was over 22,000 delays. To use the entire available sample of delays would be cause for concern in the results with regard to central limit theorem, therefore, the decision was made to partition each group of usable delays by category, and then to randomly select samples of appropriate size (as defined by the a-priori calculations presented in Appendix A) for each RQ using a random number generator as described in Chapter 3. All data points selected by this process for inclusion have been retained by the author per the guidance in Chapter 3.

Flight Frequency by Category

It is important to define the total number of flights recorded as arriving into MCO during the study's established time period, with respect to both the category of day of week as well as the category of time of day. This consideration is important because it will allow for delay frequency data to be converted to proportional data, which will be inherently more useful for the considerations made within the contents of Chapter 5. This information is listed below, in Table 4.2 and Table 4.3.

Table 4.2

Summary of Part 121 Arrivals by Day of Week

Day	*N*	%
Monday	13,516	14.98
Tuesday	11,370	12.60
Wednesday	11,480	12.72
Thursday	12,965	14.37
Friday	13,268	14.70
Saturday	13,913	15.42
Sunday	13,725	15.21
Total	90,237	100.00

Note. N = 90,237.

Table 4.3

Summary of Part 121 Arrivals by Time of Day

Time	*N*	%
Period 1	2,219	2.48
Period 2	2,891	3.24
Period 3	20,215	22.64
Period 4	22,189	24.85
Period 5	23,522	26.34
Period 6	18,268	20.46
Total	89,304	100.00

Note. N = 90,237 but 933 database entries were missing arrival time information. All percents are based off of N = 89,304 recorded arrrival times.

RQ1

RQ1 utilized a random sample of *N* = 128 flight delays. This resulted in 64 delays being selected from the group of delays that occurred on launch days, and 64 delays being selected from the group of delays that occurred on non-launch days.

From the overall data pool drawn from Transtats Tool-A, 2,302 arrival delays occurred during the 33 launch days for an average of *M* = 69.76 delays per launch day. Likewise, 20,482 arrival delays were recorded during the 302 non-launch days observed by the study, for an average of *M* = 67.82 delays per non-launch day. Thus, in terms of frequency, a higher overall number of delays was observed on days in which an orbital space launch occurred, compared to the number of delays observed on days in which no orbital space launch occurred.

Of the sample of *N* = 128 arrival delays selected for use in RQ1, a mean of *M* = 26.82 minutes was found across the total sample, with the launch category yielding an average delay of *M* = 26.03 minutes, and the no launch category yielding an average arrival delay of *M* = 27.61 minutes. The sample's overall standard deviation was found to be *SD* = 56.87 minutes, with the launch category yielding a standard deviation of *SD* = 53.78 minutes, and the no launch category yielding a standard deviation of *SD* = 60.22 minutes. The overall range of the sample was (1 – 446 minutes), the launch category range was (1 – 404 minutes), and the no launch category range was (1 – 446 minutes). This information is presented further in Table 4.4, below.

Table 4.4

RQ1 Descriptive Statistics Summary

	N	**Mean**	**SD**	**SE**	**Lower 95%**	**Upper 95%**	**Min**	**Max**
No Launch	64	27.61	60.22	7.53	12.57	42.65	1.00	446.00
Launch	64	26.03	53.78	6.72	12.60	39.47	1.00	404.00
Total	128	26.82	56.87	5.03	16.87	36.77	1.00	446.00

Note. N = 128. All figures rounded to two decimal places.

Referencing Table 4.4, it is immediately seen that the average delay on a day in which no orbital space launch occurred was 1.58 minutes longer than the average delay on a day in which a space launch occurred. Likewise, the launch category recorded a maximum delay of 404 minutes, whereas the no launch category recorded a maximum value of 446 minutes, which is 42 minutes longer than the maximum value recorded by the launch category (10.40%).

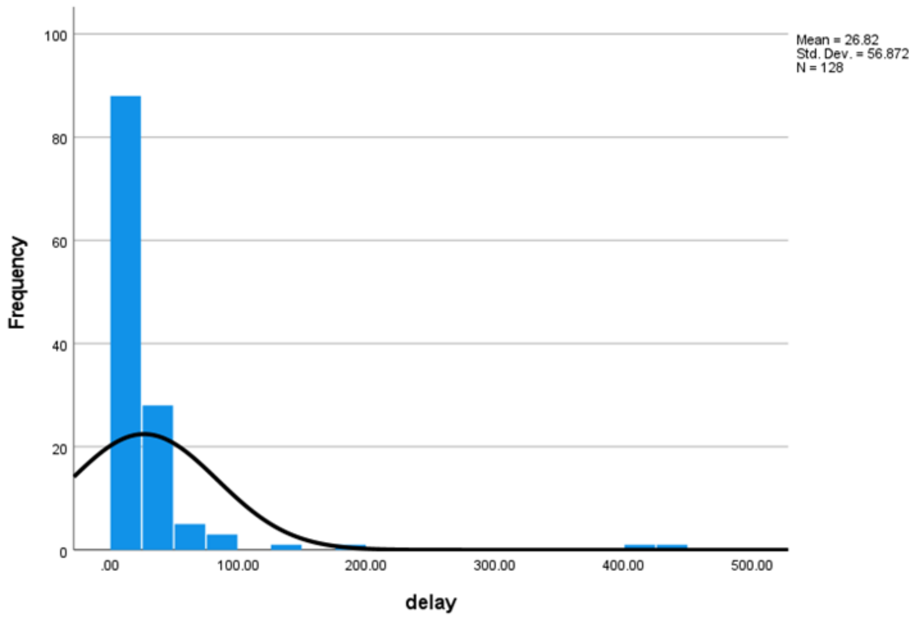

Figure 4.2. *Distribution of RQ1 Sample Data*

Figure 4.2, above, illustrates the distribution of recorded delays measured by RQ1. It is of note that the distribution displays approximately normal kurtosis (mesokurtic), however, the distribution is clearly skewed right. This skew is likely driven by the presence of two extreme scores (one per category) and the relatively low total sample mode of $Mo = 1$ *and* 3. The normality of RQ1's sample distribution was tested and reported in the Inferential Statistics section, below.

RQ2

RQ2 utilized a random sample of $N = 168$ arrival delays, of which 84 delays were drawn from the category of launch, and 84 delays were drawn from the category of no launch. Further, 24 delays were drawn from each day within the category of day of week (Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and Sunday) for a final subset of 12 arrival delays per specific category (such as Monday, launch).

From the overall data pool drawn from Transtats Tool-A, 2,302 arrival delays occurred during the 33 launch days for an average of *M* = 69.76 delays per launch day. Likewise, 20,482 arrival delays were recorded during the 302 non-launch days observed by the study, for an average of *M* = 67.82 delays per non-launch day. Thus, in terms of frequency, a higher overall number of delays was observed on days in which an orbital space launch occurred, compared to the number of delays observed on days in which no orbital space launch occurred.

Across the category of day of week, it was found that delays on Mondays occurred at an average frequency of *M* = 139.00 per day on days in which launches occurred, compared to an average of *M* = 72.12 delays on Mondays in which no launch occurred. On Tuesdays it was found that an average of *M* = 58.75 arrival delays occurred on days that a launch occurred compared to *M* = 51.32 average delays on days that no launch occurred. On Wednesdays an average of *M* = 77.67 arrival delays occurred on days that a launch occurred, compared to an average of *M* = 48.23 delays on days that no such launch occurred. On Thursdays, an average of *M* = 62.89 delays occurred on days that a launch occurred, with *M* = 67.72 average delays occurring on days that no launch occurred. On Fridays, an average of *M* = 43.00 arrival delays occurred per day that a launch occurred, compared to an average of *M* = 75.28 delays on days that no launch occurred. On Saturdays, launch days saw an average of $M = 75.00$ arrival delays, while no launch days saw an average of $M = 80.21$ delays. Finally, Sundays saw an average of $M = 72.38$ arrival delays per launch day, compared to $M = 76.86$ average arrival delays on no launch days. This information is depicted graphically as Table 4.5.

Table 4.5

RQ2 Frequency Data

Day	***Launch***	**No Launch**
Monday	139.00	72.12
Tuesday	58.75	51.32
Wednesday	77.67	48.23
Thursday	62.89	67.72
Friday	43.00	75.28
Saturday	75.00	80.21
Sunday	72.38	76.86

Note. Frequency data is presented in average number of delays per category.

Of the sample of $N = 168$ arrival delays selected for use in RQ2, a mean of $M = 26.15$ minutes was found across the total sample, with the launch category yielding an average delay of $M = 28.10$ minutes, and the no launch category yielding an average arrival delay of $M = 24.21$ minutes. Across the category of day of week, Mondays saw an average delay of $M = 23.83$ minutes, Tuesdays saw an average delay of $M = 21.25$ minutes, Wednesdays saw an average delay of $M = 31.58$ minutes, Thursdays saw an average delay of $M = 26.79$ minutes, Fridays saw an average delay of $M = 32.58$ minutes, Saturdays saw an average delay of $M = 15.13$ minutes, and Sundays saw an average delay of $M = 31.92$ minutes. Thus, ordering of the day of week category from greatest to least average arrival delay by day yields an order of Friday, Sunday, Wednesday, Thursday, Monday, Tuesday, and Saturday. This ordering is revisited and explored further in Chapter 5.

RQ2's sample had an overall standard deviation of *SD* = 37.32 minutes, with the launch category yielding a standard deviation of *SD* = 40.01 minutes, and the no launch category yielding a standard deviation of *SD* = 34.54 minutes. The overall range of the sample was (1 – 305 minutes). Information on the standard deviation values of the day of week category, as well as mean values for day of week considering the category of launch or no launch, are presented below, as Table 4.6.

Table 4.6

RQ2 Descriptive Statistics Summary

Launch Status	***Day of Week***	**N**	**Mean**	**SD**
No Launch	Monday	12	25.75	29.84
	Tuesday	12	20.58	23.85
	Wednesday	12	26.91	47.34
	Thursday	12	30.50	50.20
	Friday	12	10.42	13.14
	Saturday	12	9.42	6.91
	Sunday	12	45.92	39.15
	Total	84	24.21	34.54
Launch	Monday	12	21.92	17.21
	Tuesday	12	21.92	23.60
	Wednesday	12	36.25	29.66
	Thursday	12	23.08	26.18
	Friday	12	54.75	87.20
	Saturday	12	20.83	26.47
	Sunday	12	17.92	15.13
	Total	84	28.10	40.01
Total	Monday	24	23.83	23.91
	Tuesday	24	21.25	23.21
	Wednesday	24	31.58	38.93
	Thursday	24	26.79	39.33
	Friday	24	32.58	65.06
	Saturday	24	15.13	19.80
	Sunday	24	31.92	32.36
	Total	168	26.15	37.32

Note. N = 168. All figures rounded to two decimal places.

Referencing Table 4.6, the average delay on a day in which no orbital space launch occurred was 3.89 minutes shorter than the average delay on a day in which a space launch occurred. Across the category of day of week; Tuesday, Wednesday, Friday and Saturday saw longer average delays on launch days compared to no launch days, whereas Monday, Thursday and Sunday saw shorter average delays on launch days compared to no launch days.

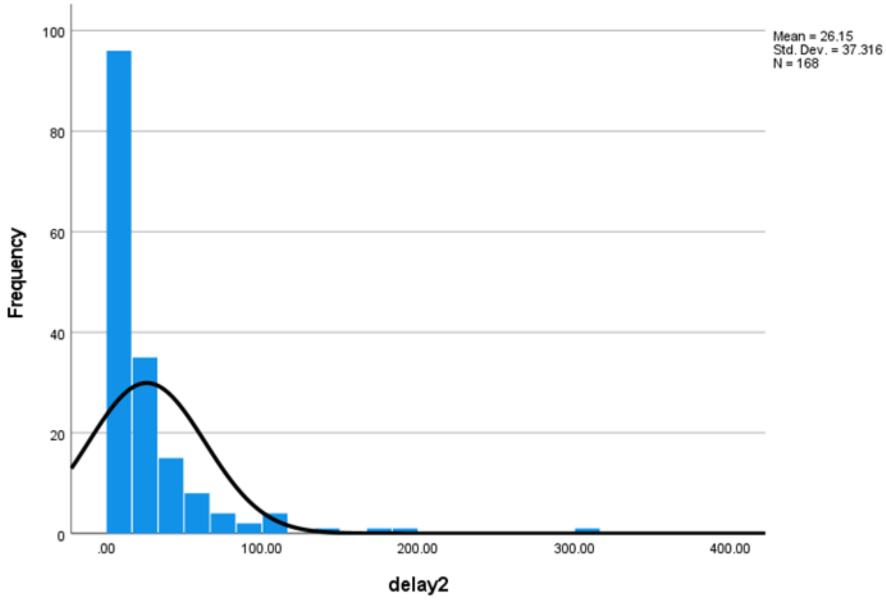

Figure 4.3. *Distribution of RQ2 Sample Data*

Figure 4.3, above, illustrates the distribution of recorded delays measured by RQ2. It is of note that the distribution displays approximately normal kurtosis (mesokurtic), however, the distribution is clearly skewed right. This skew is likely driven by the presence of three extreme scores and the relatively low total sample mode of *Mo* = 1. The normality of RQ2's sample distribution was tested and reported in the Inferential Statistics section, below.

RQ3

RQ3 utilized a random sample of *N* = 168 arrival delays, of which 84 delays were drawn from the category of launch, and 84 delays were drawn from the category of no launch. Further, 28 delays were drawn from each day within the category of time of day (0000-0359, 0400-0759, 0800-1159, 1200-1559, 1600-1959, and 2000-2359) for a final subset of 14 arrival delays per specific category (such as 0000-0359, launch).

From the overall data pool drawn from Transtats Tool-A, 2,302 arrival delays occurred during the 33 launch days for an average of *M* = 69.76 delays per launch day. Likewise, 20,482 arrival delays were recorded during the 302 non-launch days observed by the study, for an average of *M* = 67.82 delays per non-launch day. Thus, in terms of frequency, a higher overall number of delays was observed on days in which an orbital space launch occurred, compared to the number of delays observed on days in which no orbital space launch occurred.

Across the category of time of day, it was found that delays during 0000-0359 occurred at an average frequency of *M* = 5.25 per day on days in which launches occurred, compared to an average of *M* = 3.10 delays during the same time period on days that no launch occurred. From 0400-0759 it was found that an average of 4.00 arrival delays occurred on days that a launch occurred compared to 2.02 average delays on days that no launch occurred. From 0800-1159, an average of *M* = 9.43 arrival delays occurred on days that a launch occurred, compared to an average of *M* = 13.00 delays on days that no such launch occurred. From 1200-1559, an average of *M* = 21.14 delays occurred on days that a launch occurred, with *M* = 18.03 average delays occurring on days that no launch occurred. From 1600-1959, an average of *M* = 26.00 arrival delays occurred per day that a launch occurred, compared to an average of *M* = 21.14 delays on days that no launch occurred. From 2000-2359, launch days saw an average of *M* = 12.00 arrival delays, while no launch days saw an average of *M* = 16.73 delays. This information is depicted graphically as Table 4.7.

Table 4.7

RQ3 Frequency Data

Time	*Launch*	No Launch
Period 1	5.25	3.10
Period 2	4.00	2.02
Period 3	9.43	13.00
Period 4	21.14	18.03
Period 5	26.00	21.14
Period 6	12.00	16.73

Note. Frequency data is presented in average number of delays per category.

Of the sample of *N* = 168 arrival delays selected for use in RQ3, a mean of *M* = 22.53 minutes was found across the total sample, with the launch category yielding an average delay of *M* = 20.25 minutes, and the no launch category yielding an average arrival delay of *M* = 24.81 minutes. Across the category of time of day, 0000-0359 saw an average delay of *M* = 38.32 minutes, 0400-0759 saw an average delay of *M* = 16.54 minutes, 0800-1159 saw an average delay of *M* = 15.25 minutes, 1200-1559 saw an average delay of *M* = 12.25 minutes, 1600-

1959 saw an average delay of *M* = 25.79 minutes, and 2000-2359 saw an average delay of *M* = 27.04 minutes. Thus, ordering of the time of day category from greatest to least average arrival delay by day yields an order of 0000-0359 (period 1), 2000-2359 (period 6), 1600-1959 (period 5), 0400-0759 (period 2), 0800-1159 (period 3), and 1200-1559 (period 4). This ordering is revisited and explored further in Chapter 5.

RQ3's sample had an overall standard deviation of *SD* = 37.32 minutes, with the launch category yielding a standard deviation of *SD* = 33.26 minutes, and the no launch category yielding a standard deviation of *SD* = 39.53 minutes. The overall range of the sample was (1 – 296 minutes). Information on the standard deviation values of the time of day category, as well as mean values for time of day considering the category of launch or no launch, are presented below, as Table 4.8.

Table 4.8

RQ3 Descriptive Statistics Summary

Launch Status	*Time of Day*	N	Mean	SD
No Launch	Period 1	14	43.71	37.11
	Period 2	14	16.07	23.59
	Period 3	14	21.29	26.47
	Period 4	14	14.50	11.53
	Period 5	14	38.36	78.08
	Period 6	14	14.93	14.66
	Total	84	24.81	39.53
Launch	Period 1	14	32.93	33.53
	Period 2	14	17.00	16.62
	Period 3	14	9.21	9.65
	Period 4	14	10.00	8.14
	Period 5	14	13.21	12.38
	Period 6	14	39.14	66.96
	Total	84	20.25	33.26
Total	Period 1	28	38.32	35.14
	Period 2	28	16.54	20.04
	Period 3	28	15.25	20.49
	Period 4	28	12.25	10.06
	Period 5	28	25.79	56.33
	Period 6	28	27.04	49.13
	Total	168	22.53	36.49

Note. N = 168. All figures rounded to two decimal places.

Referencing Table 4.8, the average delay on a day in which no orbital space launch occurred was 4.56 minutes shorter than the average delay on a day in which a space launch occurred. Across the category of time of day; period 2 and period 6 saw longer average delays on launch days compared to no launch days, whereas all other time periods saw shorter average delays on launch days compared to non-launch days.

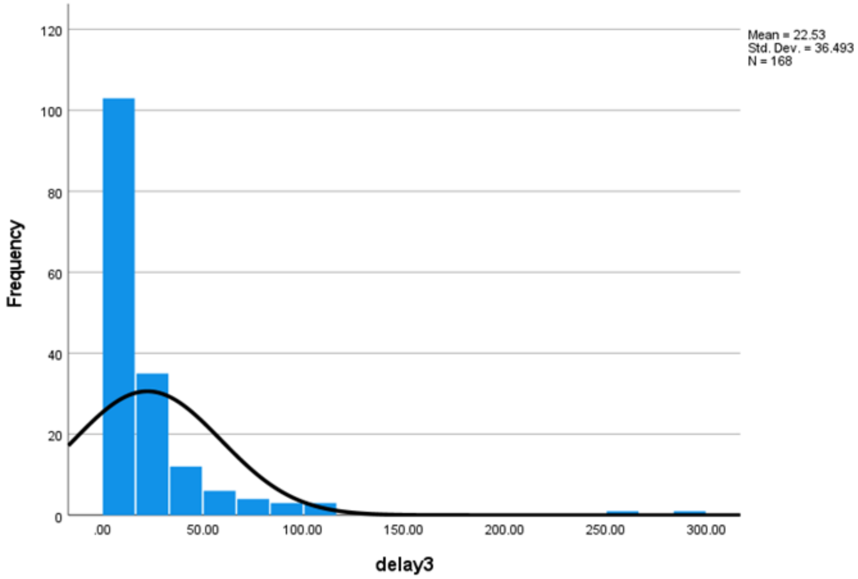

Figure 4.4. *RQ3 Sample Distribution*

Figure 4.4, above, illustrates the distribution of recorded delays measured by RQ3. It is of note that the distribution displays approximately normal kurtosis (mesokurtic), however, the distribution is clearly skewed right. This skew is likely driven by the presence of two extreme scores and the relatively low total sample mode of *Mo* = 1 and 2. The normality of RQ3's sample distribution was tested and reported in the Inferential Statistics section, below.

Inferential Statistics

RQ1

RQ1 was inferentially evaluated using the one-way ANOVA hypothesis test. Due to the selection of the ANOVA, the appropriate test statistic is the F statistic. Given the sample size of $N = 128$, and the number of groups of $G = 2$, the numerator degrees of freedom (df) is found as $df = 1$, and the denominator df is found as $df = 127$. Utilizing the alpha value established in Chapter 3 of $a = .05$, a critical value of $F_{crit} = 3.916$ is found.

Assumptions

The one-way ANOVA has three assumptions: independence, normality, and equal variance. The independence assumption of the one-way ANOVA was complied with automatically due to the sample for RQ1 being randomly selected. In order to assess the normality of RQ1's distribution a Q-Q plot was constructed; this plot is depicted below as Figure 4.5.

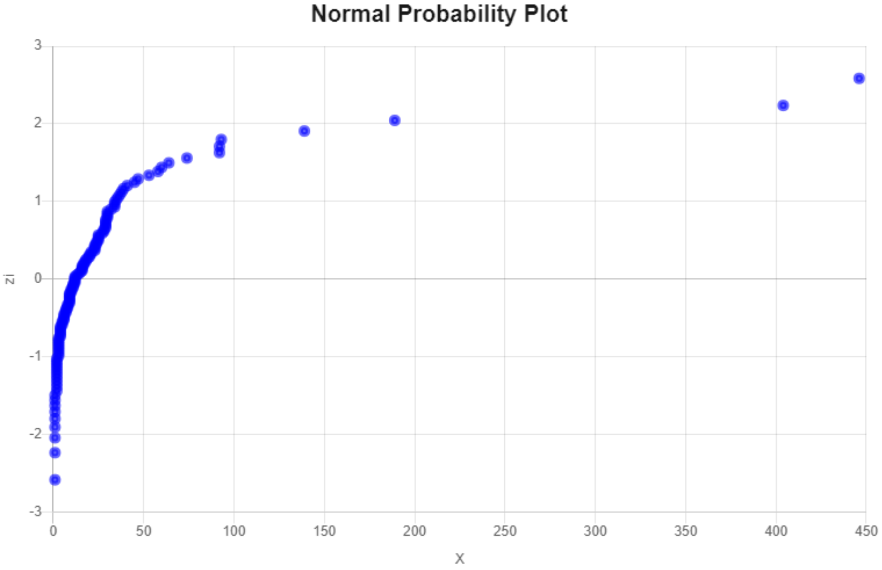

Figure 4.5, *RQ1 Q-Q Plot*

Referencing Figure 4.5, the sample distribution for RQ1 displays a moderate violation of the normality assumption. However, given that RQ1 used a robust sample size (*N* > 30), this violation is acceptable.

The equal variances assumption was tested for RQ1 via the Levene Test, which yielded a value of *p* = .798. This value is greater than RQ1's significance of *a* = .05, therefore the equal variances assumption is complied with. Thus, any significant differences between groups found by the ANOVA must be due to unequal means rather than unequal variances.

Findings

Referencing Table 4.9, below, the one-way ANOVA found that there was no significant difference in MCO Part 121 arrival delays between days that an orbital space launch occurred from Cape Canaveral $F(1, 127) = .024$, $p = .876$. Thus, we cannot reject the null hypothesis for RQ1.

Table 4.9

RQ1 ANOVA Summary

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	79.695	1	79.695	.024	.876
Within Groups	410695.172	126	3259.485		
Total	410774.867	127			

Note. $N = 128$. All figures rounded to three decimal places.

Post Hoc

A post hoc partial eta squared of $\eta^2 < 0.01$ was computed, meaning that less than 1% of the variance in arrival delays into MCO are attributable to differences between the two group means. A post hoc power of $1-\beta = .876$ was computed, an objectively high power.

RQ2

RQ2 was inferentially evaluated using the two-way ANOVA hypothesis test. Due to the selection of the ANOVA, the appropriate test statistic is the F statistic. Given the sample size of $N = 168$, an alpha value of $a = .05$, and the number of groups of $G = 14$, the following degrees of freedom and critical values are found: The main effect of launch had a degrees of freedom of $df = (1, 154)$ and therefore the critical value for the main effect of launch is found as $F_{crit} = 3.903$. The main effect of day of week had a degrees of freedom of $df = (6, 154)$ and therefore a critical value of $F_{crit} = 2.158$. The interaction of launch with day of week had a degrees of freedom of $df = (6, 154)$ and therefore a critical value of $F_{crit} = 2.158$.

Assumptions

The two-way ANOVA has three assumptions: independence, normality, and equal variance. The independence assumption of the two-way ANOVA was complied with automatically due to the sample for RQ2 being randomly selected. In order to assess the normality of RQ2's distribution a Q-Q plot was constructed; this plot is depicted below as Figure 4.6.

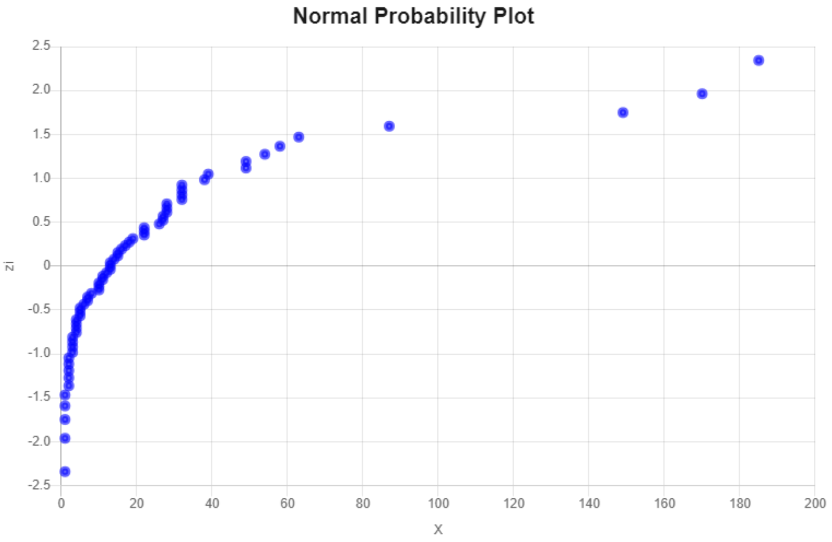

Figure 4.6. *Q-Q Plot of RQ2 Sample Data*

Referencing Figure 4.6, the sample distribution for RQ2 displays a moderate violation of the normality assumption. However, given that RQ2 used a robust sample size ($N > 30$), this violation is acceptable.

The equal variances assumption was tested for RQ2 via the Levene Test, which yielded a value of *p* = .430. This value is greater than RQ2's significance of *a* = .05, therefore the equal variances assumption is complied with. Thus, any significant differences between groups found by the ANOVA could not be due to unequal variances between groups.

Findings

Table 4.10

RQ2 ANOVA Summary

Source	***Sum Of Squares***	***df***	**Mean Square**	***F***	**Sig.**
Launch	632.60	1	632.560	.468	.495
Day of Week	6132.06	6	1022.01	.756	.606
Interaction	17597.66	6	2932.94	2.17	.049
Error	208187.67	154	1351.87		
Total	347474.00	168			
Corrected Total	232549.98	167			

Note. *N* = 168. *F* and *P* rounded to three decimal places, all other figures rounded to two decimal places.

Referencing Table 4.10, there was no significant difference in Part 121 arrival delays into MCO on days in which an orbital space launch occurred at Cape Canaveral, compared to days that no launch occurred *F*(1, 154) = .468, *p* = .495. Thus, we cannot reject the null hypothesis for main effect one (launch). There was also no significant difference in Part 121 arrival delays into MCO across the category of day of week, *F*(6, 154) = .756, *p* = .606. Thus, we cannot reject the null hypothesis for main effect two (day of week). There was a significant interaction effect found between the main effect of launch and the main effect of day of week, *F*(6, 154) = 2.17, *p* < .05. Thus, we can reject the interaction null hypothesis; there was a significant difference in Part 121 arrival delays into MCO on days that an orbital space launch occurred from Cape Canaveral compared to days that no such launch occurred, with respect to day of week.

Post Hoc

Effect size was calculated using the partial eta squared for each main effect as well as the interaction. For the launch main effect, an effect size of $\eta^2 = .003$ was found, for the day of week main effect, an effect size of $\eta^2 = 0.023$ was found, and the interaction effect yielded an effect size of $\eta^2 = 0.078$. Thus, .3% of the variance in arrival delays is being explained by launch or no launch, 2.3% of the variance in arrival delays is being explained by day of week, and 7.8% of the variance in arrival delays is being explained by the interaction of launch and day of week.

Pairwise comparisons were conducted in which only a single pair showed a significant difference; that of the Friday, launch versus no launch pair, which was significant at $p = .004$. The full results of the post hoc pairwise comparisons for RQ2 are listed as Appendix D.

Confidence interval data and standard errors were generated for both main effects and the interaction effect. All standard error and confidence interval information is included as Appendix E. An overall test power of $1-\beta = .110$ was computed, an objectively low power.

Given that RQ2 found a significant interaction effect, an interaction plot was produced and is illustrated below in Figure 4.7.

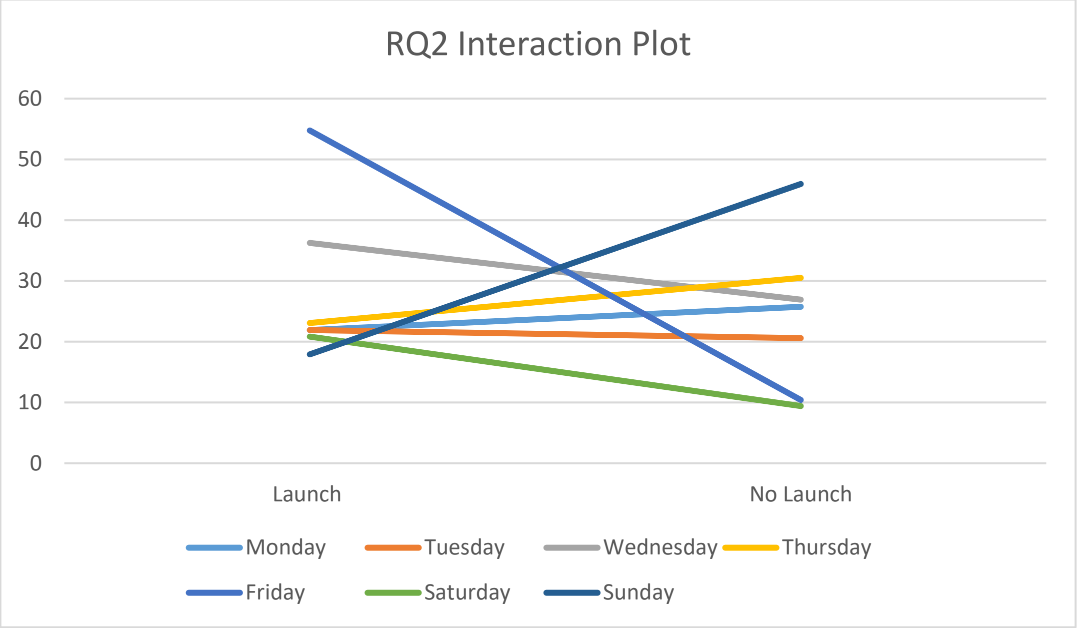

Figure 4.7. *RQ2 Interaction Plot*

Referencing Figure 4.7, there is no interaction between Saturday and Wednesday, with respect to launch. Sunday has a disordinal interaction with all days, while Friday has a disordinal interaction with all days except Saturday, with which it has ordinal interaction, with respect to launch. Wednesday has a disordinal interaction with Thursday with respect to launch. The strongest disordinal interaction present is between Friday and Sunday, with respect to launch. Finally, there are additional ordinal interactions between the following pairs: Thursday and Monday, Thursday and Tuesday, Thursday and Saturday, and Monday and Wednesday. An interpretation of the most visually significant disordinal interaction

(Friday and Sunday) would yield that on Fridays in which a launch occurred, the average arrival delay was much higher than Fridays in which no launch occurred. However, on Sundays that a launch occurred the average arrival delay was much lower compared to Sundays that no launch occurred.

RQ3

RQ3 was inferentially evaluated using the two-way ANOVA hypothesis test. Due to the selection of the ANOVA, the appropriate test statistic is the F statistic. Given the sample size of $N = 168$, an alpha value of $a = .05$, and the number of groups of $G = 12$, the following degrees of freedom and critical values are found: The main effect of launch had a degrees of freedom of $df = (1, 156)$ and therefore the critical value for the main effect of launch is found as $F_{crit} = 3.902$. The main effect of time of day had a degrees of freedom of $df = (5, 156)$ and therefore a critical value of $F_{crit} = 2.272$. The interaction of launch with time of day had a degrees of freedom of $df = (5, 156)$ and therefore a critical value of $F_{crit} = 2.272$.

Assumptions

The two-way ANOVA has three assumptions: independence, normality, and equal variance. The independence assumption of the two-way ANOVA was complied with automatically due to the sample for RQ3 being randomly selected. In order to assess the normality of RQ3’s distribution a Q-Q plot was constructed; this plot is depicted below as Figure 4.8.

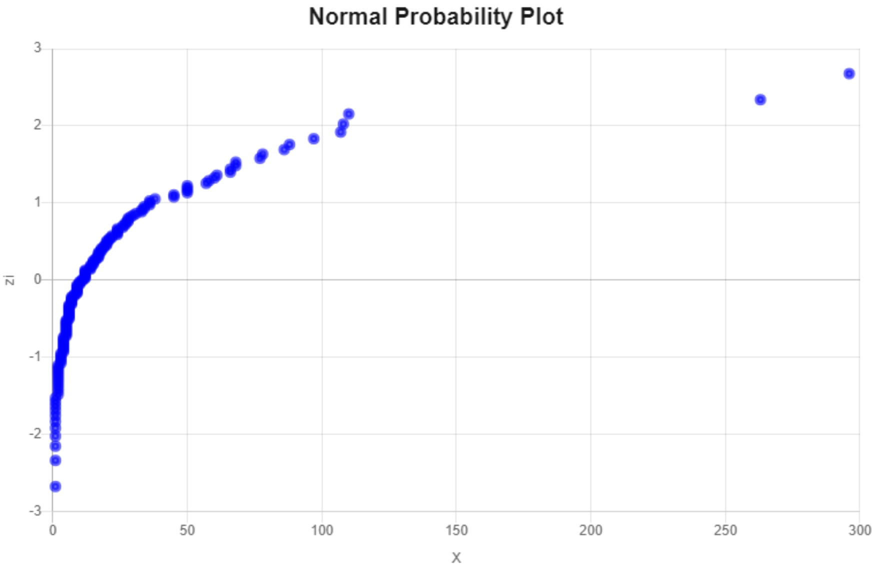

Figure 4.8. *Q-Q Plot of RQ3 Sample Data*

Referencing Figure 4.8, the sample distribution for RQ3 displays a moderate violation of the normality assumption. However, given that RQ3 used a robust sample size ($N > 30$), this violation is acceptable.

The equal variances assumption was tested for RQ3 via the Levene Test, which yielded a value of $p = .182$. This value is greater than RQ3's significance of $a = .05$, therefore the equal variances assumption is complied with. Thus, any significant differences between groups found by the ANOVA could not be due to unequal variances between groups.

Findings

Table 4.11

RQ3 ANOVA Summary

Source	*Sum Of Squares*	*df*	Mean Square	*F*	Sig.
Launch	873.15	1	873.15	.686	.409
Time of Day	13296.60	5	2659.32	2.089	.070
Interaction	9638.46	5	1927.69	1.514	.188
Error	198589.64	156	1273.01		
Total	307673.00	168			
Corrected Total	222397.85	167			

Note. *N* = 168. *F* and *P* rounded to three decimal places, all other figures rounded to two decimal places.

Referencing Table 4.11, there was no significant difference in Part 121 arrival delays into MCO on days in which an orbital space launch occurred at Cape Canaveral, compared to days that no launch occurred $F(1, 156) = .69$, $p = .409$. Thus, we cannot reject the null hypothesis for main effect one (launch). There was also no significant difference in Part 121 arrival delays into MCO across the category of time of day, $F(6, 156) = 2.09$, $p = .070$. Thus, we cannot reject the null hypothesis for main effect two (time of day). There was no significant interaction effect found between the main effect of launch and the main effect of time of day, $F(6, 156) = 1.51$, $p = .188$. Thus, we cannot reject the interaction null hypothesis.

Post Hoc

Effect size was calculated using the partial eta squared for each main effect as well as the interaction. For the launch main effect, an effect size of $\eta^2 = .004$ was found, for the time of day main effect, an effect size of $\eta^2 = .063$ was found, and the interaction effect yielded an effect size of $\eta^2 = .046$ Thus, .04% of the variance in arrival delays is being explained by launch or no launch, 6.3% of the variance in arrival delays is being explained by time of day, and 4.6% of the variance in arrival delays is being explained by the interaction of launch and time of day.

Pairwise comparisons were not conducted for this RQ due to the lack of significant findings within the ANOVA.

Confidence interval data and standard errors were generated for both main effects and the interaction effect. All standard error and confidence interval information is included within Appendix E. An overall test power of $1 - \beta = .83$ was computed, an objectively high power.

Given that RQ3 found no significant interaction effect, an interaction plot was not produced for this RQ.

Outlier Analysis

As a safeguard against the effects of extreme scores on the findings, outlier analysis and screening was conducted using the Turkey’s Fences protocol, due to the non-normal distributions of the sample data. Upon examination, the following findings occurred:

RQ1: No significant changes to the findings occurred as a result of outlier analysis.

RQ2: Main effect one (launch versus no-launch) became significant ($F = 4.74$, $p = .031$). However, this result is the opposite of the findings between these two groups that were made as the primary groups compared within RQ1, and the groups compared as main effect one in RQ3. No other significant changes to the findings of RQ2 occurred as a result of the outlier analysis process.

RQ3: Main effect two (time of day) became significant ($F = 10.62$, $p < .01$). Although this is an interesting finding, it is not surprising that there was a difference between average flight delays between the different times of the day. No other significant changes to the findings of RQ3 occurred as a result of the outlier analysis process.

Foreword on Chapter 5

Chapter 4 detailed the finer quantitative details regarding the statistical findings of RQs 1, 2 and 3. Specifically, across RQ1 and RQ3, the study was unable to reject any null hypotheses. For RQ2, the null hypothesis was able to be rejected for the interaction effect, however, these results were disputable due to the close proximity of both the F and p values to their respective critical cutoffs. Neither the null hypothesis for RQ2 main effect one no main effect two could be rejected by the study. Chapter 5, below, applies further inductive and deductive analysis to draw conclusions applicable for industry practice and future academic research.

Chapter 5

Conclusions, Implications and Recommendations

Summary of Study

The primary goal of this study was to determine inferentially if there was a statistically significant effect on Part 121 arrival delays into MCO being driven by orbital space launch operations at nearby Cape Canaveral. Unique to this study was the use of actual archival delay data; all previous studies on this subject (that could be located during the literature review process) used either dummy variables, models, or some combination of both to produce results. In this regard, the study at hand has met its goal; analysis was conducted using recorded delays from archival government sources, and it has been determined to a fair degree if there was/is a statistically significant impact on Part 121 arrival delays into MCO from orbital space launch operations at Cape Canaveral.

Summary of Findings

RQ1

The inferential analysis for RQ1 found no evidence of a significant difference in average Part 121 arrival delays into MCO between days that an orbital space launch occurred from Cape Canaveral, and days that no launch occurred. Repeated analysis with outliers removed yielded identical findings. Although not found to be statistically significant, the average delay on launch days was actually slightly lower than the average delay on non-launch days. Anecdotally, as the entirety of the data is examined, this difference increases over the established time scale of the study by several minutes; further disputing the primary research hypothesis of this study. Descriptively, the days in which orbital space launches occurred experienced a higher frequency of delayed flights (69.76 delays per average launch day) compared to those days that no space launch occurred (67.82 delays per average non-launch day). However, this frequency data is inconclusive at best; if said data were more formally examined and controlled for factors such as frequency of total arrivals into MCO during days of the week (perhaps by being expressed as ratios of said arrivals), it is possible that this difference in frequencies would fade and disappear. However, it is important to note that the majority of the launch days in the sample data did not occur on what are shown in Table 4.2 to be the busiest days (defined by total arrivals per day) of the week at MCO. This fact is interesting enough to warrant follow-up study but is beyond the scope of the current study to examine inferentially.

RQ2

RQ2 found no significant differences in arrival delays into MCO across its two main factors of launch, and day of week. However, RQ2 did identify a significant interaction effect between the two factors. Upon further inspection of these findings, the critical value for the two-way ANOVA conducted under RQ2 was $F_{crit} = 2.158$ and the critical alpha was $a = .05$. The results of the two-way ANOVA found that the interaction had an F-value of $F = 2.170$ and a significance of $p = .049$. These findings are extremely close to the cutoff scores for both the hypothesis test and the acceptable significance, and the resulting very low power that was calculated post hoc does not help make the case that this interaction is truly significant in a practical sense. Further post hoc examination of the interaction plot does seem to indicate some strong disordinal interactions between some factors, however, these are not uniform in nature, and therefore hint at a more complex relationship amongst the factors. When screened for outliers, RQ2's first main effect (launch versus no launch) became significant, however, this finding is opposite to the results of RQ1, and RQ3 main effect one, both of which compared the same groups.

RQ3

RQ3 found no significant differences across its main effects of launch, and time of day. RQ3 also found no significant interaction to be present between these main effects. When screened for outliers, main effect two (time of day) became significant. However, the confirmation that there is a difference in average flight delays depending on the time of day (with no interaction occurring from space launches) is not of major interest to this study. Post hoc examination revealed very little by way of additional interesting findings, and the computed overall post hoc power of $1-\beta > .80$ indicates that the findings of this test are likely practically accurate.

Conclusions

In light of the statistical evidence produced by Chapter 4 that disputes the original primary research hypothesis of this study, it is the overall conclusion of this study that there is currently no significant practical effect from orbital space launch operations at Cape Canaveral on Part 121 arrival delays into MCO.

Although there are some descriptive differences in the frequencies of delayed flights between launch and non-launch days, these figures are still not different enough to be of practical significance; even if found significant inferentially, a difference of 1.94 average additional delays per launch day (as descriptively found under RQ1) is not of practical significance given that MCO is averaging over 400 Part 121 arrivals per day at present time. That figure would notionally represent an increase of less than .5% arriving flights on an average launch day. However, this fact itself is anecdotal because that finding was not supported via inferential analysis. Of the various inferential tests that were conducted under the three statistical research questions, only the interaction effect of RQ2 yielded a statistically significant result, however, that finding was barley acceptable in terms of cutoff scores (*F* and *p*) and had an unacceptably low power. Therefore that singular finding can be disputed, given that all other inferential tests that were conducted found the opposite.

Visual inspection of the interaction plot generated by RQ2, as well as the various group means under all three RQs shows that there is no singular direction to whether delays on a specific day of week or time of day are affected by the presence of an orbital space launch. It is easily inferable that if in fact, orbital space launches were having a practical effect on MCO arrival delays, there should have been a consistent direction observed within the various hypothesis tests, however, there was not. On some days of the week, the average delay increases when an orbital space launch occurs, and on others, it decreases (sometimes drastically). The same can be said for the various times of day observed by this study. Further, the effect of launch versus no launch was technically tested three separate times, under three separate random samples, within this study (launch versus no launch was the singular independent variable for RQ1, and a main effect for RQ2 and RQ3). Under all three independent examinations, no significant effect was found in this factor. The only conclusion that can be made from this information is that the aforementioned asymmetric variances in delay times across differing days and time periods are not due to orbital space launches but rather a plethora of external factors. Thus, the primary conclusion of this study is that at this time, orbital space launch operations at Cape Canaveral have no practical or statistically significant effect on Part 121 arrival delays into MCO.

Implications

Implications to Prior Research

The literature review section of this study firmly established that the general consensus surrounding the relationship between space launch operations and NAS delays is both frictive, and negative. Conversely, this study's findings indicate quite the opposite; while the relationship may indeed feel frictive at times, the practical implications of said friction are simply not measurable in any statistical sense. Indeed, the factors that are being interpreted as evidence of friction, such as launch complex application processes with the FAA, activation of TFRs, or implementation of other airspace systems, may in fact simply be tangentially related phenomenon that are not currently resulting in a practical problem such as arrival delays at airports outlaying spaceports. Further, this study's findings lend evidence to the claim that such systems are fully buffering orbital space traffic and NAS traffic from delaying each other at present.

SpaceX Starship Program Licensing

Although the established research hypothesis of the study was not proven, these findings still have implications for the American commercial space launch industry. It was earlier pointed out in Chapter 4 that SpaceX is currently responsible for the vast majority of launches occurring from Cape Canaveral, and it is their stated desire to increase this presence as defined by both rate of launches and scale of said launches. At present, the next generation Starship program, which SpaceX has designed with the purpose of interplanetary transport, is being held from progressing as the FAA conducts a lengthy environmental impact assessment on the program (Federal Aviation Administration, 2022). This impact is not only aimed at the environmental impact of the program on natural ecosystems, but also on external system and safety factors such as NAS impact (2022). The findings of this study fully support SpaceX’s position that their operations are not (at present) negatively impacting NAS operations in any meaningful manner.

Growth of Cape Canaveral and MCO

A secondary implication of this study’s findings are that there is excess airspace capacity in the common areas between MCO and Cape Canaveral. Thus, it is advisable that continued increases in both orbital traffic in and outbound to Cape Canaveral and Part 121 traffic in and outbound to MCO would be of benefit to their respective parties. However, it is still likely inevitable that one day there will be an airspace conflict of practical significance between the two parties, and therefore it is advisable that this relationship continue to be studied as time permits.

Generalizability

Population Generalizability

Given the random sampling methodology that was used to collect the samples for each respective RQ, it is probable that all three RQs contained representative samples. Therefore, it is probable that the results of this study have a high degree of population generalizability.

Ecological Generalizability

The degree of ecological generalizability of this study’s findings would likely depend on what factor was varied. For example, if the study’s setting was changed from central Florida to the Denver Colorado or southeastern Texas regions, it is extremely likely that said study would have the same or very similar findings. Likewise, if the dependent variable was changed from arrival delays to departure delays, or perhaps both, it is also likely that this study's findings would prove similar to those of the follow-on study.

Limitations and Delimitations

Limitations

1. *Missing or Incomplete Archival Data.* Any data that is missing, omitted, or otherwise has been lost was not subject to my control. The use of official U.S. government data sources, and data triangulation, minimized the study's exposure to this limitation.
2. *Airline Reporting Practices.* This study assumed that all U.S. Department of Transportation reporting requirements were properly met by all Part 121 air carriers from which delay data is to be drawn. Likewise, if any individual air carrier employees responsible for reporting said figures misunderstood a reporting requirement, misidentified a reportable event, or simply caused a human error in their reporting, that was beyond the researcher's control.
3. *Real-time air carrier actions taken to mitigate delays.* It is possible that as orbital launch-related Part 121 re-routes and delays begin to take place across the Florida peninsula that individual air carriers took action to

minimize or mitigate the effects of such delay actions. This possibility was beyond the researcher’s ability to control.

4. *Skill of individual air traffic controllers during reroutes.* Once orbital launch activities being at Cape Canaveral, ATC re-routes are required for Part 121 traffic arriving into MCO. Many of these re-routings are manually conducted by air traffic controllers, and therefore, the individual differences in aptitude for this task between controllers could cause an asymmetric influence in the actual arrival delay figures from different days and time periods. This was beyond the researcher’s capability to control.
5. *Time length of orbital launch windows.* The time length for which an orbital launch window is approved for can vary from instantaneous, to several hours in duration. The variance in time length of each launch window was beyond the researcher’s ability to control.
6. *Effects of Covid-19 on Air Travel.* The ebbs and flows in Part 121 flights that have fluctuated following the March 2020 outbreak of Covid-19 were not within the control of the researcher.

Delimitations

1. *Decision to utilize selected archival data sources.* The research questions presented by this study were best addressed using ex post facto analysis, and therefore existing data a necessity. Appropriate U.S. government archives were selected for use in this study due to the high probability that

their contained data would have a high degree of integrity. The selection of these data archives helped to maximize the population generalizability of the study's results.

2. *Decision to examine MCO arrivals rather than arrivals and departures.* In order to properly measure the issue of orbital launch delays on Part 121 traffic, the scope of study had to be narrow enough to allow for precise results. Further, literature tells us that there is a spherical relationship present between Part 121 arrival and departure delays that would affect the accuracy of any results of a test that used both metrics as dependent variables. This concept was expanded upon above, in Chapter 2. Although outside of the scope of this study, this topic could make for an interesting subject of follow-on research.
3. *Decision to examine MCO and not Miami International (MIA) or other south Florida airports.* MCO was selected as the subject airport for this study due to its closer proximity to Cape Canaveral's range safety areas compared to MIA and other south Florida airports. It was considered that a comparison could be made between delay impacts at MCO and those at MIA, however, after review, it was determined that this concept is outside the scope of this project and better left for future academic research. It could also be argued that the significantly smaller Melbourne Airport (MLB) is more geographically closer to Cape Canaveral and may therefore suffer

from a more significant Part 121 delay impact due to this fact. While this could be true, due to the very limited amount of daily Part 121 arrivals into MLB, that hypothesis would be nearly impossible to evaluate statistically at this time due to both the small available sample of MLB's 121 arrivals and likewise the resultant low power of any findings. The ecological generalizability of the results may be affected by this to some degree, however, the use of a single location for study controlled for the potential effects of a location threat to internal validity.

4. *Decision not to use pre-COVID-19 Part 121 archival data.* This study was focused on producing a slot-assignment model that will be practically useful to future generations of professionals, as well as the current one. The depression in Part 121 flying caused by Covid-19 was temporary, and in the previous twelve months the rate of orbital space launches occurring from Cape Canaveral has been exponentially increasing. Therefore, it was ideal to collect data from the most recently-available archival records.
5. *Decision to use the one-way ANOVA rather than independent-means t-test in RQ1.* As explained in Chapter 3, this study was already going to be checking the data for compliance with the assumptions of the ANOVA for addressing RQ2 and RQ3. Therefore, it was simpler to also use the ANOVA to address RQ1, given that the one-way ANOVA theoretically produced identical results to the independent-means t-test in the context of

this study. This should not have affected the generalizability of the study's results.

6. *Decision to exclude delays coded due to weather from sample data.* As detailed in Chapters 2 and 3, each Part 121 delay analyzed by this study was coded by the Department of Transportation by delay cause. Given that MCO is located in central Florida and therefore is prone to tropical weather patterns, no delays that were coded as due to weather were used as sample data in this study. This action prevented the possible effects of weather as a confounding variable on the study's findings.

Recommendations for Industry Practice

Preventing Future Delay Impacts and Slot Assignment

The secondary objective of this study was to identify the ideal launch slot assignment sequence to allow for minimal delay impact to NAS traffic. The initial plan to construct this model was based on an outcome that confirmed the overall research hypothesis of this study. In that case, a simple ordering of days and time period from lowest to highest average delay would have sufficed. However, in light of both the actual results of the study, and ancillary findings such as frequency data that should be considered, this effort becomes slightly more complicated.

When constructing this slot assignment model, there are actually two inputs identified within this study that must be considered to create a proper sequence: average delay in minutes per category and average number of delays in that category. If we start by ordering the various categories of day and time during launch days by average delay length, we generate the following sequences:

Day: Sunday, Saturday, Monday, Tuesday, Thursday, Wednesday and Friday.

Time: Period 3, Period 4, Period 5, Period 2, Period 1, and Period 6.

In order to properly account for the impact of frequency data, the average delay on launch days can be multiplied by the average frequency of delay, which yields the average total minutes of delay per category. If this metric is applied, the following superior sequence is generated:

Day: Tuesday, Sunday, Thursday, Saturday, Friday, Wednesday and Monday.

Time: Period 2, Period 3, Period 1, Period 4, Period 5 and Period 6.

When compared to the figures presented in Chapter 4 regarding total number of flights by category, it is clear that this output is not simply an artifact of seeing lower delays due to lower volumes of arrivals in a given category. Thus, the ideal starting point (defined as minimal average delay-minutes per category) in terms of day to conduct an orbital space launch from Cape Canaveral would be Tuesday, and the optimal time period would be 0400-0759. If we compare this to the independent variable mode data from Chapter 4, the present day of week that sees the most launches is a tie between Sunday and Wednesday, and time period 2 (0400-0759) is actually the least-utilized time period for launches.

In summary, as both orbital launch and arrival rates in the central Florida region continue to grow over the coming years, it would be wise to adopt a launch slot sequence model that minimizes delay impact to both modes of transportation. Doing so in a proactive manner could prevent any serious delays from occurring for years to come due to the increased operational efficiency between the two modes of transportation. In situations where multiple launch solutions are calculated for a given launch (a common feature of pre-launch planning) it would be wise to opt for windows that follow the corrected flow models above by day and time, as possible.

Recommendations for Future Research

Closer Analysis of Frequency Data

Given the findings of this study it is advisable that frequency data, in terms of the number of flights delayed during orbital space launch events, be more closely monitored and perhaps analyzed inferentially. If this study were quasi-replicated, with the dependent variable being changed from average delay in minutes to average frequency of flight delays or proportion of flights delayed, the Chi Square could be used as the primary inferential tool in such an analysis. It would be of interest to the academic community to see if the findings of such a study match the findings of the present study or differ in some way.

Repeated Diagnostic Observations on a Fixed Timescale

With both Part 121 arrivals into MCO and orbital space launches from Cape Canaveral expected to grow over the years to come, it is possible that an airspace delay conflict between the two transportation modes is only a matter of time. In order to continually assess any potential delay impact between the two modes of transportation, this study could be replicated and repeated on a fixed time interval, such as every five years. Thus, the overall design of this study would function as a diagnostic tool, alerting the academic community to the perhaps inevitable eventuality that a practically significant delay conflict between orbital space launch operations and Part 121 arrivals begins.

Conclusion

There is at present no delay impact of statistical or practical significance on MCO from orbital space launch operations at Cape Canaveral that could be detected by the study at hand. The majority opinion of the literature on this subject leans into the idea that the central Florida segments of the NAS are on the precipice of disaster due to the effects of space launch operations, however, this is simply not true at the present time. It is beneficial to both the academic community and the aerospace industry as a whole that actual data has now been measured and analyzed rather than simply speculated using some manner of model. Even in light of these findings, there is one consideration that must be heeded by future generations: While the findings of the current study will certainly stand for a time, in the rapidly changing environments of both Part 121 aviation and orbital space launch operations, it would be wise to monitor this issue on a regular basis.

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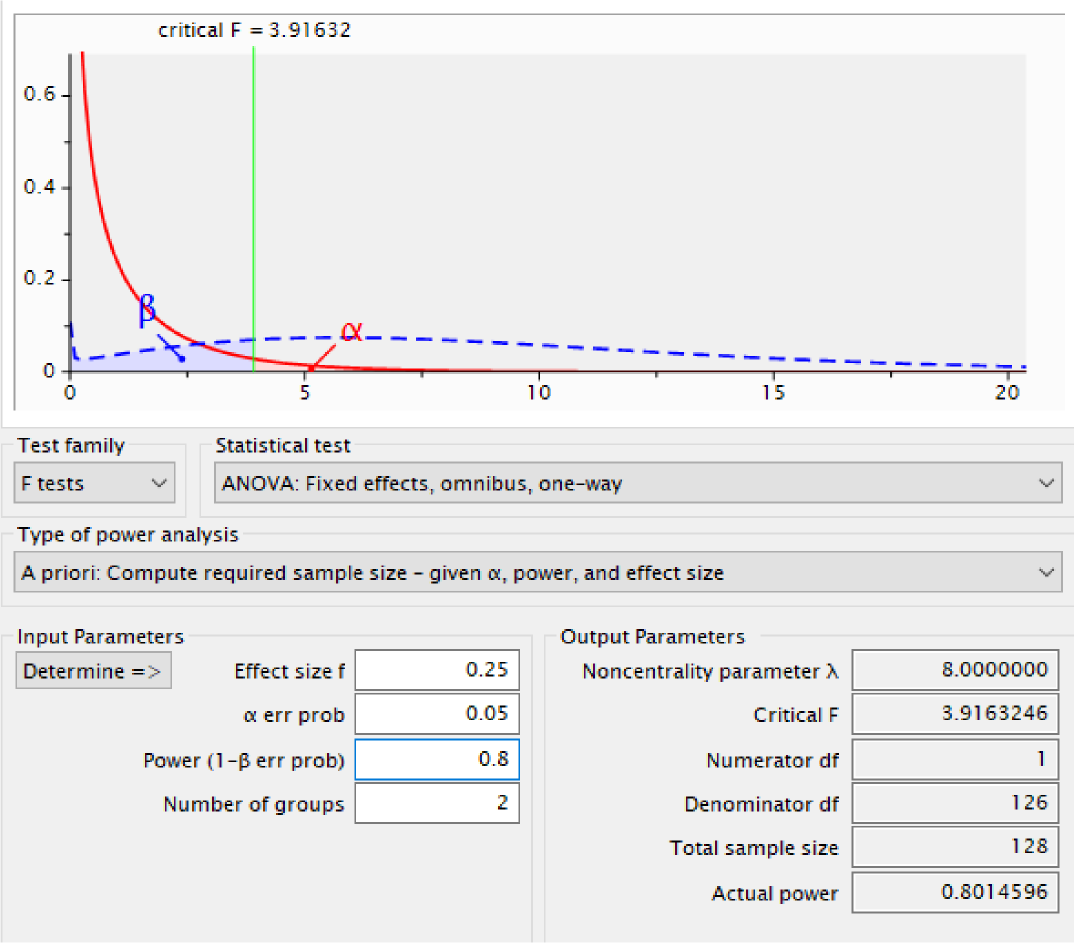
Appendix A

A-Priori Sample Size Computations

Research Question 1



Test family: F tests

Statistical test: ANOVA: Fixed effects, omnibus, one-way

Type of power analysis: A priori: Compute required sample size – given α, power, and effect size

Input Parameters

Effect size f 0.25

α err prob 0.05

Power (1–β err prob) 0.8

Number of groups 2

Output Parameters

Noncentrality parameter λ 8.0000000

Critical F 3.9163246

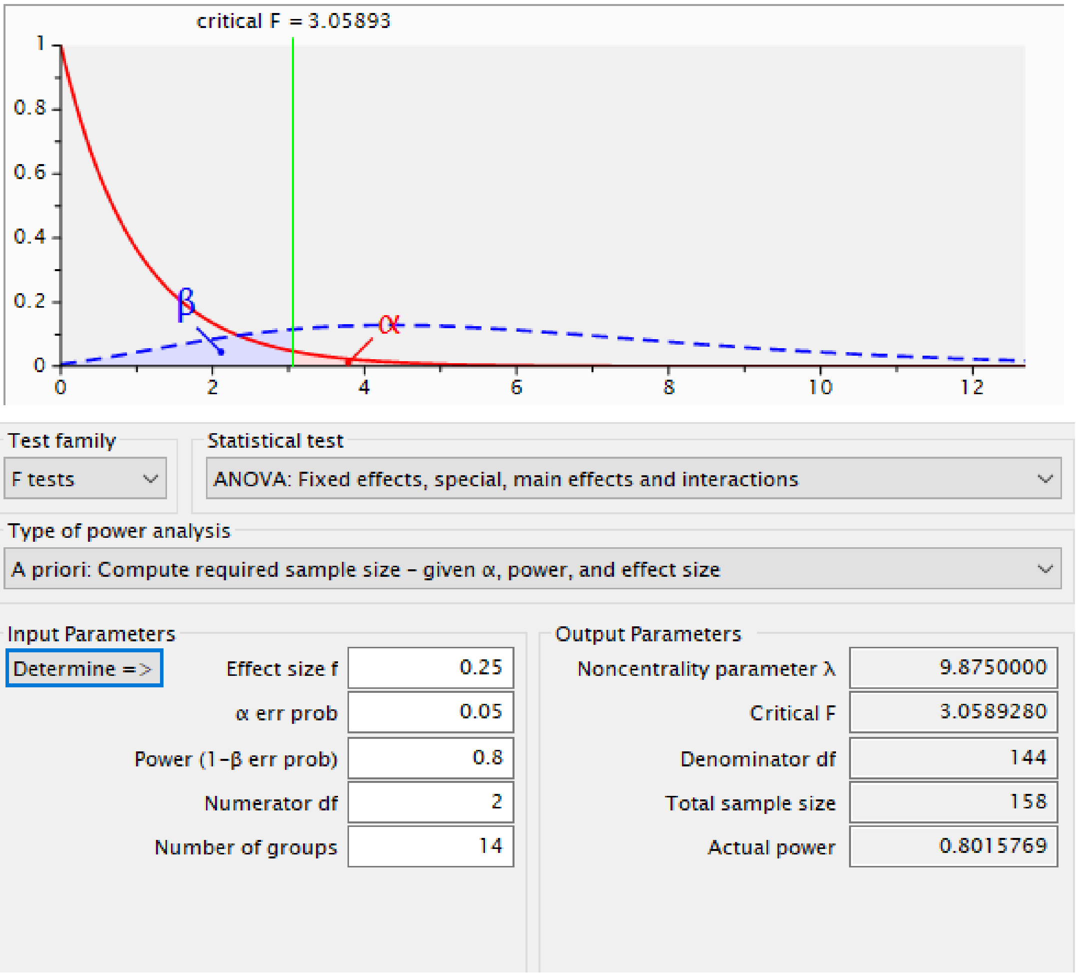
Numerator df 1

Denominator df 126

Total sample size 128

Actual power 0.8014596

Research Question 2



Test family: F tests

Statistical test: ANOVA: Fixed effects, special, main effects and interactions

Type of power analysis: A priori: Compute required sample size – given α, power, and effect size

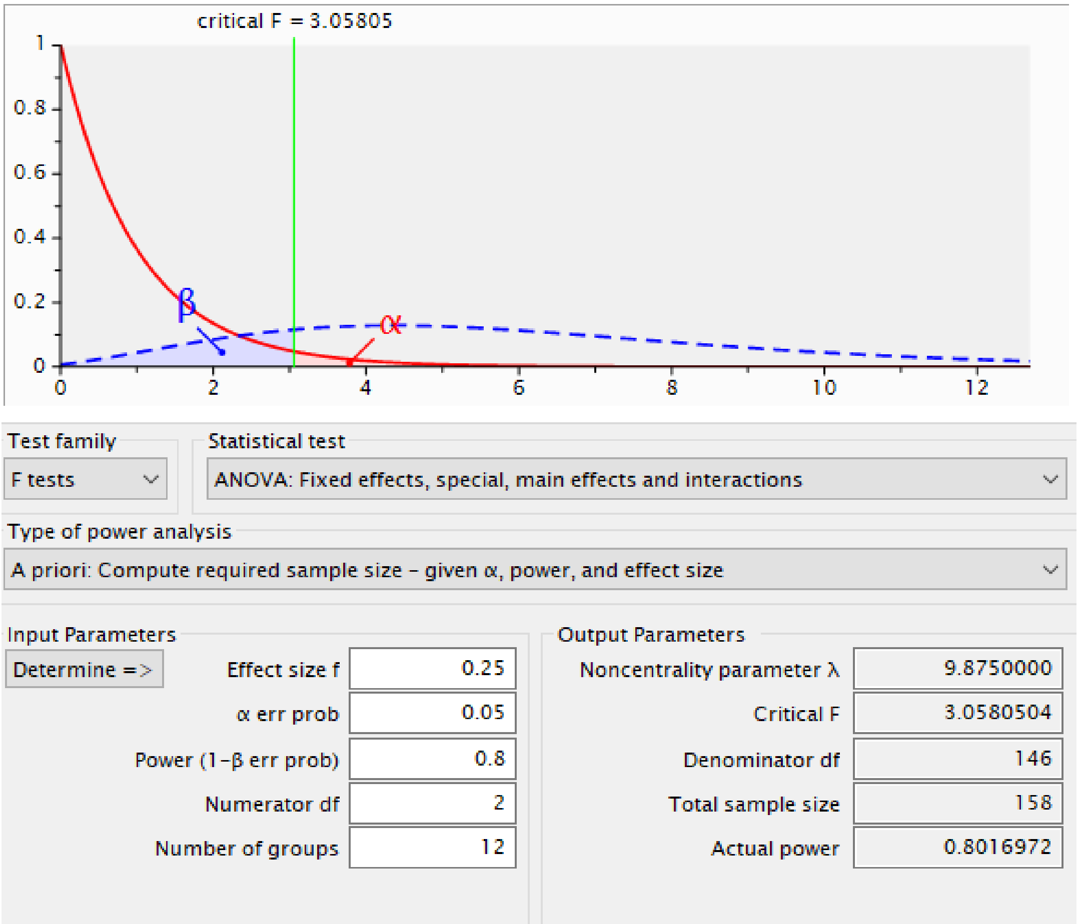
Input Parameters

Effect size f 0.25
α err prob 0.05
Power (1–β err prob) 0.8
Numerator df 2
Number of groups 14

Output Parameters

Noncentrality parameter λ 9.8750000
Critical F 3.0589280
Denominator df 144
Total sample size 158
Actual power 0.8015769

Research Question 3



Test family: F tests

Statistical test: ANOVA: Fixed effects, special, main effects and interactions

Type of power analysis: A priori: Compute required sample size – given α, power, and effect size

Input Parameters

Effect size f: 0.25

α err prob: 0.05

Power (1–β err prob): 0.8

Numerator df: 2

Number of groups: 12

Output Parameters

Noncentrality parameter λ: 9.8750000

Critical F: 3.0580504

Denominator df: 146

Total sample size: 158

Actual power: 0.8016972

Appendix B

Assumptions of the One-Way ANOVA and Factorial ANOVA

Table B.1

Levene Test Results

RQ	*Levene*	Sig.
1	.066	.798
2	1.026	.430
3	1.391	.182

Note. All figures rounded to three decimal places.

Appendix C

Delay Removals by Category and Month

Table C.1

Sample Data Deletes

Month	***Weather***	**No A-0**	**Security**	**Late Aircraft**	**Total Measured Delays**
Sep 20	5	44	2	78	788
Oct 20	9	15	4	100	1155
Nov 20	13	34	1	115	1550
Dec 20	17	73	6	242	2359
Jan 21	21	48	3	195	1665
Feb 21	40	257	3	242	2317
Mar 21	24	72	4	392	2781
Apr 21	36	215	6	555	2815
May 21	30	51	12	567	2925
Jun 21	129	386	22	1173	4428
Total	324	1195	63	3659	22783

Note. Total Measured Delays indicates the remaining number of acceptable delays used by the study.

Appendix D

RQ2 Post Hoc Pairwise Comparisons

Table D.1

RQ2 Post Hoc Pairwise Comparisons

Day	Factor 1	Factor 2	Mean Dif.	SE	Sig.	Lower	Upper
Monday	Launch	No Launch	-3.83	15.01	.80	-33.49	25.82
Tuesday	Launch	No Launch	1.33	15.01	.93	-28.32	30.99
Wednesday	Launch	No Launch	9.33	15.01	.54	-20.92	38.99
Thursday	Launch	No Launch	-7.42	15.01	.62	-37.07	22.24
Friday[a]	Launch	No Launch	44.33	15.01	.004	14.68	73.99
Saturday	Launch	No Launch	11.42	15.01	.45	-18.24	41.07
Sunday	Launch	No Launch	-28.00	15.01	.06	-57.65	1.65

Note. All figures rounded to two decimal places except the significance level of Friday. Lower and Upper signify the upper and lower bounds of the 95% confidence interval for the difference, respectivly. All figures are in minutes.

[a.] Significant pair.

Appendix E

Standard Error and Confidence Interval Data

RQ2

Table E.1

RQ2 Main Effect One

Variable	*Mean*	SE	Lower	Upper
Launch	24.214	4.012	16.289	32.139
No Launch	28.095	4.012	20.170	36.020

Note. Lower and Upper represernt the lower and upper bounds of a 95% confidence interval, respectivley. All figures rounded to three decimal places.

Table E.2

RQ2 Main Effect 2

Day	*Mean*	SE	Upper	Lower
Monday	23.833	7.505	9.007	38.660
Tuesday	21.250	7.505	6.424	36.076
Wednesday	31.583	7.505	16.757	46.410
Thursday	26.792	7.505	11.965	41.618
Friday	32.583	7.505	17.757	47.410
Saturday	15.125	7.505	.299	29.951
Sunday	31.917	7.505	17.090	46.743

Note. Lower and Upper represernt the lower and upper bounds of a 95% confidence interval, respectivley. All figures rounded to three decimal places.

Table E.3

RQ2 Interaction

Launch	***Day***	***Mean***	**SE**	**Upper**	**Lower**
No Launch	Monday	25.750	10.614	4.782	46.718
	Tuesday	20.583	10.614	-.384	41.551
	Wednesday	26.917	10.614	5.949	47.884
	Thursday	30.500	10.614	9.532	51.468
	Friday	10.417	10.614	-10.551	31.384
	Saturday	9.417	10.614	-11.551	30.384
	Sunday	45.917	10.614	24.949	66.884
Launch	Monday	21.917	10.614	.949	42.884
	Tuesday	21.917	10.614	.949	42.884
	Wednesday	36.250	10.614	15.282	57.218
	Thursday	23.083	10.614	2.116	44.051
	Friday	54.750	10.614	33.782	75.718
	Saturday	20.833	10.614	-.134	41.801
	Sunday	17.917	10.614	-3.051	38.884

Note. Lower and Upper represernt the lower and upper bounds of a 95% confidence interval, respectivley. All figures rounded to three decimal places.

RQ3

Table E.4

RQ3 Main Effect One

Variable	*Mean*	SE	Lower	Upper
Launch	24.810	3.893	17.120	32.499
No Launch	20.250	3.893	12.560	27.940

Note. Lower and Upper represernt the lower and upper bounds of a 95% confidence interval, respectivley. All figures rounded to three decimal places.

Table E.5

RQ3 Main Effect 2

Time Period	*Mean*	SE	Upper	Lower
1	38.321	6.743	25.003	51.640
2	16.536	6.743	3.217	29.855
3	15.250	6.743	1.931	28.569
4	12.250	6.743	-1.069	25.569
5	25.786	6.743	12.467	39.105
6	27.036	6.743	13.717	40.355

Note. Lower and Upper represernt the lower and upper bounds of a 95% confidence interval, respectivley. All figures rounded to three decimal places.

Table E.6

RQ3 Interaction

Launch	*Time Period*	*Mean*	SE	Upper	Lower
No Launch	1	43.714	9.536	24.879	62.550
	2	16.071	9.536	-2.764	34.907
	3	21.286	9.536	2.450	40.121
	4	14.500	9.536	-4.336	33.336
	5	38.357	9.536	19.521	57.193
	6	14.929	9.536	-3.907	33.764
Launch	1	32.929	9.536	14.093	51.764
	2	17.000	9.536	-1.836	35.836
	3	9.214	9.536	-9.621	28.050
	4	10.000	9.536	-8.836	28.836
	5	13.214	9.536	-5.621	32.050
	6	39.143	9.536	20.307	57.979

Note. Lower and Upper represernt the lower and upper bounds of a 95% confidence interval, respectivley. All figures rounded to three decimal places.