



**NAVAL
POSTGRADUATE
SCHOOL**

MONTEREY, CALIFORNIA

THESIS

**CORRELATION ANALYSIS
OF NAVY FLIGHT MISHAPS**

by

Ho Kyung Kang

June 2023

Thesis Advisor:

Ruriko Yoshida

Second Reader:

Jefferson Huang

Approved for public release. Distribution is unlimited.

THIS PAGE INTENTIONALLY LEFT BLANK

| | | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------------|--------------------------------------------|
| REPORT DOCUMENTATION PAGE | | | <i>Form Approved OMB No. 0704-0188</i> |
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC, 20503. | | | |
| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE June 2023 | 3. REPORT TYPE AND DATES COVERED Master's thesis | |
| 4. TITLE AND SUBTITLE CORRELATION ANALYSIS OF NAVY FLIGHT MISHAPS | | 5. FUNDING NUMBERS | |
| 6. AUTHOR(S) Ho Kyung Kang | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000 | | 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A | | 10. SPONSORING / MONITORING AGENCY REPORT NUMBER | |
| 11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. | | | |
| 12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited. | | 12b. DISTRIBUTION CODE A | |
| 13. ABSTRACT (maximum 200 words) Flight mishaps are a crucial part of military aviation communities' operations because they negatively impact our military. The U.S. Navy's Naval Safety Center Annual Reports document mishap matters to include total mishap numbers each year, and aircraft model. The reports display whether the current year's mishaps have increased or decreased over the previous five years, but fail to provide any further analysis regarding correlations related to mishaps. The purpose of this research is to conduct a correlation analysis on the classes of flight mishaps through supervised learning techniques (i.e., Random Forest and Multinomial Logistic Regression analyses) to identify highly correlated variables related to mishap Classes A, B, and C. Naval Safety Command provided 10 years of flight mishap reporting data, which contained 754 observations with 13 variables. We found the "mishap type" and "aircraft model" variables correlate to the flight mishap classes the most, when predicting flight mishap classes. Mishap type is used to standardize mishap reporting and data collection; based on the Naval Aviation Safety Management System, there are 21 mishap types that may be selected during the mishap investigation process. Aircraft model describes the specific aircraft platform(s) that is involved in a mishap, including 26 aircraft models. Our correlation analysis provides the first step towards finding out the root causes of the flight mishaps and offers insights for future researchers. | | | |
| 14. SUBJECT TERMS Navy Aviation Mishap, prediction, supervised learning models, Random Forests, Multinomial Logistic Regression, flight mishap, mishap class | | 15. NUMBER OF PAGES 61 | |
| | | 16. PRICE CODE | |
| 17. SECURITY CLASSIFICATION OF REPORT Unclassified | 18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified | 19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified | 20. LIMITATION OF ABSTRACT UU |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release. Distribution is unlimited.

CORRELATION ANALYSIS OF NAVY FLIGHT MISHAPS

Ho Kyung Kang
Captain, United States Army
BSB, Indiana University, Bloomington, 2012

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

**NAVAL POSTGRADUATE SCHOOL
June 2023**

Approved by: Ruriko Yoshida
Advisor

Jefferson Huang
Second Reader

W. Matthew Carlyle
Chair, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Flight mishaps are a crucial part of military aviation communities' operations because they negatively impact our military. The U.S. Navy's Naval Safety Center Annual Reports document mishap matters to include total mishap numbers each year, and aircraft model. The reports display whether the current year's mishaps have increased or decreased over the previous five years, but fail to provide any further analysis regarding correlations related to mishaps. The purpose of this research is to conduct a correlation analysis on the classes of flight mishaps through supervised learning techniques (i.e., Random Forest and Multinomial Logistic Regression analyses) to identify highly correlated variables related to mishap Classes A, B, and C. Naval Safety Command provided 10 years of flight mishap reporting data, which contained 754 observations with 13 variables. We found the "mishap type" and "aircraft model" variables correlate to the flight mishap classes the most, when predicting flight mishap classes. Mishap type is used to standardize mishap reporting and data collection; based on the Naval Aviation Safety Management System, there are 21 mishap types that may be selected during the mishap investigation process. Aircraft model describes the specific aircraft platform(s) that is involved in a mishap, including 26 aircraft models. Our correlation analysis provides the first step towards finding out the root causes of the flight mishaps and offers insights for future researchers.

THIS PAGE INTENTIONALLY LEFT BLANK

Table of Contents

| | |
|-----------------------------------------------------|-----------|
| 1 Introduction | 1 |
| 1.1 Research Question | 2 |
| 1.2 Thesis Outline | 3 |
| 2 Background | 5 |
| 2.1 Flight Mishaps | 5 |
| 2.2 Literature Review | 9 |
| 3 Methodology | 13 |
| 3.1 Data Collection and Processing. | 13 |
| 3.2 Exploratory Data Analysis. | 20 |
| 3.3 Analysis Method | 24 |
| 3.4 Summary | 27 |
| 4 Findings | 29 |
| 4.1 Findings from EDA | 29 |
| 4.2 Findings from Random Forests Analysis | 29 |
| 4.3 Findings from MLR Analysis | 31 |
| 4.4 Overall Findings | 33 |
| 5 Conclusion | 35 |
| 5.1 Answer to Research Question | 35 |
| 5.2 Recommendations for Future Research. | 35 |
| 5.3 Conclusion. | 36 |
| List of References | 37 |
| Initial Distribution List | 39 |

THIS PAGE INTENTIONALLY LEFT BLANK

List of Figures

| | | |
|------------|-------------------------------------------------------------|----|
| Figure 2.1 | The “Swiss cheese” model of accident “causation.” | 8 |
| Figure 3.1 | Aggregate Mishap Counts by Mishap Type | 21 |
| Figure 3.2 | Class A Mishap counts by Mishap Type | 21 |
| Figure 3.3 | Class B Mishap counts by Mishap Type | 22 |
| Figure 3.4 | Class C Mishap counts by Mishap Type | 23 |
| Figure 3.5 | Mishap Type by Aircraft | 24 |
| Figure 3.6 | Gini Index Impurity Branch Example | 26 |
| Figure 4.1 | Confusion Matrix for Random Forests Model | 30 |
| Figure 4.2 | Gini Index | 31 |
| Figure 4.3 | Confusion Matrix for MLR | 32 |

THIS PAGE INTENTIONALLY LEFT BLANK

List of Tables

| | | |
|-----------|-----------------------------------------------------------------------------------------|----|
| Table 2.1 | Mishap Classification. Source: Naval Safety Command (2019) . . . | 9 |
| Table 3.1 | Web-enabled Aviation Mishap and Hazard Reporting System (WAMHRS) Variables | 13 |
| Table 3.2 | Naval Aviation Mishap Types Source: Department of Navy (2014). | 15 |

THIS PAGE INTENTIONALLY LEFT BLANK

List of Acronyms and Abbreviations

| | |
|-------------------|------------------------------------------------------|
| AGL | Above Ground Level |
| CFIT | Controlled flight into terrain |
| CRTHFC | Command Resilience Team Human Factors Council |
| DOD | Department of Defense |
| DON | Department of Navy |
| EDA | Exploratory Data Analysis |
| FOD | Foreign Object Damage |
| HFACS | DoD Human Factors Analysis and Classification System |
| MLR | Multinomial Logistic Regression |
| MSL | Mean Sea Level |
| NA | Not Applicable |
| NAVSAFECEN | Naval Safety Center |
| NCMAS | National Commission on Military Aviation Safety |
| NPS | Naval Postgraduate School |
| OOCF | Out of Control Flight |
| PHYSEP | Physiological |
| RADM | Rear Admiral |
| RMI | Risk Mitigation Information |
| SOP | Standard Operating Procedure |

| | |
|---------------|---------------------------------------------------------|
| TFOA | Things Falling Off Aircraft |
| USA | U.S. Army |
| USAF | U.S. Air Force |
| USN | U.S. Navy |
| WAMHRS | Web-enabled Aviation Mishap and Hazard Reporting System |

Executive Summary

Flight mishaps are a crucial part of military aviation communities' operations. They want to know what happened, why the mishap occurred, and how to mitigate future mishaps. They want to study the mishaps because the mishaps negatively impact our military.

One way that U.S. Navy (USN) shares flight mishap information is through the USN Naval Safety Center Annual Report. The USN publishes Naval Safety Center Annual Report on safety and mishap matters with the mishap classification and total mishap numbers for each year and aircraft model (Naval Safety Center 2021, p. 8). The reports show many simple bar charts with aggregate mishap numbers to indicate whether the current year's mishaps have increased or decreased compared to the previous year and last five years. While these reports and numbers are important, they fail to provide any insight or analysis regarding the causes of the mishaps. At most, the report highlights the Navy Safety Center's most recent updates to the following parts of the report in regards to the safety policy and procedures: instructions, systems, and guides (Naval Safety Center 2021, p. 8).

In order to gain useful insights into the causes of the mishaps, it is important to conduct a thorough analysis to find out which features are related to Navy flight mishaps.

The purpose of this research was to conduct a correlation analysis on the recorded Navy flight mishaps through supervised learning techniques—Random Forests analysis and Multinomial Logistic Regression (MLR) analysis—to identify variables that are highly correlated with the flight mishap classes. The results of our research can be used to provide the first step towards finding out the root causes of the flight mishaps.

Naval Safety Command provided the data, which contains 10 years' worth of information on the flight mishap reports from Naval Safety Command (Barnhill 2022). The data originally contained 36 variables, but we reduced them down to 13 variables. We removed unnecessary variables that had too many blanks or were indicated as not applicable to prevent any less meaningful data from affecting our analysis.

Our response variable was the mishap class: A (\$2,500,000 or more and/or aircraft destroyed & Fatality or permanent total disability), B (\$600,000 or more but less than \$2,500,000

& Permanent partial disability or three or more persons hospitalized as inpatients), or C (\$60,000 or more but less than \$600,000 & Nonfatal injury resulting in loss of time from work beyond day/shift when injury occurred) (Naval Safety Command 2019). Our predictors were Aircraft Models (F-18A, MH-60R, EA-18G, etc), Mishap Types (Human Factor, Wildlife Strike, System Failure, etc), and thirteen other predictors.

The two techniques that we used to classify mishaps and identify important variables are Random Forests analysis and MLR analysis. Random Forests produce a model that can predict the flight mishap classification as accurately as possible. We identified the variables that are most relevant to the flight mishap classes by using a Gini index, which is generated during the process of making the Random Forests. MLR analysis also predicts the flight mishap classification and identifies variables that are highly correlated with the flight mishap classes.

Our analysis indicates that the Mishap Type and Aircraft Model variables matter the most to the flight mishaps. The Gini index from Random Forests analysis shows the important variables sorted by importance. They are the most influential variables when predicting the mishap classes. One may say these two variables are the biggest parts of the reports, and thus, the results are somewhat obvious in general. However, the Mishap Type and Aircraft Model are part of the report and although people assume they are important, our analysis verifies and confirms that the two variables are important when it comes to the flight mishaps. Our correlation analysis provides the first step towards finding out the root causes of the flight mishaps and offers insights for future researchers. Future researchers can use our findings to conduct a more extensive analysis of the other causes of flight mishaps.

List of References

Barnhill D (2022) Private Email Communication, accessed October 20, 2022.

Naval Safety Center (2021) Annual Report 2021. Accessed March 22, 2023, <https://navalsafetycommand.navy.mil/Portals/29/Documents/220510-annual-report-2021.pdf>.

Naval Safety Command (2019) Current Mishap Definitions and Reporting Criteria.
Accessed April 11, 2023,
<https://navalsafetycommand.navy.mil/Resources/Current-Mishap-Definitions/>.

THIS PAGE INTENTIONALLY LEFT BLANK

Acknowledgments

I would like to express my deepest gratitude to my advisor, Dr. Ruriko Yoshida, for her unwavering support, mentorship, and expertise that guided me through every stage of this thesis. I would also like to express my sincere gratitude to CDR David Barnhill for his subject matter expertise and tremendous support that helped me to understand the aircraft models, aviation communities, and the flight mishap process.

Additionally, I would also like to thank my second reader, Dr. Jefferson Huang, for his dedication to enhance the quality of this thesis.

Lastly, I extend my appreciation to my wife, Jin Joo (Pearl) Kang, for her unwavering and boundless support. Thank you for accompanying and supporting me throughout the rewarding journey of completing this rigorous study.

THIS PAGE INTENTIONALLY LEFT BLANK

CHAPTER 1:

Introduction

In military aviation communities, flight mishaps are a crucial part of their operation, meaning they want to know about the mishaps in terms of what happened, why mishaps occurred, and what they could do to mitigate future mishaps. They want to study the mishaps because they negatively impact our military. For instance, Rear Admiral (RADM) Mark Leavitt stated at the Department of Defense (DOD) Aviation Safety Mishap Review and Oversight Process hearing before the Subcommittee on Tactical Air and Land Forces of the Committee on Armed Services in 2018 that “Any loss of aircraft, aircrew, or maintainers negatively affects the lethality and resilience of our Navy-Marine Corps team.” According to the Aviation Safety Mishap Review and Oversight Process hearing before the Subcommittee on Tactical Air and Land Forces of the Committee on Armed Services in 2018, all three branches, U.S. Army (USA), U.S. Navy (USN), and U.S. Air Force (USAF), are striving to implement preventive measures to avoid flight mishaps. The measure that RADM Leavitt stressed at the oversight process was that “after investigating mishaps... we immediately disseminate those lessons learned from each one to the respective community of interest.”

One way that USN shares flight mishap information is through the USN Naval Safety Center Annual Report. The USN publishes the Naval Safety Center Annual Report on safety and mishap matters with the mishap classification and total mishap numbers for each year and aircraft model. The reports show many histograms and simple bar charts with aggregate mishap numbers to indicate whether the current year’s mishaps have been increased or decreased compared to the previous year and last five years. While these reports and numbers are important, they fail to provide any insight or analysis regarding the causes of the mishaps. At most, the report highlights the Navy Safety Center’s most recent updates to the following parts of the report in regards to the safety policy and procedures: instructions, systems, and guides (Department of the Navy 2022, p. 8). It also briefly mentioned that human factors were the significant contributors to flight mishaps. (Department of the Navy 2022, p. 8) However, there was no detailed analysis of these factors.

Analyzing the causes of flight mishaps is very crucial because of two things, money and

people. First, aircraft are very expensive and the DOD has limited monetary resources to support the aviation community. For example, according to the National Commission on Military Aviation Safety (NCMAS) report to the President and the Congress of the United States, the cost of aircraft lost from 2013 to 2020 was \$11.6 billion, due to 186 aircraft (National Commission on Military Aviation Safety 2020). Second, our people are the most valuable assets that we have, and we do not want to lose them and see them get injured. Furthermore, according to NCMAS report, 224 lives were lost from 2013 to 2020 (National Commission on Military Aviation Safety 2020). Thus, overcoming these challenges would be highly beneficial to the DOD because it could save money and people.

In order to gain useful insights into the causes of mishaps, it is important to conduct a thorough analysis to find out which features are most correlated to Navy flight mishaps.

Presently, the Navy Safety Command believes that human factors are the single most significant contributor to flight mishaps. However, it is important to analyze the Navy flight mishaps to verify their existing claim that human errors are the greatest contributor and to offer a deeper understanding of how other factors may also contribute to flight mishaps.

Our Exploratory Data Analysis (EDA) shows that human factors are not the number one cause of the mishap aggregates, and the variables that are most highly correlated to the flight mishap class are Mishap Type and Aircraft Model.

1.1 Research Question

The purpose of this research was to conduct a correlation analysis on the Navy flight mishap data using supervised learning techniques to identify which variables are the most correlated with flight mishaps. The results of our research can be used to provide the first step towards finding out the root causes of the flight mishaps.

Our research sought to answer the following question:

- What are the variables that are most highly related to flight mishaps?

1.2 Thesis Outline

This thesis is organized as follows: In Chapter 2, we provide detailed background on flight mishaps by defining the mishaps and different types of mishaps, and we articulate the purpose of this research: We investigate correlations of different factors with the types of mishaps. In addition, we provide a literature review on flight mishaps.

In Chapter 3, we describe our research methodology, including data collection and processing procedures, EDA, and our analysis methods which are the Random Forests and Multinomial Logistic Regression (MLR).

Then in Chapter 4, we describe the results and findings from our analysis and we end this thesis with conclusions and recommendations for future researchers in Chapter 5.

THIS PAGE INTENTIONALLY LEFT BLANK

CHAPTER 2: Background

Navy flight mishaps occur every year. The Naval Safety Center publishes an annual report on safety and mishap matters with their classification and total mishap numbers by aircraft type. However, these reports and numbers are ostensibly missing any insights or analysis of the mishaps. Reporting pure numbers of what mishaps occur and how the mishaps happen is important. However, it is also important to deep dive into finding out the roots causes of problems or verify the information was provided and determine if the known mishap causes are related or not relevant.

2.1 Flight Mishaps

Before getting into a detailed analysis of Navy flight mishaps, we need to have a common shared knowledge about mishaps to understand the rest of the thesis. Thus, we begin by defining the flight mishaps, explaining the common causes of the mishaps, and conclude by providing the purpose of the mishap investigation, and the main classes of mishaps.

2.1.1 Definition of Flight Mishaps

Both the DOD and Department of Navy (DON) “define a mishap as, an unplanned event or series of events that results in damage to DOD property; occupational illness to DOD personnel; injury to on- or off-duty DOD military personnel; injury to on-duty DOD civilian personnel; or damage to public or private property, or injury or illness to non-DOD personnel caused by DOD activities” (Department of the Navy 2022, p. 5).

2.1.2 Causes of Flight Mishaps

There are many different causes of flight mishaps, but when it comes to the dominant cause, most experts in the field of the Navy and Marine Corps safety will readily agree that human factors are the dominant cause. The Navy and Marine Corps Safety Investigation and Reporting Guide states that mishaps occur due to “a series of events deriving from multiple latent failures and/or hazardous conditions that provide the opportunities for an

active failure to occur resulting in either a near-miss or a mishap” (Department of the Navy 2022, p. 5). According to the guide, however, “the human factor is the greatest influence to contributing to root causes” (Department of the Navy 2022, p6). The human factor is not only the greatest player in terms of the flight mishaps, but it is also the factor that is hardest to mitigate over time. As described in the guide, “while mishaps involving mechanical factors have been greatly reduced over the years those attributable to human error continue to plague the DoD” (Department of the Navy 2022, p. 6).

Human Factor

According to the DOD, the human factor is the biggest contributor to mishaps. Human factors possibly contain many categories and sometimes it is a broad term because “every hand that operates or fix military equipment, or is involved in the writing of policies, Standard Operating Procedure (SOP), risk assessments, or operational plans has an opportunity to introduce human error which can easily result in a cascading effect of errors, omissions, or deviations from standard that influence the occurrence of a near-miss or mishap” (Department of the Navy 2022, p. 6). Just like the Safety Investigation and Reporting Guide’s statements above, the human factors can be ambiguous, opaque, and not clear, meaning simply identifying the human factor alone as the biggest threat to the Navy mishap may not be very helpful to the overall prevention of flight mishaps. Because of the vagueness of the human factor, Dr. Wiegmann and Dr. Shappell used James Reason’s conceptualized version of human error factor known as “Swiss Cheese” model to better explain the human factor (Wiegmann and Shappell 2003, p. 47).

“Swiss Cheese” Model

The Swiss Cheese Model can eliminate some of the ambiguity regarding human factors. According to *A Human Error Approach to Aviation Accidents Analysis: The Human Factors*, Wiegmann, and Shappell state that the Swiss Cheese model has four layers or four different human errors, Unsafe Acts, Preconditions for Unsafe Acts, Unsafe Supervision, and Organizational Influences. (Wiegmann and Shappell 2003) The unsafe acts are the only active failures, which mean that these mishaps are due to a direct human error. The other three conditions, Preconditions for Unsafe Acts, Unsafe Supervision, and Organizational Influences, are categorized as latent failures, which mean that all three conditions are influ-

encing and potentially leading to mishaps and could “directly affect operator performance” (Wiegmann and Shappell 2003, p. 48).

Either an active or latent failure leads to the mishap. Figure 2.1 depicts a version of the Swiss Cheese model that the Navy and Marine Corps Safety Investigation and Reporting guide uses to describe the concept of the model. The Department of the Navy (2022) safety guide describes the model as follows. In order for an accident to happen, the following occur:

- a problem starts from any of the four layers and it could start from the top, Organizational Influences, or it could start from the bottom, Unsafe Acts;
- a problem needs to go through the "holes";
- if the problem goes through only one hole, then the issue is from an unsafe act from a person or people who are directly involved with the accident; and
- if the problem goes through the entire four cheese holes, then the issue comes from organizational influence, meaning there are some organizational system flaws that led to the accident.

The Navy and Marine Corps *Safety Investigation and Reporting Guide* describes how “each slice of cheese is an opportunity to stop an error” (Department of the Navy 2022). At this point, we have narrowed the causes of mishap to human factors, and the Swiss cheese model. Regardless of the causes of the mishap, the mishap negatively affects to the unit.

Overall, mishaps degrade every aspect of a unit’s readiness. The Navy and Marine Corps Safety Investigation and Reporting Guide clearly states that “all mishaps, regardless of cause, degrade combat power or mission effectiveness” (Department of the Navy 2022, p. 7). Because mishaps diminish the mission effectiveness and readiness our forces, we need to know why mishaps happen and come up with solutions to prevent them. In order to do that, we need to collect and analyze the relevant data from mishap investigations.

2.1.3 Purpose of the Mishap Investigation

The current operating procedure of the Navy when it deals with mishaps is to conduct a mishap investigation. The purpose of the mishap investigation is “to discover the multiple hazardous conditions and failures that collectively allow mishaps to occur” (Department of

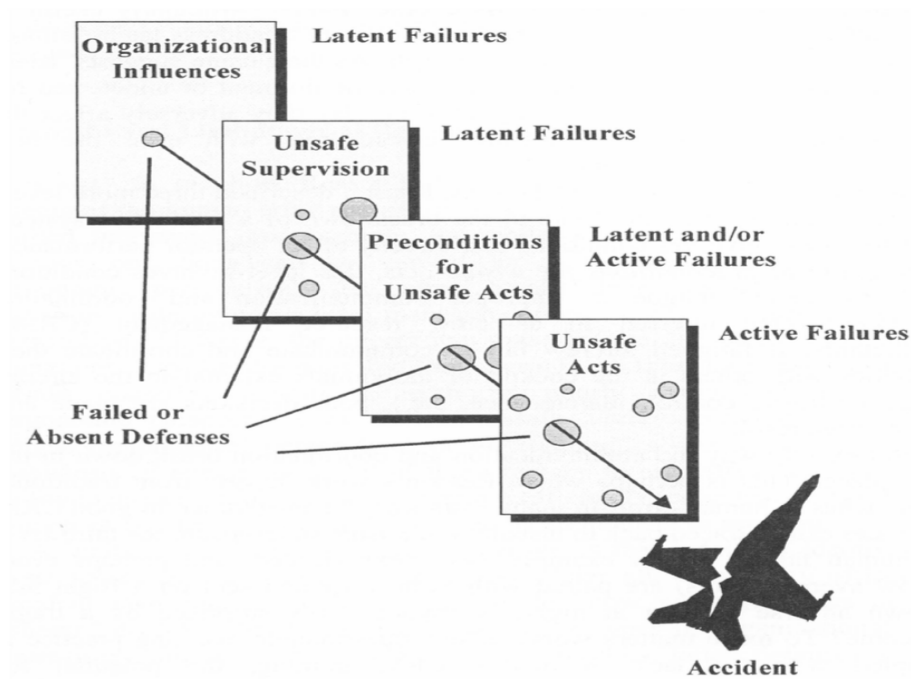


Figure 2.1: The “Swiss cheese” model of accident “causation.”
 Source: Wiegmann and Shappell (2003)

the Navy 2022, p8). In other words, the Navy conducts the investigation to identify causal factors that contribute to the mishaps, to prevent future mishaps, and to maintain accurate record-keeping for monitoring and analyzing past mishaps.

2.1.4 Mishap Classification

One section from the mishap investigation report classifies which categories the mishaps are in. The Naval Safety Command has the most current Mishap classification definitions. There are total of five classes, A, B, C, D, and E. (Naval Safety Command 2019). The class can be measured by the total property damage cost and/or fatality or injuries associated with the mishap as depicted in Table 2.1 (Naval Safety Command 2019).

Table 2.1 shows the current mishap class definition that is broken down into three parts, first column shows the classes of the mishaps, second column describes the dollar amount threshold that categorizes mishap classes, and third column talks about the seriousness of fatalities or injuries of the mishaps.

According to the Naval Safety Command, the mishap reporting cost threshold changes were effective 01 Oct 2019 meaning the fatal/injury section stayed the same but the dollar amounts has changed (Naval Safety Command 2019).

The mishap classification is our response variables that we will analyze later on with other variables in chapter 3. One of our research goals is to find any correlations between these features and the response variables.

2.2 Literature Review

In this section, we review the literature and demonstrate how previous studies may have missed important features related to flight mishaps or the cause of the mishaps. There have not been many studies about finding a correlation between mishap classification and mishap investigation reports' input variable that can lead to find true causes of the flight mishap. However, there are some studies that discuss the causation of flight mishaps, and most of them indicate that the human factor is the greatest influence when it comes to the causes of

Table 2.1: Mishap Classification.
Source: Naval Safety Command (2019)

| Mishap Class | Total Property Damage | Fatality/Injury |
|--------------|-----------------------------------------------|-------------------------------------------------------------------------------------------|
| A | \$2,500,000 or more and/or aircraft destroyed | Fatality or permanent total disability |
| B | \$600,000 or more but less than \$2,500,000 | Permanent partial disability or three or more persons hospitalized as inpatients |
| C | \$60,000 or more but less than \$600,000 | Nonfatal injury resulting in loss of time from work beyond day/shift when injury occurred |
| D | \$25,000 or more but less than \$60,000 | Recordable injury or illness* not otherwise classified as a Class A, B, or C |
| E | \$1 or more but less than \$24,999 | Injury or damage not otherwise classified as a Class A, B, C, or D |

the flight mishaps.

2.2.1 Human Factor Mishap Cause

Human factors are definitely one of the important features when we study about the causes of flight mishaps. The current body of literature focused on flight mishaps emphasizes that the human factors are the leading cause of the flight mishap. Naval Safety Center (NAVSAFECEN) states that “human factors remain the most significant contributor to mishap rates across all platforms and communities, with complacency and policy non-compliance rating highest among causal factors” (Naval Safety Center 2021, p8). In the Navy and Marine Corps Safety Investigation and Reporting Guide, it claims that “the human factor is the greatest influence to contributing and root causes” (Department of the Navy 2022, p6). The guide also states that “85% of all mishaps are caused by human error” (Department of the Navy 2022, p6). According to an article, “Human Factors Beyond the Flight Stations” by Lt. Nick Morris, “more than 80% of mishaps are attributable to some sort of human error” (Morris and Patrol & Reconnaissance Squadron VP-10 2022). The human factor error’s contribution to the flight mishap is so great that the DOD even made a DoD Human Factors Analysis and Classification System (HFACS) to monitor any human factor related errors (Miranda 2018). Many studies suggest that human factors are the greatest causes of the flight mishaps, but it is doubtful that the human factor is the only important cause that we need to focus on.

2.2.2 Other Flight Mishap Cause

Besides human factors, Controlled flight into terrain (CFIT) is another cause of the flight mishap when it comes to the fatality and airframe losses. As previously mentioned, there are not many studies about finding causes of the flight mishaps other than those that focus on the human factor. According to Major Moroze’s, and Dr. Snow’s paper *Causes and Remedies of Controlled Flight into Terrain in Military and Civil Aviation*, “CFIT accidents continue to be a primary cause of fatalities and airframe losses in aviation” (Moroze and Snow 1991). The CFIT led “almost \$2 Billion, 200 fatalities, and 100 aircraft lost over the 10 years alone” (Moroze and Snow 1991). This research primarily focused on the Air Force mishap from 1987 to 1996. Both these CFIT study and the human factor studies demonstrate that

the scope of studies on the correlation or causation of the flight mishap is narrow, which demonstrates a gap in the literature on the flight mishap research.

2.2.3 Potential Gaps in the Flight Mishap Studies

This tendency of being focused only on the human factor and maybe one other factor may lead us to exclude any other potential features that are as important as the human factor or more important. The tendency can create gaps about the flight mishap causes, and as result it is possible that previous studies may have overlooked any important features that contributed to the flight mishap or cause of the mishaps.

This research helps both verifying the human factors correlations to the flight mishap or finding other important features that related to the flight mishap.

THIS PAGE INTENTIONALLY LEFT BLANK

CHAPTER 3: Methodology

3.1 Data Collection and Processing

In this section, we explain the obtained data in detail, including its source, limitations, size, content, definition, etc. Once we have clear understanding of the data, we explain how we processed the data to be suitable for our analysis methods.

3.1.1 Data Collection

We obtained the data from Naval Safety Command, which contains information on 10 years' worth of flight mishap reports. This data does not contain any time stamps, which means that we are not able to conduct any time series analysis. Due to the sensitivity of the information, which may correspond to certain people who are involved with the mishaps, the date-time group information is excluded. The data was originally formatted in Excel spreadsheets with many tabs. Among many tabs, there is one main tab that we used in our research. The older version of flight mishap investigation called Web-enabled Aviation Mishap and Hazard Reporting System (WAMHRS). The WAMHRS contains 754 observations with 36 variables. Some of the key highlights of the variables are the classes of mishaps; A, B, or C, aircraft models, the mishap events short narratives, the events characterization, sky conditions, wind gust, temperature, etc.

Key Variables

Table 3.1 shows variable names, their terms, and their definition for the WAMHRS report. When the Navy generates the mishap reports through WAMHRS, an investigating officer collects as much information about each variable as possible to complete the report.

Table 3.1. WAMHRS Variables

| Variables | Plain English | Explanation |
|-----------|---------------|-------------|
|-----------|---------------|-------------|

| | | |
|------------------|-------------------------------------|---------------------------------------------------------------|
| EVENT SEVTY C | Sensitivity Code | Mishap Class A, B, or C |
| EVENT CATG C | Category Codes | Codes for Event Category |
| EVENT CATG | Category | Whether Aircraft Flight or Aircraft Flight-Related Incident |
| EVENT CHARZN C | Characterization Codes | Codes for Mishap Types |
| EVENT CHARZN | Characterization | Mishap Types |
| EVENT SHORT NARR | Short Narrative | Narrative of the mishap incidents |
| ACFT MODEL | Aircraft Model | Types of aircraft that are involved with mishap |
| ICING I | Icing Indicated | Was icing present? |
| SITE ELEV MSL | Site Elevation Mean Sea Level (MSL) | Elevation of mishap location in terms of MSL |
| ALTM SETG HG | Altimeter Setting | Altimeter Setting in terms of millimeters of mercury |
| BRIEFG TYPE | Weather Briefing Type | Type of weather briefing received (in-person; automated, etc) |
| BRIEFG UTLZN | Briefing Utilization | Was the briefing used? |
| CEILG AGL | Cloud ceiling in AGL | Cloud ceiling in feet Above Ground Level (AGL) |
| CEILG I | Ceiling Indicated | Ceiling Indicated? |
| DEWPT TEMP F | Dewpoint temperature (F °) | Self-explanatory |
| AIR TEMP F | Outside Air Temperature (F °) | Self-explanatory |
| HORIZON C | Horizon Category | Horizon Category |
| HORIZON | Horizon Visibility | Horizon visible or not |
| REL HMDY PCT | Relative percent humidity | Self-explanatory |

| | | |
|-------------------|------------------------------------|---------------------------------------------------------------------|
| SKY CNDN RMKS | Sky Condition Remarks | Remarks on the sky condition |
| WTR TEMP F | Water Temperature (F °) | Self-explanatory |
| WIND DIRN DEG | Wind Direction in degrees magnetic | Self-explanatory |
| WIND GUST VEL KTS | Wind Gust Velocity in Knots | Self-explanatory |
| WIND VEL KTS | Wind Velocity in Knots | Self-explanatory |
| BRIEFG ACCY C | Briefing Accuracy Category | Self-explanatory |
| WX RELATED C | Weather Related Category | Category indicating whether the weather was a factor |
| WX RELATED | Weather Related | Was the mishap due to weather |
| ICING CMTS | Icing Comments | |
| VSBLY TOWER | Visibility Tower | Visibility at the tower of the airfield (in statute miles) |
| VSBLY SM | Visibility | Visibility reported as part of the weather brief (in statute miles) |

Table 3.2 explains mishap types and their definitions.

Table 3.2. Naval Aviation Mishap Types
Source: Department of Navy (2014).

| Variables | Definition |
|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| Abrupt Maneuver | Damage or injury caused by intentional abrupt maneuvering. |
| Airfield Operations | Mishaps occurring during takeoff, landing or other powered movement on prepared airfield surfaces, austere fields and helicopter landing zones. |

| | |
|------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Cabin and Cargo | Miscellaneous occurrences in either the flight deck, passenger cabin or cargo compartment. Flight, flight related, ground ops. |
| Controlled flight into terrain | Collision with terrain, water, trees or a manmade obstacle during flight prior to planned touchdown. |
| Environment and Weather | Mishaps resulting from encounters with weather or man-made environmental phenomena. |
| External Operations | Mishaps related to personnel or equipment physically attached but external to the aircraft. |
| Fire or Explosion | Mishaps initiated by an external source of fire or explosion. |
| Foreign Object Damage (FOD) | Damage due to foreign objects or debris from another failed aircraft or UAV component. |
| Fuel-Related (FUEL) | One or more power plants experienced reduced or no power output due to a fuel anomaly. |
| Ground Handling and Servicing Operations | Mishaps resulting from improper ground handling or servicing, or as the result of the failure of ground handling or servicing equipment. |
| Insufficient Power (IPOWER) | Mishaps resulting in ground or water impact when power required exceeds power available. Flight, UAV. |
| Midair Collision (MIDAIR) | Collision between aircraft or UAV when intent for flight exists. |
| Physiological | Injury, illness or abnormal symptoms experienced by aircrew or others as a result of the dynamic flight environment. Flight, flight related. |
| Pilot Loss of Control In-Flight (PLOCI) | Aircrew failure to maintain control of the aircraft or UAV while in flight. |

| | |
|----------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Power Plant Failure or Malfunction (POWER) | Failure or malfunction of a thrust-producing system or related components. |
| Ship-Related (SHIP) | Mishaps resulting from ship-board flight or ground operations or the failure of unique ship-board equipment for launching, maintaining or recovering aircraft or UAVs. flight, flight related, ground ops, UAV |
| System Failure or Malfunction (non-power plant) (SYSTEM) | Failure or malfunction of a system or component - other than the power plant. |
| Whiteout or Brownout (WOBO) | Mishaps resulting from encounters with WOBO conditions during takeoff or landing. |
| Wildlife Strike (BASH) | Damage due to collisions with wildlife or resulting from wildlife activity. |
| Out of Control Flight (OOCF) | Out of Control Flight with unintended deviation from controlled flight |
| Other (OTHER) | Any occurrence not covered under another category. |

3.1.2 Data Processing

We obtained the Navy flight mishap data and analyzed the data to identify which variables are important for predicting the flight mishap class.

In order to feed our data into our model, we had to reduce the categorical variables' levels because the Random Forests model, which we will discuss later in this chapter, has a bias toward categorical variables that have many levels. It generally considers the categorical variables with many levels to be more important variables, although they may not be. We also omitted variables that have many blanks or Not Applicables (NAs).

One of categorical variables that we worked on was the mishap type variable. Originally, it

had 27 levels. In order for us to accurately reduce the categories, we read every single line of the mishap narrative description to reassign its level. We received help from a subject matter expert who has worked in the aviation field more than 15 years for the verification purpose. After thoroughly reading 754 lines of the mishap narratives, we were able to reduce the number from 27 to 14 levels. The 14 levels are as follow:

- Foreign Object Damage
- Wildlife Strike
- Environment/Weather
- Fire/Explosion
- Midair Collision
- Controlled Flight Into Terrain
- HUMAN FACTOR
- Loss of Control
- System Failure or Malfunction (Non-Powerplant)
- Ship-Related/Embarked Landing
- Power Failure
- Things Falling Off Aircraft
- OTHER
- External Operations

The items that did not survive our filters were as follow:

- Undetermined
- OOCF
- General Hazard
- Airfield Operations
- Catastrophic Failure
- Physiological (PHYSEP)
- Abrupt Maneuver
- CFIT
- Insufficient Power
- Fuel
- Ground Handling & Servicing Operations
- Whiteout/Brownout
- Cabin/Cargo
- Blank

The other categorical variable that we focused on was the aircraft type. Originally, the variable had 55 different aircraft models. For this reducing process, we also had great amount of help from the subject matter expert for this work as well. When we reduced and combined the aircraft models, we considered the similarity of type, mission, purpose, size, and capacity of the aircrafts. For example, the left side of the bulleted list are the original aircraft model categories and the right side of the bulleted list shows how we re-categorized the original models.

- NU001B, T044C → AUX PROPELLER AIRCRAFT → MISC JET AIRCRAFT
- C002A → C002A
- C026, C026D → C026
- C026D, E002C, E002C+, E002D → E002
- E006B → E006B
- EA006B → EA006B
- EA018G, F018G → EA018G
- F005F, F005N, T038C → F005I
- F018A, F018A+, F018C → F018A/C
- F018D, F018F → F018D/F
- F018E → F018E
- F035C → F035C
- MH053E → MH053E
- MH060R, MH060S, SH060F → MH060
- AV008B, F016A, F016B, S003B → P003C, EP003E → P003
- P008A → P008A
- T006A, T006B, T034C → PRIMARY TRNG AIRCRAFT
- SH060B → SH060B
- C020D, C037B, C040A, C130F, C130T, KC010A, KC130T, KC135R → SUPPORT AIRCRAFT CARRY
- T039G, T039N → T039
- T045C → T045C
- TH073A → TH073A
- TH057B, TH057C → TRNG HELICOPTER;
- MQ008B, MQ008C, RQ021, UC012F, UC012M → UNMANNED
- HH060H, MV022B, UH001Y, UH060L, UH072A → UTILITY HELICOPTER

We were not able to reduce the levels of both the sky condition remarks, and the event short narrative variables. Their nature and uniqueness of the levels were so varied that we decided to remove them entirely from the data.

The other step that we conducted to clean up the data was removing unnecessary variables that had too many blanks or are indicated as NAs. This step was necessary in order to avoid any less meaningful data blending into our research. The following bullets points are the list of variables with their NAs count.

- SITE ELEV MSL SITE ELEV MSL: 433 NAs
- ALTM SETG HG: 330 NAs
- BRIEFG TYPE C: 75 NAs
- BRIEFG UTLZN C: 136 NAs
- CEILG AGL 599: NAs
- DEWPT TEMP F: 429 NAs
- AIR TEMP F: 306 NAs
- REL HMDY PCT: 566 NAs
- WTR TEMP F: 559 NAs
- WIND DIRN DEG: 362 NAs
- WIND GUST VEL: KTS 541 NAs

- WIND VEL KTS: 376 NAs
- BRIEFG ACCY C: 140 NAs
- WX RELATED C: 87 NAs
- VSBLY TOWER: 565 NAs
- VSBLY SM: 298 NAs

3.2 Exploratory Data Analysis

In this section, we present what we know about the data before going into further analysis. This EDA offers brief snapshots of the data that allow us to understand more about the data in detail.

3.2.1 Mishap Types by Classes

Mishap Type by All Classes

In this section, we tally up the numbers of events by mishap types and by the classes. Figure 3.1 shows aggregate mishap counts by mishap type. As depicted in the bar chart, System Failure or Malfunction (Non-Powerplant) has the highest number of events - 164 mishaps. Wildlife Strike has 117 mishaps. Foreign Object Damage has 84 mishaps. Human Factor has 74 mishaps. Environment/Weather has 65 mishaps. Things Falling Off Aircraft (TFOA) has 62 mishaps. Power Failure has 47 mishaps. CFIT has 30 mishaps. Fire/Explosion has 26 mishaps. Other has 22 mishaps. Midair Collision has 19 mishaps. Ship-Related/Embarked Landing has 18 mishaps. Loss of Control has 16 mishaps. External Operations has 10 mishaps.

Mishap Type by Class A

Figure 3.2 shows counts of Class A Mishap by mishap type. As depicted in the bar chart, CFIT, Loss of Control, Power Failure, and System Failure or Malfunction (Non-Powerplant) occurred most frequently, with 10 mishaps. Fire/Explosion and Human Factor have 7 mishaps. Foreign Object Damage has 6 mishaps. TFOA has 5 mishaps. Environment/Weather, Midair Collision, Other, and Wildlife Strike have 3 mishaps. Ship-Related/Embarked Landing has 2 mishaps. External Operations has 1 mishap.

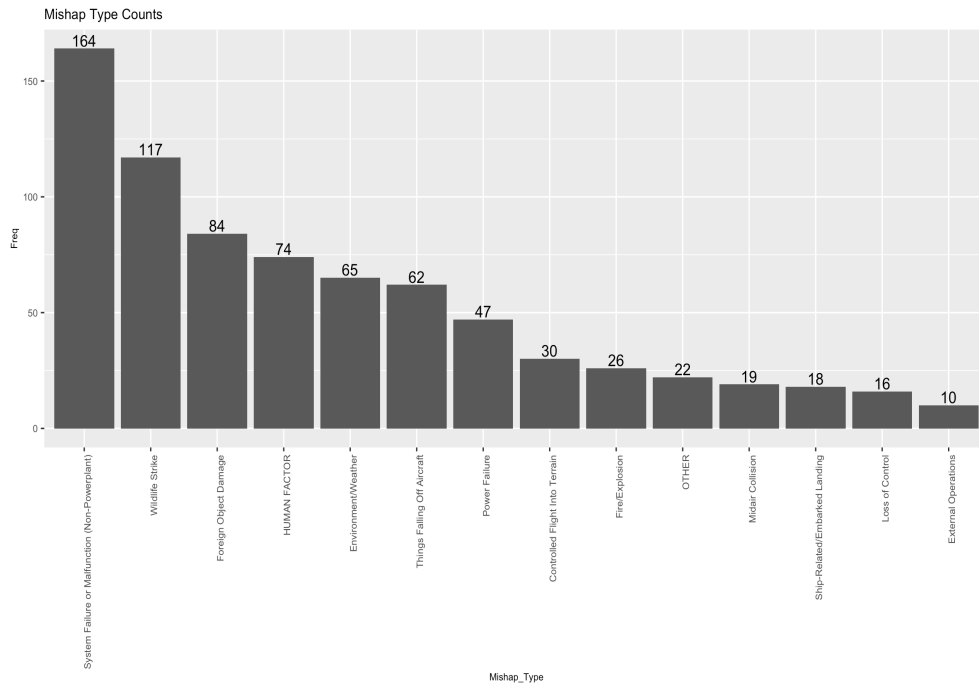


Figure 3.1: Aggregate Mishap Counts by Mishap Type

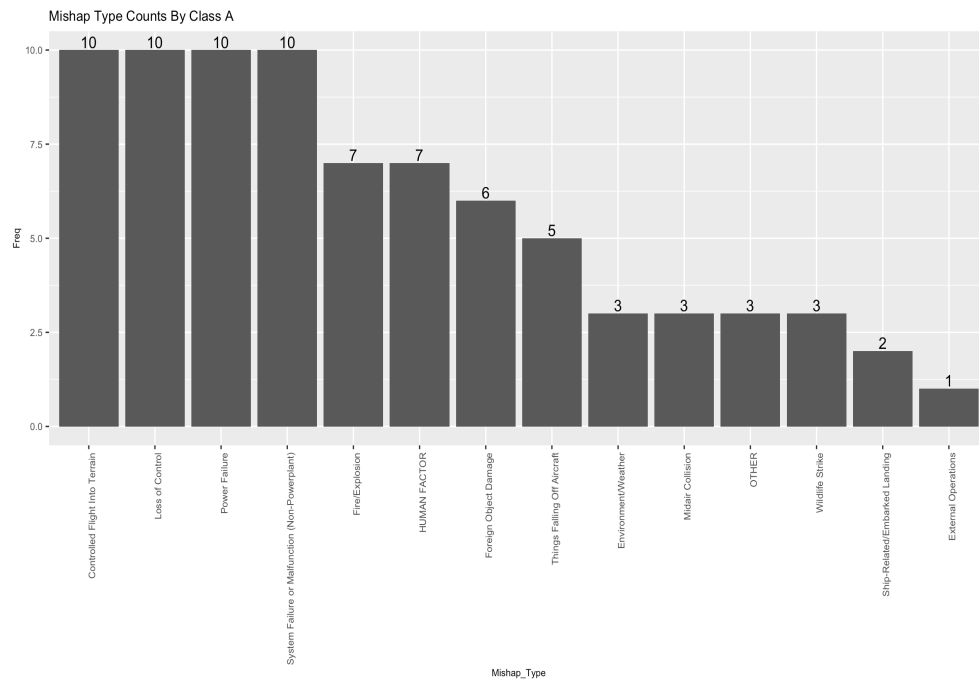


Figure 3.2: Class A Mishap counts by Mishap Type

Mishap Type by Class B

Figure 3.3 shows counts of Class B mishap by mishap type. As depicted in the bar chart, Foreign Object Damage is the highest number event as 18 mishaps. System Failure or Malfunction (Non-Powerplant) has 18 mishaps. Wildlife Strike has 17 mishaps. Power Failure has 9 mishaps. Environment/Weather, and TFOA have 8 mishaps. Fire/Explosion has 7 mishaps. Ship-Related/Embarked Landing has 6 mishaps. CFIT and Midair Collision have 4 mishaps. Human Factor has 2 mishaps. External Operations, Loss of Control, and Other have 1 mishap.

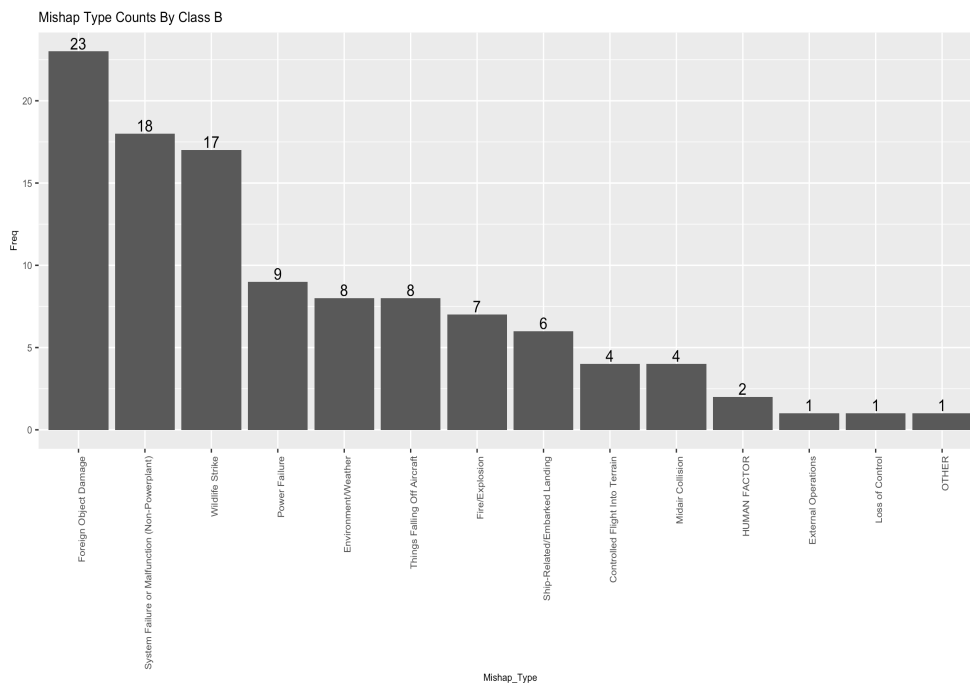


Figure 3.3: Class B Mishap counts by Mishap Type

Mishap Type by Class C

Figure 3.4 shows counts of Class C mishap by mishap type. As depicted in the bar chart, System Failure or Malfunction (Non-Powerplant is the highest number event as 136 mishaps. Wildlife Strike has 97 mishaps. Human Factor has 65 mishaps. Foreign Object Damage has 55 mishaps. Environment/Weather has 54 mishaps. TFOA has 49 mishaps. Power Failure has 28. Other has 18 mishaps. CFIT has 16 mishaps. Fire/Explosion has 12 mishaps.

Midair Collision has 12 mishaps. Ship-Related/Embarked Landing has 10 mishaps. External Operations has 8 mishaps. Loss of Control has 5 mishaps.

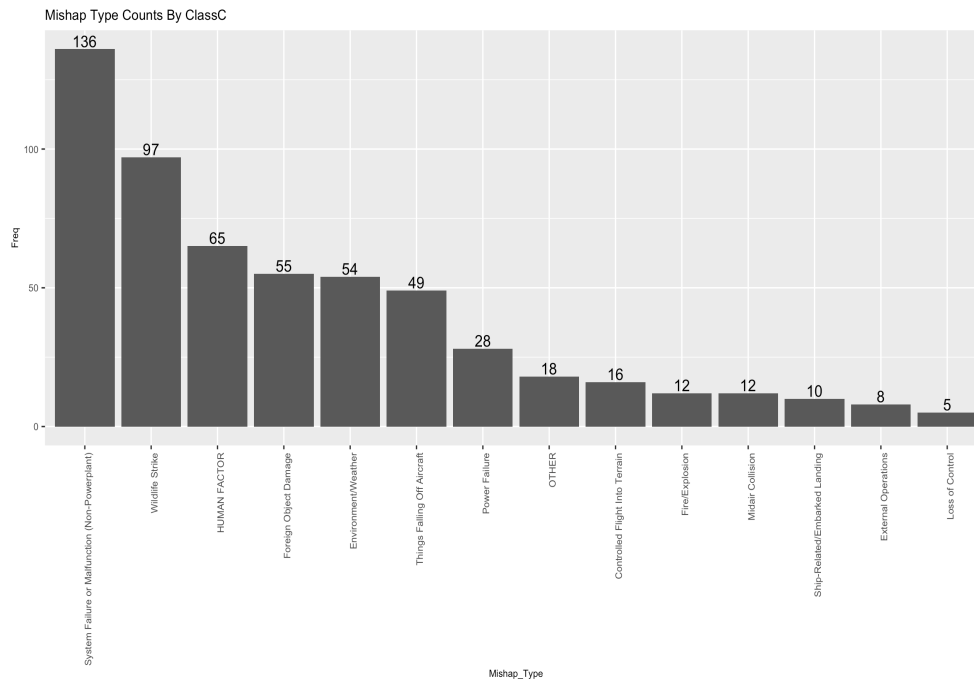


Figure 3.4: Class C Mishap counts by Mishap Type

Based on the aggregated counts for mishap by mishap type, we found out that there are many other flight mishap factors that contribute to the overall mishaps than human factors as the literature and the other studies emphasized.

3.2.2 By Aircraft with mishap types

Figure 3.5 shows number of mishaps per mishap types by aircraft models in the data.

| | Controlled Flight | Environment/Weather | Fire/Explosion | Foreign Object Damage | Midair Collision | Wildlife Strike | HUMAN FACTOR |
|-----------------------------|-------------------|---------------------|----------------|-----------------------|------------------|-----------------|--------------|
| F018E_type | 2 | 22 | 9 | 20 | 7 | 1 | 9 |
| MH060R_type | 14 | 6 | 1 | 4 | 1 | 1 | 14 |
| F018D_F_type | 3 | 9 | 5 | 26 | 1 | 5 | 15 |
| F018A_C_type | 1 | 5 | 3 | 10 | 6 | 9 | 6 |
| EA018G_type | 0 | 0 | 0 | 1 | 0 | 49 | 2 |
| T045C_type | 3 | 0 | 2 | 3 | 0 | 7 | 3 |
| P008A_type | 0 | 4 | 0 | 2 | 0 | 6 | 1 |
| E002_type | 0 | 3 | 2 | 0 | 0 | 8 | 0 |
| PRIMARY_TRNG_AIRCRAFT_type | 0 | 1 | 0 | 5 | 0 | 0 | 5 |
| TRNG_HELICOPTER_type | 2 | 0 | 0 | 0 | 1 | 1 | 7 |
| MH053E_type | 1 | 1 | 0 | 3 | 0 | 0 | 1 |
| P003_type | 1 | 3 | 0 | 1 | 2 | 1 | 2 |
| E006B_type | 0 | 0 | 0 | 0 | 0 | 15 | 0 |
| UNMANNED_type | 0 | 4 | 0 | 0 | 0 | 0 | 2 |
| UTILITY_HELICOPTER_type | 2 | 3 | 0 | 1 | 0 | 0 | 2 |
| AUX_PROPELLOR_AIRCRAFT_type | 1 | 2 | 2 | 2 | 1 | 1 | 0 |
| F005_type | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| C026_type | 0 | 0 | 1 | 2 | 0 | 2 | 0 |
| EA006B_type | 0 | 0 | 0 | 0 | 0 | 7 | 0 |
| F035C_type | 0 | 0 | 0 | 2 | 0 | 2 | 0 |
| SUPPORT_AIRCRAFT_CARRY_type | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| MISC_JET_AIRCRAFT_type | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| C002A_type | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| SH060B_type | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| T039_type | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| TH073A_type | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | 30 | 65 | 26 | 84 | 19 | 117 | 74 |

| | Loss of Control | System Failure or | Power Failure | Ship-Related/Emb | Things Falling Off A | OTHER | External Operations |
|-----------------------------|-----------------|-------------------|---------------|------------------|----------------------|-------|---------------------|
| F018E_type | 2 | 33 | 12 | 5 | 10 | 3 | 1 |
| MH060R_type | 2 | 41 | 14 | 5 | 12 | 4 | 6 |
| F018D_F_type | 3 | 20 | 4 | 2 | 9 | 3 | 1 |
| F018A_C_type | 0 | 25 | 2 | 4 | 8 | 2 | 0 |
| EA018G_type | 0 | 5 | 0 | 0 | 1 | 0 | 0 |
| T045C_type | 5 | 7 | 4 | 0 | 1 | 5 | 0 |
| P008A_type | 0 | 5 | 2 | 0 | 0 | 2 | 0 |
| E002_type | 0 | 3 | 2 | 1 | 2 | 0 | 0 |
| PRIMARY_TRNG_AIRCRAFT_type | 0 | 2 | 1 | 0 | 5 | 0 | 0 |
| TRNG_HELICOPTER_type | 1 | 3 | 1 | 0 | 3 | 0 | 0 |
| MH053E_type | 0 | 4 | 3 | 0 | 1 | 2 | 0 |
| P003_type | 1 | 4 | 0 | 0 | 1 | 0 | 0 |
| E006B_type | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| UNMANNED_type | 0 | 2 | 1 | 0 | 2 | 0 | 0 |
| UTILITY_HELICOPTER_type | 0 | 1 | 0 | 0 | 2 | 0 | 0 |
| AUX_PROPELLOR_AIRCRAFT_type | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F005_type | 0 | 2 | 1 | 1 | 1 | 0 | 0 |
| C026_type | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| EA006B_type | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F035C_type | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| SUPPORT_AIRCRAFT_CARRY_type | 0 | 2 | 0 | 0 | 2 | 0 | 0 |
| MISC_JET_AIRCRAFT_type | 0 | 0 | 0 | 0 | 1 | 0 | 2 |
| C002A_type | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| SH060B_type | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| T039_type | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| TH073A_type | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 3.5: Mishap Type by Aircraft

3.3 Analysis Method

In this section, we explain the analysis methods that we use to analyze the flight mishap data. We used the Random Forests method and MLR technique, which are supervised learning methods.

In *Machine Learning* Huddleston and Brown state that “The goal in supervised learning is

to use available observations to predict a response variable associated with new observation (where the response will not be known beforehand)” (Huddleston and Brown 2018, p2). The response variable is the dependent variable, meaning it depends on the other variables when it comes to predicting the response variable. On the other hand, independent variables, which are also called predictors or features, are the ones that are being used to predict the response variable. Thus, in our study, mishap class of A, B, and C is our response variable and the rest of the variables are the independent variables.

3.3.1 Random Forests

Random Forests are an aggregate of many randomly generated decision trees that are used together to make predictions. According to G. James et al.’ *An Introduction to Statistical Learning*, making Random Forests is like “building these decision trees, each time a split in a tree is considered, a random sample of m predictors is chosen as split candidates from the full set of p predictors” (James et al. 2013, p319). As noted in the book, “a fresh sample of m predictors is taken at each split, and typically we choose $m \approx \sqrt{p}$ ” (James et al. 2013, p319). m is the number of selected explanatory variables that would be used to build the Random Forests each iteration. p is the total number of explanatory variables in our data. We choose the sample predictors in this way to have the lowest variance, meaning lowest error rate, and to avoid any bias that Random Forests may have towards the greater influenced variables.

Gini Index

We used the Gini index to measure variable importance. The Gini index is defined as

$$1 - \sum_{i=1}^C p_i^2,$$

where p_i is the frequency of class in i in the set (Yoshida 2022). The Gini index measures the decision tree branches’ impurities. This means that when decision trees are branching out, each branch has its own impurity score. For example as in Figure 3.6, the left branch of mixture of 2 As, 2 Bs is more impure than right branch, which only contains 3 Bs. Then the Gini index for the left leaf is $1 - (2/4)^2 - (2/4)^2 = 0.5$ and the Gini index for the right leaf is $1 - (0/3)^2 - (3/3)^2 = 0$. The left side of the leaf’s Gini impurity score is 0.5 and the right side of the leaf’s Gini impurity score is 0. The variables that lead to lower Gini index

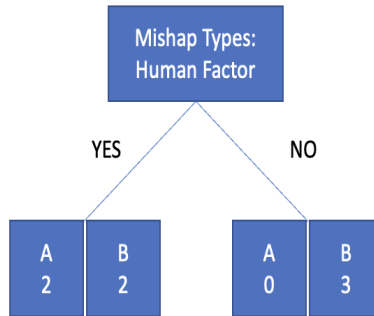


Figure 3.6: Gini Index Impurity Branch Example

In this picture, the Gini index for the left leaf is $1 - (2/4)^2 - (2/4)^2 = 0.5$ and the Gini index for the right leaf is $1 - (0/3)^2 - (3/3)^2 = 0$. The left side of the branch shows more impure representation, and right side of the branch shows less impure, meaning more pure and stronger Gini Index scores.

scores are stronger and more important when it comes to determining relevance with the response variable.

Confusion Matrix

We used the confusion matrix to measure the accuracy of the model’s predictions. The confusion matrix is a $c \times c$ matrix, where c is the number of classes in the response categorical variable, whose (i, j) th cell is the number of observations whose true response variable is i and predicted response variable is j under a given model. With the confusion matrix, we can estimate the accuracy rate of a given model, as well as true negative and positive rates of a given model. For more details, see James et al. (2013).

3.3.2 Multinomial Logistic Regression

The other methodology we used for the research was MLR because we wanted to compare with Random Forests in terms of predicting the mishap classes. Additionally, it was also good model to use in classification analysis while not losing its interpretability. In a *Multinomial logistic regression in workers’ health* article, Grilo defined MLR as “a predictive model once it is used to predict the probabilities of the different possible outcomes of a categorically distributed dependent variable, given a set of independent variables” (Grilo et al. 2017). In plain English, MLR is calculating probabilities of picking one response

variable relative to other response variables. For example, in the flight mishap case, we are calculating the log odds of selecting flight mishap class B over our base case flight mishap class A, and also the odds of selecting flight mishap class C over our base case flight mishap class A. The following equations represent the example case.

$$\log \left(\frac{P[Y_i = \text{ClassB}|x_{i1}, \dots, x_{ip}]}{P[Y_i = \text{ClassA}|x_{i1}, \dots, x_{ip}]} \right) = \beta_{10} + \beta_{11}x_{i1} + \dots + \beta_{1p}x_{ip},$$

and

$$\log \left(\frac{P[Y_i = \text{ClassC}|x_{i1}, \dots, x_{ip}]}{P[Y_i = \text{ClassA}|x_{i1}, \dots, x_{ip}]} \right) = \beta_{20} + \beta_{21}x_{i1} + \dots + \beta_{2p}x_{ip},$$

where β_{1j}, β_{2j} for $j = 1, \dots, p$ are parameters for this model, which we wish to estimate from the given data. Here, Y_i is the response variable for the i th observation, and x_{ij} is the j th predictor of the i th observation.

3.4 Summary

In summary, this chapter details the entire process of conducting our research from collecting and cleaning the data, exhibiting EDA, and explaining our main methods; the Random Forests and MLR. Most notably, we used the Random Forests to come up with a model that can predict the flight mishap classification as accurately as possible and we identified the important variables that highly relevant to the flight mishap response variable by using Gini index in the process of making the Random Forests. Also, we used MLR model to predict the flight mishap classification and find highly correlated variables to the flight mishaps.

THIS PAGE INTENTIONALLY LEFT BLANK

CHAPTER 4: Findings

In this chapter, we discuss key findings that we discover from our research. One of the findings is from EDA related to human factors that many studies emphasized on, and we also discuss about our findings from the Random Forests and MLR analysis of the flight mishaps.

4.1 Findings from EDA

After examining the aggregate tally of mishap counts by mishap types in Figure 3.1, there are factors that have higher contributions than the human factor in terms of the mishap counts. Unlike in the literature review, which states that the human factor is the leading cause of the flight mishaps, our data suggests that system failure, wild strike, and foreign object damage have higher contribution than the human factor. system failure takes 22%, wildlife strike is 16%, foreign object damage is 11%, and the human factor is 10% in the overall tally of the mishap counts.

Figure 3.2, Figure 3.3, and Figure 3.4 also suggest that the human factor is not the leading cause when it comes to mishap counts. At most, the human factor is in the top third place as shown in Figure 3.4. Thus, the 10-years' worth of flight mishap report data suggests that there are many other crucial mishap contributors other than the human factor in the aviation community.

4.2 Findings from Random Forests Analysis

Examination of the confusion matrix for Random Forests model reveals that the overall prediction accuracy was 77% with 95% confidence interval from 70% to 84%, meaning at any point if we were to run the model again, the prediction accuracy can fall between 70% to 84%. Figure 4.1 is the confusion matrix from the Random Forests models results. More importantly as in Figure 4.2, the top two most important variables based on the Gini index are Mishap Type and Aircraft Model. According to the Gini Index, these two variables are highly correlated with the flight mishaps.

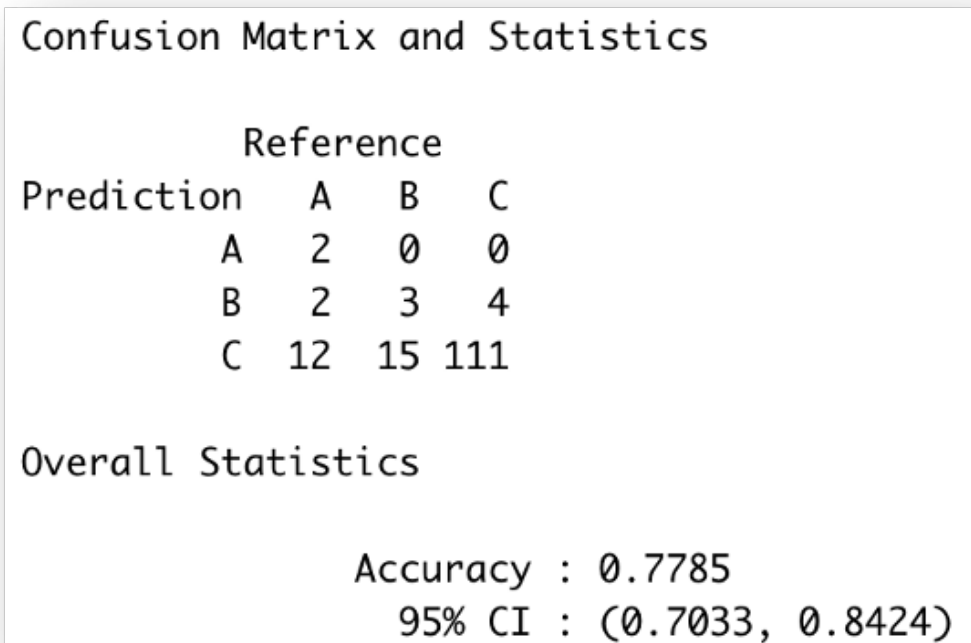


Figure 4.1: Confusion Matrix for Random Forests Model
 Confusion Matrix for Random Forests Model with Estimated Accuracy Rate with 95% Confidence Interval. An estimated accuracy rate based on a confusion matrix accuracy is closer to 78% with 95% confidence interval from 70% to 84%.

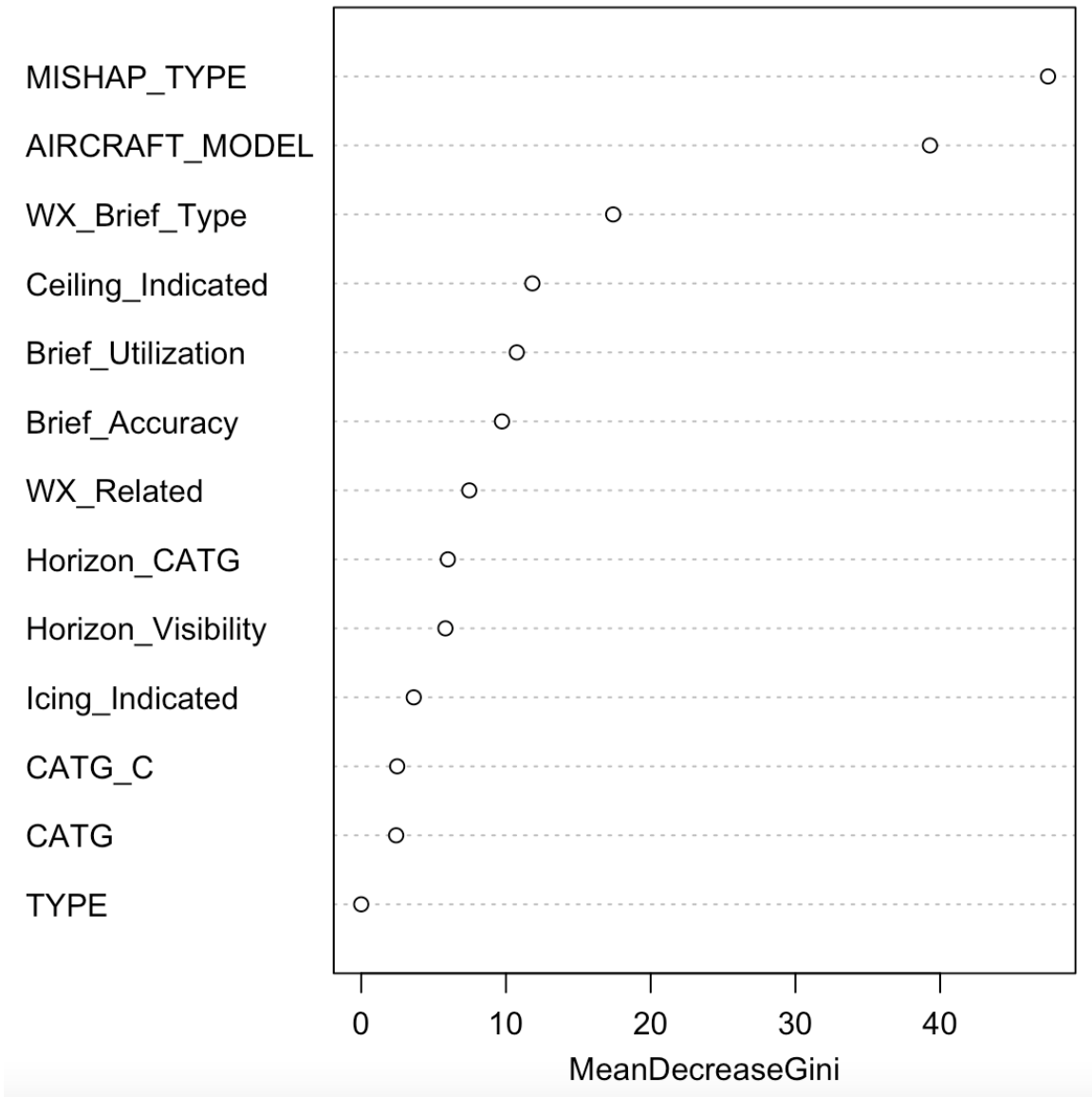


Figure 4.2: Gini Index
 Gini Index lists the features in descending order from the ones that are the most important at the top to the lower priority features at the bottom.

4.3 Findings from MLR Analysis

Examination of the MLR confusion matrix reveals that the overall prediction accuracy was 72% with 95% confidence interval from 64% to 79% as depicted in Figure 4.3. More

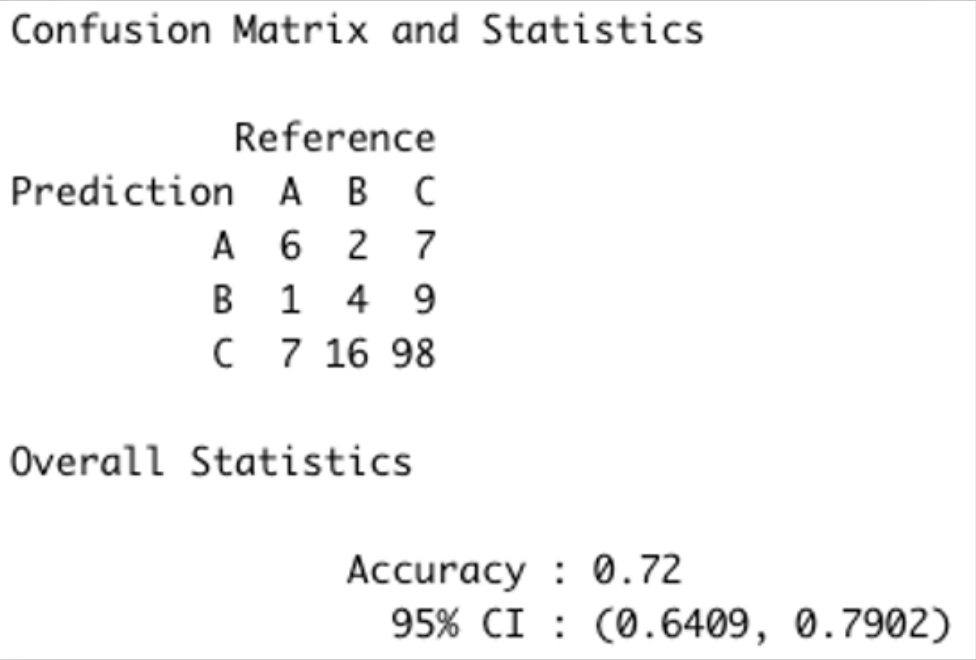


Figure 4.3: Confusion Matrix for MLR
 Confusion Matrix for MLR with Estimated Accuracy Rate with 95% Confidence Interval. An estimated accuracy rate based on a confusion matrix is 72% with 95% confidence Interval from 64% to 79%.

importantly, when it comes to finding out the probability of predicting mishap class B over mishap class A, the variables that have statistically significant influences are Aircraft Model and Mishap Type according to the p-value that is less than 1%. Also, when it comes to finding out the probability of predicting mishap class C over mishap class A, the variables that have statistically significant influences are also Aircraft Model and Mishap Type according to the p-value that is less than 1%. The result of the MLR analysis indicates that Mishap Types and Aircraft Model variables were two key players in the flight mishap class.

Findings from the analysis from Random Forests model and MLR analysis suggest the important variables that are highly correlated to flight mishaps are Mishap Type and Aircraft Model. Although the 95% confidence intervals of estimated accuracy rates were both pretty

similar from 14% to 15%, the Random Forests method did a slightly better job at predicting the flight mishap classes.

4.4 Overall Findings

Findings from the analysis from Random Forests model and MLR analysis suggest the important variables that are highly correlated to flight mishaps are Mishap Type and Aircraft Model. Although the 95% confidence intervals of estimated accuracy rates were both pretty similar from 14% to 15%, the Random Forests method did a slightly better job at predicting the flight mishap classes.

THIS PAGE INTENTIONALLY LEFT BLANK

CHAPTER 5: Conclusion

5.1 Answer to Research Question

This research sought to identify the important variables that are highly correlated to flight mishaps. After conducting two supervised learning techniques, Random Forests analysis and MLR analysis, we found out that the highly correlated variables are Mishap Type and Aircraft Model.

The results learned from our analysis emphasize the two important variables in finding the correlations between the variables and the flight mishap classes. Based on our findings, the following recommended future research will be a useful guide for future researchers to build upon our research.

5.2 Recommendations for Future Research

5.2.1 Causal Inference to Find Causes of the Flight Mishaps

Our study and research have focused on finding the correlations between the variables and the flight mishaps. Since we have the information about the correlations, future researchers can now deep dive into these two variables, Mishap Type and Aircraft Model, to find a root cause of the flight mishaps by conducting causal inference analysis using Bayesian networks.

5.2.2 Finding Variable Importance Analysis with All Mishap Classes

Although the current mishap class definition has five different mishap classes from A through E, the data limited us to conduct analysis on the mishap class A through C. Future researchers can conduct the same analysis using the Random Forests analysis and MLR analysis with all mishap classes including mishap class D, and mishap class E.

5.2.3 Obtaining Date-Time Group

If future researchers had the Date-Time information corresponded to each flight mishap observation, future researchers can conduct time-sensitive analysis and predicting the next flight mishaps. If the Navy Safety Command is reluctant to share the specific date-time, future researchers may simply ask for a day and/or night category to do further analysis on the flight mishaps. The day and night information should not be sensitive to anyone and the information may lead to find crucial information about the flight mishaps.

5.2.4 Conduct Analysis on Risk Mitigation Information and Compare with the Current Analysis

Our current research is solely focused on WAMHRS reports. There is data that is dedicated to the Risk Mitigation Information (RMI) reports. We recommend future researchers conduct the same analysis and find the important variables on the RMI and compare the results with WAMHRS to see if there are similarities or differences.

5.3 Conclusion

Through examination of our findings, it becomes clear that the Mishap Type and Aircraft Model variables matter the most to the flight mishaps. One may say these two variables are the biggest parts of the reports, and thus, the results are somewhat obvious in general. However, the mishap type and aircraft models are part of the report and although people assume they are important, our analysis verifies and confirms that the two variables are important when it comes to the flight mishaps. Our correlation analysis provides the first step towards finding out the root causes of the flight mishaps and offers insights for future researchers. Therefore, with these proved findings, the future researchers can use our findings to conduct a more extensive analysis of the other causes of flight mishaps.

List of References

- Department of Navy (2014) Naval Aviation Safety Management System. Accessed April 11, 2023, <https://www.secnav.navy.mil/doni/Directives/03000%20Naval%20Operations%20and%20Readiness/03-700%20Flight%20and%20Air%20Space%20Support%20Services/3750.6S.pdf>.
- Department of the Navy (2022) The Navy and Marine Corps Safety Investigation and Reporting Guide. Accessed March 1, 2023, https://navalsafetycommand.navy.mil/Portals/29/Documents/2022-Safety_Investigation_and_Reporting_Guide-221102.pdf?ver=7fPTIYpyneQozi4zO37cTw%3d%3d.
- Grilo LM, Grilo HL, Goncalves SP, Junca A (2017) Multinomial Logistic Regression in Workers' Health. *Defence & Peace Economics* <https://doi.org/10.1080/10242690701505419>.
- Huddleston SH, Brown GG (2018) *Machine Learning*, INFORMS Analytics Body of Knowledge (Wiley Online Library).
- James G, Witten D, Hastie T, Tibshirani R (2013) *An Introduction to Statistical Learning* (Springer).
- Miranda A (2018) Understanding Human Error in Naval Aviation Mishaps. *Human Factors* .
- Moroze ML, Snow MP (1991) Causes and Remedies of Controlled Flight into Terrain in Military and Civil Aviation, Air Force Research Laboratory. Accessed April 11, 2023, <https://apps.dtic.mil/sti/pdfs/ADA430280.pdf>.
- Morris NP, Patrol & Reconnaissance Squadron VP-10 (2022) Human Factors Beyond the Flight Station. Accessed March 23, 2023, https://navalsafetycommand.navy.mil/Portals/29/Documents/VOL64-NO3-JUN22_Approach.pdf.
- National Commission on Military Aviation Safety (2020) Report to The President and The Congress of The United States december 1, 2020. Accessed April 27, 2023, https://www.globalsecurity.org/military/library/report/2020/ncmas_final_report_20201201.pdf.

Naval Safety Center (2021) Annual Report 2021. Accessed March 22, 2023, <https://navalsafetycommand.navy.mil/Portals/29/Documents/220510-annual-report-2021.pdf>.

Naval Safety Command (2019) Current Mishap Definitions and Reporting Criteria. Accessed April 11, 2023, <https://navalsafetycommand.navy.mil/Resources/Current-Mishap-Definitions/>.

Wiegmann DA, Shappell SA (2003) *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System* (Abingdon: Routledge), 1 edition.

Yoshida R (2022) Random forest. Lecture, Advanced Data Analysis, August 13, Operations Research Department, Naval Postgraduate School, Monterey, CA.

Initial Distribution List

1. Dudley Knox Library
Naval Postgraduate School
Monterey, California



DUDLEY KNOX LIBRARY

NAVAL POSTGRADUATE SCHOOL

WWW.NPS.EDU

WHERE SCIENCE MEETS THE ART OF WARFARE