IDENTIFICATION, EVALUATION, AND CAUSAL FACTOR DETERMINATION OF MAINTENANCE ERRORS COMMON TO MAJOR U.S. CERTIFICATED AIR CARRIERS

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Submitted to the Faculty of the
Graduate College of the
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in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF EDUCATION
May, 2021

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ACKNOWLEDGEMENTS

This study would not have been possible without the support of many who helped me complete my educational journey. First and foremost, I am eternally grateful for the tremendous love and support given to me by my wife, Ruth Harper, who encouraged me to stay focused on my studies despite all the sacrifices it placed on our lives. None of this would have been possible without you.

I am thankful for my Chair and Dissertation Advisor, Dr. Timm Bliss, whose mentorship has helped me not only through this dissertation but throughout my years as an undergraduate and later as a graduate student. Many years have passed since my journey began but I could always count on you for advice and support. I also wish to acknowledge and thank my dissertation committee members Dr. Chad Depperschmidt, Dr. Mallory Casebolt, and Dr. Adrienne Sanogo for their recommendations that helped me complete my dissertation. I truly appreciate your advice.

To my friends and peers in the aviation industry, I thank you for your support and encouragement as I balanced my career and educational goals. Together we have seen many changes in the aviation industry throughout the years. It has been an honor working with you and being part of it all.

Finally, I am grateful to my late parents Bob and Verda Harper who impressed upon me at an early age that life is an adventure and to be passionate at whatever I may choose to do. The passion they inspired has brought me here today.

Name: ROBERT J. HARPER

Date of Degree: MAY 2021

Title of Study: IDENTIFICATION, EVALUATION, AND CAUSAL FACTOR DETERMINATION OF MAINTENANCE ERRORS COMMON TO MAJOR U.S. CERTIFICATED AIR CARRIERS

Major Field: APPLIED EDUCATIONAL STUDIES

Abstract: The purpose of this mixed methods study was the identification of common errors, causal factors and corrective actions related to maintenance errors affecting aircraft with more than 70 seats and operated by major U.S. air carriers. FAA compliance action letters obtained by FOIA for American Airlines, Southwest Airlines, and United Airlines were examined to identify errors and causal elements for categorization and further study. Delta Air Lines letters were requested but not provided by the FAA. Participants were randomly selected from FAA listings of certificated mechanics and asked to complete a survey. Quantitative data was acquired from 48 participants that met selection criteria and completed the survey. Qualitative data was acquired from interviews conducted with nine of the survey participants. Using the categories developed from the FAA data, the study found common errors with the completion of maintenance entries, handling of maintenance documents, content of maintenance instructions, installation of parts, deviations from maintenance procedures, and maintenance steps or tasks that were overlooked or not performed. Dominant causal factors were identified as failure to follow instructions or procedural requirements, and maintenance and process instructions that contain inaccurate information or lacked sufficient detail. The dominate human factors identified in the study were complacency and lack of attention. Study participants noted that complacency was primarily responsible for failure to follow instructions. Performance of repetitive or simple tasks was a causal factor that drove complacency. Direct or indirect demands on mechanics to quickly return aircraft to service also contributed to the performance of maintenance without the use of instructions. Significant corrective actions taken by air carriers included the imposition of controls to prevent the release of flight plans for aircraft that have overdue inspection items, improvements to allow for greater access to maintenance manuals, and a program for the review of instructions by maintenance personnel prior to publication. Suggested corrective actions include automation of manual processes used to track recurring inspections, improved drafting of instructions with mechanic involvement, improved training of new mechanics to instill good habits and providing maintenance instructions through the use of personal electronic devices.

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CHAPTER I

INTRODUCTION

The operation and maintenance of large commercial passenger aircraft is prone to errors that can have devastating consequences. These consequences can include the loss of aircraft, injuries, or even fatal outcomes to aircraft occupants or those on the ground. Errors committed by flight crews operating passenger aircraft tend to receive much attention by the public and investigators. However, flight operations are just one operational segment wherein errors can be committed. Ground operations and aircraft maintenance comprise other operational segments that are prone to errors. Aircraft maintenance is susceptible to the commission of errors due to the multitude of maintenance tasks which typically require technicians to remove and replace parts in confined spaces and who are often under time constraints to return aircraft to service (Reason & Hobbs, 2003).

Aircraft maintenance is not only costly for air carriers but errors committed by maintenance personnel can further impact airlines through operational delays or accidents (Kanki & Hobbs, 2008). Maintenance errors committed by aircraft maintenance personnel have been determined to be responsible for 12 to 15 percent of all aircraft accidents and incidents (Rashid, Place & Braithwaite, 2014). Human factors are recognized as causal factors that lead to the commission of errors and they have been identified as the root cause of 80 to 90 percent of all aircraft accidents (Erjavac, Iammartino, & Fossaceca, 2018; Shanmugam & Robert, 2015). Human factors can affect aviation maintenance at different stages of the maintenance process and can impact planning, training, aircraft facilities, test equipment, engineering, maintenance instructions, documentation, inspection, and management (Shanmugam & Robert, 2015). Errors can also be repetitive. A 1997 study conducted by Alan Hobbs who interviewed aircraft technicians noted 86 safety related incidents of which over half were of a type that had previously occurred (Reason & Hobbs, 2003).

Although it is evident that human factors play a key role in the commission of maintenance errors, identification of repetitive maintenance errors shared in common by commercial passenger air carriers is of importance. The identification of these errors and their causal factors would help determine what proactive efforts are required to eliminate or reduce the occurrence of such errors which in turn would enhance the safety of aircraft operated by air carriers.

Statement of the Problem

Research conducted on aircraft maintenance errors related to United States (U.S.) registered commercial aircraft has predominantly been reactive utilizing statistical data available from the NASA Aviation Safety Reporting System (ASRS) and reports published by the National Transportation Safety Board (NTSB) (Erjavac, et al., 2018; Lattanzio, Patankar, & Kanki, 2008). In 2010, proactive research focused on the use of maintenance instructions was conducted by Liang, Lin, Hwang, Wang, and Patterson using an on-line maintenance assistance platform providing visual instructions as a supplement to traditional printed maintenance instructions. Both reactive and proactive research provide conclusive evidence that a variety of factors affect the commission of maintenance errors but the research does not identify the most common maintenance errors shared by U.S. air carriers or actions that could be collectively undertaken by the industry to prevent those errors. Because of the lack of recent information specific to maintenance performed on aircraft operated by U.S. air carriers, additional research is required to identify the most common types of maintenance errors shared by these air carriers to determine the causal factors that drive the commission of these errors.

Purpose of the Study

The purpose of this study is to identify and analyze maintenance errors that are committed by major U.S. certificated air carriers with the intent of identifying and categorizing common errors, the causal factors that led to the commission of these errors, and corrective action measures to mitigate the errors.

Research Questions

Given the significance that maintenance errors have on the U.S. airline industry, three research questions were proposed for this mixed methods study:

1. What errors are common to maintenance performed on aircraft operated by major U.S. air carriers certificated under FAR Part 121?
2. Why are these maintenance errors committed?
3. What actions have been or could be instituted to prevent the commission of maintenance errors on aircraft operated by major U.S. air carriers?

Definitions of Terms

The following definitions are provided to help readers understand the meaning of certain terminology associated with this study.

Accident – “An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage” (National Transportation Safety Board, 2010).

Causal Factor - “A major unplanned, unintended contributor to an incident (a negative event or undesirable condition), that if eliminated would have either prevented the occurrence of the incident or reduced its severity or frequency. Also known as a critical causal factor or contributing cause” (Causal Factor, n.d.).

Contributing Factor - “Anything that affects how a maintenance technician or inspector does his/her job” (Boeing, 2013, p. 4).

Error - “The failure of planned actions to achieve their desired goal, where this occurs without some unforeseeable or chance intervention” (Reason and Hobbs, 2003, p.39).

Human Error - “Any human action or inaction that exceeds the tolerances defined by the system with which the human interacts” (as cited in Latorella and Prabhu, 2000, p.134).

Incident - “An occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations” (National Transportation Safety Board, 2010).

Violation - “A human action (or human behavior) that intentionally deviates from the expected action (or behavior)” (Boeing, 2013, p.2).

The following acronyms are provided to help readers understand the meaning of certain terminology associated with this study.

A&P: Airframe and Powerplant

AMM: Aircraft Maintenance Manual

AMT: Aviation Maintenance Technician

ASAP: Aviation Safety Action Program

ASM: Air Seat Mile

ASRS: Aviation Safety Reporting System

BOW: Bill of Work

CA: Compliance Action

CMO: Certificate Management Office

DCT: Data Collection Tool

EDA: Element Design Assessment

EPA: Element Performance Assessment

ETOPS: Extended Twin-engine Operations Performance Standards

FAA: Federal Aviation Administration

FIM: Fault Isolation Manual

FOIA: Freedom of Information Act

FSIMS: Flight Standards Information Management System

HL: Hazard letter

IPC: Illustrated Parts Catalog

LOI: Letter of Investigation

MEDA: Maintenance Error and Decision Aid

MEL: Minimum Equipment List

MOR: Mandatory Occurrence Report

OEM: Original Equipment Manufacturer

PAH: Production Approval Holder

ROI: Record of Inspection

SAS: Safety Assurance System

SPA: System Performance Assessment

USPS: United States Postal Service

VDRP: Voluntary Disclosure Reporting Program

Significance of the Study

This mixed methods study focuses on the identification of maintenance errors that are common to major U.S. certificated passenger air carriers. Air travel has become commonplace for the public who expect aircraft to be maintained to the highest standards. Mistakes that are made during the maintenance process can be costly to the air carriers and pose safety hazards for passengers and crew members. Understanding these maintenance errors and the causal factors that drive them can support proactive measures to prevent the recurrence of the errors. Comparison of common errors within the U.S. air carrier industry can aid in the prioritization of these proactive measures in effort to reduce or eliminate the errors. This study provides information that can be used to recognize common maintenance errors and causal factors within the air carrier industry so that action can be taken to avoid consequences that affect airworthiness of the aircraft and reduce the risks to the flying public.

Assumptions

The following assumptions are made for this study:

1. The participants selected for completion of the survey and those selected for interviews provided a true account of their experiences relevant to the scope of this study.
2. Insight gained from the experiences shared by the participants is representative of what other members of the population that maintain aircraft for major U.S. air carriers experience.

Limitations

The following limitations are applied to this study:

1. The study and final analysis of data focused on participants engaged in the performance of maintenance on U.S. certificated air carriers that provide scheduled passenger services under Part 121 of the Federal Aviation Regulations and operate aircraft with more than 70 seats. Although information was obtained from survey participants that do not perform maintenance for air carriers meeting the above parameters, this information was excluded from the final analysis and results of this study.
2. Selection of the initial survey participants was limited to a random sample taken of FAA certificated mechanics that reside within 15 miles of key airports used as maintenance hubs by American Airlines, United Airlines, Delta Air Lines and Southwest Airlines. These hub cities were identified as: Tulsa, Oklahoma; Chicago, Illinois; Dallas, Texas; Ft. Worth, Texas; Atlanta, Georgia; and, Houston, Texas.

3. Data unrelated to maintenance of aircraft including but not limited to flight operations, ground operations, fueling, deicing, and cargo was excluded from this study.
4. Initial data obtained from the Federal Aviation Administration (FAA) regarding air carrier inspection reports for base-line analysis was limited to the FAA's 2018 fiscal year which began on October 1st, 2017 and ended on September 31st, 2018.
5. Participants interviewed for this study were limited to those participants that were involved with maintenance functions on aircraft operated by major U.S. air carriers and have at least two years of experience.
6. General limitations affecting this study are noted as those resulting from the small sample size selected for the initial survey and follow-up interviews, the relevancy of participant experience with the subject matter, cultural differences and varying background of each participant.
7. Analysis of the research data and subsequent interpretation of the results by both the researcher and readers of the report may be influenced by prior knowledge, past experience or lack of it. This may place limitations on the acceptance and application of the analysis data within the industry.

Organization of the Study

This mixed methods study is described in five parts: the introduction, a literature review that includes a review of inspection data provided by the FAA, the methodology section, research findings, and conclusions. Included at the end of the study is a list of references and an appendix containing the survey questions, survey reliability results, the semi-structured list of questions used for the interviews, and the Institutional Review Board approval letter.

CHAPTER II

REVIEW OF LITERATURE

A review of prior research found that error analysis is predominantly reactive following major accidents or incidents. This section will review current research on maintenance errors within the airline industry, causal factors which have been identified, the theoretical perspective for the study, and a summary.

Maintenance Errors Within the Airline Industry

Much attention has been given to maintenance errors that are directly associated with aircraft accidents. Significant maintenance error induced aircraft crashes include the crash of an American Airlines DC10 at Chicago's O'Hare airport in 1979, the crash of a Japan Air Lines 747 into Mount Osutaka in 1985, the loss of a cockpit window on a BAC1-11 over Oxfordshire in 1990, and the in-flight break-up of an Embraer 120 over Eagle Lake, Texas in 1991 (Reason & Hobbs, 2003). A study of 92 aircraft accidents found that 26 percent of them were affected by maintenance errors that played a role in the sequence of events leading up to the accidents (Liang et al., 2010). Another study determined that human error was responsible for 70 to 80 percent of all aviation accidents of which 15 to 20 percent were maintenance related (Chiu & Hsieh, 2016; Erjavac, et al., 2018). Traditional error identification in the airline industry is predominantly reactive and casual factors are only identified after an aircraft accident had occurred (Rashid, et al., 2014; Logan, 2008).

Airline accidents are not acceptable to society (Logan, 2008). The rise in the number of maintenance related errors has heightened both public and industry attention toward accident avoidance and proactive measures aimed at the identification of human factors that caused the errors (Logan, 2008; Shanmugam & Robert, 2015). In an effort to determine the cause of errors, the Boeing Company (2013) developed its Maintenance Error and Decision Aid (MEDA) system in response to customer requests and the need to address maintenance errors. Boeing defines an error as "a human action (or human behavior) that unintentionally deviates from the expected action (or behavior)" and defines violations as "a human action (or human behavior) that intentionally deviates from the expected action (or behavior)" (Boeing, 2013, p.2).

Boeing's development of the MEDA process incorporated information from a 2004 report issued by the United Kingdom Flight Safety Committee who applied their Mandatory Occurrence Report (MOR) process to maintenance errors. They identified the following top ten causes of errors listed in order from the highest level of occurrence to the lowest:

1. Failure to follow published technical data or local instructions
2. Using unauthorized procedures not referenced in technical data
3. Supervisors accepting non-use of technical data or failure to follow maintenance instructions

4. Failure to document maintenance properly in maintenance records or work package
5. Inattention to detail/complacency
6. Incorrectly installed hardware on an aircraft/engine
7. Performing an unauthorized modification to the aircraft
8. Failure to conduct a tool inventory after completion of the task
9. Personnel not trained or certified to perform the task
10. Ground support equipment improperly positioned for the task.

(Boeing, 2013, p. 3)

Boeing estimates that errors are likely to be caused by several contributing factors of which 80 percent to 90 percent can be controlled by management while the remainder can be controlled by maintenance personnel. Therefore, Boeing argues that management has the ability to institute changes to avoid future occurrences of similar errors (Boeing, 2013). A proactive approach aims to detect and identify root causes for errors before they result in an aircraft accident rather than identify the causes of errors during the investigation of an aircraft accident (Rashid, et al., 2014).

Causal Factors of Maintenance Errors

Maintenance related errors can come from two directions: maintenance personnel may fail to discover a fault or fail to perform required maintenance tasks in full or in part, or; maintenance personnel may take direct actions that lead to a failure that otherwise would not have occurred (Reason & Hobbs, 2003). Failure to follow procedures or following procedures that have vague or conflicting instructions are key factors that drive the commission of errors (Eiff & Suckow, 2008). A controlled study conducted on maintenance documentation found that user complacency along with poor work card instructions are major contributors to the commission of paperwork errors (Drury, 1998). This was further validated when two causal factors emerged in studies of aircraft maintenance errors, one causal factor was attributed to issues with maintenance instructions themselves and the other attributed to the actions taken by those performing tasks in a manner that is contrary to the documented instructions (Lattanzio, et al., 2008). Documentation errors can include missing or incorrect information, conflicting information, and information that is difficult for maintenance personnel to interpret (Lattanzio, et al., 2008). FAA sponsored research that reviewed manufacturers' documentation found that errors contained within the maintenance instructions were a leading cause of maintenance errors (Lattanzio, et al., 2008).

User error includes failure to read or follow instructions, failure to retrieve the instructions, failure to perform required safety inspections, or failure to document work that was performed (Lattanzio, et al., 2008). Failure to use written instructions can lead to errors. A survey of technicians in a petrochemical plant found that only 58 percent of respondents said that they had the procedures open and available as they performed the work (Reason & Hobbs, 2003). The survey results also determined that 56 percent of the operators and 51 percent of the managers had developed their own procedures in lieu of the established procedures for accomplishing the work (Reason & Hobbs, 2003). When respondents were asked why they did not comply with the established procedures, they stated various reasons that included unawareness of the procedures, tasks would not be completed if the instructions were precisely followed, a preference on using their own knowledge, and an assumption that they are already well familiar with the procedures (Reason & Hobbs, 2003).

Communication issues have also been identified as a causal factor of maintenance errors. A study on maintenance errors reviewed 1,182 Aviation Safety Reporting System (ASRS) reports and found that insufficient communication comprised eight percent of all the reports received and of that eight percent, over one-half were directly related to work turn-over communication issues (Parke & Kanki, 2008). Complacency was identified as a causal factor of maintenance related errors in a study of one airline over a two-year period. The repetitive and monotonous nature of the maintenance tasks drove complacency which led to the failure to use or follow technical instructions (Liang et al., 2010). Environmental factors such as poor lighting, confined spaces, and weather conditions can hide defects that would normally be found during a visual inspection by a maintenance inspector (Marais & Robichaud, 2012).

To help understand what causes maintenance errors, in the 1990's Boeing developed its MEDA process by incorporating information previously gathered by the U.S. Navy during the development of the Navy's Human Factors Analysis and Classification System - Maintenance Extension (HFACS-ME). In addition to analyzing errors, the Navy's system also examined errors to determine if rule violations had occurred. Violations are classified into three categories defined as "routine - a maintainer engages in practices, condoned by management, that bend the rules; "situational" - a maintainer strays from accepted procedures to save time, bending a rule; and "exceptional" - a maintainer willfully breaks standing rules disregarding the consequences." (Boeing, 2013, p. 3).

Maintenance Errors Identified by the FAA

Title 49 of the United States Code (49 U.S.C.) and Title 14 of the Code of Federal Regulations (14 CFR) provide the statutory power and authority for the Federal Aviation Administration (FAA) to regulate aviation. One of the FAA's many responsibilities is to ensure that air carriers conduct operations in compliance with federal regulations. The FAA accomplishes this in part by utilizing their Safety Assurance System (SAS) that provides the tools and procedures to verify that certificated air carriers maintain operations in a safe manner while meeting all regulations and standards. The SAS program is a risk-based approach that provides for the use of performance assessments in the form of checklists that FAA personnel can use to help determine if the air carrier meets FAA requirements and industry standards. The assessments consist of top-level reviews that look at System Performance Assessments (SPA), mid-level Element Design Assessments (EDA) that look at individual system processes from a design perspective, and base level Element Performance Assessments (EPA) that look at the product or performance of each system (FAA, 2019a). All three assessments use standardized checklists that provide FAA personnel with the means to adequately review and identify systems and actions that are contrary to the regulations. The Element Performance (EP) Data Collection Tools (DCT) are the checklists that FAA inspectors routinely use to conduct inspections of air carriers and identify discrepancies that are later documented in formal compliance action letters sent to the air carriers.

Each air carrier that is certified by the FAA to carry passengers under FAR Part 121 is assigned a FAA Certificate Management Office (CMO) who must perform SAS inspections and document any discrepancies that are noted. The discrepancies are presented to the air carrier in writing and air carriers are obligated to respond with corrective action. The corrective action taken by the air carrier is reviewed by the FAA and if approved, a closure letter is sent to the air carrier. Both the initial investigation letters and the closure letters contain a wealth of information concerning the discrepancies identified by FAA inspectors during their inspections of the air carriers for compliance. Unfortunately, these letters are not published but are kept on file by each FAA CMO for their assigned air carrier.

In an effort to gather insight regarding errors committed by US air carriers, copies of correspondence related to inspections performed by the FAA of the four largest US air carriers were requested in accordance with the provisions of the Freedom of Information Act (FOIA). Four major US air carriers were selected for review based on the highest number of air seat miles (ASMs) reported by the United States Department of Transportation - Bureau of Transportation Statistics (www.bts.gov) for the twelve-month period ending on September 30th, 2018. The four air carriers with the highest number of ASMs for this period were identified as American Airlines (247,763,901 ASMs), United Airlines (241,075,102 ASMs), and Delta Air Lines (235,325,726 ASMs), and Southwest Airlines (157,317,793 ASMs). Each of the FOIA requests asked for copies of compliance action documents submitted between October 1st, 2017 and September 30th, 2018 which coincides with the FAA's 2018 fiscal year. The fiscal year is also reflected by the FAA in the file case numbering sequence that is used to document the compliance action letters.

The FOIA requests defined Compliance Actions as actions taken by the FAA in accordance with FAA Order 8900.1, Flight Standards Information Management System

(FSIMS), Volume 14, Compliance and Enforcement, that result in written correspondence between the FAA and each of the air carriers regarding deficiencies noted by the FAA. The FAA must perform its duties in accordance with FAA Order 8900.1, Volume 14 and this particular section specifies how FAA inspections and investigations must be conducted. (FAA, 2016). Requested correspondence was further defined in the FOIA requests as consisting of all Compliance Action (CA) letters, Hazard letters (HL), Record of Inspection (ROI) letters, and Letters of Investigation (LOI) on file. The FAA was asked to provide copies of FAA correspondence issued to the air carrier, written correspondence submitted by the air carrier to the FAA in response to the compliance action, and written correspondence issued by the FAA to the air carrier closing each compliance action.

The FOIA requests also defined certain documentation that was not requested as it was either not required for this study or is prohibited from release under FOIA guidelines. Personal notes, memos, and/or checklists that may have been made or completed by FAA Inspectors during the course of their inspection activities were not requested. Documentation related to compliance actions initiated by the FAA against individuals or organizations other than directly to these air carriers was not requested since the initial focus of this research was limited to the air carriers. Documentation regarding voluntary disclosures submitted by these air carriers to the FAA were not requested due to the exemptions and protections extended to the release of voluntary disclosures submitted to the FAA. Also excluded were documents and correspondence related to Aviation Safety Action Program (ASAP) submissions that have been accepted into this program by the FAA since these submissions are also protected from release under FOIA.

The FOIA requests were mailed to the FAA on February 25th, 2019 and were subsequently accepted and issued individual FOIA tracking numbers for further action. Three responses were received along with electronic scans of compliance actions from the FAA CMO's for American Airlines, United Airlines, and Southwest Airlines within the response period specified by the FOIA requirements. The response to FOIA Request No. 2019-004459GL for United Airlines inspection records was received along with copies of 25 compliance action letters comprising 195 pages. This response also stated that the FAA found 373 pages of documents related to investigative notes, drafts of correspondence, and file checklists which were not provided since they were excluded from the initial FOIA request. The response to FOIA Request No. 2019-004607 for Southwest Airlines inspection records was provided with copies of 93 compliance action letters comprising 290 pages. The response stated that only four documents comprising a total of eight pages were withheld as they related to events that were already accepted into the air carrier's voluntary disclosure program. The response to FOIA Request No. 2019-004608 for American Airlines inspection records was provided along with copies of 89 compliance action letters comprising 501 pages. The response also stated that only 20 documents comprising 105 pages were withheld as they related to events already accepted into the air carrier's voluntary disclosure program.

However, the response letter dated July 9th, 2019 that was received regarding FOIA Request No. 2019-004290 for Delta Air Lines inspection records did not provide the requested documentation. Delta's FAA CMO gave the following reasoning in the response letter for not providing copies of the compliance action letters:

> It should be noted that the Delta CMO utilizes a Memorandum of Understanding with Delta Air Lines which drives most compliance action activities into the Voluntary Disclosure Program, which has robust corrective action controls. This, in combination with the fact that most quality escapes at Delta involve individuals, which are captured in the Aviation Safety Action Program, is why there is not a large quantity of compliance action information (FAA response letter, July 9th, 2019).

A copy of the Memorandum of Understanding with Delta Air Lines referenced by the FAA was not provided. However, 19 pages of general email correspondence concerning the review and approval of a training curriculum for the 757 and the A319/A320/A321 aircraft were supplied. The email correspondence appears to be unrelated to a specific FAA compliance action and does not reference any FAA compliance action file numbers. The lack of any compliance documents is in stark contrast to what was provided by the FAA CMOs for the other three air carriers. The position taken by Delta's FAA CMO also appears to contradict FAA Advisory Circular 00-58B (FAA, 2009) regarding Voluntary Disclosure Reporting Programs (VDRP) which states:

> In evaluating whether an apparent violation is covered by this policy, the FAA will ensure that the following five conditions are met: (1) The certificate holder, qualified fractional ownership program, or PAH has

notified the FAA of the apparent violation immediately after detecting it and before the Agency has learned of it by other means…(p. 4)

The existence of a memorandum of understanding between the FAA and Delta that allows the conversion of FAA identified violations into air carrier submitted voluntary disclosures appears to conflict with the intent of this Advisory Circular. In addition, FAA Order 8000.89 (2016a,) regarding the designation of VDRP information as protected from public disclosure also states that regulated entities are required to make initial notification to the FAA of a VDRP submission and must provide specific details of the apparent violation. The submissions must also be clearly identified as VDRP submissions. This sequence of events must take place before an air carrier is formally notified of an apparent violation by the FAA. Appendix A of this Order contains public comments and FAA responses submitted prior to enactment and it contains an FAA response that stated "FAA policy prohibits acceptance of a submission under the VDRP when the FAA has already learned of the violation on its own" (FAA Order 8000.89, 2016a, p. A-2). The requirements contained in both the Advisory Circular and the FAA Order appear to be in direct conflict to the FAA's position in their FOIA response whereby they allow FAA initiated compliance actions to be driven directly into Delta's Voluntary Disclosure Program.

An appeal was lodged regarding the FAA's FOIA response noting the language in both the Order and the Advisory Circulars and arguing that FAA identified violations are not eligible for automatic inclusion in an air carrier's VDRP program. A decision regarding the appeal had not been made at the time this study was concluded. Therefore, this study utilized the data submitted for FAA inspections conducted at American

Airlines, United Airlines, and Southwest Airlines. The lack of data related to FAA inspections of Delta Air Lines imposed an additional limitation on the initial research and data that was gathered for this study.

A review of compliance action documents provided for United Airlines, American Airlines, and Southwest Airlines was performed using a web-based program known as Dedoose and developed by SocioCultural Research Consultants, LLC (2019). This program is designed for qualitative analysis and allows the user to import spreadsheets, audio files, visual files, and transcripts or text as Word or Adobe PDF files. Data taken from these files can be highlighted and tagged with user created codes. Dedoose also allows for the direct importation of survey data from data collection programs such as Qualtrics and Survey Monkey. All data that is imported or entered into the Dedoose program is encrypted and only accessible to the researcher and those who are extended user rights by the project owner thus ensuring security of the information.

The documents received from the FAA were imported into Dedoose as PDF files. They were subsequently tabulated and given file names using the FAA assigned compliance action file numbers. Each compliance action document was then coded using initial descriptors to identify the air carrier, the type of operation observed by the FAA, and if the letter was an initial notification letter sent to the air carrier or a letter closing-out the compliance action. Although requested by FOIA, the FAA provided very few copies of correspondence submitted to it by these air carriers. However, the majority of FAA close-out letters reiterated what the air carrier had discovered during their investigation into the discrepancy and included the corrective action that was taken. The close-out letters provided sufficient information to determine what action had been taken by the air carrier to address the discrepancy. The coding of the FAA's initial observations was performed separately by applying descriptors to observations while coding of the casual factors reported in the FAA's close-out letters was conducted using a separate set of descriptors that were specific to the causal factors.

Initial review of the documents found that some of the compliance action letters predated the 2018 fiscal year reporting period specifically request by FOIA. In addition, several other compliance actions had been provided which were addressed to individuals, not the air carrier. Given that these compliance actions had not been requested but were supplied in error, they were subsequently removed and excluded from the review process. This left a remainder of 194 compliance actions of which 14 were issued to United Airlines (UA), 87 were issued to American Airlines (AA), and 93 were issued to Southwest Airlines (SW). These compliance actions were then coded with descriptors to identify the type of air carrier operation that was subject to the FAA compliance action. The four descriptors used to identify the type of operations are maintenance operations, flight operations, non-maintenance ground operations, and one for actions that were later withdrawn by the FAA. Figure 2.1 illustrates the results of the initial analysis which depicts 128 compliance actions related to maintenance activities, 46 related to flight activities, 19 related to ground activities and one action that had been withdrawn. Maintenance related compliance actions accounted for over half of the compliance actions received by American Airlines and Southwest Airlines during the FAA's 2018 fiscal year and which were provided in response to the FOIA requests.

Figure 2.1

Categorization of FAA Compliance Actions by Air Carrier and Category

Comparison Field Groups / Target Field Groups	MAINTENANCE	GROUND	FLIGHT	WITHDRAWN	Total
Air Carrier					
UA	4 (28.6%)	7 (50%)	2 (14.3%)	1 (7.1%)	14
AA	75 (86.2%)	1 (1.1%)	11 (12.6%)	0	87
SW	49 (52.7%)	11 (11.8%)	33 (35.5%)	0	93
Category					
MAINTENANCE	128 (100%)	0	0	0	128
GROUND	0	19 (100%)	0	0	19
FLIGHT	0	0	46 (100%)	0	46
WITHDRAWN	0	0	0	1 (100%)	1

Further analysis of the compliance action letters was performed to identify the specific actions that had been observed and found questionable by the FAA. The text of each letter was examined and general descriptors were developed and tagged to excerpts in the letters for qualitative analysis. The review noted that some FAA compliance actions captured multiple issues or discrepancies that were listed in a single letter. Therefore, the total number of coded discrepancies was greater than the actual number of compliance letters. The following is a description of each descriptor that was used to code the FAA reported discrepancies as they were entered into the Dedoose analytical platform:

- Parts and material storage: This code is applicable to observations related to the improper storage of parts and materials. This can include both aircraft parts and raw materials, chemicals, and other related items used to repair aircraft.
- Maintenance instruction issues: This code is applicable to discrepancies that involve written instructions observed to be insufficient, incorrect, or are missing.
- Management control issues: This code is applicable to errors related to the lack of oversight or control of aircraft maintenance. This may include planning issues related to work card assignment, review of completed work cards, Bill of Work (BOW) issues, turn-over reporting, or verification of aircraft status following maintenance.
- Mechanical discrepancies: This code is applicable to mechanical discrepancies observed by the FAA and reported to the air carrier without inference to a specific maintenance error.
- Missing documentation or tags: This code is applicable to observations relating to records, documents, tags, and placards that are missing or incorrect.
- Missing parts or equipment: This code is applicable to observations related to parts and equipment that is missing.
- Maintenance entry errors: This code is applicable to observations of maintenance entry discrepancies. This can also include omission of entries that should have been made to document maintenance actions taken or required.
- Procedure not FAA approved: This code is applicable to observations related to maintenance procedures, policies, and practices that require FAA approval but were not approved or submitted to the FAA for approval.

- Task deviation: This code is applicable to observations of deviations that were made from stated instructions or maintenance requirements as defined in maintenance manual instructions, documented procedures, or work instructions. This also includes the application of work instructions that were not applicable to the aircraft or maintenance task under observation.
- Task not performed: This code is applicable to observations of maintenance actions including inspections, procedures, or work tasks that were not performed or missed in whole or in part nor were alternate means of accomplishment applied. This also includes non-performance of an entire work card or procedure.
- Tool calibration issues: This code is applicable to observations regarding tools and equipment calibration that are found to be missing or expired. It does not include observations related to missing tools and equipment unless the error is associated with the tool calibration tracking program.
- Training or qualification issues: This code is applicable to observations related to the training and qualifications of maintenance personnel. It includes observations of individuals that were not qualified to perform the work, lacked recurrent training, or failed to undertake or complete training.

Analysis of the results are displayed below in Figure 2.2. The results found that American Airlines had the greatest number of maintenance discrepancies of which maintenance entry errors were dominant with 86 reported errors. Task deviation errors were the second highest category with 37 instances followed by 31 instances of tasks that should have been accomplished but had not been performed. Southwest Airlines was found to have task deviation errors as their highest error category with 18 reported discrepancies followed by errors attributed to tasks that were not performed and errors associated with maintenance instructions with both categories each having 11 reported errors. The small volume of documents provided for United Airlines compliance actions resulted in only seven reported maintenance errors which found that task deviation errors were the most common with three reported occurrences. This is followed by two incidents that found maintenance tasks that had not been performed, one incident attributed to errors with the maintenance instructions, and another error related to missing documentation.

Figure 2.2

Discrepancies Observed by the FAA

Descriptor Matrix / Codes	Parts and material storage	Maintenance instruction issues	Management control issues	Mechanical descrepancies	Missing documentation or tags	Missing parts or equipment	Maintenance entry errors	Procedure not FAA approved	Task deviation	Task not performed	Tool calibration issues	Training or qualification issues
UA		1			1				3	2		
AA	9	16	5	17	10	2	86	3	37	31	14	22
SW	2	11	5	2	5	1	7	2	18	11		

Analysis of compliance action closure letters required the creation of a different set of descriptors for casual actions to reflect *why* the errors had occurred. This is in contrast to the descriptors developed for the initial compliance action letters that identified *what* errors were observed. The review also noted that closure letters were not provided for 12 of the compliance actions. It is possible that air carrier responses to compliance actions were still in development and not available at the time the information was requested by FOIA. The lack of closure letters prevented the coding of causal factors related to the discrepancies noted in those letters. It was also observed that in a few instances, air carriers reported multiple causes for a single compliance error. This necessitated the assignment of multiple causal codes to that error. The following is a description of each code developed for categorization and coding of the causal factors reported to the FAA by the air carriers and were included in the FAA's compliance action closure letters:

- Instruction error: The cause for the error was attributed to maintenance and process instructions that contained inaccurate information, incomplete instructions, or instructions that did not include detailed instructions for the task.
- Discrepancy found invalid: Upon review, the air carrier determined that the discrepancy reported by the FAA was invalid and was not a compliance issue.
- Failure to follow instructions: The cause for the error was attributed to a failure to follow maintenance instructions or procedural requirements. This includes failure to follow general air carrier policy and procedural instructions.
- Ineffective process controls: The cause for the error was attributed to ineffective control of the maintenance process or a lack of a measurement process.
- Administrative or program error: The cause of the error was attributed to maintenance related programs and policies that were found inadequate, lacked sufficient detail, or required revision.
- Lack of training or knowledge: The cause for the error was attributed to maintenance personnel lack of training or knowledge.

- Maintenance entry error: The cause of the error was attributed to individuals who made mistakes documenting maintenance and related tasks by failing to communicate clearly, entering incorrect information, or omitting relevant information.
- Unknown: The cause of the error was not listed in the compliance action closure letter or the closure letter lacked sufficient detail to identify the causal factors.

Analysis of the results are displayed below in Figure 2.3. The air carriers reported that 13 of the FAA observed discrepancies were invalid and that the observed actions were correct and in compliance with regulatory and airline requirements. Analysis of the compliance action closure letters also found that no causal information was provided for 13 of the FAA reported observations. Analysis of the remaining closure letters identified the top three causal factors for each of the three air carriers. The top three causal factors for American Airlines are maintenance entry errors with 84 verified mistakes, failure to follow instructions with 77 verified mistakes, and instruction errors responsible for 18 mistakes. The top three causal factors for Southwest Airlines are failure to follow instructions with 14 verified mistakes, instruction errors were responsible for nine mistakes, and administrative or program errors were responsible for seven of the mistakes. The small number of compliance actions provided for United Airlines made it difficult to determine the top three causal factors related to the errors observed by the FAA. Two of the causal factors were attributed to mistakes associated with instruction errors and the remaining three causal factors attributed to mistakes associated with failure to follow instructions, administrative or program error, and the lack of training or knowledge.

Figure 2.3

Causal Factors Reported by Air Carriers

Descriptor Matrix / Codes	Instruction error	Discrepancy found invalid	Failure to follow instructions	Ineffective process controls	Administrative or program error	Lack of training or knowledge	Maintenance entry error	Unknown
UA	2	1	1		1	1		
AA	18	11	77	8	12	12	84	4
SW	9	1	14	2	7	1	5	9

Surprisingly, the compliance action closure letters that identified actions taken by the air carriers seldom made mention of human factors as causal factors. There were 19 instances where the closure actions noted human factors as a contributor to the commission of errors. Of the 19 instances, eight were attributed to lack of awareness by one or more employees, seven were attributed to complacency, three were attributed to lack of attention, one was attributed to distraction, and one was attributed to human factors as a general category without further delineation. There is the possible that root cause analysis was performed internally by the air carriers but not reported to the FAA or alternatively, the FAA may have omitted this information from some of the compliance action closure letters. Analysis of these results are displayed below in Figure 2.4.

Figure 2.4

Human Factors as Causal Elements Reported by Air Carriers

Descriptor Matrix / Codes	Lack of attention	Distracted	Complacency	Lack of awareness	Human factors cited by air carrier
UA			3	1	1
AA	3	1	3	5	
SW			1	2	

The review of literature together with the analysis and review of the FAA's 2018 compliance actions taken against three of the four largest air carriers in the U.S. suggest that the most predominant maintenance errors are associated with maintenance record entries, failure to follow instructions, and errors involving the content of maintenance instructions. Corrective action taken by the three air carriers suggest that the top causal factors are failure to follow instructions, maintenance instruction errors, and maintenance entry errors. Human factors are recognized as contributors to the commission of errors. However, the corrective actions reported in the FAA's compliance action closure letters made little mention of them choosing instead to focus on the subject of the error itself for corrective action and closure.

Theoretical Framework

The theory that informs this study is human error theory and the dynamics of error causation developed by Dr. James Reason and described in his book *Human Error* (1990). Reason applied several tenants of cognitive psychology theories that he made after observing and cataloging human errors. (Larouzée & Guarnieri, 2015). What began with a self-observation of a mistake he had made in 1977 when he confused his cat's food dish for his teapot drove Reason to question the causes of human error (Larouzée & Guarnieri, 2015). According to Reason (1990), human error is defined as "a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency" (p. 9).

Human error theory was further refined to examine errors from both a person approach and from a systems approach (Reason, 2000). The person approach is traditionally used to describe errors as unsafe acts committed by individuals whereas a systems approach provides much more information to help identify latent issues that may have contributed to the unsafe acts (Reason, 2000). Reason's theory on human error is useful to this study as it will allow maintenance errors to be studied in a controlled manner to determine causal factors that lead to the commission of the errors.

Summary

Both the public and the airline industry have a greater awareness of maintenance induced errors and the need to avoid them to prevent accidents and incidents (Logan, 2008; Shanmugam & Robert, 2015). Previous research has linked some of the errors to acts of complacency following written instructions, errors associated with written instructions, and the lack of turn-over reporting (Druary, 1998; Parke & Kanki, 2008; Lattanzio, et al., 2008). A review of compliance actions supplied by the FAA regarding errors observed at three of the top four U.S. air carriers found that the most predominant maintenance errors are associated with maintenance record entries, failure to follow instructions, and errors involving maintenance instructions. This study sought to further identify the predominant maintenance errors within the U.S. airline industry and evaluate the causal factors that allowed them to occur. Beneficiaries of this study include the airlines that operate commercial aircraft, government agencies responsible for ensuring that maintenance is properly performed, personnel and firms that perform maintenance activities, and the flying public who expect commercial aircraft to be properly maintained.

CHAPTER III

METHODOLOGY

This chapter describes the research design selected for the study, the participants, data collection, reliability and validity, data analysis, and a summary of the methodology.

Research Design

This study employed the mixed-methods research approach to provide initial confirmatory research using quantitative data gathered through the use of surveys followed sequentially by the performance of interviews to gather qualitative data (Patton, 2015). Creswell and Plano Clark (2018) describe the core characteristics of mixed method research as the means to acquire both qualitative and quantitative data allowing integration of the data to achieve results using a research design that is both logical and lies within established principles and theory. Employing the mixed-method approach allows the use of both quantitative and qualitative research methods to support and supplement each other thus providing a better understanding of the research problem than would be possible using either research method by itself (Gay, Mills, & Airasian, 2012).

The specific type of mixed methods design selected for this research is the explanatory sequential design which provides for two phases for data acquisition performed in sequence using quantitative methods for data acquisition followed by the use of qualitative methods (Creswell & Plano Clark, 2018, Creswell & Guetterman, 2019). This type of design is also known as the QUAN-qual model as it places priority and weight on the quantitative data that is initially gathered while fostering the use of qualitative data to further explain the results (Gay, et al., 2012, Creswell & Guetterman, 2019). The first phase permits quantitative data to be acquired and analyzed using descriptive statistics as a generalized approach toward answering the research questions. Use of this design facilitates the accomplishment of the second phase by providing the ability to select a sample of first phase participants for follow-up acquisition of data. The second phase further explores and adds definition to the results obtained during the first phase through in-depth qualitative methodology and analysis of descriptive data (Creswell & Plano Clark, 2018). The explanatory sequential mixed-method design for this study provided the quantitative means to identify maintenance errors and causal elements common to maintenance performed on aircraft operated by major U.S. air carriers while allowing for in-depth review of errors and causal factors through qualitative means (Creswell & Guetterman, 2019). A disadvantage of this design is that it requires a greater length of time to complete the acquisition of data (Creswell & Plano Clark, 2018).

The quantitative portion of the mixed methods design for this study employed the survey design research method utilizing a structured set of questions with a set of ordinal frequency-based responses that allows for analysis using descriptive statistical analysis tools. The use of a survey as a quantitative instrument to gather data relative to commission of maintenance errors was particularly useful prior to the commencement of qualitative research through interviews as it provided a better understanding of the overall responses provided to each of the survey questions. The survey is considered a descriptive survey as its purpose is to gather data that will help determine trends and incidence (Kelley-Quon, 2018). Of key interest for this study was the identification of errors, causal factors, and human factors that are the most prevalent during the performance of maintenance on aircraft operated by major U.S. air carriers.

The use of mail surveys has been shown to have a much higher response rate than those that are administered through a web site (Fowler, 2014). In addition, the lack of e-mail addresses for the participants together with the possibility that participants may not have reliable Internet access are some of the disadvantages associated with administering the survey online (Fink, 2013). Survey response rates can also be improved using gift or cash incentives (Fink, 2013). This study adopted an incentive in the form of a five-dollar Starbucks gift card as advance consideration for completion of the survey. Providing an incentive at the same time that a participant receives a traditional survey has generally been shown to be effective at increasing the survey response rate (Schonlau, Fricker & Elliott, 2002).

The qualitative portion of the mixed methods design used the grounded theory design to study a sample of the survey participants through interviews to gain better insight into the most common errors that occur with maintenance activities performed on aircraft operated by major U.S. air carriers. Each interview was conducted using the same set of open-ended questions in a semi-structured format supplemented with additional unstructured questions to elicit personal stories to add validity and depth to the survey results. To encourage participation in the interview process, individuals were offered a cash incentive of 100 dollars for completing the interview process.

According to Patton (2015), “Qualitative data can put flesh on the bones of quantitative results, bringing the results to life through in-depth elaboration.” (p.230). Utilizing the mixed methods design approach where quantitative data was acquired using surveys coupled with the acquisition of qualitative data using the grounded theory design provides a better understanding of the research problem (Creswell & Guetterman, 2019). The application for this study was approved by the Oklahoma State University Institutional Review Board on February 6th, 2020 and is attached as Appendix D.

Participants

This study was focused on the identification of errors made or encountered by mechanics performing maintenance on aircraft operated by major U.S. airlines and determination of causal factors that led to the commission of the errors. Participants for this study were mechanics and maintenance qualified personnel that were directly involved with the performance of maintenance on such aircraft.

Population. The population for this study consists of all individuals in the U.S. that hold an airframe or power plant certificates issued by the Federal Aviation Administration (FAA) and who were actively performing maintenance functions on U.S. registered aircraft. The population does not include individuals who are non-certificated individuals. The goal of this study was not to generalize to larger groups although the results of this study may be transferrable to other individuals who may not hold FAA mechanic certificates but who are involved with maintenance of aircraft. The target population or sampling frame was comprised of all FAA certificated mechanics that appear on the listing of FAA certificated individuals that existed at the time it was downloaded from the FAA’s website on January 28th, 2020. A review of the FAA’s database found that there are over 270,000 individuals who held airframe and/or powerplant mechanic certificates worldwide (FAA, 2019).

Sampling method. The initial sampling method used to identify the sample population for the first phase of this study is multistage cluster sampling. This method allows the selection of the sample to be conducted in several stages if the subject population is large and cannot be easily defined (Creswell & Guetterman, 2019). There are thousands of FAA certificate mechanics domiciled throughout the world who are engaged in a variety of occupations that may or may not be related to maintenance of U.S. air carrier aircraft. The first phase of research involved the selection of a sample population of maintenance mechanics from the entire population based on their residential proximity to the maintenance hubs of the four largest U.S air carriers. It was from this group that randomly selected individuals were selected and sent an invitation to complete the survey. The second phase involved the selection of individuals from those who completed the survey and who indicated their willingness to be interviewed. Individuals for the second phase of research were selected based on their willingness to participate and having met the experience requirements pertaining to maintenance on aircraft operated by major U.S. air carriers.

The first step to determine the population of FAA certificated mechanics made use of the database maintained by the FAA of certificated individuals which is available to the public and can be downloaded from the FAA's web site at: https://www.faa.gov/licenses_certificates/airmen_certification/releasable_airmen_download/. This database contains the mailing addresses for each individual and the type of certificates held. The database was initially sorted to identify only those individuals that held an aircraft maintenance technician certificate issued by the FAA for airframe, power plant, or a combination of both specialties. Over 270,000 individuals were initially identified as meeting this qualification. The resultant listing was sorted again to identify those individuals that reside within 15 miles of the major airport maintenance hubs belonging to American Airlines, United Airlines, Delta Air Lines, and Southwest Airlines located in Tulsa, Oklahoma; Chicago, Illinois; Dallas, Texas; Ft. Worth, Texas; Atlanta, Georgia; and, Houston, Texas. There were 12,064 individuals who met this criterion. The purposeful selection of these geographic areas was intended to allow a greater opportunity for selection of individuals performing maintenance on aircraft operated by these air carriers.

Initial Survey Sample. An initial random purposive sample of participants for completion of the survey were selected from the target population provided that meet the following criteria:

- Hold an aircraft maintenance technician certificate issued by the FAA for airframe, power plant, or a combination of both specialties.
- Have addresses that are located within 15 miles of key airports used as maintenance hubs by American Airlines, United Airlines, Delta Air Lines and Southwest Airlines. These hub cities are identified as: Tulsa, Oklahoma; Chicago, Illinois; Dallas, Texas; Ft. Worth, Texas; Atlanta, Georgia; and, Houston, Texas.

Secondary Interview Sample. A purposive sample of participants for the interview process was selected from the sample population of individuals that responded to the initial survey and who met the following criteria:

- Have stated on the initial survey that they are involved with the performance of maintenance on aircraft operated by major airlines.
- Have stated on the initial survey that they had a minimum of two years' experience performing aircraft maintenance.
- Have stated their desire to participate as a subject for the interview process.

Factors such as age, gender, or ethnicity did not exclude participants from the interview sample. However, a minimum of two years of experience was required for those willing to be interviewed given that each participant must have sufficient knowledge of air carrier maintenance activities. Aircraft mechanics that were not involved with maintenance activities performed on aircraft operated by an FAA certificated air carrier were disqualified from the interview portion of the study. Aircraft mechanics domiciled outside of the United States were also be excluded from the sample due to the difficulty communicating with individuals residing at remote locations and the influence that foreign aircraft regulatory agencies may have on maintenance activities.

The desirable sample size for the initial survey portion of this study was initially set at 100 with the expectation that a minimum of 50 participants involved with the performance of maintenance on aircraft operated by major air carriers would respond and complete the survey. The desirable number of participants anticipated for the interview portion of this study was expected to be no less than five and no more than ten individuals. These numbers were deemed adequate for gathering of quantitative and qualitative data necessary for a the mixed-methods study of predominate maintenance errors and the causal factors relative to aircraft owned and/or operated by major U.S. airlines.

Survey Sample Results. The listing of 12,064 individuals that comprised the sample population was randomly sorted using a table of random digits generated by using a Microsoft Excel software command. From the randomly sorted list, the first 100 individuals were selected to receive a request to participate in the study. Each of the 100 individuals was mailed a letter describing the study and a request to complete an enclosed survey. A consent form was also provided that had to be signed and returned with the survey to indicate acceptance for inclusion in the study as a participant. An incentive in the form of a five-dollar Starbucks gift card was also provided. A stamped and addressed envelope was also provided so that participants could return the survey and signed consent letter.

Of the initial 100 survey requests that were sent, six surveys were completed and returned of which four were completed by individuals who indicated that they were involved with the performance of maintenance on aircraft with more than 70 seats and operated by major airlines. Three surveys were returned by recipients who stated that they did not wish to take the survey. The United States Postal Service (USPS) returned an additional 13 survey requests after determining that they were not deliverable and could not be forwarded to an alternate address. No responses were received from the remaining 78 surveys that had been mailed. The lack of responses coupled with the return of undeliverable survey requests prompted the need for selection of additional individuals from the sample population and the need for a more efficient method to conduct the survey.

An alternate method for survey completion was adopted whereby the survey could be accessed by participants using a web-based survey portal administered by

Qualtrics, a provider of customer focused software tools (Qualtrics, Provo, UT). Rather than mail a request letter together with a paper copy of the survey, the consent form, gift card, and a return envelope, additional individuals that were selected were mailed a revised survey request letter that summarized the purpose of the study and mentioned the availability of a five-dollar Starbucks gift card for completing the survey. Instructions on accessing the survey through the Qualtrics website were also provided that included a web address as well as QR code that a recipient could scan on a smartphone and automatically be directed to the survey. The consent form was incorporated into the Qualtrics site and participants were required to identify themselves and indicate their consent to be included in the study before being allowed to take the survey. The survey questions and the order in which they were presented to the participants remained identical on both the original mail-in survey and the Qualtrics web-based survey. The incentive offered to participants did not change but the language in request letter and consent form were revised to indicate that the incentive would be offered to individuals upon completion of the web-based survey. At the conclusion of the web-based survey, participants were asked if they wished to receive the incentive and if so, they were instructed to provide an email address or mailing address that was used to send the incentive. The Oklahoma State University Institutional Review Board was contacted regarding these changes and a reply was received on May 28th, 2020 that stated no modification was required regarding their original approval for this study as it did not increase the risks or change the study population.

Individuals were also prompted for their willingness to be interviewed for the second phase of the study at the conclusion of the survey. This was facilitated using the

Qualtrics platform which allowed for the request to appear in the survey after participants had answered the demographic question regarding their maintenance background. Those that indicated they were engaged in the performance of maintenance for major airlines would be prompted with a follow-on question asking if they were willing to be interviewed and informing them of the incentive offer available to those who were selected and completed the interview process. Participants who indicated their willingness to be interviewed were then prompted for their contact information and further instructed that if selected, they would be receiving a separate consent form sent to them through the mail that would have to signed and returned prior to commencement of the interview.

An additional 400 individuals were selected from the sample population who were listed immediately following the initial 100 individuals that appeared on the randomly sorted listing. Of the 400 who were sent the letters, 31 completed the survey. There were 37 survey request letters that were returned as undeliverable by the USPS. This response rate was also deemed insufficient, and another 500 individuals were selected from the sample population and sent the survey request letter. The 500 individuals selected from the sample population were those who appeared on the randomly sorted listing immediately following the initial 100 individuals and subsequent 400 individuals that had been selected. Of this group of 500 individuals, 34 participants completed the survey. There were 71 survey request letters that were returned as undeliverable by the USPS. The combined results of the 1000 survey requests that had been sent resulted in the generation of 71 survey responses of which 48 responses were completed by individuals that perform maintenance on airline operated aircraft having more than 70 seats. A total of 128 survey request letters were returned by USPS as undeliverable.

Interview Sample Results. There were 12 individuals that completed the survey and who indicated their willingness to be interviewed for the second phase of the study. Of these 12 individuals, ten were randomly selected and mailed consent forms for review and signature. Nine of these individuals returned the consent forms and were subsequently interviewed. The interviews were conducted by telephone and recorded with the prior consent of each participant. The recordings were transcribed and all identifying information was redacted. Each of these participants are identified in this study using applied pseudonyms of Participant A through Participant I.

Data Collection

Data collection for this mixed methods study used a survey as the instrument to gather quantitative data for the first phase of the study and interviews conducted using a semi-structured list of questions to gather qualitative data for the second phase of the study. The design of the survey used a cross-sectional survey design which focused on gathering information at a single point in time to "examine current attitudes, beliefs, opinions, or practices" of the respondents (Creswell & Guetterman, 2019, p. 386). A limited amount of qualitative data was also gathered during the first phase of this study from comments left in response to the three open response questions contained in the survey.

The second phase of the study gathered data through interviews of survey participants who were selected from those participants that completed the survey and who indicated their willingness to be interviewed. The interviews were performed using a semi-structured interview process where participants were asked a specific set of questions supplemented by additional non-structured questions to allow further exploration of responses provided to the structured questions (Merriam & Tisdell, 2016). A lengthy list of questions was not used since doing so might result in lack of focus and prompt extraneous information not sought by the researcher (Gay, et al., 2012). The questions were written to elicit participant knowledge of errors and behaviors based on the participant's knowledge and experiences in the workplace (Merriam & Tisdell, 2016).

The interview process collected data using individual interviews that were conducted over the telephone. An informed consent document was mailed to each participant and interviews were not performed until the consent forms had been signed and returned. Interviews were scheduled with each participant to minimize any impact to the participant's schedule. An audio recording of the interview was made with the consent of the participant. The recording allowed for transcription of the interview and coding after the interview.

Instruments. The instrument used to gather data for quantitative analysis was a survey constructed using an attitude scale that can capture a participant's beliefs toward a situation (Gay, et al., 2012). This type of survey is considered a descriptive survey which "does not assume a hypothesis but instead serves to collect data that will be reported to understand overall trends, incidence and prevalence of the outcome of interest" (Kelley-Quon, 2018, p.361). The survey questions employed an ordinal scale to provide the means to perform statistical analysis on the results (Creswell & Guetterman, 2019). Each question provided five choices to reflect the relative frequency of the occurrence noted in the question. The first five choices for each question regarding the frequency of occurrence are: 1. Never, 2. Rarely, 3. Sometimes, 4. Regularly, and 5. Often. This affords the opportunity for each survey participant to identify the frequency of occurrence for each item under study. A sixth response selection was included that provided each participant with the ability to indicate that they prefer not to respond to a question.

The 21 survey questions were arranged into three sections. The first section contained 11 questions focused on the type of errors that was previously identified during the review of the FAA's compliance actions. The errors were categorized as having involved one of the following attributes:

- Storage of aircraft parts and materials.
- Content of maintenance instructions.
- Scheduling and/or control of the maintenance process.
- Handling of maintenance documents, records, tags, forms, or placards.
- Installation of parts or equipment.
- Completion of maintenance entries.
- Maintenance performed using procedures that are not accepted or approved.
- Maintenance steps or tasks performed that deviate from written instructions or procedure.
- Maintenance steps or tasks that were overlooked or not performed.
- Handling, usage, or control of calibrated tools and equipment.
- Training requirements, recurrent training, or maintaining of qualifications.

A twelfth question was included that asked participants to describe other maintenance errors they have observed that do not fall into one of the previously mentioned 11 categories. A text block was provided to capture the responses.

The second section of the survey contained seven questions focused on the cause of maintenance errors. There were six causal factors identified during analysis of the air carrier responses noted in the FAA compliance action closure letters. The first six questions asked participants to indicate the frequency that each of these causal factors were responsible for maintenance errors that had been committed in their workplace. The six causal factors were identified as:

- Policies and procedures that are inadequate, lack sufficient detail, or do not contain current information.
- Failure to follow maintenance instructions or procedural requirements.
- Ineffective controls over the maintenance process or the lack of a measurement process.
- Maintenance and process instructions that contain inaccurate information or lacked sufficient detail.
- Maintenance personnel lacking sufficient training or knowledge.
- Failure to make maintenance entries or omitting relevant information in logbooks, maintenance records, or other record keeping documents.

A seventh question was included that asked participants to describe other types of causal factors other than those noted in the previous questions that they believed were responsible for causing maintenance errors in their workplace. The survey provided a text block to capture written responses to this question.

The third section of the survey was devoted to the identification of human factors that cause or contribute to maintenance errors known to the survey participants. The analysis of FAA compliance action closure letters noted that four types of human factors were mentioned as having caused or contributed to some of the maintenance errors that were reported. These human factors were identified as lack of awareness, complacency, distraction, and lack of attention. Participants were asked to indicate the frequency that each of these four human factors caused or contributed to maintenance errors. A fifth question was included to allow participants to list other human factors that they believed may have caused or contributed to maintenance errors in their workplace. A free text block was also provided to allow participants the ability to respond.

The fourth and final section of the survey contained three questions that elicited demographic information. The first question asked if the participants were actively engaged in the performance of aircraft maintenance. The choices were (a) yes, (b) no, and (c) prefer not to respond. The second question prompted the participants to indicate the category of aviation in which they are involved. The choices were (a) general aviation, (b) corporate aviation, (c) air taxi and commuter aviation that operate as unscheduled passenger services using aircraft with 19 seats or less, (d) regional airlines that provide scheduled passenger services using aircraft with 70 passenger seats or less, (e) major airlines that have scheduled passenger services using aircraft with more than 70 seats, (f) cargo carrier, (g) other, (h) none, and (i) prefer not to respond. The third question asked participants to indicate how many years of experience they have with aircraft maintenance activities. The choices were expressed in ranges identified as (a) no experience, (b) up to 2 years' experience, (c) 2 years but less than 5 years' experience, (d) 5 years' but less than 10 years' experience, (e) 10 years' but less than 20 years' experience, (f) greater than 20 years' experience, and (g) prefer not to respond. The survey questions used for this study are attached as Appendix A.

The instrument used to conduct the secondary phase of research was a list of semi-structured questions employed in the interview process to gather in-depth data for qualitative analysis. The interview method for gathering data is particularly useful as it can provide data that occurred in the past and is not observable (Gay, et al., 2012). Each interview was conducted by following a series of semi-structured open-ended questions that had been prepared in advance. Using standardized questions can minimize variation for data collection purposes (Patton, 2015). As the semi-structured questions were answered, additional questions were asked to help clarify or further explore information provided by the participant. An informal interview approach was adopted for non-standardized questions to further understand the information from each participant's perspective (Patton, 2015). The list of semi-structured questions that was developed and used during the interview process is attached as Appendix B.

Reliability and Content Validity

Establishing reliability and content validity within mixed methods research designs that incorporated both quantitative and qualitative research requires the use of several approaches to validate data quality and the interpretation of the results (Creswell & Plano Clark, 2018).

The reliability of the survey instrument used for the initial quantitative phase of this mixed-method research study must ensure that participant scores are consistent and meaningful with respect to the elements under study (Gay, et al., 2012, Creswell & Guetterman, 2019, Creswell & Plano Clark, 2018). Validity with respect to quantitative research is best described as how well an instrument measures what it is supposed to measure (Creswell & Guetterman, 2019, Robinson & Leonard, 2019). A test or survey is considered reliable if participants answer a question in the same manner that they answer related questions (Creswell & Guetterman, 2019).

According to Creswell and Guetterman (2019), to ensure reliability, it is important that the questions in the survey are written so that they are clear to the survey participants and that the method used to administer the survey are standardized. The survey used for this study was drafted using simple language and terms that should be understood by the participants, all of whom are required to understand the English language as a requirement for holding an FAA mechanic's certificate. Pre-testing of the survey was accomplished by test subjects chosen from the Tulsa, Oklahoma area who were known to the researcher and who were certificated mechanics with experience working for a major U.S. air carrier. They were asked to take the survey and provide their comments and recommendations. Their comments and recommendations were then used to further edit and improve the survey. The test participants were subsequently excluded from the purposeful random sample of participants selected for the survey. Once testing was completed, the final version of the survey was administered in paper format to the initial 100 participants selected for the study. An additional 900 participants that were selected from the sample population were sent a letter that requested their completion of the survey as an on-line survey accessible through the Qualtrics website. In both instances, the survey questions and the order in which they were listed remained unchanged.

Measuring the internal consistency of the instrument to support reliability was accomplished by examining how a participant's answers are scored throughout the survey using Cronbach's alpha. This test is applied to the survey results by comparing how the results for each survey question relate to each other and to the results of the entire survey (Gay, et al., 2012). Cronbach's alpha was developed by Lee Cronbach in 1951 as a means of measuring the internal consistency of a test or instrument and is expressed as a number between 0 and 1.0 (Tavakol & Dennick, 2011). To support the internal consistency of a test or survey, the questions should be interrelated with each other and unidirectional (Tavakol & Dennick, 2011). Cronbach's alpha values that range from 0.70 to 0.95 are considered acceptable values to indicate internal consistency although values in excess of .90 may suggest that several of the questions on the survey are measuring identical items (Tavakol & Dennick, 2011). A low alpha value may indicate that the survey questions are not interrelated or that there are not enough questions in the survey itself (Tavakol & Dennick, 2011).

Measuring the internal consistency of the survey questions was conducted using the survey data generated by the 48 participants who indicated they were primarily involved with the performance of aircraft maintenance functions on aircraft owned or operated by major air carriers. Of the 27 questions in the survey, 21 were designed as Likert style questions using the same series of ordinal frequency-based responses. Analysis was conducted using the software program, Statistical Package for the Social Sciences (SPSS) to measure Cronbach's alpha for these 21 questions. Cronbach's alpha was calculated on the entirety of the 21 questions and repeated using the data from the first 11 questions that focused on the frequency of specific error types and again on the remaining 10 questions that focused on the causal factors of maintenance errors.

The results of the measurements found that the Cronbach's alpha for the 21 questions was .915 which indicates a high level of internal consistency. Although readings in excess of .90 may suggest that some of the questions may be measuring identical items, other than the structure of the questions, each one is unique with respect to a specific type or error or causal factor. The measurement was repeated but limited to the 11 questions related to maintenance errors and this resulted in a Cronbach's alpha of .869 which also demonstrates a high level of internal consistency. The remaining 10 questions related to causal factors were also analyzed and were found to have a Cronbach's alpha of .839.

Cronbach's alpha was also calculated to determine how internal consistency would change upon the removal of each question from the three groupings that were measured. The removal of an individual question from each grouping resulted in a change to the Cronbach's alpha of plus or minus .01 which does not impact the overall reliability of the survey. The tables identifying the Cronbach's alpha for each group and the resultant change in alpha for each grouping if questions were deleted is attached as Appendix C.

Trustworthiness and credibility. Trustworthiness is defined as "a feature essential to the validity of qualitative research; is established by addressing the credibility, transferability, dependability, and confirmability of study findings" (Gay, et al., 2012, p. 632). Credibility is a key element of trustworthiness and is established by how well the researcher was able to describe the topic and how accurately the information represented in the study matches what was expressed by the participants (Bloomberg & Volpe, 2016, p. 162).

Trustworthiness and credibility can also be maintained through triangulation which involves the use of multiple sources or methods to provide a better understanding and corroboration of the research data (Bloomberg & Volpe, 2016). The mixed method design to be used for this study supports triangulation through the sequential use of quantitative methodology to acquire data followed by qualitative methodology to better understand the research problem (Creswell & Guetterman, 2019). Mixed-methods triangulation allows for comparative analysis of qualitative data with quantitative data to determine consistency (Patton, 2015). Comparison of the quantitative data gathered from the initial survey to the qualitative data gathered from the interviews and subsequent comparison to the inspection data acquired from the FAA provides triangulation and the basis for establishing trustworthiness and credibility of the research.

Reflexivity and positionality. Reflexivity is a self-conducted introspective review undertaken by researchers to understand the how and why they perceive, view, and interpret what they see and hear (Patton, 2015). Understanding one's own perspectives through self-reflection is critical to research since it can affect the gathering and analysis of data by introduction of bias (Patton, 2015). Reflexivity in this study requires that researchers continually examined their actions through self-reflection throughout the research process. (Bloomberg & Volpe, 2016). Patton (2015) defines reflexivity as a form of self-reflection whereby qualitative researchers must look inward at themselves and consider how they have been affected by "cultural, political, social, linguistically, and economic origins" (p.70). Reflexivity requires researchers to become self-aware so that they can understand what they know and how they came to know information (Patton, 2015). This information is useful in qualitative research as it helps researchers recognize how they formed their own perspectives while also allowing them to recognize the perspectives of those under study (Patton, 2015).

Understanding reflexivity has made me realize that much of what I already know has influenced the selection of my research topic. My previous work as a quality assurance specialist for a major U.S. airline has provided me with insight into known issues and problems. Knowing these issues provided an advantage for designing a study that would focus on elements related to maintenance errors and what may cause those errors. However, my prior knowledge may also adversely affect the study as it may blind me from seeing alternatives or becoming aware of perspectives held by the participants in my study. It is possible that I might subconsciously assume that all the research participants and readers of the research report have similar backgrounds and experiences that I hold. Having such a perception could impact the study by failing to fully explain or delineate certain concepts or outcomes. Alternatively, participants and readers of this study may have different levels of knowledge that could lead them to different interpretations.

As the researcher, I considered reflexivity throughout this study from the initial research design, development of instrumentation, gathering of survey data, and interviews through the final step involving data analysis to ensure that the perspectives of both participants and readers is maintained. This included ensuring that the focus this study on maintenance errors and causes was on those noted by the FAA during their surveillance activities of the four largest air carriers in the U.S. during the FAA's 2018 fiscal year. Maintenance errors and causes that may have been known to me but were not noted by the FAA or mentioned by any of the participants in this study were purposely omitted from this study.

Positionality is a consideration that qualitative researchers must consider regarding their interaction with participants. A researcher may have insider knowledge of the working environment under study and this can have an effect on that researcher's positionality with respect to the study (Merriam & Tisdell, 2016). While having insider knowledge may help a researcher better understand the subject of the research and identify the sample population, it can be detrimental if the study participants become suspicious of the researcher's motives perhaps thinking that the study is about them rather than the topic itself thus preventing the participants from speaking openly (Merriam & Tisdell, 2016). It is also possible that a researcher's positionality may be unintentionally introduced to the participants which could drive them to providing information that they believe would satisfy that researcher's agenda (Merriam & Tisdell, 2016).

To control positionality and prevent my knowledge of the aviation industry from affecting the researcher-participant relationship, I refrained from discussing my prior knowledge and work history with the participants. I introduced myself as a university student and discussed the topic of my study. I focused on asking the interview questions as they were described in the list of semi-structured interview questions and encouraged the participants to explain some of their observations. To ensure that the interviews were conducted with minimal interference from positionality, I allowed the participants to speak without influence and without acknowledging any knowledge I may have previously acquired from the industry. Fortunately, none of the interview participants asked if I had worked in the aviation maintenance environment under study therefore, I was never placed into a position where I would have had to explain my background and possibly influence the information provided to me by the participants. Awareness that my prior background and knowledge has a direct impact on my positionality and the impact it may have on the study participants has enabled me to avoid such consequences through suppression of any comments or statements that might influence the qualitative data gathered for the study.

Data Analysis

The first research question for this study was addressed using quantitative data gathered by the survey. This was supplemented by qualitative data from the three survey questions that elicited additional comments and the interviews where participants described what errors they have seen or experienced. This generated information that was analyzed to identify the types of errors that are committed. Information to answer the second research question was also obtained from quantitative data from the survey and the qualitative data provided by interviewed participants who were asked open-ended questions to provide further details regarding the causal factors for the errors that they had discussed. The third research question is exploratory and participants were asked during the interview process to identify what actions they have witnessed that had been implemented and were successful in the prevention of the maintenance errors. They were also asked for their opinions as to what other actions could have been taken to prevent such errors.

The mixed-methods approach toward research using an explanatory sequential design required the use of three phases for data analysis: the first involved the analysis of quantitative data, the second required analysis of the qualitative data, and the third required an analysis of how the qualitative data explains the quantitative data and answers the research questions (Creswell & Plano Clark, 2018). Quantitative interpretation is defined as "summarizing the major quantitative results and then comparing the results with the initial research questions asked to determine how the questions or hypotheses were answered in the study" (Creswell & Plano Clark, 2018, p. 216). For this study, the survey results were analyzed to first identify what errors, casual factors and human factors are most prevalent for maintenance activities performed on aircraft operated by major airlines that have more than 70 seats. It was possible to segregate this data from survey responses provided by participants engaged in maintenance activities other than that performed for major airlines due to the demographic survey questions that were answered by the participants. Descriptive statistics were used to identify the frequency and central tendency to analyze the survey results (Creswell & Guetterman, 2019). Analysis of Likert-type questions that have responses structured as ordinal measurement scales are best analyzed using frequencies to determine variability and by determining the mode to identify central tendency (Boone & Boone, 2012). Frequency for each of the questions was determined by identifying the number of times a specific response to a question was chosen (Gay, et al., 2012). Measures of central tendency was measured by determining the mode which is the numerical response chosen more often by the participants than the other responses for each question (Gay, et al., 2012).

Qualitative analysis was conducted by examination of the responses provided for the three open-text questions contained in the survey and of the data acquired through the interview process. The detailed review of the raw data followed by categorizing of the data into patterns can reveal findings or trends (Patton, 2015). Discovery of similar patterns and themes from the interview data allowed for the identification and categorization the types of maintenance errors, the contributing factors, and preventative measures that have been or were recommended to prevent the errors. The content analysis method was used for "identifying, organizing, and categorizing the content of narrative text" followed by the use of deductive analysis to "examining the data for illumination of predetermined sensitizing concepts or theoretical relationships" (Patton, 2015, p. 551).

The analysis of the quantitative data gathered during the first phase of this research provided the basis for further qualitative inquiry and the resultant qualitative data was then used to answer the research questions. The volume of data generated by the participant surveys and interviews required a structured method to code the results for analytical review. This was accomplished using Dedoose software provided by SocioCultural Research Consultants, LLC (2019) that allows for the importation of survey data from data collections programs such as Qualtrics and Survey Monkey for quantitative analysis in addition to manual entry provisions of the survey data. The Dedoose program also accepted transcripts of interviews which were then coded and analyzed using the qualitative analytical visual display features provided by the program. The results of the data analysis for both the quantitative data and qualitative data were linked together in a joint display to provide a visual representation of how the qualitative findings support the quantitative results (Creswell & Plano Clark, 2018).

Summary

This study was conducted using a mixed-methods, explanatory sequential research design wherein research was conducted in two phases with the first focused on the acquisition of quantitative data followed by a second phase that acquired qualitative data. The participants for this study were identified as individuals who held a mechanic's certificate issued by the FAA and who perform maintenance on aircraft having more than 70 seats and are owned or operated by major airlines. Purposeful selection was conducted from the total population of 270,000 FAA certificated mechanics domiciled in the United States to identify the sample population to 12,064 individuals that resided within 15 miles of the major airport maintenance hubs belonging to American Airlines, United Airlines, Delta Air Lines, and Southwest Airlines located in Tulsa, Oklahoma; Chicago, Illinois; Dallas, Texas; Ft. Worth, Texas; Atlanta, Georgia; and, Houston, Texas. Random selection was performed to identify 1000 individuals each of whom were sent a request by USPS mail to participate in the study. A total of 71 participants completed the surveys and of those, 48 participants met the selection criteria for inclusion in the first phase of the study. Of these 48 participants, nine participants were interviewed for the second phase of the study.

Data collection for the first phase of this study was accomplished using a survey comprised of 27 questions of which 21 were designed as Likert style questions using the same series of ordinal frequency-based responses to measure the occurrence of specific maintenance errors and causal factors. The responses to these questions provided quantitative data for analysis using descriptive statistics to determine the predominance of certain errors and causal factors that were observed in the maintenance environment. The survey also included three open-ended questions which provided additional qualitative data for analysis. The second phase of the study collected qualitative data from interviews conducted with nine of the survey participants. The interviews were conducted using a series of semi-structured open-ended questions designed to elicit greater detail regarding maintenance errors and causal factors known to the participants. The interviews were transcribed, and information was coded into categories and sub-categories to provide data for qualitative analysis.

The reliability and validity of the survey was initially performed through pre-testing of the survey questions by test-subjects that held FAA mechanics certificates and worked for a major U.S airline. The final draft of the survey incorporated changes as a result of the testing and test-subject comments. Post reliability testing of the survey conducted on the responses provided by the participants to the 21 Likert style questions found that the Cronbach's alpha was .915 indicating a high level of internal consistency. The testing was conducted again by separating the questions into two groups of 11 and 10 which resulted in Cronbach's alpha scores of .869 and .839 respectively indicating acceptable levels of internal consistency. The validity and trustworthiness of the data was established through triangulation and analysis of consistency between the quantitative data and qualitative data gathered by this mixed-method study.

Analysis of the quantitative data was performed using descriptive statistics to determine the predominate errors and causal factors as reported in the survey by the participants. Qualitative data was analyzed by initially transcribing the participants' interviews and coding the information into the Dedoose software platform. The results from the analysis of the quantitative and qualitative data allowed for the identification of predominate maintenance errors and causal factors common to the performance of maintenance on aircraft operated by major U.S. certificated air carriers.

CHAPTER IV

FINDINGS

The findings from this mixed-methods study are presented in two sections. The first section is focused on the findings relative to the quantitative and qualitative data gathered using the survey administered to the research participants. The participants were asked to respond to 21 questions by selecting an appropriate response from a set of ordinal frequency-based responses that were repeated for each of the questions. The survey consisted of 11 questions focused on maintenance errors, six questions focused on causes related to maintenance errors, and four questions pertaining to human factors that contribute to the commission of maintenance errors. These results were analyzed using descriptive analysis techniques to determine which of the maintenance errors, causal factors and human factors are more prevalent than others from the participants' perspectives. Descriptive statistics used for the analysis of each question included the determination of the mode and the frequency for each of the response selections calculated as a percentage of the total responses for that question. The survey also included three open-ended questions that allowed participants the ability to add additional comments relative to errors, causal factors, and human factors. These comments are also included in the first section of this chapter dedicated to the results and analysis of the survey data.

The second section presents the findings that resulted from the interviews conducted of the nine participants who agreed to participate in the qualitative phase of this study. Each participant was interviewed using a series of semi-structured questions that were designed to gather responses relative to specific errors known to that participant (See Appendix B). The interviews were recorded, transcribed, and systematically coded to identify the types of maintenance errors, causal factors, human factors, and corrective action measures that were implemented. Participants were also asked to identify additional corrective action measures they believe should have been taken to prevent the errors from recurring. Although each error or incident as described by the participants was associated with one or more causal factors that impacted the error, this study does not attempt to define such associations. The interview findings are presented as a qualitative review of errors and causal factors by category. This is followed by a description of corrective action measures that had been implemented to mitigate particular errors along with suggested corrective actions as recommended by the participants.

Survey Findings

Maintenance Errors. The results from the first section of the survey containing 11 questions are tabulated and displayed in Table 1. Analysis of descriptive statistics are based on the number of responses received for each question and adjusted for instances where survey participants chose not to respond. Calculating the mode is accomplished by determining the response that was selected by the highest number of participants for each question (Gay, et al., 2012). Identification of the mode helps establish a measure of central tendency or the middle score among a group of scores (Gay, et al., 2012). The first six questions were found to have a higher mode of three whereas the last five questions had a mode of two. This indicates that the survey participants observed a greater frequency of errors with respect to the first six questions. Closer review of the frequencies attributed to the responses for these six questions found that over 50 percent of participants indicated they selected *Sometimes* for having seen errors concerning the handling of maintenance documents, records, tags, forms, or placards; errors with the installation of parts or equipment; and errors regarding the completion of maintenance entries. Of these three categories, errors with respect to the handling of maintenance documents, records, tags, forms, or placards was observed *Regularly* by 22.9 percent of the participants and *Often* by another 10.4 percent. Errors related to the completion of maintenance entries were observed *Regularly* by 27.7 percent and *Often* by 8.5 percent of the participants.

Table 1

Frequency of Maintenance Errors

Variable	n	Mode	Never	Rarely	Sometimes	Regularly	Often
			n %	n %	n %	n %	n %
Have seen errors with respect to the storage of parts and materials	48	3	4.2%	27.1%	47.9%	12.5%	8.3%
Have seen errors with the content of maintenance instructions	48	3	0.0%	20.8%	45.8%	25.0%	8.3%
Have seen errors with the scheduling and / or control of the maintenance process	48	3	2.1%	33.3%	39.6%	18.8%	6.3%
Have seen errors with the handling of maintenance documents, records, tags, forms, or placards	48	3	0.0%	16.7%	50.0%	22.9%	10.4%
Have seen errors with the installation of parts or equipment	48	3	2.1%	39.6%	52.1%	4.2%	2.1%
Have seen errors with the completion of maintenance entries	47	3	0.0%	12.8%	51.1%	27.7%	8.5%
Have seen errors regarding maintenance steps or tasks performed using procedures that are not accepted or approved by the FAA	47	2	21.3%	46.8%	27.7%	4.3%	0.0%
Have seen errors regarding maintenance steps or tasks performed that deviate from written instructions or procedures	47	2	8.5%	42.6%	42.6%	6.4%	0.0%
Have seen errors regarding maintenance steps or tasks that were overlooked or not performed	47	2	12.8%	44.7%	31.9%	10.6%	0.0%
Have seen errors with the handling, usage, or control of calibrated tools and equipment	48	2	18.8%	52.1%	22.9%	6.3%	0.0%
Have seen errors with training requirements, recurrent training, or maintaining of qualifications for those assigned to perform maintenance	48	2	12.5%	43.8%	29.2%	10.4%	4.2%

Note. n = number of total responses received for the survey question; n % = the percentage of responses (n) received for each response; Mode = the most common response received for the survey question using numerators of 1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Regularly, and 5 = Often.

It was noted that in addition to the three errors that had mid-point frequency distributions of over 50 percent, a fourth error related to the content of maintenance instructions was observed to have high frequency distributions at the far right of the frequency scale. This error was seen *Regularly* by 25.0 percent of the participants and *Often* by 8.3 percent. The data gathered by the survey is considered ordinal non-parametric data and as such the precise interval between each of the responses is un-defined. However, by calculating the total percentage of survey participants that answered each question with a selection of *Sometimes*, *Regularly* or *Often*, the top three errors observed by the majority of participants become more apparent and were identified in order of percentages as follows:

87.3 percent Errors observed with the completion of maintenance entries

83.3 percent Errors observed with the handling of maintenance documents, records, tags, forms, or placards

79.1 percent Errors observed with the content of maintenance instructions

Participant Comments Regarding Maintenance Errors. The 12th question on the survey asked participants to list other types of maintenance errors that they may have observed and to comment on how likely these errors occur during the performance of maintenance. Eighteen participants provided comments although the majority of the comments related to causal factors and not the identification of other types of errors. The comments attributed to causal factors were subsequently added to the data discussed in later sub-sections of this study related to causal factors and human factors.

There were no comments that identified errors not already included in the survey, but several of the comments provided examples of certain errors for consideration. One survey participant commented that “confirmation checks or required inspection check items [were] being completed by the same individual or not completed at all, sometimes.” The survey did not include a specific question related to the observation of errors committed by a person who completes tasks that were intended for completion others. However, this observation can be classified as an extension of errors associated with maintenance steps or tasks that were overlooked or not performed specifically if the secondary inspections were required to be performed by a different individual. Alternatively, the observation can be associated with maintenance errors associated with the performance of maintenance steps or tasks that deviate from written instructions or procedures given that it was not completed precisely as noted in those instructions. The error itself is significant as it illustrates that a key maintenance task that requires a second individual to verify the work performed by another was not performed.

Another participant stated “the issue I have seen is mostly with unlicensed mechanics who use tribal knowledge without manual reference. Often these people don't know how to look it up and fail probably 80 percent of the time to check aircraft effectivity.” This observation can be associated with several of the errors noted in the survey including errors associated with training requirements, errors with the performance of maintenance tasks that deviate from instructions, and errors concerning the installation of parts and materials. What is significant regarding the comment is the observation relates to the use of unlicensed mechanics that perform maintenance for major air carriers. The content of the survey was targeted toward the sample population of licensed mechanics and did not include questions regarding the actions of unlicensed mechanics. Although this study was not focused on this population of individuals, it is noted that errors identified in the survey can also be committed by maintenance personnel who are unlicensed individuals.

An example was provided for an error related to maintenance steps or tasks performed that deviate from written instructions and procedures. The survey participant commented:

> Maintenance instructions are for the most restrictive of tasks i.e... pull circuit breakers (multiple) when powering down aircraft accomplished [the] same tasks much quicker. You are still removing power but in a different manner. I have seen FAA Inspectors issue a violation against AMTs because they didn't follow [the manual] "exactly". Example is the fault isolation manual, FAA Inspectors violate AMTs regularly because they do not replace the components listed in the order of the FIM manual. Most Fault Isolation Manuals are "constantly" under revision due to errors and inaccuracies.

This comment is of interest as it describes errors related to the performance of work that deviates from published instructions. However, the comment also illustrates that errors exist with the maintenance instructions themselves which may lack alternative methods that can be used to perform maintenance tasks or may list instructions that are out of sequence to the steps necessary to perform maintenance. The comment also notes that deviation from published manuals or failure to follow the specific sequence of steps in the instructions have resulted in the issuance of compliance actions by the FAA.

Causal Factors. The results from the second section of the survey containing six questions related to what may cause maintenance errors are tabulated and displayed in Table 2. Using the same methodology used to analyze error categories, the causal factors were also analyzed and frequencies displayed with calculations based on the number of responses for each question and adjusted for questions to which some participants may have chosen not to respond. Four of the six questions were found to have a mode of three whereas the other two questions had a mode of two. However, examination of the response frequencies for the two questions that had a mode of two found that one question received high frequency responses of *Regularly* and *Often* that was comparable to similar response frequencies for the four causal factor questions that were found to have a response mode of three.

Table 2

Frequency of Maintenance Error Causal Factors

Variable	n	Mode	Never	Rarely	Sometimes	Regularly	Often
			n %	n %	n %	n %	n %
Policies and procedures that are inadequate, lack sufficient detail, or do not contain current information cause maintenance errors	48	3	8.3%	37.5%	41.7%	10.4%	2.1%
Failure to follow instructions or procedural requirements cause maintenance errors	48	3	4.2%	39.6%	43.8%	10.4%	2.1%
Ineffective controls over the maintenance process or the lack of a measurement process cause maintenance errors	47	2	10.6%	55.3%	25.5%	6.4%	2.1%
Maintenance and process instructions that contain inaccurate information or lacked sufficient detail cause maintenance errors	48	3	12.5%	35.4%	39.6%	2.1%	10.4%
Maintenance personnel lacking sufficient training or knowledge cause maintenance errors	48	2	8.3%	37.5%	31.3%	10.4%	12.5%
Failure to make maintenance entries or omitting relevant information in logbooks, maintenance records, or other record keeping documents cause maintenance errors	48	3	16.7%	33.3%	37.5%	8.3%	4.2%

Note. n = number of total responses received for the survey question; n % = the percentage of responses (n) received for each response; Mode = the most common response received for the survey question using numerators of 1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Regularly, and 5 = Often.

Prioritization using the mode alone was insufficient to identify the primary cause of maintenance errors. Selecting the causal factor having the highest percentage calculated for the mid-point frequency selection of *Sometimes* would not take into consideration the high response percentages allocated to the greater frequency responses for *Regularly* and *Often*. Therefore, the six causal factors were ranked in order from high to low by totaling the frequency percentages allocated to the selections of *Sometimes*, *Regularly*, and *Often* by the participants in the survey.

56.3 percent Failure to follow instructions or procedural requirements.

54.2 percent Policies and procedures that are inadequate, lack sufficient detail, or do not contain current information.

54.2 percent Maintenance personnel lacking sufficient training or knowledge.

52.1 percent Maintenance and process instructions that contain inaccurate information or lacked sufficient detail.

50.0 percent Failure to make maintenance entries or omitting relevant information in logbooks, maintenance records, or other record keeping documents.

34.0 percent Ineffective controls over the maintenance process or the lack of a measurement process.

The totalization of frequency percentages for the mid to high frequency responses selected by the participants illustrate that, with the except of the causal factor regarding ineffective controls over the maintenance process or the lack of a measurement process, all other causal factors were equally identified as responsible for maintenance errors.

Participant Comments Regarding Causal Factors. An open-ended question was included in the survey immediately following the causal factor questions that prompted participants to list any other causal factors that they may have observed and to comment on how likely the causes contributed to maintenance errors. Although none of the comments revealed causal factors that were not already identified in the survey, the comments provided further details and qualitative data that illustrated the impact some of the causal factors have on aircraft maintenance.

A comment related to the failure to follow instructions or procedural requirements was attributed by a participant to instances when a mechanic is "rushing through a job and not reading all of the instructions". The pressure to complete work assignments was also cited by another survey participant who noted "members of management have pressured people in order to maintain schedule resulting in errors". A third survey participant provided another comment that errors can result from pressures exerted on the mechanic:

> The error comes from the pressure put upon a technician by supervision, to perform a job with improper tooling, resulting in damage to the aircraft, or personnel injury to the technician. This is not a widespread problem, but a problem, just the same, that still happens more than this technician cares for.

With respect to maintenance and process instructions that contain inaccurate information or lacked sufficient detail, one participant acknowledged that the introduction and assignment of a new modification to an aircraft can result in multiple errors with the instructions, all of which require correction as they are discovered. This type of causal factor was echoed by another participant who noted that inaccurate information or lack of sufficient detail is the result of "poorly written MX [maintenance] procedures written by someone who has no MX [maintenance] experience". Other survey participants voiced additional concerns that too much information added to the maintenance and process instructions cause errors and confusion. For instance, one participant noted a practice whereby one air carrier creates and incorporates consolidated listings of multiple manufacturer part numbers into the maintenance instructions and this created confusion that has led to the installation of incorrect parts on aircraft by mechanics who relied on these instructions as the authority for eligibility. Another survey participant commented that part installation errors were partly due to "illegal parts due to incorrect substitutions during the purchasing process".

Problems are not only limited to the contents of maintenance manuals but can extend to higher level airline policy manuals. One survey participant noted that "policies and procedures are so elaborate and convoluted that it is difficult to keep up with it when it should (must) be included in applicable maintenance manual or job card".

Other comments regarding the cause of maintenance errors were directed towards issues where maintenance personnel lack sufficient training or knowledge. One participant noted that "training requirements are given 'extreme latitude' by the airlines and they take every advantage to reduce costs by getting the absolute minimums approved". This observation coincides with another survey participant's view regarding how an airline selects its mechanics:

> Usually, the training and knowledge that is lacking is due to using HR, [Human Resources] who know absolutely nothing about aircraft maintenance, to decide

> who moves forward in the hiring process. Combine that with minimum training requirements for aircraft types after hiring = [equals] errors.

The training process itself was the subject of a comment made by a survey participant who noted that those who conduct training may have ulterior motives regarding the completion of the training assignment: “When the training process is performed by peers that have a vested interest in the grading and documentation of the training then there is a major gap between what is being taught and what actually is learned”. This was further supported by comment from another survey participant who wrote “the training department's interest is getting the name and employee number on a document that shows the employee knows the information”. Together, these comments reflect that the effectiveness of maintenance training given to maintenance personnel is impacted by training instructors who are more interested in the completion of the assignment rather than the training itself. The skill level of mechanics was also noted by a survey participant who commented:

> The ability of the mechanic to look up the repair for the right aircraft is a big problem. Also, many workers can't read an electrical drawing or blueprint. You would be surprised to see how many maintenance workers can't properly use a simple volt ohm meter…. classroom training isn't enough. There should be 100 percent pass of the proper use of common tools. There should be follow-up training by the shop Tech Crew Chiefs after classroom instruction.

Mechanics are affected by more than just the lack of maintenance specific training. A comment was submitted by a survey participant which noted the “failure to understand and use proper grammar, and an overall lack of knowledge of the use of the

English language causes inaccurate and incomplete documentation of corrective actions taken to address discrepancies”. Although English is the universal language recognized for most aviation activities including maintenance, the participant’s comment regarding comprehension for those to whom English is a second or third language is an area of concern that was not addressed by this research. However, it is a logical observation that those who may not fully comprehend the English language may require additional training to avoid misinterpretation of maintenance instructions or errors documenting repairs.

Proper training of maintenance personnel is essential to avoid the commission of errors during aircraft maintenance. One survey participant summarized this on the survey by stating that “poorly trained mechanics in a fast-paced environment leads to the majority of the mistakes”. Training issues may also have roots that predate the hiring of mechanics by major U.S. air carriers as noted by a survey participant who submitted this comment:

> I've witnessed way too many A&P technicians that lack the skill and competency to be working on any kind of aircraft. I often wonder how these techs even get through the aircraft maintenance schools and obtain an FAA airframe and powerplant license.

Human Factors. The results from the third section of the survey containing four questions regarding the frequency that each human factor contributes to maintenance errors is displayed in Table 3. As with the descriptive statistics related to maintenance errors and causal factors, the calculations are based on the number of responses for each question that were adjusted for instances where participants preferred not to respond.

The descriptive statistics noted that the questions for all four of the listed human errors resulted in responses with a mode of three. However, the four questions had different frequency response rate percentages particularly for the three higher response rates of *Sometimes*, *Regularly*, and *Often*.

Table 3

Frequency of Human Errors that Induce Maintenance Errors

Variable	n	Mode	Never	Rarely	Sometimes	Regularly	Often
			n %	n %	n %	n %	n %
Lack of awareness cause maintenance errors	48	3	2.1%	37.5%	52.1%	4.2%	4.2%
Complacency cause maintenance errors	48	3	2.1%	20.8%	45.8%	22.9%	8.3%
Distractions cause maintenance errors	47	3	0.0%	25.5%	59.6%	14.9%	0.0%
Lack of attention cause maintenance errors	47	3	0.0%	27.7%	57.4%	12.8%	2.1%

Note. n = number of total responses received for the survey question; n % = the percentage of responses (n) received for each response; Mode = the most common response received for the survey question using numerators of 1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Regularly, and 5 = Often.

To provide some degree of prioritization between the four human factors addressed in the survey, they were ranked in order from high to low in accordance with the total of the response rate percentages allocated to participant selections of *Sometimes*, *Regularly*, and *Often.*

77.0 percent Complacency cause maintenance errors

72.3 percent Lack of attention cause maintenance errors

64.5 percent Distractions cause maintenance errors

60.5 percent Lack of awareness cause maintenance errors

Comparing the total percentage of participants who observed these human factors at higher frequencies of *Sometimes* or greater illustrates that complacency and lack of attention were identified by the survey participants as the two key factors that caused or contributed to maintenance errors. However, the remaining two human factors must be considered equally important given that over 50 percent of the respondents indicated that they are also contribute to errors at frequencies of *Sometimes* or higher.

Participant Comments Regarding Human Factors: Participants in the survey were asked to identify additional human factors that they believe cause or contribute to maintenance errors. One participant cited physical and environmental factors such as "fatigue or heat or working too many hours" can cause mechanics to "not follow written instructions carefully". Several participants identified that the lack of morale, stress, or pressure to accomplish tasks is also a contributor to errors.

Examples to support the effect that certain human factors have on the performance of maintenance were provided as written comments on the survey. Regarding distractions, one survey participant stated maintenance work is regularly affected by "several outside vendors that create distractions in the workplace". Another participant mentioned that "when entertainment devices such as television, laptops and video players are allowed in work areas there is bound to be lapses in concentration". Lack of attention was illustrated with another survey participant's comment that mechanics were "doing the work like they did at a previous employer, but not following [the policies of] the new employer who follows the manual instructions".

Complacency was the subject of several emphatic comments submitted by survey participants. One participant stated: "Complacency! Attitude of 'that's how we've always done it.' is common in aviation MX [maintenance]". Another survey participant commented: "Ignorance causes most errors in any workplace. LOOK IT UP, AND IF YOU DON'T KNOW....ASK!!".

Interview Findings

Maintenance Errors. Coding and analysis of the maintenance errors recounted by the participants during the interviews noted that there were eight instances of maintenance errors related to the installation of parts followed by four instances related to the storage and handling of parts. Other errors included three instances related to the performance of maintenance steps or tasks that deviate from written instructions or procedures, three instances where maintenance steps or tasks were not preformed or overlooked, three errors with the content of maintenance instructions, two errors concerning the scheduling and/or control of the maintenance process, one error with the completion of maintenance entries, and two maintenance related errors that fell outside of the categories listed in the original survey. No errors were mentioned by the participants with respect to the handling of maintenance documents, records, tags, forms, or placards; errors with maintenance steps or tasks performed using procedures that are not accepted or approved by the FAA; errors with the handling, usage, or control of calibrated tools and equipment; or errors with respect to training requirements. The following is a description of the errors sorted by classification and paraphrased according to the comments provided by the participants:

Errors related to the installation of parts.

- Flight augmentation computers were not properly secured in the aircraft electronics compartment and had slid out of their mounting racks during flight (Participant A).
- A brake anti-skid module had been installed on the aircraft with its two high pressure hydraulic lines reversed (Participant B).

- Installation errors were made with the attachment of the ground shielding wiring for the wing slat proximity sensors (Participant E).
- A flight control actuator fitting was mis-drilled during installation onto the aircraft (Participant F).
- A structural support doubler was mis-drilled during installation on the fuselage (Participant F).
- A hydraulic actuator failed a pressure test due to an o-ring that had been installed in the incorrect order (Participant G).
- Incorrectly sized hardware was installed to secure the anti-ice ducting to the engine nose cowling (Participant G).
- An incorrect elevator/aileron control computer was installed on an aircraft that had been previously modified for a different version of the computer (Participant H).

Errors related to the storage of parts and materials.

- Serviceable and unserviceable parts were comingled in the same storage bins (Participant G).
- Hoses, lines, and other parts with openings were not stored with protective caps or covers over the openings (Participant G).
- Movement of hoses and tubing from one location to another was performed without caps or protective covers in place to protect against contamination (Participant G).

- Hardware and other parts, some of which were unidentified or from different manufacturing lots, were comingled together in storage bins and drawers (Participant G & H).

Errors related to the deviation from instructions or procedures.

- Elevator free-play checks were performed to airline instructions which deviated from the manufacturer's instructions (Participant C).
- Procedures were not followed during push-back of an aircraft from the maintenance hangar resulting in a tow bar disconnect (Participant C).
- An aircraft was operated with two aircraft spoilers that had been placed into a maintenance configuration instead of operational configuration as required by the maintenance instructions (Participant H).

Errors related to steps or tasks not preformed or overlooked.

- Wing to body fairing fasteners were not torqued upon installation as required by the aircraft maintenance instructions (Participant D).
- Failure to release the main landing gear oleo strut pressure in accordance with instructions prior to removal and partial disassembly of the landing gear (Participant E).
- Circuit breakers had been pulled in addition to others specified by the maintenance instructions and were not reset following maintenance. (Participant H).

Errors related to the content of maintenance instructions.

- A lavatory door hinge pin that was discovered to have protruded through the top of the fuselage had not been previously inspected due to maintenance instructions that limited inspection to the lower lavatory door hinge pin (Participant C).

- Work card instructions that had been re-written into a different format were found to contained numerous errors (Participant F).
- Instructions were not broken down far enough to cover all the steps required to perform the maintenance task (Participant I).

Errors related to the scheduling/control of the maintenance process.

- An aircraft that was not qualified for Extended Twin-Engine Operations Performance Standards (ETOPS) was scheduled and flown on an extended over-water flight (Participant A).
- Aircraft scheduled for repetitive inspections had over-flown the dates or flight hours on which the inspections were due (Participant A).

Errors with the completion of maintenance entries.

- Maintenance personnel signed for the accomplishment of an ETOPS inspection in the logbook for a non-ETOPS aircraft (Participant A).

Other maintenance related errors not categorized.

- A mechanic operating a tug was pulling an aircraft out of the hangar and ran the wing tip into the side of the hangar (Participant F).
- A composite flight control being cured under pressure in an autoclave was damaged when the vacuum bag surrounding it ruptured (Participant I).

Causal Factors. Coding and analysis of causal factors was performed using information gathered during the interview process. Each of the participants were asked to comment as to the causal factors related to the maintenance errors they had discussed.

Some of the participants provided multiple causal factors for each error therefore each causal factor was independently coded for this study. They were also asked to identify any outside factors beyond those described in the initial survey that they believe contributed to the errors. There were 11 reported instances where errors were caused by maintenance and process instructions that contained inaccurate information or lacked sufficient detail. Nine instances were reported where the failure to follow instructions or procedural requirements contributed to the errors. Five instances were reported where the lack of training or knowledge contributed to the maintenance errors. One instance was described where the lack of controls over the maintenance process was responsible for an error. No instances were reported of causal factors related to the omission or failure to make maintenance entries or causal factors related to the inadequacies of policies and procedures. However, there were five instances of causal factors mentioned by participants that do not fit the elements previously identified on the survey. The following are paraphrased descriptions of the causal factors provided by the participants and sorted by classification:

Instructions that are inaccurate or have insufficient information.

- The sequence used for torquing a bolt on an elevator and measuring free play was incorrect and did not match instructions published by the manufacturer (Participant C).
- Inspection instructions did not include the requirement to inspect the upper lavatory hinge pin for migration (Participant C).

- Procedures for pushback of aircraft following maintenance at the hangar failed to address the difference of procedures to be followed when pushback is accomplished by a Captain instead of a mechanic (Participant C).
- Work card was incorrectly titled and used to inspect the main landing gear axle damage for impact damage although the work card instructions were specifically written for overheat damage to the axle (Participant D).
- Work card in use by mechanics was found to have multiple errors that required work stoppage until it could be revised with instructions that could be followed by the mechanics (Participant F).
- The assembly illustrations for the hydraulic actuator showed the assembly of the o-rings and seals in the wrong sequence (Participant G).
- Minimum Equipment List (MEL) procedures regarding the lock-out of spoilers contained general information and lacked concise maintenance instructions specific to the lock-out of a specific spoiler set (Participant H).
- Illustrated Parts Catalogs (IPCs) contained superseded part numbers and parts not applicable to the airline's fleet which caused confusion (Participant H).
- Maintenance manuals were not revised in a timely manner to preclude the use of outdated information by mechanics (Participant I).
- Work Cards contained complex maintenance instructions that required work from multiple mechanics over several shifts to complete. However, the instructions on the work cards lacked enough space for individual mechanics to sign for the work they had accomplished (Participant I).

- Maintenance check card instructions were written out of sequence compared to how the maintenance work was accomplished on the aircraft (Participant I).

Failure to follow instructions or procedural requirements.

- The mechanic that installed the flight augmentation computers failed to follow the maintenance instructions which required that the computers be locked into place upon installation to the aircraft (Participant A).
- High pressure hydraulic lines were reversed when installed to the brake anti-skid module in contrast to the correct instructions noted in the maintenance manual and illustrations (Participant B).
- Mechanic failed to depressurize the correct aircraft hydraulic system in accordance with maintenance procedures prior to towing the aircraft (Participant C).
- Mechanics installed wing to fuselage fairings using an impact gun and failed to torque screws after installation as required by the maintenance manual (Participant D).
- The left main landing gear strut was not depressurized completely in accordance with the maintenance instructions before the landing gear was partially disassembled for removal from the aircraft (Participant E).
- Mechanic that was pushing an aircraft out of the hangar did not follow procedures causing substantial damage to the aircraft. (Participant F).
- Mechanics had installed the wrong fasteners before discovering that the maintenance manual had been previously revised to identify the correct hardware (Participant G).

- Circuit breakers were not re-configured or re-set after completion of work in accordance with maintenance manual requirements (Participant H).
- Incorrect elevator aileron control computer was installed on an aircraft contrary to specific notes in the illustrated parts catalogue (IPC) that identified the specific computers that were eligible for installation on aircraft that had or had not been modified (Participant H).

Lack of training or knowledge.

- Lack of training on how to access various maintenance manuals and IPCs to determine correct part numbers and effectivity to an aircraft (Participant H).
- Shop mechanics not normally assigned to aircraft overhaul are required to take computer-based training on certain aircraft systems such as emergency slides but lack familiarity and intimate knowledge to perform the work when temporarily re-assigned to perform such maintenance on the aircraft (Participant I).
- The mechanic that failed to depressurize the landing gear strut prior to removal from the aircraft may not have been properly trained (Participant E).
- Mechanics that had difficulty attaching the ground shielding on wires for the slat proximity sensors lacked skills gained through experience regarding the amount of shielding to cut back and how much heat to apply (Participant E).
- The older age of the workforce will drive many to retire, and the airlines will be losing the knowledge held by those individuals. New mechanics that are mentored by some of the older mechanics may have been taught bad habits

which they may follow unless the newer mechanics are re-educated or educated correctly when they are initially hired (Participant B).

Ineffective or lack of controls over the maintenance process.

- Existing controls to ensure that aircraft are re-inspected at required intervals at through stations or overnight stations were ineffective (Participant A).

Other causal factors that were not categorized.

- Management's push to have work completed quickly leads to mechanics taking shortcuts while performing maintenance (Participant B).
- Lack of computers and printers or equipment that is broken prevents mechanics from accessing maintenance instructions or printing copies which contribute to the commission of errors (Participant B and Participant H).
- Upper management's focus on expediting work accomplishment can cause mechanics to avoid spending time reading the maintenance instructions (Participant D).
- Mis-drilled holes in fittings and doublers were caused by human error (Participant F).
- Unavailability of protective end caps, plugs, and fittings contribute to errors involving the storage and handling of hoses, tubes and other parts with un-covered ports and openings (Participant G).

Human Factors. The participants were asked to identify any human factors that they believe contributed to the errors that they had discussed during the interview. The comments provided were coded into four human factors categories previously listed in the survey. Many of the comments were directed toward complacency followed by lack of attention and lack of awareness. Distractions were not cited by the interview participants, but several commented that stressful conditions imposed by time constraints and management oversight drove some to take short cuts while performing maintenance. Stress was not one of the categories identified in the survey, but comments attributed to it are identified and reported as a separate category for non-categorized human factors.

Complacency. Several participants cited complacency as a significant human factor that contributed to the commission of errors. They attributed the repetitive nature and simplicity of the maintenance tasks as the element which would drive a mechanic toward complacency. While describing an error that resulted in aircraft damage, Participant F commented that complacency results from the "kind of task you do day in and day out" and "I've done this 100 times". This reasoning agrees with similar comments made by Participant D who stated:

> Unless it's some AD driven task, if a mechanic is doing something over and over and over again, they will not consult the manual. That would be like tire changes. I know it's wrong, but sometimes I do get it. If you were to use the manual every single time, it would take you 10 times longer to do some things. That is a very, very common thing for repetitive tasks, not to look it up (Participant D).

Familiarity with repetitive maintenance tasks drives complacency with respect to the need to review the manual instructions prior to performing the tasks. Avoiding the review of the maintenance tasks is seen as the means to save considerable time expended to complete the maintenance tasks. This attitude was also described by another participant who commented:

> I think a lot of times it's just a time factor. It takes time to look that stuff up and even if you have a simple task in front of you, it's real [*sic*] easy to just take it apart, see the broken or worn part, replace it, and put the same or equivalent fasteners back in it that you took out (Participant G).

The amount of time required to review maintenance instructions can drive mechanics to read certain sections of the maintenance instructions and skip others. Participant H offers an example of how haste can cause a mechanic to miss important information:

> I think it's haste. I think a lot of it's being in a hurry. There's [*sic*] some very sharp guys out there. They maybe are too sharp, I'll put it this way. And they're like, "Okay that makes sense for me to pull the circuit breaker and leave it open, so we're good there, and I don't need to read that last part. Last part is a bunch of cautions," and I know because I've done it too before in the past. "I know better. That's just a disclaimer at the end so I'm not going to read that." I think that's what it comes down to. Guys just kind of overthink, they assume. And I've done it. I've probably made similar mistakes. They look at the last paragraph as the fine print (Participant H).

Complacency is also driven by the content of the maintenance instructions and part catalogs. Participant H noted that the proliferation of modification programs on some aircraft has affected the installation eligibility of parts for those modified aircraft. Mechanics that look for the replacement part in the parts catalog and are confronted with multiple notes that limit the installation of certain part numbers to different aircraft based on modification status. For an airline with a fleet of aircraft that includes one type of aircraft but at different modification levels, it can be difficult to determine the correct replacement part for each aircraft. Participant H commented that mechanics are not "See Note A, See Note B, See Note C type people." They can get "worn out from that and they say, 'yeah, yeah, yeah, It's the right one. It's the right one.' and they'll install that [incorrect] part, and that was happening a lot".

Lack of attention. Several participants provided information which could be categorized as lack of attention which would likely contribute to some of the errors discussed during the interviews. For instance, although the specific causal factor could not be determined as to what may have caused the vacuum bag surrounding the flight control in the autoclave to burst and damage the flight control, it was suggested that it could have been a lack of attention due to the repetitive nature of the bagging process: "I think its lack of attention that you just didn't pay enough attention to the stress points, the critical, I say critical…. points where the bag will fail if you don't get it protected properly" (Participant I).

Some errors may have various contributing factors such as the error involving the failure to release the pressure from the main landing gear strut before its partial disassembly and removal from the aircraft. In this instance, the maintenance card was comprised of approximately 200 pages and included a specific step to deplete the pressure. The participant surmised that there may have been several factors which affected the individual who was responsible for the task:

> The only thing I can think of is that either the person wasn't properly trained, or when they were being trained, they didn't pay attention carefully as to exactly what to do, or they did not read the AMM, aircraft maintenance manual, very carefully (Participant E).

A mechanic's lack of attention together with complacency can lead to significant errors. This was a likely combination that existed with an error described by Participant A, who described an error with a non-ETOPS aircraft that was inspected and released for an over-water ETOPS flight. The process to release the aircraft required the completion of a pre-departure check where maintenance personnel must walk around the aircraft and perform inspections culminating in the signing of the logbook. This was accomplished despite the absence of emergency aircraft equipment such as additional life rafts and a hydraulic driven generator. As for why this occurred, the participant commented:

> Maintenance wise? They were probably just "Okay, let's get it done", and they went out and did it. But I don't know how they could have done it without signing the blocks that they checked all the emergency equipment because it wasn't all there. So, I just think as far as maintenance goes, it's not outside factors, it's all just basically human error; being lackadaisy, "Hey, here's our flight. Let's go do it," and they don't double check everything. They just go through, "Yep, yep, yep, yep, okay here it is. Sign it off." They didn't really check it (Participant A).

The human error described by Participant A provides an example where lack of attention and complacency acting together can cause an error. Clear determination of one human factor over another as the primary causal factor of an error may be problematic in some situations.

Lack of awareness. While most of the human factors mentioned by the participants focused on complacency and lack of attention, lack of awareness was mentioned as one of the factors that contribute to the commission of errors. Participant D noted that some mechanics become dependent on work cards and air carrier developed maintenance instructions for the work scope. As a result, they become unaware of that they should be reviewing the aircraft maintenance manual (AMM) to retrieve additional information that supplements the work cards issued for the task. This was explained as a possible contributor for an error that was committed when a landing gear wheel and brake assembly was removed and caused impact damage to the axle. The cause of the damage was the failure to use the proper tool to protect the axle, but an additional error was made during the inspection of the axle after it was damaged. Rather than looking at the AMM for damage tolerance and repair instructions, the mechanics relied on the use of an inspection work card originally written for heat damage to the axle, not impact damage. The mechanics relied on the applicability of the work card due in part to its title which simply referred to axle damage. Lack of awareness regarding the need to review other manuals for specific instructions and perhaps lack of awareness on the part of the work card author who used a generic title on a work card specific for one type of axle damage were contributors to the error.

Other Factors. Several interview participants commented that there were additional human related factors that contributed to some of the errors they had described. These factors include stress related situations encountered by mechanics, physical issues, and working conditions affecting the mechanics while they were performing repairs. Stress placed upon the mechanic to quickly return the aircraft to service was one such factor shared by several participants. This was previously mentioned with errors that were associated with complacency but is some instances stress can be the root cause of errors. The stress from pressure driving the need to complete a maintenance task was noted by Participant F who described an error made by a mechanic that rendered a $20,000 hydraulic actuator fitting unusable when it was mis-drilled:

> In this case, he might have felt some pressure and I mean pressure like, “Hey, how long is it going to take you to do this?” That kind of thing. In the back of your mind and you know you work for an airline, there’s always that little bit of pressure that, “I need to get this done. Because we need the airplane, the airplane needs to go fly” (Participant F).

Similar thoughts were expressed by Participant A who noted that pressure to get aircraft back into service is something that mechanics working for an airline experience:

> I would say again, you’ve got the push from management, “Hurry up, get this plane done. We need to get it on the flight line.” Like I said, you always have that push going to get this plane ready for flight in the morning. I mean, that could be a contributing factor (Participant A).

The perception that time is of the essence in the airline maintenance environment can affect something as simple as storing unserviceable parts removed from aircraft or components. Such a situation was noted by Participant G who stated:

> It’s people in a hurry coupled with maybe there’s not a drawer for unserviceable [parts], for that unserviceable component, but there is for serviceable ones, so you just put it in the drawer so at least you know where it is. It might be wrong but that’s sometimes what ends up happening. I think guys just get in a hurry. Time always seems of the essence, you know. When you don’t have quite everything you need sometimes, you just cut corners and that’s just a fact in the industry, unfortunately (Participant G).

The older age of mechanics and familiarity with new technology can be a contributing factor for maintenance errors. One participant commented that older mechanics may find they are at a disadvantage regarding their ability to access computerized maintenance instructions:

> The average age of the mechanics where I work is probably 59 years old. So, sometimes their familiarity with computerized maintenance manuals and such is not the best that it could be. Because they didn't grow up with the technology (Participant B).

Environmental conditions were also cited as a factor that can induce mistakes. Participant E noted that environmental conditions could have played a role with the partial disassembly and removal of the main landing gear from the aircraft. While the specific error was traced to failure to completely release the pneumatic pressure in the main landing gear strut prior to removal and disassembly, the participant added:

> Just that it was just really hot… and summers here are so hot, and our hangars are heated in the winter, but they're not air conditioned in the summer. So, people get a little bit tired of the heat and they maybe get a little bit sloppy or whatever (Participant E).

The time of day the work is performed is yet another environmental factor that can contribute to errors. Participant B identified that the mechanics that worked on the original installation of the anti-skid module where the two hydraulic lines were installed in reverse had worked on night shift and may have been affected by fatigue. This participant noted:

> First of all, it's on graveyard shift when it was initially worked on which most of our maintenance is done during the night. But you always have to wonder the fatigue factors involved because especially if it happened to be the guy's Monday. Because a lot of mechanics turn around the day shift to be with their families on the weekend and when they come in on their Monday, they're very tired because they've been up a long time (Participant B).

The comments provided by the participants offer evidence that a wide range of human factors have led to the commission of maintenance errors. The examples provided by the participants identified complacency as the prevalent human factor that can cause errors although other examples highlighted lack of attention and lack of awareness as contributors. Of particular interest were the observations and comments made by the participants regarding stress and the influence that time demands have on the mechanics who perform repairs on aircraft. Stress imposed on mechanics due to implied or direct demands to complete repair work quickly and returned aircraft to service is a predominant theme that can contribute to errors during the performance of maintenance.

Corrective Actions. Qualitative data gathered from the interview participants included information relative to the corrective actions which had been taken by their respective air carriers to mitigate the errors and prevent them from re-occurring. In addition, participants were asked to provide information regarding what corrective actions they believe should have been taken to address the errors. Several participants noted that their airline took basic corrective action by simply counseling the employees who made the errors. Some of the participants recalled corrective actions that went beyond counseling and included manual revisions or system improvements. Many participants offered suggestions regarding additional actions that could have been taken to mitigate the errors. Descriptions of the corrective actions that were taken and those that were suggested are listed categorically with respect to the causal factor to which the error applied.

Corrective action for ineffective or lack of controls. Corrective action was taken to fix the system that tracked and controlled repetitive aircraft inspections to prevent aircraft from being operated beyond the dates or flight hours on which additional inspections or maintenance actions were due. The cause of these errors was attributed in part to tracking harmonization issues following the merger of the participant's air carrier with another. Although a system for tracking the due dates was in use, alerts were occasional missed which allowed the due dates to be overlooked. The airline implemented a policy change that required manual tracking of the due dates to prevent the operation of the aircraft beyond the due dates. In addition, corrective action was taken to lock out or prevent the aircraft from being dispatched for flight. The success of this action was noted as follows:

> We now have the ability to lock the flight plan out to where the Captain cannot pull it up until the maintenance has been performed. You've got to remember each little work group has their own kingdom. The dispatchers are their own little kingdom and everybody else has their own little kingdom and the release of the flight plan was Dispatch's deal. So, for us to be able to put a lock on it and say, "You can't have it.", they did not want to give up that authority, but the company said, "No, you're giving that authority up. We're tired of paying fines" (Participant A).

Although the airline's corrective action reduced the number of instances of aircraft that overflew the due dates for certain inspections and maintenance requirements, the participant suggested that a more modern approach should have been taken:

> In the world of electronic technology, you think that we would be right up there with the best, but we're back doing things by hand and by paper… Well, I personally think that they've probably kind of have got somewhat of a handle on it with the tracking, tracking it manually. But again, I think that with today's modern computers and stuff, I think a computer could do it a lot better than we do manually (Participant A).

Corrective action for inaccurate instructions. Corrective action to address the errors caused by policies and procedures that are inadequate, lack sufficient detail, or do not contain current information was provided by several participants.

Inaccurate instructions were the cause of errors committed by mechanics who had inspected the elevators of several aircraft incorrectly. Mechanics had performed the inspection using instructions for torquing a bolt and measuring free play to certain specifications. Participant C described the incident which was subsequently attributed to incorrect maintenance instructions published by the airline that deviated from the manufacturer's instructions. The airline acted by notifying its mechanics that the work had been performed incorrectly and published a revision to the procedures that matched the aircraft manufacturer's instructions. However, Participant C believes that action should have been taken much earlier had the airline monitored the rejection rate of elevators that failed the inspection. The elevator had a history of failed measurements which required removal and further inspection by an outside repair contractor who found no faults when they inspected them using the manufacturer's instructions. Had the engineers monitored the removals, the error would have been recognized and the cause determined much earlier.

Maintenance instructions that lacked sufficient detail was the causal factor regarding a forward lavatory door hinge pin that had migrated through the top of the door and protruded through the outer skin of the fuselage. Participant C noted that it "looked like a little antenna, like a three or four-inch antenna" protruding through the fuselage. The cause was traced to work instructions that focused inspections on the bottom of the door hinge in the belief that migration of the pin would only occur downward due to gravity. Once the error was discovered, the airline revised the work instructions and took an additional action to place a kink in the hinge pin of all similar doors to preclude future migration. No additional corrective action was suggested by the participant as it was felt this error was unique and the action taken by the airline was sufficient.

The error related to main landing gear axle damage caused by the removal of a wheel and brake assembly and was later released for service after a set of incorrect inspection instructions was used to perform the inspection is another example of flawed instructions. Participant D noted that the inspection work card used to inspect the damage was discovered to have a non-specific title and this was corrected by the airline. In addition, the airline required that new work cards developed over the following year had to be reviewed by a mechanic with an A&P certificate or another person in the maintenance department who had technical knowledge. This error was notable as it demonstrated the mechanics dependence on work card instructions and the reluctance of mechanics to review other aircraft maintenance manuals for references and information.

Participant D believes additional action to preclude similar errors should focus on the review of work cards, engineering changes, or modification instructions by mechanics prior to publication. Although the airline took action to require new work cards to be reviewed for a one-year period, Participant D commented that the person writing the instructions “need to have some hands-on technical experience or be working with somebody who does, because there’s more that you don’t see” and further added: “an engineer that has their A&P is 10 times better than an engineer that doesn’t”. Creating work cards and maintenance instructions with input from line mechanics would ensure that the instructions are correct for the repair tasks.

Participant F also suggested that improvements to the accuracy of maintenance instructions are needed and that those who write the instructions should have knowledge of the aircraft. This participant encountered a work card that was incorrect which caused a work stoppage until the instructions could be revised. Although the airline has existing procedures which allow work cards to be submitted to the quality department who then would contact the engineers who can revise the work cards allowing work to continue, this participant commented that a review process should be in place before the instructions are published:

> Well, of course, they should have been caught before the paperwork was published, but again, engineers are human too. And really in their defense there are a lot of young, and I don't mean any disrespect here but young students that do internships with [airline name redacted], they're given tasks like to copy and paste instructions on the paperwork, and we were finding this especially during the summer, we would get new revisions and a lot of these things would just be

> copied and pasted and then published. And I don't know if their reviewing process is maybe lacking a little bit or things just slip by because they're human too. But yeah, a lot of these interns would just rewrite these work cards as instructed and they would get published. So, they should have been caught, but maybe their controls were lacking a little bit (Participant F).

Corrective action for failure to follow instructions. Failure to follow maintenance instructions or existing procedures can have a detrimental effect on aircraft safety and airworthiness. Several participants provided descriptions of errors attributed to this causal factor and commented on the corrective action that was taken to address the errors. Suggested corrective action measures were also provided.

The error reported by Participant B that involved the brake anti-skid module which was discovered to have its hydraulic lines reversed was initially traced to the mechanic who installed it and may not have used the maintenance instructions. Once the initial discrepancy had been reported by the pilots, troubleshooting to identify the problem took several mechanics working over multiple shifts to identify and correct it. Mechanics attempted different repairs before the root cause was finally identified. Corrective action taken by the airline included publication of a newsletter article to alert other mechanics of this problem. While this error with the anti-skid module and the hydraulic lines may seem unique, Participant B noted that in his career “there’s been hundreds and hundreds of those types of errors”. The participant suggested that continuity during the repair process and documenting the work performed by each shift could have reduced the length of time required to troubleshoot the problem. Continuity can be addressed in two ways: the assignment of one person who is given oversight of the problem as it is repaired over multiple shifts would provide a single point of continuity; and ensuring that correct turnovers are completed from one shift to another.

The error involving the scheduling and pre-departure inspection by maintenance personnel of an aircraft for an ETOPS flight that was not equipped for such flights prompted a comment from Participant A that additional training and awareness could be an effective countermeasure against similar error recurrence. This error was missed by several individuals from other departments in addition to the mechanics. These individuals included the aircraft schedulers who assigned the aircraft and the pilots who accepted the aircraft and conducted the over-water flight. The causes were primarily attributed to human error as there were existing procedures that if followed, would have prevented the error from occurring. The participant was unaware of any specific actions taken by the airline to address the error other than making everyone aware of it and asking everyone to slow down and become more observant. However, Participant A suggested that increased awareness by offering additional ETOPS training might have helped avoid the error. This would include reminding the pilots and mechanics to verify that the aircraft logbook has the letters ETOPS on its cover as this is a requirement of the airline's ETOPS program and is readily visible to mechanics and crew members who must review the logbook before flight.

The error involving the flight augmentation computers that slid out of their racks while in flight due to the failure to secure them in place was an example where maintenance instructions were not followed. Existing policies and maintenance requirements were already in place which required the verification that the computers had been installed correctly. Participant A commented that corrective action taken by the airline was focused on counseling the individuals involved with the error. However, the participant indicated that the error may have been influenced by human factors and it was suggested that added emphasis should be placed on “the biggest thing, just slow down, even if you’re getting pressure, you’ve just got to slow down and make sure you’ve done it right” (Participant A).

Corrective action that would eliminate failures to follow instructions may be more difficult to implement particularly for maintenance tasks that are simple or repetitive. An error cited by Participant D involving the failure to properly torque the fasteners attaching the wing to fuselage body fairings is an example where specific maintenance instructions were not followed due to the nature of the maintenance tasks. The manufacturer had revised the maintenance instructions to include a required torque value when installing the screws. The error was caught by an FAA inspector who observed that the screws were being installed using an impact gun at an aircraft overhaul facility contracted by the airline to perform maintenance. Further investigation by the FAA and the airline revealed that the screws are not torqued when installed on other similar aircraft in its fleet. The airline took corrective action to verify that the screws were properly torqued on approximately 30 aircraft which required re-torquing approximately 100,000 fasteners. They also performed an analysis and determined that the installation of fasteners using an impact gun without checking the torque would not be a safety risk and subsequently revised the language on their work cards to allow installations to be conducted without the need for torquing the screws. However, the causal factors whereby the manufacturer’s minor revision to the maintenance instructions had been overlooked was not directly addressed by the airline. The repetitive and simplistic nature of a maintenance task can contribute to complacency by a mechanic with respect to the need to read the maintenance manual. Participant D provided illustrations as to what may drive a mechanic to perform simple maintenance tasks without the need to read the maintenance instructions:

> Let's say you're troubleshooting something in the cockpit, and you think that it's a light in the overhead is out. You replace the bulb, and it's not going. You take the voltage and you're not getting a voltage reading. You just want to pull that panel down and just make sure the wires connected. You just run the wire there. You've done that task 1,000 times. You know it's four screws and that panel drops, but technically there's a maintenance procedure for dropping that panel. It probably says things like make sure the airplane is secure, all this other BS that wouldn't really apply to this quick situation. For that one, it would be dropping an overhead, technically the manual says the plane has to be powered down, the plane has to be chocked, maintenance personnel can't be around flight controls, yada, yada, yada. For that reference, it's assuming you're going to be doing some major work, but if you just want to pull it down to check, to take a reading on a wire, if you get a bad inspector and you get caught, they may say, "Hey, where's your reference for pulling that down," so a simple task like that. Now, most mechanics, if the inspector came up and said and asked that, they would just lie and say, "Yeah, I pulled it up. It's on the computer, and it's shut down now." If the inspector actually pulled it up and started questioning everything, the mechanic would just say yes, yes, and yes, because how would the inspector

> prove he didn't do it? Most are smart enough for simple things like that to get around them (Participant D).

This participant added that improvements in technology should help mechanics access the maintenance instructions which might reduce instances where the instructions may be difficult or time consuming to retrieve:

> Things are getting better in terms of access to manuals, I know, because now that the FAA is looking at this more and airlines are under more scrutiny to do [maintenance] word for word, which I'm kind of in the middle there. A professional mechanic should be able to make some judgments on his own without having to be verbatim in a manual. I'm not saying a mechanic, if it's a crack in a spar, probably needs to get an engineer involved at that point or probably check a manual, but the things like removing a simple secondary structure panel, that's something a mechanic should be able to do without scrutiny and without pulling a manual up. …now is, they're getting more technology-wise. I don't know if that's the smaller carriers, but I have on my phone, in my iPad, I can pull the manuals up and check. They even have mechanic specific applications, too, so you can pull the manuals up. It's much more, even more clear, than the regular manuals. There are some things being done to mitigate this…but it is a known thing, the OEMs, the airlines, are aware of the time it takes to pull data up (Participant D).

A similar observation regarding how maintenance manuals should be used as a corrective action measure to prevent the installation of incorrect parts was noted by Participant G. In this instance, the error involved the installation of bolts that were too long, and which were used to attach anti-ice ducts to the engine nose cowling. Initially, the error was attributed to the listing of incorrect fasteners in the manufacturer's maintenance manual. The manufacturer corrected this by publishing a revision to the manual that identified the correct fasteners. However, the revision was not noticed by the mechanics who continued to replace the bolts with bolts having the same dimension as those that were removed. As explained by the participant:

> [The manufacturer] came out with a revised page, of course, for that manual calling out the correct length of bolts and that was something that you had to check because a lot of times those things would come in and we'd take them apart and we'd have the wrong hardware in them and a lot of guys just put the same hardware back in or, for instance, a new bolt but the same length as the old one and if you're not reading that manual you would miss that revision and the problem isn't solved at all. It's kicked on down the road which isn't a good thing, but that could have been a big deal, but fortunately someone caught it. The information was in numerous different places and you had to gather up the information on the repairs or the materials from several different places within a manual or a series of manuals. A lot of people struggled with that. I did too, and it's just the manuals can be very difficult to sort through and pick out the information you need, what's important, and what doesn't pertain to it. I think that's the biggest factor with manuals, right there, and that leads to people not wanting to look at them, but I always read them (Participant G).

This participant suggested that the airline should have taken additional corrective action to notify the group of mechanics that a revision had been issued to the maintenance manual regarding the maintenance of the anti-ice ducts.

> I think, well my company at least I think, could get information out a lot better than they did or they probably even still do now. I think just getting information to the shop floor is the most critical thing in that industry, and that's what they seem to be not really very good at. I think there could have been maybe just a team meeting about that, because we're all working on that stuff and there was a core group of us, and I'm only talking a dozen or 15 people that did this particular task, but I don't think it's any big trick to have a quick meeting with 10 or 15 people and say, hey look, this hardware is wrong and it's in the book now but you got to pay attention, make sure you make the change, et cetera, and they don't do that. They just stick it in the book and leave it to you to be responsible for looking… I think they could do a better job of getting information out. There's a lot more reasons for it than just that, but I think that's the biggest thing (Participant G).

Although it takes time for mechanics to navigate the manuals in search of instructions and replacement parts, this participant also commented that changes in technology may lead to changes in behavior that may drive more mechanics to look up the maintenance instructions:

> In general, the best thing that happened to prevent that was somewhere along the line [it was] putting all the manuals online. The industry got more computerized as time went on, especially 10 years ago or so, but I think the biggest thing that

> helped was in order to open up those manuals, the individual mechanic had to scan his ID card into the computer. That tells whoever looks at that stuff later who was in that computer and looking at what at a given time. If something were to happen later, they can pull up that record and see if you actually opened up that manual or not, so that gave you incentive to open up that manual every day, as far as I'm concerned. I think, I mean, working for corporate America has kind of got a certain nastiness to it, but that's just the way the game is.... it feels like a lot of times you're being spied on electronically. But really, I think that was a real help because that tells a guy, well, I better be on record as having opened-up this manual because in the old days with books nobody knew who opened the book and who didn't. There's no way to keep track, but there certainly is now. If you scan your timecard in a card reader to open up the overhaul manual, then there's a record of it right there. That gives you incentive (Participant G)

Most of the participants noted that with some exceptions, air carriers took immediate action to correct the errors noted by the participants. Mechanics were counseled, maintenance instructions and work cards were revised, and newsletter articles and bulletins were issued. However, several of the participants had similar concerns that failure to follow maintenance instructions are related to human factors such as complacency due to the performance of repetitive or simple tasks. Technological improvements were identified by several participants as a partial solution that will provide mechanics with ease of access to the maintenance instructions. The ability for an airline to identify the identity of mechanics who access the manuals may provide an incentive for those that wish to be on record as having reviewed the manuals. Although these steps may help reduce the number of instances where instructions were not accessed during maintenance, they may not eliminate errors committed by mechanics who rely on their knowledge and experience to perform repetitive or simple maintenance tasks instead of reviewing the maintenance instructions.

CHAPTER V

SUMMARY, CONCLUSIONS & RECOMMENDATIONS

This mixed-method study gathered quantitative data from 48 participants who completed a survey and qualitative date from nine of the participants who were interviewed. The combination of the quantitative data and the qualitative data achieved what Patton (2015) had described as "placing flesh on the bones" when compared to studies that rely solely on quantitative data (p.230). The survey results identified that certain maintenance errors were observed at a higher frequency than others. Survey data regarding the causal factors that drove the commission of the errors found two of the six causal factors were observed by the participants to have a higher frequency of occurrence. However, analysis of the qualitative data provided as comments by survey participants and qualitative data provided by participants that were interviewed found several common threads that further defined certain errors and causal factors which should be of concern to U.S. major air carriers and professionals in the aviation maintenance industry.

This chapter summaries the research conducted for this study and offers conclusions with respect to the research questions that were proposed. Additional observations which were not anticipated prior to the commencement of this study are also noted. This chapter concludes with recommendations offered for further consideration and research.

Summary

Maintenance errors within the airline industry have been associated with aircraft accidents such as the crash of an American Airlines DC10 in 1979, the crash of a Japan Air Lines 747 in 1985, the loss of a cockpit windshield on a BAC1-11 in 1990, and the in-flight break-up of an Embraer 120 in 1991 (Reason & Hobbs, 2003). Maintenance errors have been shown to have played a role in 26 percent of aircraft accidents (Liang et al., 2010). A study of human error found that this is responsible for 70 to 80 percent of aviation accidents and of these, 15 to 20 percent were related to maintenance activities (Chiu & Hsieh, 2016; Erjavac, et al., 2018).

Proactive measures to determine the cause of errors was taken by the Boeing Company who introduced its Maintenance Error and Decision Aid (MEDA) system that identified the top ten causes of maintenance errors (Boeing, 2013). Boeing acknowledges that maintenance errors can be caused by several factors and that management personnel have the ability to control or prevent over 80 percent of these factors (Boeing, 2013). Reason and Hobbs (2003) noted that maintenance errors can be initiated in one of two ways: maintenance personnel may fail to identify a problem or repair it properly, or; maintenance personnel may undertake an action that leads to a failure which would not otherwise have occurred. Other studies have shown that failure to follow written procedures or deviating from those procedures can cause errors (Drury, 1998; Eiff & Suckow, 2008; Lattanzio et al., 2008). Maintenance instructions that contain inaccurate or missing information are another casual factor that can lead to the commission of errors

(Lattanzio, et al., 2008). A focused study of an airline over a two-year period found that failure to use or follow maintenance instructions was caused by complacency which occurred due to the repetitive and monotonous nature of the maintenance tasks (Liang et al., 2010).

To identify the common errors and causal factors that may exist among the top four major U.S. air carriers, Freedom of Information Act (FOIA) requests were sent to the FAA that asked for FAA compliance action letters issued to American Airlines, Delta Air Lines, Southwest Airlines, and United Airlines for the FAA's 2018 fiscal year. The requests resulted in the acquisition of 87 compliance action letters for American Airlines, 93 compliance actions letters for Southwest Airlines, and 14 compliance action letters for United Airlines. The FAA did not provide compliance action letters for Delta Air Lines claiming that they have a memorandum of understanding with Delta that allows compliance activities to be driven into that air carrier's voluntary disclosure program thus preventing the release of the documents (FAA response letter, July 9th, 2019). This response was appealed in accordance with FOIA procedures and has yet to be resolved. Initial research to identify common maintenance errors and casual factors was limited to the review of compliance action letters for the remaining three air carriers.

Analysis of the FAA compliance action letters noted that of the total received, 75 letters issued to American Airlines, 49 letters issued to Southwest Airlines, and 4 letters issued to United Airlines were maintenance related. Further analysis noted that errors observed by the FAA fell into 12 categories with one of those categories identified as general in nature. Causal factors reported in the FAA compliance action closure letters were observed to fall into six distinct categories along with four categories for human factors. The top errors noted in the FAA compliance action letters were:

- Errors observed with maintenance entries (93 instances)
- Errors observed where deviations were made from instructions (58 instances)
- Errors observed where maintenance tasks were not performed (44 instances)
- Errors with the maintenance instructions (28 instances)

The top causal factors noted in the FAA compliance action closure letters were:

- Failure to follow instructions (92 instances)
- Failure to make correct maintenance entries (89 instances)
- Inaccurate or incomplete maintenance instructions (29 instances)

The top human factors noted in the FAA compliance action closure letters were:

- Lack of Awareness (8 instances)
- Complacency (7 instances)

The categories identified for errors, causal factors, and human factors from the analysis of the FAA compliance action letters were used to develop the survey instrument to gather quantitative data for the first phase of this study. The survey collected quantitative data from 48 participants who indicated that they were involved with maintenance on aircraft operated by U.S. air carriers that have more than 70 seats. The survey results were supplemented with qualitative data submitted by participants who provided additional commentary in their responses to the three open-text survey questions. Qualitative data was also obtained from the second phase of the study which involved interviews of nine participants using a list of semi-structured questions. The combined data from the survey and interviews was used to answer the three research questions.

Conclusions

Three research questions were proposed which are addressed by the findings generated by this study. The results of this study also provided additional observations that had not been anticipated.

First research question. The first research question asked: What errors are common to maintenance performed on aircraft operated by major U.S. air carriers certificated under FAR Part 121?

The results of this study produced mixed results that made it difficult to single out one single category of error over another as the most common. However, certain error categories were reported by survey participants to have a higher frequency of occurrence whereas other error categories appeared more dominant in the descriptions of maintenance errors provided by participants as commentary in the surveys.

Quantitative data found that of the eleven types of errors listed on the survey, three had been observed by participants more frequently than the others. These errors were identified as:

- Errors observed with the completion of maintenance entries
- Errors observed with the handling of maintenance documents, records tags, forms, or placards
- Errors with the content of maintenance instructions

Commentary provided by participants in the survey focused attention on two additional error categories identified as:

- Errors regarding maintenance steps or tasks performed that deviate from written instructions or procedures
- Errors regarding maintenance steps or tasks that were overlooked or not performed

In contrast, the qualitative data gathered from individual participant interviews found that the following error categories dominated the discussions from high to low:

- Errors related to the installation of parts
- Errors related to the storage of parts and materials
- Errors regarding deviation from instructions or procedures
- Errors related to steps or tasks not performed or overlooked
- Errors related to the content of maintenance instructions
- Errors related to the scheduling/control of the maintenance process
- Errors with the completion of maintenance entries

Comparison of the data acquired from the survey with the data acquired from the participant interviews found commonality with three types of errors:

- Errors observed with the completion of maintenance entries
- Errors regarding the deviation from instructions or procedures
- Errors related to steps or tasks not performed or overlooked

The common errors identified by this research compare directly with the common errors previously identified during the review of the FAA compliance action letters. The review of the FAA compliance action letters found that 86 errors related to maintenance entries, 37 errors involving deviation from maintenance instructions and 31 errors were related to tasks that were not performed. The high number of errors related to incorrect maintenance entries noted by the FAA agrees with the higher frequency of similar errors reported by the survey participants. Similarly, the higher number of errors noted by the FAA regarding deviations from maintenance instructions and errors related to tasks not performed or overlooked agree with the higher incidence of errors reported by the interview participants.

The largest anomaly noted was the category related to errors observed with the handling of maintenance documents, records tags, forms, or placards. Survey participants noted that such errors occur at a relatively higher frequency than all other errors which agree with the FAA data. However, participants that were interviewed did not provide examples of errors that could be directly associated with this category. It is possible that this type of error may not have been viewed as significant compared to other errors described by the participants who were interviewed.

Second research question. The second research questions asked: Why are these maintenance errors committed?

Analysis of the quantitative data gathered from the survey together with the qualitative data collected from the interviews identified several causal factors and human factors that are dominant over others. With the exception of the low frequency of observations for the causal factor related to ineffective controls over the maintenance process, the remaining five causal factors were found to have almost identical frequency levels. However, additional qualitative data obtained from written comments submitted with the survey noted the importance and severity of two causal factors when compared to the remainder. These two causal factors are:

- Failure to follow instructions or procedural requirements

- Maintenance and process instructions that contain inaccurate information or lacked sufficient detail

The results from the survey correlate with the qualitative data obtained from the participants who were interviewed. These participants provided 11 instances where they believe that inaccurate or incomplete maintenance instructions were responsible for maintenance errors. This was followed closely by nine instances where the participants recalled errors caused by failure to follow instructions or procedural requirements.

Comparison of theses causal factors with those identified during the initial research that examined FAA compliance action documents found that there is also correlation. The FAA compliance action closure letters found that failure to follow instructions and instructions that contained inaccurate or incomplete information were primary maintenance error causal factors. The FAA data also identified the failure to make maintenance entries or omission of entries as a common causal factor. However, the survey results and interview data do not suggest that this is a predominant causal factor. It is possible that the FAA may identify this more frequently during their inspections and reviews of air carrier maintenance records than the participants who may spend the majority of their time physically working on aircraft.

Failure to follow instructions and maintenance instructions that contain inaccurate information or lack sufficient detail are issues that have been previously identified by others as major causal factors of maintenance errors. Boeing's Maintenance Error and Decision Aid (MEDA) system listed the failure to follow published technical data as the highest contributor to maintenance errors (Boeing, 2013). Manufacturer's documentation that contained errors within the maintenance instructions was noted to be a leading cause of maintenance errors in an FAA sponsored study (Lattanzio, et al., 2008).

The identification of common causal factors also included an analysis of human factors that cause maintenance errors. Four human factors were included in the survey and the responses verified that all four were causal factors for maintenance errors. However, two of the human factors were observed by the survey participants at a higher frequency. These were identified as:

- Complacency
- Lack of Attention

Qualitative data from both the survey comments and interviews found that these two human factors were also of great significance. Of the two, complacency was established as the leading human factor that contributed to the commission of errors. This agrees with another study conducted of an airline over a two-year period that identified complacency as the cause of maintenance errors (Liang et al., 2010).

A causal factor that was not anticipated by this study was the impact of stress on complacency. As explained by several participants, the demand to return aircraft to service quickly, either implied or directed by supervision, can drive mechanics to take short cuts and avoid accessing the maintenance manuals. This happens frequently with simple or repetitive tasks that are familiar to mechanics who believe that they can complete the tasks without the need to retrieve the manuals instructions. Coupled with the perception that anyone looking up maintenance instructions may be doing so to slow the repair process, mechanics may avoid using the maintenance manuals. Of the causal factors identified by this study, failure to follow instructions or procedural requirements due to complacency and the need to return the aircraft to service is of the highest concern.

Third research question. The third research question asked: What actions have been or could be instituted to prevent the commission of maintenance errors on aircraft operated by major U.S. air carriers?

This study relied on qualitative data obtained from interviewed participants who were asked to identify successful corrective action measures that had been taken by their air carrier to mitigate errors. They were also asked to comment on corrective actions that they believe should also be taken to prevent errors. The participants noted that most of the corrective actions taken by the air carriers involved actions specific to mitigating the error that had been identified. Such actions included counseling of mechanics who made the errors, correcting the errors by replacing components or repairing damage, issuing training bulletins, and in some instances revising maintenance instructions to either clarify existing instructions or to add instructions that qualify any deviations that may have been taken. With few exceptions, most corrective actions taken by the air carriers were localized to that error and not universal in coverage. Corrective actions that were deemed effective by the participants are noted below along with some of their suggestions for improvement:

Ineffective or lack of controls:

Action taken: To prevent aircraft from operating beyond the required inspection due dates or flight hours while in service, controls were established by the airline to lock-out the issuance of flight plans and prevent the dispatch of aircraft until required maintenance work was accomplished and validated.

Suggested action: Automate all maintenance scheduling and other record keeping processes to eliminate the manual scheduling and tracking of aircraft in service.

Inadequate or inaccurate instructions:

Action taken: Action was taken to implement a one-year plan that required a review of all new work cards by a technical team to ensure accuracy before the cards and instructions are published.

Suggested actions: All maintenance instructions and revisions should be written by experienced engineers working in harmony with mechanics to develop instructions that are both accurate and match the work performed by mechanics to maintain the aircraft. Individual manuals, parts catalogs, and maintenance instructions should be combined into one source or database to eliminate the need for a mechanic to retrieve information from separate manuals. Maintenance personnel should also be briefed on revisions to maintenance instructions that are applicable to their work area at the time the revisions are published to avoid instances where revisions may be overlooked.

Failure to follow instructions:

Actions taken: Action was taken to establish electronic databases containing maintenance instructions that are revised and updated so that the information is never older than 24 hours. The information can also be accessed by mechanics on portable devices such as tablets and smartphones.

Suggested action: Several participants acknowledged that failure to follow instructions is a key causal factor that can be attributed to complacency, which is driven in part by the performance of repetitive or simple maintenance tasks and expectations to quickly return the aircraft to service. While specific actions related to these factors were not provided, one participant suggested that it may help if better training was adopted for new mechanics to instill good habits rather than having new mechanics trained to follow bad habits handed down by senior mechanics. Another participant suggested that there should be level at which a professional mechanic could make a judgement regarding the performance of simple tasks without the requirement for specific instructions. Several participants acknowledged that efforts are already underway in the industry to provide maintenance instructions electronically and available on personal electronic devices.

Additional Observations. While this study focused on the quantitative and qualitative data gathered from the survey and participant interviews, two observations were noted during the initial research conducted prior to commencement of the survey and interviews.

The information provided by the FAA in response to the researcher's FOIA requests for FAA compliance action letters did not include any letters that had been issued to Delta Air Lines. Delta's FAA CMO stated that they have a memorandum of understanding with Delta that drives all compliance activities into Delta's voluntary disclosure program. This action may not be in accordance with FAA procedures and appears to be in conflict with FAA oversight activities of the other three air carriers. An appeal was lodged asking for the documents to be released noting that FAA guidance material has restrictions that do not allow the FAA to place all FAA discovered errors into an airline's voluntary disclosure program. No information has been received regarding the status of the appeal and as a result, this study did not include a review of FAA compliance actions that may exist regarding maintenance errors found at Delta Air Lines.

A second observation was noted with the identification of the sample population. This study assumed that the records maintained and updated by the FAA were current and the information and addresses for the mechanics was correct in the database. However, of the 1000 survey requests that were sent to mechanics who were randomly selected from the sample population, 128 survey request letters were returned as undeliverable. This represents a database error of 12.8 percent which was not expected. Other than reduce the number of survey respondents, this observation does not directly affect the study but is indicative of a database error within the FAA that may require further analysis and study.

Recommendations

Four recommendations are offered based on the results of this study:

1. One of the key findings of this study involved issues where mechanics failed to follow instructions or procedural requirements. Participants in this study noted that this happens particularly if the tasks are simple or repetitive. Others mentioned that this can happen due to implied or direct supervisory demands that the aircraft be returned to service as soon as possible. While this study identified these factors, it did not explore these causal elements further nor did it analyze at what skill level it would be acceptable for mechanics to perform work without referring to maintenance instructions. Further study is recommended to examine situations involving the performance of simple or repetitive tasks and the causal factors that may drive mechanics to perform maintenance without referencing the maintenance instructions.
2. The study identified issues with maintenance instructions that contained inaccurate information or lacked detail. Interview participants noted that these types of errors frequently appear on work cards published by the air carriers. Causal factors related to the lack of knowledge and experience of the work card authors was cited by the participants as a dominant issue. Suggestions for corrective action included the pairing of mechanics with engineers and other work card authors to validate the instructions prior to publication. While the suggestion has merit, this study did not explore the effectiveness of the corrective action and further study is recommended to determine if this action will eliminate many of the errors associated with the maintenance instructions.

3. This study was limited in scope to the 48 participants who responded to the survey request and met the criteria for inclusion in the study. This number was too small to perform a pure quantitative study where results could be measured for hypothesis testing at high confidence levels. While this researcher believes that qualitative study offers deeper insights into situational settings, additional quantitative statistics and hypothesis testing may be possible if a larger number of participants could be obtained from the population sample. It is recommended that further quantitative research be undertaken and expanded to include a greater number of participants that would allow for greater statistical analysis.
4. The FAA database that identifies individuals who hold non-airmen FAA certificates such as those issued to mechanics should be the focus of additional research. This study unexpectedly found that over 12 percent of the mechanics selected for participation in this study could not be contacted at the address of record. It is recommended that further research be undertaken to identify the extent the database information is incorrect, the causal factors that drove the errors, and identify what actions can be taken to ensure that the database reflects current addresses for the certificate holders.

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APPENDICES

Appendix A

Survey

COLLEGE OF EDUCATION, HEALTH AND AVIATION

Survey – Identification of Aircraft Maintenance Errors and What May Cause These Errors

Section I

To the best of your knowledge and personal experience, please answer the following statements by indicating the frequency that you have observed the following types of aircraft maintenance errors in your workplace. Please circle only one answer for each question.

1. I have seen errors occur with respect to the storage of aircraft parts and materials.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

2. I have seen errors with the content of maintenance instructions.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

3. I have seen errors occur with the scheduling and/or control of the maintenance process.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

4. I have seen errors occur with the handling of maintenance documents, records, tags, forms, or placards.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond.

5. I have seen errors occur with the installation of parts or equipment.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

6. I have seen errors occur with the completion of maintenance entries.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

7. I have seen maintenance steps or tasks performed using procedures that are not accepted or approved by the FAA.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

8. I have seen maintenance steps or tasks performed that deviate from written instructions or procedures.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

9. I have seen maintenance steps or tasks that were overlooked or not performed.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

10. I have seen errors occur with the handling, usage, or control of calibrated tools and equipment.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

11. I have seen errors occur with training requirements, recurrent training, or maintaining of qualifications for those assigned to perform maintenance.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

12. In the space below, please list any other types of maintenance errors you may have observed that are not mentioned above and indicate how likely you feel that these errors occur during the performance of maintenance. (Response is optional)

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Section II

This next section is focused on the cause of maintenance errors. To the best of your knowledge and personal experience, please indicate the frequency that the listed cause is responsible for errors that have been committed in your aircraft maintenance workplace. Please circle only one answer for each question.

13. Policies and procedures that are inadequate, lack sufficient detail, or do not contain current information cause maintenance errors in my workplace.

   1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

14. Failure to follow maintenance instructions or procedural requirements cause maintenance errors in my work place.

1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

15. Ineffective controls over the maintenance process or the lack of a measurement process cause maintenance errors in my work place.

1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

16. Maintenance and process instructions that contain inaccurate information or lacked sufficient detail cause maintenance errors in my work place.

1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

17. Maintenance personnel lacking sufficient training or knowledge cause maintenance errors in my work place.

1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

18. Failure to make maintenance entries or omitting relevant information in logbooks, maintenance records, or other record keeping documents cause maintenance errors in my work place.

1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

19. In the space below, please list any other causes not mentioned above that you believe are responsible for maintenance errors in your workplace and indicate how likely you feel that they contributed to the commission of the maintenance errors. (Response is optional)

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Section III

To the best of your knowledge and personal experience, please respond to the following statements by indicating the frequency that each listed human factor has caused or contributed to errors in your workplace. Please circle only one answer for each question.

20. Lack of awareness cause maintenance errors in my workplace.

1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

21. Complacency cause maintenance errors in my workplace.

1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

22. Distractions cause maintenance errors in my workplace.

1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

23. Lack of attention cause maintenance errors in my workplace.

1. Never 2. Rarely 3. Sometimes 4. Regularly 5. Often 6. Prefer not to respond

24. In the space below, please list any other human factors not mentioned above that you believe caused or contributed to maintenance errors in your work place and indicate how likely you feel that they contributed to the maintenance errors. (Response is optional)

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Section IV

The last few questions are general demographic questions. Please circle only one answer for each question.

25. Are you actively engaged in the performance of aircraft maintenance?

a. Yes
b. No
c. Prefer not to respond

26. Please select the category of aviation in which you are primarily involved with the performance of aircraft maintenance functions:

    a. General aviation
    b. Corporate Aviation
    c. Air Taxi and commuter aviation (unscheduled passenger services using aircraft with 19 seats or less)
    d. Regional airlines (scheduled passenger services using aircraft with 70 passenger seats or less)
    e. Major airlines (scheduled passenger services using aircraft with more than 70 seats)
    f. Cargo carrier
    g. Other (Please indicate in text box)
    h. None
    i. Prefer not to respond

27. Please indicate how many years of experience you have with aircraft maintenance activities by selecting one of the following:

    a. No experience
    b. Up to 2 years' experience
    c. 2 years but less than 5 years' experience
    d. 5 years' but less than 10 years' experience
    e. 10 years' but less than 20 years' experience
    f. Greater than 20 years' experience
    g. Prefer not to respond

Appendix B

Semi-Structured Interview Questions

Note: This list of questions can be repeated as necessary to capture information on several different errors known to the participant. The intent of the interview is to gather more qualitative information specific to each maintenance error that is discussed. Participants can state that they prefer to not respond to any of the questions listed below.

1. With respect to errors or incidents resulting from the commission of errors, please describe a maintenance error that occurred within the past 2 to 4 years and which you may have seen or have first-hand knowledge that affected you or another co-worker.
    a. Describe the maintenance action or task that was being performed?
    b. Where did this take place?
    c. When did this take place?
    d. What were the working conditions present at the time the task was performed?
    e. What were the sequence of tasks that were performed?
    f. If more than one person was performing the task, what responsibilities and tasks were performed by each of the team members?
    g. Was the maintenance task one that is considered a routine (repetitive) task?
    h. At what point in the process was the error initially identified?

2. With respect to this error or mistake, in your opinion what do you believe were the contributing factors that led to the error?
    a. What were the outside factors that contributed to the error?
    b. Describe the human factors that contributed to the error?

3. Describe action that was taken at your work place to prevent this error from happening again?

4. To the best of your knowledge, describe similar occurrences of this error at your work place?

5. What action do you believe should be taken to prevent this error from happening again?

Appendix C

Survey Internal Consistency Measurements

Cronbach's Alpha calculated for all 21 questions:

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.915	.917	21

Cronbach's Alpha calculated for 11 questions focused on maintenance errors:

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.869	.868	11

Cronbach's Alpha calculated for the 10 questions focused on causal and human factors:

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.839	.848	10

Cronbach's Alpha calculated for the 21-question bank if a question is deleted:

Variable	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Parts and materials errors	54.58	112.249	.434	.528	.914
Maintenance instruction errors	54.36	108.325	.675	.823	.908
Scheduling and/or Control of the maintenance process.	54.71	110.574	.546	.653	.911
Maintenance documents, records, tags, forms, or placards errors	54.31	111.037	.531	.688	.912
Installation of parts or equipment errors	54.91	113.537	.501	.606	.912
Completion of maintenance entry errors	54.27	113.336	.427	.706	.914
Use of procedures that are not accepted or approved by the FAA	55.40	111.018	.596	.689	.910
Deviation from written instructions or procedures.	55.13	111.345	.601	.658	.910
Maintenance steps or tasks that were overlooked or not performed	55.16	107.362	.772	.698	.906
Handling, usage, or control of calibrated tools and equipment errors	55.42	112.340	.499	.600	.912
Training requirements, recurrent training, or maintaining of qualifications errors	55.11	104.692	.761	.780	.906
Policies and procedure issues cause errors	54.98	108.522	.661	.737	.909
Failure to follow instructions or procedures cause errors	54.91	113.719	.407	.697	.914
Ineffective controls over the maintenance process cause errors	55.22	109.040	.677	.671	.908
Maintenance and process instructions that contain inaccurate information or lacked detail cause errors	55.02	108.295	.551	.756	.912
Maintenance personnel lacking sufficient training or knowledge cause errors	54.78	108.177	.534	.660	.912
Failure to make maintenance entries or omitting relevant information in records cause errors	55.02	112.204	.398	.509	.915
Lack of awareness cause errors	54.89	113.465	.443	.751	.913
Complacency cause errors	54.44	109.616	.606	.709	.910
Distractions cause errors	54.69	112.765	.621	.564	.910
Lack of attention cause errors	54.69	112.856	.548	.705	.911

Cronbach's Alpha calculated for the 11 questions related to errors if a question is deleted:

Variable	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Parts and materials errors	27.20	32.605	.432	.313	.868
Maintenance instruction errors	26.98	30.911	.633	.478	.853
Scheduling and/or Control of the maintenance process.	27.26	31.219	.569	.439	.858
Maintenance documents, records, tags, forms, or placards errors	26.89	31.388	.602	.466	.855
Installation of parts or equipment errors	27.52	33.322	.515	.423	.861
Completion of maintenance entry errors	26.87	32.516	.514	.544	.861
Use of procedures that are not accepted or approved by the FAA	28.02	32.822	.495	.560	.862
Deviation from written instructions or procedures.	27.72	33.007	.510	.515	.861
Maintenance steps or tasks that were overlooked or not performed	27.76	30.408	.748	.636	.845
Handling, usage, or control of calibrated tools and equipment errors	28.04	32.531	.514	.449	.861
Training requirements, recurrent training, or maintaining of qualifications errors	27.70	29.105	.725	.661	.845

Cronbach's Alpha calculated for the 10 questions related to causal factors if a question is deleted:

Variable	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Policies and procedure issues cause errors	24.63	25.305	.598	.552	.817
Failure to follow instructions or procedures cause errors		26.873	.453	.490	.831
Ineffective controls over the maintenance process cause errors	24.87	25.760	.589	.486	.819
Maintenance and process instructions that contain inaccurate information or lacked detail cause errors	24.65	25.165	.489	.673	.830
Maintenance personnel lacking sufficient training or knowledge cause errors	24.46	24.298	.533	.559	.826
Failure to make maintenance entries or omitting relevant information in records cause errors	24.67	26.758	.361	.208	.842
Lack of awareness cause errors	24.54	26.254	.561	.546	.822
Complacency cause errors	24.11	24.499	.697	.602	.808
Distractions cause errors	24.33	27.158	.588	.416	.822
Lack of attention cause errors	24.33	26.714	.585	.537	.821

Appendix D

Institutional Review Board Acceptance Letter

Oklahoma State University Institutional Review Board

Date:	02/06/2020
Application Number:	IRB-20-61
Proposal Title:	IDENTIFICATION, EVALUATION, AND CAUSAL FACTOR DETERMINATION OF MAINTENANCE ERRORS COMMON TO MAJOR U.S. CERTIFICATED AIR CARRIERS
Principal Investigator:	Robert Harper
Co-Investigator(s):	
Faculty Adviser:	Timm Bliss
Project Coordinator:	
Research Assistant(s):	
Processed as:	Exempt
Exempt Category:	

Status Recommended by Reviewer(s): Approved

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in 45CFR46.

This study meets criteria in the Revised Common Rule, as well as, one or more of the circumstances for which continuing review is not required. As Principal Investigator of this research, you will be required to submit a status report to the IRB triennially.

The final versions of any recruitment, consent and assent documents bearing the IRB approval stamp are available for download from IRBManager. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be approved by the IRB. Protocol modifications requiring approval may include changes to the title, PI, adviser, other research personnel, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms.
2. Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3. Report any unanticipated and/or adverse events to the IRB Office promptly.
4. Notify the IRB office when your research project is complete or when you are no longer affiliated with Oklahoma State University.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact the IRB Office at 405-744-3377 or irb@okstate.edu.

Sincerely,
Oklahoma State University IRB

VITA

Robert J. Harper

Candidate for the Degree of

Doctor of Education

Thesis: IDENTIFICATION, EVALUATION, AND CAUSAL FACTOR DETERMINATION OF MAINTENANCE ERRORS COMMON TO MAJOR U.S. CERTIFICATED AIR CARRIERS

Major Field: Applied Educational Studies – Aviation & Space Education

Biographical:

Education:

Completed the requirements for the Doctor of Education in Applied Educational Studies – Aviation and Space Education at Oklahoma State University, Stillwater, Oklahoma in May 2021.

Completed the requirements for the Master of Science in Aviation Sciences at Oklahoma State University, Stillwater, Oklahoma in 2011.

Completed the requirements for the Bachelor of Science in Aviation Management at Oklahoma State University, Stillwater, Oklahoma in 2007.

Experience:

Oklahoma State University – Adjunct professor for undergraduate courses: International Aerospace Issues, Aviation Labor Relations, and Aerospace Organizational Communications, 2011 to present.

American Airlines Inc. – Quality Assurance Manager, Quality Control Supervisor, Sr. Auditor, Technical Representative, Maintenance Instructor, Aircraft Maintenance Technician, 1986 through 2018.

Professional Memberships - American Society for Quality