APPLICATION OF DUPONT’S DIRTY DOZEN FRAMEWORK TO COMMERCIAL AVIATION MAINTENANCE INCIDENTS

By

Greg Michael Mellema

A Dissertation Submitted to the College of Aviation
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Aviation

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ABSTRACT

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Title: APPLICATION OF DUPONT'S DIRTY DOZEN FRAMEWORK TO COMMERCIAL AVIATION MAINTENANCE INCIDENTS

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This study examined the 12 preconditions for maintenance errors commonly known as the Dirty Dozen and applied them to actual incident and accident data provided by a participating airline (PA). The data provided by the PA consisted of Maintenance Event Reports (MERs) (reactive), Maintenance Operations Safety Assessment (MOSA) reports (proactive), and the results of the 2017 Maintenance Climate Awareness Survey (MCAS) (subjective). The MER and MOSA reports were coded by aviation maintenance subject matter experts (SMEs) using the 12 Dirty Dozen categories as the coding scheme, while the MCAS responses were parsed according to the precondition category they best represented. An examination and qualitative analysis of these data sets as they related to the Dirty Dozen categories answered the following research questions: (1) How does the reactive data (MER) analysis compare to the proactive (MOSA) analysis in terms of the Dirty Dozen? Do they echo similar Dirty Dozen categories, or do they seem to reflect different aspects of the Dirty Dozen? (2) What other preconditions for maintenance error become apparent from the analyses? What do they have in common? How complete is the Dirty Dozen? (3) What insights can be gleaned from the subjective report data (MCAS) with regard to maintenance personnel's perceptions of the organization's safety culture? The results revealed not only the presence of each Dirty Dozen category to some degree, but also the difference in sensitivity of the MER (reactive) and MOSA (proactive) to the 12 Dirty Dozen categories. Recommendations for practice and future research are discussed.

DEDICATION

For Mom & Dad, for whom this work was completed just a little too late. We miss you. For Cheryl, thank you for your love and patience. And for my daughter, my reason for being, my inspiration for the past 22 years. Here it is Katie, proof that you can do anything you set your mind to.

ACKNOWLEDGMENTS

> Every man is the sum-total of his reactions to experience. As your experiences differ and multiply, you become a different man, and hence your perspective changes. This goes on and on. Every reaction is a learning process; every significant experience alters your perspective.
>
> ~ Hunter S. Thompson

Unlike so many fresh-faced young graduates, I wrote this dissertation at the not-so-tender age of 55. Now, looking back at the arc of my life and an aviation career spanning over three decades, I must acknowledge those who influenced me, those who taught me. Those who made me better, who encouraged me when I fell into despair, and, recognizing potential even when I did not, never let me give up on myself. In this task, I will utterly fail as there are so many people I am grateful to… but, here goes.

For Bob Clark, who taught me that quality and craftsmanship are an aircraft mechanic's stock-in-trade and must never be compromised. For Al Stuhlmacher, who saw the potential and set me on this most excellent path. For Mike Hoke and Lou Dorworth, who took a chance on me and introduced me to the world of composites. For all the soldiers I served with, from whom I learned what true patriotism, courage and sacrifice look like. For my classmates in the Ph.D. program, for their time and encouragement. For my dissertation committee members and advisor, Dr. Haydee Cuevas, Dr. David Esser, Dr. Bruce Conway, Dr. Shari Frisinger, and Dr. Dothang Truong, who held me to the highest standard that I may truly learn. For Dr. Alan Stolzer for admitting me to the program and talking me down off the ledge at least twice. For Dr. James Sands for his support and encouragement. And, for Gordon Dupont, for his amazing insight, generosity, and dedication to our industry. Thank you all, here's to hoping I was worth the trouble. Cheers!

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CHAPTER I

INTRODUCTION

This study examined the 12 preconditions for maintenance errors commonly known as the Dirty Dozen and applied them to actual accident and incident data provided by a participating airline (PA). These 12 preconditions for maintenance error were originally conceived by Gordon Dupont of Transport Canada in the early 1990s (Dupont, 1997). Since then, the Dirty Dozen framework has been widely accepted by airworthiness authorities comprising 11 countries: Canada, Australia, Singapore, China, Sweden, Holland, Hungary, the United Kingdom, Ireland, Portugal, and the United States (CASA, 2013; G. Dupont, personal communication, October 28, 2017). However, despite this industry acceptance, the amount of scientific research that exists to support the framework is limited, especially when compared to the volumes of research dedicated to understanding aircrew and pilot error and their underlying causes. For example, the literature review for the current research revealed a general disparity between human factors research concerning flight crew and mechanics. To help illustrate this disparity, a search in Google Scholar for "aircraft maintenance error" returned 238,000 results while a search for "pilot error" returned over 2.5 million results. While this hardly qualifies as empirical evidence, it does underline the inconsistency in research efforts. The study sought to develop a new way in which to systematically identify preconditions to maintenance error, allowing an organization to take steps to preclude these preconditions from manifesting as incidents or accidents.

The examination of human factors research in terms of aviation maintenance surged around 1990, presumably from a series of high-profile air disasters in the 70s and

80s in which aircraft maintenance was implicated (Chang & Wang, 2010; Dorn, 1996; Gramopadhye & Drury, 2000). Certain human error models and theories developed during this timeframe have become widely if not universally accepted. Examples include Reason's (1990) Swiss Cheese model which illustrates how "holes" in an organization's systematic defenses can line up, allowing an accident to occur. Also, Dorn's (1996) adaptation of Edward's (1988) Software, Hardware, Environment, Liveware, or SHEL model characterized the interaction of these elements within a system such as aircraft maintenance operations. Additional contemporary works by Shappell and Weigmann (2000), Merritt and Klinect, (2006), Maurino (2005), and others have developed models or reactive systems and taxonomies designed to help accident investigators determine *what* maintenance error occurred, but these systems do not necessarily offer any insight as to *why* it occurred.

During this same period, certain proactive systems were developed such as Maintenance Line Operations Safety Assessments, or M-LOSA (Crayton, Hackworth, Roberts, & King, 2017; IACO, 2002). M-LOSA and M-LOSA-like systems are thought to reduce the chance of maintenance errors occurring through regular auditing (observation) of personnel on the job (Klinect, 2008) in order to identify and stem potentially hazardous activities before they are able to manifest as incidents or accidents. However, while M-LOSA reports and their kind may offer an explanation as to a maintenance error's proximate cause, they do not actively seek to identify any higher-order distal cause such as preconditions for maintenance error that may be present.

In 1993, Gordon Dupont of Transport Canada examined as many as 2,000 maintenance-related accident and incident reports previously attributed to human error.

In seven months, Dupont and his team were able to synthesize from these reports a framework of 12 overarching preconditions for maintenance error that have come to be known as the Dirty Dozen:

- Lack of Communication
- Complacency
- Lack of Knowledge
- Distractions
- Lack of Teamwork
- Fatigue
- Lack of Resources
- Pressure
- Lack of Assertiveness
- Stress
- Lack of Awareness
- Norms

Each Dirty Dozen element has a set of *safety nets* associated with it. Safety nets are regulations, policies, and practices or procedures thought to reduce the possibility that any given precondition will actually manifest as an incident or accident. These preconditions for maintenance error seemed to resonate with the personnel in the aviation industry as they offered some explanation as to *why* incidents and accidents occurred. By 1997, the proliferation of the Dirty Dozen framework was well underway. Within just a few more years, Dirty Dozen posters adorned the walls of many maintenance facilities inside and outside the U.S. and Canada (see Appendix B). Whether its success can be attributed to (a) effective marketing (posters, etc.), (b) the industry-wide assumption there was substantial scientific research to support it, (c) an intuitive sense that it was “correct” based on experience, or some combination of these three, the Dirty Dozen found itself well-established in aviation maintenance culture worldwide.

Statement of the Problem

The aviation industry is perpetually looking for new means to enhance safety and reduce costs, even if only incrementally. Proactive means (e.g., preventative measures) are preferred over reactive means (e.g., post-mishap analysis), as they do not require that an incident or accident has already occurred along with all the attendant damage, cost, and potential loss of life. However, most proactive means lack sufficient prognosticative power and are therefore of limited value. As such, in order to decrease maintenance errors, it is important to evaluate both reactive and proactive data to expose existing preconditions for error. This is a key element missing from the literature and thus forms the basis for the research problem – more effective analytical methodologies are needed to continue to drive maintenance errors down. To address this problem, it is posited that an examination of an organization’s maintenance culture through the construct of the Dirty Dozen will yield useful information identifying the presence of preconditions for maintenance errors. Once uncovered, a mitigating strategy can be devised to address the specific preconditions that are present, thereby reducing the total number of incidents and accidents that are able to manifest as a result.

Significance of the Study

As stated previously, the aviation industry has sought new ways to enhance safety almost since the Wright brothers first powered flight in 1903. Throughout these many decades, the professionals dedicated to enhancing aviation safety do not recognize a point of diminishing returns, at least not in the traditional sense. Thus, the aviation culture traditionally welcomes safety improvements great and small. The results of the current research provide the industry with yet another tool, another means by which to enhance safety by reducing the number of incidents and accidents that come to fruition by identifying and ultimately reducing the existence of preconditions to maintenance error in the organization.

The International Civil Aviation Organization (ICAO) lists over 300 potential preconditions for error (ICAO, 1993). However, these are general preconditions and are not specific to aircraft maintenance. While it may never have been intended as such, the Dirty Dozen's popularity has essentially made it a standard in terms of what are considered the most common preconditions specific to maintenance error. Since this standard has been embraced so thoroughly across the aviation maintenance and safety culture, it would be useful to have some assurance that it is both complete and effective. Ma and Grower (2016), and even Dupont himself, have suggested that the Dirty Dozen may or may not be suitably complete as is. Therefore, evidence suggesting the completeness, or lack thereof, of the Dirty Dozen construct will be important and useful to any organization seeking to reduce its maintenance errors by identifying and reducing its preconditions for maintenance error.

Purpose Statement

The purpose of this qualitative study was to explore the possibility of using DuPont's Dirty Dozen for more than just a simple list of preconditions for maintenance error of which mechanics should be wary. Specifically, the study used the Dirty Dozen to examine three types of reports from a PA for evidence suggesting the presence of one or more preconditions for error. It was posited that if the preconditions for maintenance error are present, the maintenance errors themselves are likely not far behind. Additionally, the more prevalent the precondition, the more likely the maintenance error is thought to occur (Hobbs & Williamson, 2003). Therefore, the results of the study yielded specific areas for the PA to focus on to enhance its safety culture.

The types and titles of the reports made available by the PA were (a) reactive - maintenance event reports (MER), (b) proactive - maintenance operations safety assessments (MOSA), and (c) subjective - results from the airline's maintenance climate awareness survey (MCAS). Such an examination of any one of these reports would yield useful information about the PA's maintenance culture. However, since proactive, reactive, and subjective data each have their own strengths and weaknesses, the examination of all three types of reports was posited to illustrate the PA's maintenance culture in a more holistic and complete manner. Additional details concerning the reports and how they were analyzed will be discussed in Chapter III.

Research Questions

The aviation industry has recognized the Dirty Dozen as the 12 most common preconditions for maintenance error for roughly two decades. The Dirty Dozen has been used extensively in aviation human factors training in the U.S. and abroad and figures prominently in the Federal Aviation Administration's (FAA) (2008) aviation maintenance handbook, human factors addendum. Unfortunately, its potential has been leveraged for little else. The current research used the Dirty Dozen to examine three types of reports provided by the PA and, in doing so, answered the following research questions:

1. How does the reactive data (MER) analysis compare to the proactive (MOSA) analysis in terms of the Dirty Dozen? Do they echo similar Dirty Dozen categories, or do they seem to reflect different aspects of the Dirty Dozen?

2. What other preconditions for maintenance error become apparent from the analyses? What do they have in common, or are any of them similar to the additional preconditions suggested by Ma and Grower (2016)? In terms of typical preconditions for maintenance error, how complete is the Dirty Dozen?
3. What insights can be gleaned from the subjective report data (MCAS) with regard to maintenance personnel's perceptions of the organization's safety culture?

Delimitations

The PA operates a fleet of over 100 Boeing 737 aircraft to destinations in eight different countries. The PA also employs approximately 3,000 maintenance-related personnel full-time. The number and type of reports and their scope can be seen in Table 1. Despite the limitations described below, the process is generalizable since the Dirty Dozen framework is largely agnostic in terms of its application across the aviation operational spectrum, be it maintenance personnel involved in commercial, cargo, or agricultural aviation. However, specific results of the application would be expected to vary from one airline to another due to the host of ethnographic variables in play at any given organization (i.e., airlines in different countries).

Table 1

Report Names, Types, Number

Report Name	Type	Number	Date Range
Maintenance Event Reports (MER)	Reactive	25	Jun – May 2017
Maintenance Operations Safety Assessment (MOSA)	Proactive	60	Sep – Nov 2017
Maintenance Climate Awareness Survey (MCAS)	Subjective	26	Feb – Apr 2017

Note. While only one MCAS summary report was provided, 26 elements of the report were identified as having analytical value to the current research.

Limitations and Assumptions

One limitation of the current study was the finite number of reports that could be provided by the PA within a reasonable timeframe (see Table 1). While more reports would certainly enhance the overall validity of the research, the impact to cost and schedule was deemed too great by the airline. However, it was posited that the rich variety of reports (proactive, reactive, and subjective) would help mitigate any issues concerning validity that might arise from the reduced data set. A second limitation was the timeframes in which the data from the different reports were collected (see Table 1). While there was a significant overlap in the collection of the MER and MCAS data, the MOSA observations were conducted over four months later. The PA was asked about significant turnover of personnel or major training events that may have influenced respondent's behavior or perceptions during that four-month period. The PA stated no such events had occurred. So, while data collected from the exact same timeframe would have been preferable, there did not appear to be any obvious reason to suspect that MOSA data collected in the last quarter of the calendar year would have been appreciably different than data collected in the first quarter of the same year.

Two assumptions for the current research were: 1) personnel filing accident and incident reports (MERs) were skilled, knowledgeable, and honest, and 2) no malice was associated with their reporting. The primary assumption made for MOSA reports was that the observers were also skilled and knowledgeable personnel making sincere efforts to proactively identify potential errors or preconditions for errors. The PA had specific requirements for being a MOSA observer. MOSA observers must:

- have more than four years of experience as a mechanic
- be qualified in the tasks observed
- have knowledge of the PA's procedures
- have knowledge of technical English
- have taken the required safety course
- personal characteristics that reveal ethics, neutrality, and good interpersonal relationships
- ability to generate a report with clarity and objectivity

It is further assumed that the respondents to the MCAS answered honestly and accurately to the best of their individual abilities.

Definitions of Terms

Accident — "An occurrence associated with the operation of an aircraft that 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" (U.S. Dept. of Transportation, 2016, p. 1).

Aircraft Maintenance	" 'Maintenance' includes inspection, overhaul, repair, preservation, and the replacement of parts, but excludes preventive maintenance" (Aeronautics and Space, 2018, p. 10).
Crew Resource Management	"The effective use of all available resources for flight crew personnel to assure a safe and efficient operation, reducing error, avoiding stress and increasing efficiency" (FAA, 2004, p. 1).
Dirty Dozen	"The Dirty Dozen are the 12 most common causes of a maintenance person making an error in judgment which results in a maintenance error. They are lack of communication, complacency, lack of knowledge, distraction, lack of teamwork, fatigue, lack of resources, pressure, lack of assertiveness, stress, lack of awareness, and norms" (Dupont, 1997, p. 1).
Federal Aviation Administration	"An agency of the United States Department of Transportation with authority to regulate and oversee all aspects of civil aviation in the United States" (FAA, 2009, p. G-2).
General Aviation	All civil aviation operations other than scheduled air services and nonscheduled air

	transport operations for remuneration or hire (Fabry, 1990, p. 238).
Human Factors	"A multidisciplinary field encompassing the behavioral and social sciences, engineering, and physiology, to consider the variables that influence individual and crew performance for the purpose of optimizing human performance and reducing errors" (FAA, 2009, G-3).
Incident	"An occurrence other than an accident that affects or could affect the safety of operations" (Transportation, 2016).
Line Operations Safety Assessment	LOSA, "A formal process that requires expert and highly trained observers to ride the jump seat during regularly scheduled flights to collect safety-related data on environmental conditions, operational complexity, and flight crew performance. Confidential data collection and non-jeopardy assurance for pilots are fundamental to the process" (FAA, 2006, p. 2). This basic model has been adapted for use in aircraft maintenance (M-LOSA) and ramp operations (R-LOSA).

Pilot Error	"An accident in which an action or decision made by the pilot was the cause or a contributing factor that led to the accident" (FAA, 2009, p. G-4).
Preconditions for Maintenance Error	See "Dirty Dozen" definition.
Safety Management System	SMS, "The formal, top-down, organization-wide approach to managing safety risk and assuring the effectiveness of safety risk controls. It includes systematic procedures, practices, and policies for the management of safety risk" (FAA Order 8000.369, A-2).
Safety Risk Management	SRM, "A process within the SMS composed of describing the system, identifying the hazards, and analyzing, assessing, and controlling risk" (FAA Order 8000.369, A-2).
SHEL Model	Originally posited by Edwards (1972), it is "the relationship of human factors and the aviation environment" (Reinhart, 1996, p. 6-10). Specifically, the interactions of (S) software, (H) hardware, (E) environment, and (L) liveware within the system or aircraft.
Swiss Cheese Model	Theoretical model first posited by Reason (1990) to describe accident causation

	comprising: a) organizational influences, b) unsafe supervision, c) preconditions for unsafe acts, and d) the unsafe acts themselves.
Threat Error Management	"The Threat and Error Management (TEM) model is a conceptual framework that assists in understanding the inter-relationship between threats, errors, and undesired aircraft states in dynamic and challenging operational contexts" (Maurino, 2005, p. 1).

List of Acronyms

A4A	Airlines for America, formerly ATA
AC	Advisory circular
AD	Airworthiness directive
ASRS	Aviation Safety Reporting System
A&P	Airframe and power plant
CASA	Civil Aviation Safety Authority
CFR	Code of federal regulations
CRM	Crew resource management
FAA	Federal Aviation Administration
GA	General aviation
HFACS-ME	Human Factors Analysis and Classification System-Maintenance Extension
IATA	International Air Transport Association
LOSA	Line operations safety assessment
MCAS	Maintenance climate awareness survey
MEDA	Maintenance Error Decision Aid

MER	Maintenance event report
MOSA	Maintenance operations safety assessment
NASA	National Air & Space Administration
NTSB	National Transportation Safety Board
PA	Participating airline
SHEL	Software, hardware, environment, liveware
SME	Subject matter expert
SMS	Safety management system
SRM	Safety risk management
TEM	Threat and error management

CHAPTER II

REVIEW OF THE RELEVANT LITERATURE

Before engaging in any research regarding preconditions for error as they may relate to aircraft maintenance, a suitable structure should be established that contextualizes maintenance errors within aviation safety as a whole. According to the Federal Aviation Administration (FAA), while pilot error continues to be the leading cause of hull-loss accidents in the commercial aviation industry, maintenance errors are the second leading cause (FAA, 2014). The work of Marx and Graeber (1994) and, more recently, Patankar and Taylor (2004) estimate the maintenance error contribution to commercial aircraft accidents worldwide between 12% and 15%. Approaching the problem in an even broader scope, the International Air Transportation Association (IATA) examined safety reports filed between 2003 and 2008 and found that improper maintenance was linked to aircraft accidents worldwide as much as 40% of the time (IATA, 2008).

In and of themselves, these figures are cause for concern. However, since each flight-hour results in an average of 12 maintenance man-hours (Hobbs, 2008), it is not unreasonable to suggest that a maintenance error may be up to 12 times more likely to occur and manifest during any given flight-hour when compared to a pilot error. Marais and Robichaud (2012) found that the likelihood of a maintenance-related accident to result in fatalities is approximately 6.5 times greater than non-maintenance-related accidents. They also found that, in accidents resulting in fatalities, those accidents related to maintenance errors generated an average of 3.6 times more fatalities, giving rise to the theory of a “fatality risk magnifier” (Marais & Robichaud, 2012, p. 111) associated with maintenance-related accidents. Regardless of the specific calculations used, it seems clear that maintenance errors play a significant role in commercial aviation safety, making any efforts to reduce them worthwhile.

Human Factors in Aviation Maintenance

The study of human factors as it relates to aircraft maintenance began in earnest in the early 1990s. Experts seem to agree this was partly due to the general adoption of human factors research, especially in terms of pilots and aircrew. However, they also agree this was partially due to the sequence of high-profile air disasters in the 1980s in which aircraft maintenance was implicated (Chang & Wang, 2010; Dorn, 1996; Gramopadhye & Drury, 2000). Some of the more notable examples include the 1988 Aloha Airlines flight 243. The aircraft experienced explosive decompression attributed, in part, to insufficient inspections on the part of the operator (Hendricks, 1991). In 1989, a BM AirTours 737 experienced a windshield blowout owing to the incorrect bolts being used on installation. That same year, a United Airlines DC-10 crash-landed in Sioux City, Iowa, killing 111 passengers. The United incident, arguably one of the most infamous of its time, was found to be due to inadequate engine inspection techniques (Haynes, 1991; Latorella & Prabhu, 2000).

Since the early 1990s, a considerable amount of research has been conducted attempting to characterize human factors as they relate to aircraft maintenance. As a result, several theories and models have been developed. While the models differ somewhat in their approach and focus, researchers seem to agree that aviation inspection and maintenance tasks are not only varied and complex but are also performed under a constant time-pressure state and often in less than ideal environmental conditions (Hobbes, 2008; Latorella & Prabhu, 2000).

Error Types

Early maintenance human factors work conducted by Dorn (1996) utilized Edwards' (1988) classic SHEL model to study 101 civilian and military aircraft accidents occurring between 1983 and 1992. This conceptual framework is used to examine the complex interaction between four elements: a system's *software*, or rules, processes, and policies; its *hardware*, machinery and equipment; the often-demanding *environment*; and its *liveware*, or the humans that operate and maintain the system. Each of these elements typically has numerous sub-elements relevant to the particular application comprising its taxonomy. Edwards further posited that failures could occur not only at the elemental level but also at the interface between elements. Dorn (1996, p. 19) adapted the SHEL model to aviation maintenance using 28 elements seen in Table 2.

Table 2

SHEL Model Adapted for Aviation Maintenance

Software	Hardware	Environment	Liveware
Maintenance Instruction	Tools	Lighting	Mechanic
Regulation / Policy	Ground Equipment	Noise	Inspector
Accepted Practice	Supplies / Parts	Ventilation	Depot Mechanic
Schedule	Aircraft Equipment	Weather	Supervisor
Automated Forms	Aircraft	Workspace	Other Manager
	Clothing / Gear	Aircraft Off-Station	Pilot
	Computers		Logistics Manager
			Trainer
			Admin. / Clerical
			Inspection Agency

Dorn's study showed that while maintenance instruction (software) was involved with 63% of the accidents examined, the mechanics themselves (liveware) contributed to 58% of the accidents and were deemed the primary cause in 27 of those accidents. Moreover, since the accident investigation boards of the day tended to stop investigating once they uncovered the failed element, reports contained scant information about the causes or underlying nature of these element failures. As a result, "unknown" is the first item on Dorn's Pareto chart describing 23 underlying causes of the failures accounting for 39 of the 101 accidents examined.

Dorn's (1996) work was instrumental in demonstrating the shortcomings of aviation accident investigation and reporting, especially from a human factors point of view. While it certainly helped to highlight the role humans and their inherent limitations play in aviation accidents, it also illustrated the need for accident investigation and reporting techniques to evolve and expand the breadth and depth of collected data. To this end, Goldman, Fiedler, and King (2002) reviewed National Transportation Safety Board (NTSB) accident investigation reports from the 10-year span between 1988 and 1997. The reports were limited to Title 14 of the Code of Federal Regulations (14 CFR), Part 91 general aviation (GA) accidents, and did not include reports from revenue generating operations under Parts 121 or 135. However, for the purposes of the current research, the study revealed much about aviation maintenance professionals in general and the types of errors likely to occur while engaged in maintenance activities. Within the reports, the NTSB classified maintenance activities as follows (Goldman, et al., 2002, p. 1):

- routine maintenance
- service of aircraft equipment
- inspection
- compliance with airworthiness directives (AD)
- annual inspection
- adjustment
- alignment
- installation
- lubrication
- modification
- replacement
- major repair
- major alteration
- service bulletin/letter
- design change
- overhaul/major overhaul, rebuild/remanufacture

Using these more contextual classifications, a frequency distribution was calculated. The distribution revealed that errors associated with the *installation* of a component were a factor or the primary cause of 20% of the accidents. Other factors and/or causes included *maintenance* (14.7%), *inspection* (13.8%), and *annual inspection* (8.3%). These first four factors alone comprise over 50% of the accidents reviewed. Unfortunately, to say that 20% of maintenance-related accidents are attributable to an installation error of some sort lacks the specificity necessary to take any meaningful action. Additionally, while contextual schemes such as this tend to promote a more vivid and comprehensive data collection, the relationships they reveal are most often correlational but not necessarily causal (Latorella & Prabhu, 2000). While Goldman et al. (2002) certainly built upon Dorn's work to legitimize human factors in terms of aviation maintenance as a genuine concern, the NTSB classification of maintenance activities used was vague and of little value in terms of determining the actual events or errors that might lead to an accident (Boyd & Stolzer, 2015).

Human Error Classification

Safety Management Systems (SMS) have become ubiquitous in the aviation industry and are accepted as the most effective framework from which to build a positive and effective safety culture (Ma & Rankin, 2012). According to Stolzer, Halford, and Goglia (2015), one of the pillars of SMS is safety risk management (SRM) which comprises (a) system description (design), (b) hazard identification, (c) risk analysis, (d) risk assessment, and (e) controlling the risk. Human error classification systems are essentially a systems approach that seeks to classify various types of human errors and are often more qualitative in nature (Reason, 1990; Woods, Cook, & Sarter, 1995).

One highly effective application of this approach is the Human Factors Analysis and Classification System - Maintenance Extension, or HFACS-ME. HFACS-ME comprises aspects of Reason's Swiss Cheese Model, Edward's SHEL Model, as well as Heinrich's Domino Theory (Schmidt, Lawson, & Figlock, 2001). HFACS-ME breaks down human error into four levels (orders) as shown in Figure 1. At the first order level, management conditions, mechanic conditions, and working conditions essentially set the stage for a mechanic's actions to result in an accident. The first and second order categories help identify where issues are located within a system or organization, while the third order categories add the necessary specificity to develop adequate intervention strategies (Shappell & Weigmann, 2000).

The creators and advocates of HFACS-ME stress that it is a flexible and adaptable system. The categories can, and should, be altered as necessary to fit a particular application or organization. By itself, this flexibility generates a rich interaction of possibilities, particularly at the third order level. However, it also paves the way for the possible integration of preconditions for error discussed later in this chapter.

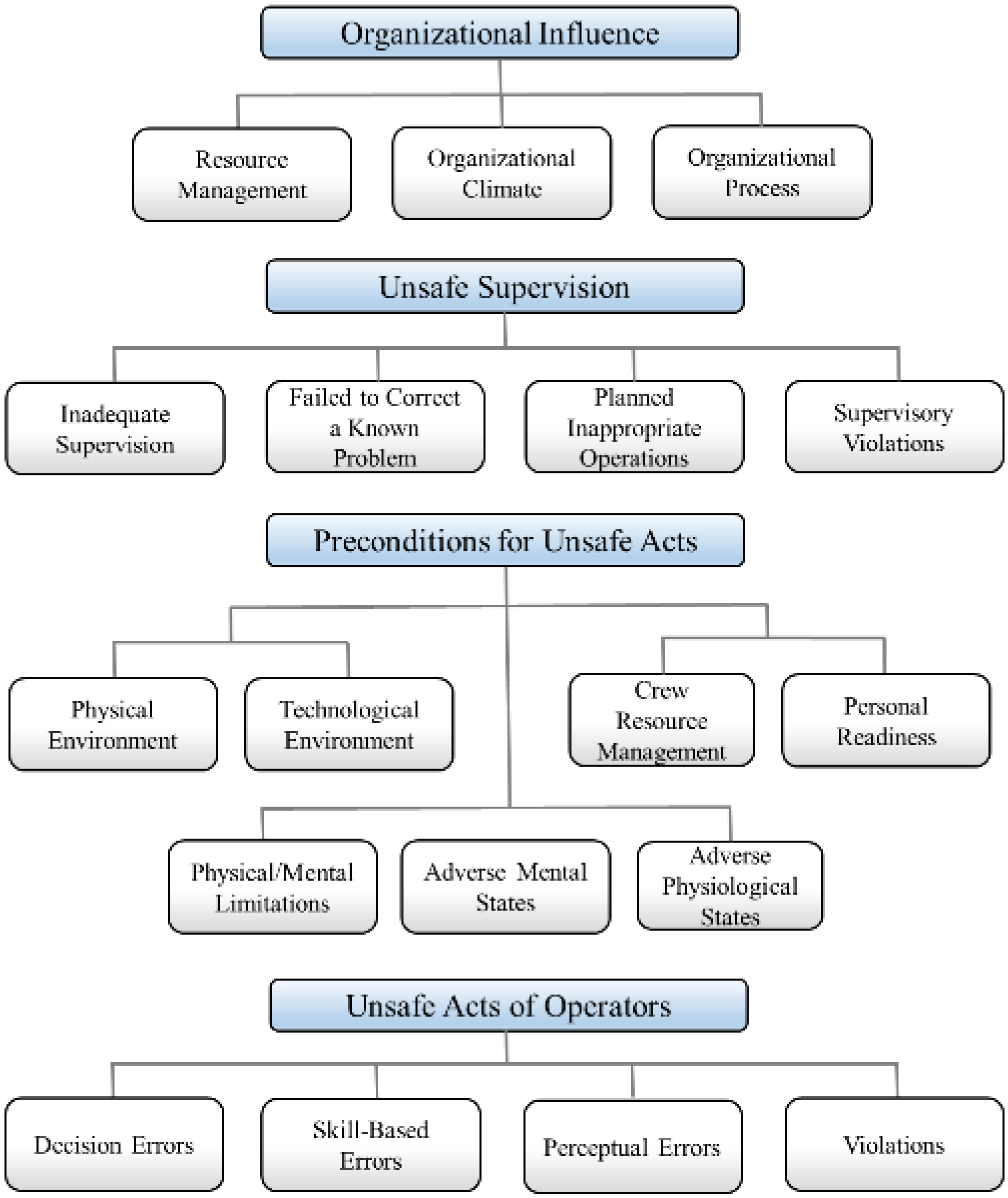

Figure 1. HFACS-ME model. Shows the four levels of failure: (1) unsafe acts, (2) preconditions for unsafe acts, (3) unsafe supervision, and (4) organizational influences. Adapted from Hooper and O'Hare, 2013, p. 2.

Threat and Error Management (TEM)

The Threat and Error Management (TEM) model is a conceptual framework that aids in understanding the relationship between human performance and system performance and how they relate to safety. The basic TEM model considers the interaction of *threats, errors,* and *undesired states,* all of which are accepted as inherent in complex systems, and focuses on their management in an operational setting (Merritt & Klinect, 2006). Within this framework, these three overarching domains are further defined in the FAA's AC 120-90 (Appendix A, p. 1) as follows:

- Threats - events or errors that (a) occur outside the influence of the flight crew, (b) increase the operational complexity of a flight, and (c) require crew attention and management if safety margins are to be maintained.
- Errors - action or inaction that leads to a deviation from crew or organizational intentions or expectations. Errors in the operational context tend to reduce the margin of safety and increase the probability of adverse events.
- Undesired Aircraft State (UAS) - a position, condition, or attitude of an aircraft that clearly reduces safety margins and is a result of actions by the flight crew. It is a safety-compromising state that results from ineffective error management.

Threats can be subdivided into two categories, latent and overt. Latent threats are inherent in the system or organization and are often not identified until they manifest, causing an accident or incident. Overt threats are active and present threats to safety (e.g., weather conditions) and may be further classified as anticipated or unexpected

(Maurino, 2005). Within the crew resource management (CRM) context, threats can be prepared for, errors can be remedied (repaired), and undesired aircraft states can be recovered. However, during normal (safe) operations, should a threat or error manifest that is not adequately prepared for, repaired, or recovered, the result is an incident or accident (Figure 2a). In this sense, it is not unlike Reason's (1990) renowned Swiss Cheese Model in that incidents and accidents occur as a result of specific holes in a system's defenses "lining up" (Figure 2b).

These definitions were originally developed for flight-deck and crew operations within the discipline of CRM. However, by simply couching these definitions within a maintenance or operations scenario rather than a flight-deck scenario, the TEM model has been found to be equally effective in maintenance and ramp operations applications (Klinect, Murray, Merritt, & Helmreich, 2003; Langer & Braithwaite, 2016; Ma & Rankin, 2012).

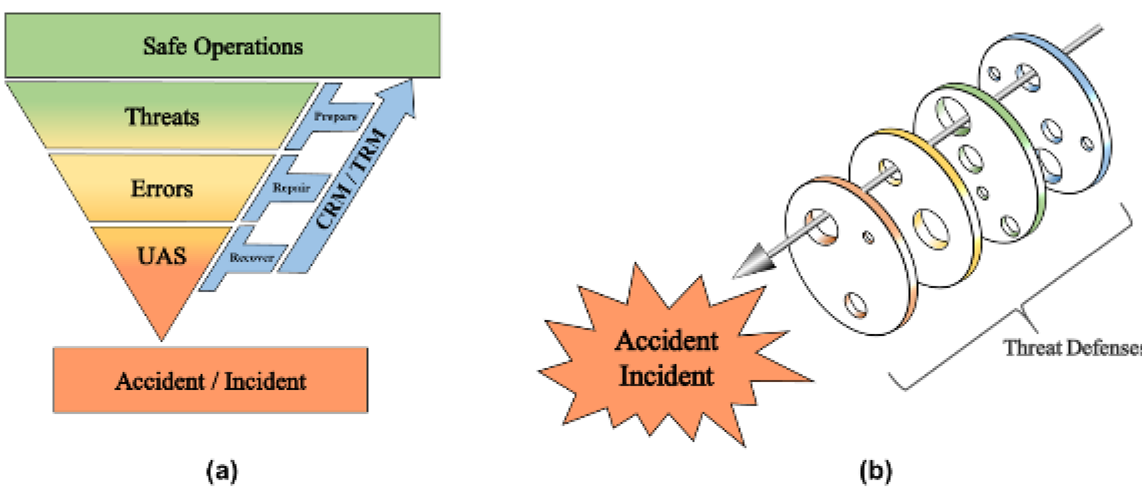

Figure 2. TEM Model (a) and Reason's Swiss Cheese Model (b).. Both engender the notion that threats can become accidents/incidents when gaps in the system's defenses align. Adapted from Reason, 1990, and Maurino, 2005.

TEM, LOSA, and M-LOSA

Managing threats and errors assumes they have been identified and are known to exist. Unfortunately, this is not always the case. The Line Operations Safety Assessment (LOSA) was originally developed, under funding from the FAA, as a joint venture between the University of Texas at Austin Human Factors Research Project and Continental Airlines (Crayton, Hackworth, Roberts & King, 2017; IACO, 2002). Leveraging the TEM model, LOSA is a collection of publicly available tools for gathering safety data during day-to-day airline operations.

LOSA is a pragmatic approach in that one of its key tenets "emphasizes prevention through the identification of hazards and the introduction of risk mitigation measures before the risk-bearing event occurs and adversely affects safety performance" (Klinect, 2008, p. 6). So, while most systems prior to LOSA were reactive in nature, responding to an accident or incident in an attempt to discover the root cause(s) and take remedial action after-the-fact, LOSA provides a means for organizations to perform self-assessments by monitoring routine operations to help reveal errors or threats that were previously unknown.

This aspect of LOSA makes it an effective proactive tool in terms of threat and error management, setting it apart from its predecessors. Another important aspect of LOSA and LOSA-like systems is their subscription to the notion that threats and errors can never be eliminated completely, but constant monitoring and analysis can allow an organization to chip away at them, incrementally reducing the effects of threats and errors over time in a cost-effective manner (FAA, 2013; Helmreich, Klinect, & Wilhelm, 2017). Since its operational deployment in March 2001, LOSA has demonstrated its effectiveness and is now in widespread use in airlines worldwide and is endorsed by the FAA, EASA, and ICAO (FAA, 2013).

After the success of LOSA in flight operations, the FAA sponsored a project in 2008 to examine the basic LOSA methodology to determine its applicability to maintenance and ramp operations. Together with Airlines for America (A4A, formerly the Air Transport Association), the FAA formed the Maintenance and Ramp Human Factors Taskforce committee. After three years of development, R-LOSA (Ramp-LOSA) and M-LOSA (Maintenance-LOSA) were finally realized (Ma & Rankin, 2012). In order to assure the fledgling methodology's survival, the committee developed and tested an entire suite of data collection tools and made them publicly available on the FAA's website. These tools include observation forms (ramp and maintenance operations), error codes, threat codes, electronic database templates, basic LOSA procedures, as well as training packages for ramp and maintenance operations (Crayton et al., 2017). The committee also made available detailed instructions for deploying these systems as well as cost-benefit analysis tools to help support the business case for implementation of these systems in an organization.

Heinrich, Petersen, and Roos (1980) first presented the theory of the Heinrich Ratio. This theory suggests that the relatively small number of catastrophic accidents are actually just "the-tip-of-the-iceberg" and that "for every major accident, there are 10 less serious accidents, 30 incidents, and 600 hazardous acts" (FAA, 2015, p. 6). If valid, this theory suggests the reactive investigation of every accident has something to offer in terms of mitigating or eliminating future accidents, thereby reducing risk. Conversely, it also means that any proactive assessment program like M-LOSA that allows an organization to discover and correct some of those 600 hazardous acts should have a noticeable and perhaps substantial impact on accidents and incidents (Gramopadhye & Drury, 2000). In this way, M-LOSA represents a significant improvement in the industry's ability to reduce accidents by working the problem of maintenance errors in both a reactive and proactive sense. Looking more broadly at the evolution of human factors as a discipline, it can fairly be said that incremental progress has been the norm.

Preconditions for Maintenance Errors: The Dirty Dozen

In reviewing the extant literature concerning aviation maintenance errors, a substantial amount of research supports models and theories of human behavior as it relates to maintenance errors (Gramopadhye & Drury, 2000; Langer & Braithwaite, 2016; Reason, 1990; Schmidt, Lawson, & Figlock, 2001). Additionally, significant effort has been applied to generating taxonomies to accompany these models and theories to help researchers understand *what* happened in terms of a given maintenance error. However, little research exists to explain *why* it happened. Historically, accident investigators have applied one or more of the aforementioned models and taxonomies to their investigations to essentially reverse-engineer the sequence of events that made the accident manifest physically. Boeing's Maintenance Error Decision Aid (MEDA), introduced in the mid-1990s, took a systems approach to merge accepted theories of accident causation (Reason, 1990; Schmidt, Lawson, & Figlock, 2001) with a host of contributing factors, some of which are also Dirty Dozen categories (Boeing, 2013). MEDA's novel approach allowed it to perform reasonably well as a reactive investigation tool. However, much as the scientific axiom states - correlation does not equal causation, revealing what failed in a system does not necessarily reveal the underlying reason that it failed and, may even belie it to some degree. For this and other reasons, it is worthwhile to examine the contributing factors or preconditions for maintenance errors.

The 12 preconditions for maintenance errors were developed by Gordon Dupont of Transport Canada in the mid-1990s with assistance from colleagues from the Royal Canadian Air Force. Dubbed *the Dirty Dozen*, they are best described by the FAA as "twelve human factors that degrade people's ability to perform effectively and safely, which could lead to maintenance errors. These twelve factors were soon adopted by the aviation industry as a straight-forward means to discuss human error in maintenance" (FAA, 2008, p. 14-11). The Dirty Dozen categories are defined in Table 3.

Table 3

Dupont's Dirty Dozen

Precondition for Error	Definition
Lack of Communication	Failure to transmit, receive, or provide enough information to complete a task.
Complacency	Overconfidence from repeated experience performing a task.
Lack of Knowledge	Shortage of the training, information, and/or ability to successfully perform.
Distractions	Anything that draws your attention away from the task at hand.
Lack of Teamwork	Failure to work together to complete a shared goal.
Fatigue	Physical or mental exhaustion threatening work performance.
Lack of Resources	Not having enough people, equipment, documentation, time, parts, etc., to complete a task.
Pressure	Real or perceived forces demanding high-level job performance.
Lack of Assertiveness	Failure to speak up or document concerns about instructions, orders, or the actions of others.

Stress	A physical, chemical, or emotional factor causing physical or mental tension.
Lack of Awareness	Failure to recognize a situation, understand what it is, and predict the possible results.
Norms	Expected, yet unwritten, rules of behavior.

Note. Adapted from the FAA (n.d.).

The Dirty Dozen is broadly accepted as a maintenance human factors framework worldwide, endorsed in publications by the FAA, European Aviation Safety Agency (EASA), Australia's Civil Aviation Safety Authority (CASA), Transport Canada, and the RAF, among others (Adams, 2009; CAA, 2013; FAA, 2008). The Dirty Dozen is part of the core human factors training conducted by notable international training organizations such as Delta TechOps, Lufthansa Technik, and Aveos (Adams, 2009). Additionally, the FAA offers a free course in the Dirty Dozen at their human factors website, and the FAA's Aircraft Maintenance Technician handbook chapter on human factors devotes over 15 of its 28 pages to the Dirty Dozen (FAA, 2008).

However, when compared to the volumes of research behind systems, theories and models such as Edwards' SHEL Model (1988), Reason's Swiss Cheese Model (1990), TEM, HFACS-ME, MEDA, and M-LOSA, that have been adopted by the industry, Dupont's (1997) Dirty Dozen's origin and development is considerably more modest. In 1993, Dupont was working for the Canadian airworthiness authority, Transport Canada. Dupont, along with an industry liaison committee and members of the Canadian Department of National Defence [*sic*] examined between 1,500 and 2,000 aviation maintenance incident and accident reports simply attributed to some form of human error. After approximately seven months of careful examination and discussion, the team determined the bulk of these maintenance-related human errors could be attributed to one or more of 12 basic preconditions for error (G. Dupont, personal communication, August 10, 2017). These preconditions quickly became known as the “Dirty Dozen”. Shortly after the run of aircraft accidents in the 80s and 90s, the FAA’s Dr. Bill Shepherd initiated a series of meetings aimed at investigating the issue of human factors as it relates to aircraft maintenance operations (Dupont, n.d.). It was at these meetings between 1993 and 1997 Dupont first presented the Dirty Dozen to the international consortium co-sponsored by the United States, Canada, and the United Kingdom. Although, at that point, the popularity of the program was undeniable as thousands of posters depicting the Dirty Dozen had already been ordered and shipped to organizations worldwide (Dupont, 1997). All 12 Dirty Dozen posters can be seen in Appendix B.

Unfortunately, the seemingly universal acceptance of the Dirty Dozen across the aviation maintenance industry belies the amount of scientific research supporting it. The Dirty Dozen is mentioned in a modicum of peer-reviewed publications (Latorella & Prabhu, 2000; Patankar & Taylor, 2001). It is also discussed in the FAA’s human factors quarterly newsletter in an article by Ma and Grower (2016) in which the authors posit the possibility of three additional preconditions: not admitting to limitations, lack of operational integrity, and lack of professionalism. Hobbs and Williamson (2003) examined 17 contributing factors (preconditions) for error from several taxonomies and found a relationship between certain types of errors and certain contributing factors. Unfortunately, only five of the Dirty Dozen preconditions were represented in the study. A brief mention of the Dirty Dozen is also in a NASA’s (2008) Aviation Safety Reporting System (ASRS) monthly safety bulletin, Callback, referencing seven ASRS reported accidents and how some of the 12 preconditions played a role. Apart from these, very little scientific evidence supporting the framework's validity in aviation exists. This seems incongruent in an industry that has historically required a relatively high level of rigor in terms of policies and programs it embraces.

As odd as it may seem, some level of validity and scientific rigor was found in the field of medical science. In 2015, Marquardt, Treffenstadt, Gerstmeyer, and Gades-Buettrich noted a lack of validated, applied models addressing cognitive performance in the medical industry. Reasoning the technical requirements and complexity of surgical operations are presumed to be equivalent to highly demanding work settings in other fields, the researchers designed a survey with categories based on the Dirty Dozen (Marquardt et al., 2015). Using the survey instrument, the researchers queried 215 practicing surgical ophthalmologists to measure any degradation of cognitive performance of the surgical team.

This might seem like a labored analogy; however, it is not the first time aircraft maintenance has been likened to the medical profession. In 1999, Taylor compared the cultural attributes of aircraft mechanics, pilots, and surgeons and concluded mechanics and surgeons shared a strong sense of individualism on the job. Later, Hobbs equated the invasive nature and iatrogenic risk of many medical and surgical procedures to the domain of aircraft maintenance, stating "preventative maintenance in aviation often requires us to disassemble and inspect normally functioning systems, with the attendant risk of error" (Hobbs, 2008, p. 2).

The study by Marquardt et al. (2015) noted the surveyed surgeons felt the categories were very similar in terms of their impact on cognitive performance (Figure 3) and concluded there was “no overall dominant performance limiting factor” (Marquardt et al., 2015, p. 217), validating the idea that the categories themselves have merit in terms of identifying error sources in highly technical applications. While the researchers lauded the Dirty Dozen’s comprehensive nature and adaptability, they also criticized it, claiming that in a surgical application, some of the categories of the Dirty Dozen overlap, making it difficult to clearly assess which preconditions for error were responsible and to what degree. This suggests that while the Dirty Dozen framework is indeed applicable and highly adaptable, it may not be an off-the-shelf solution for the operating rooms of ophthalmology. The researchers stated they planned to apply the framework to other areas of healthcare in the near future.

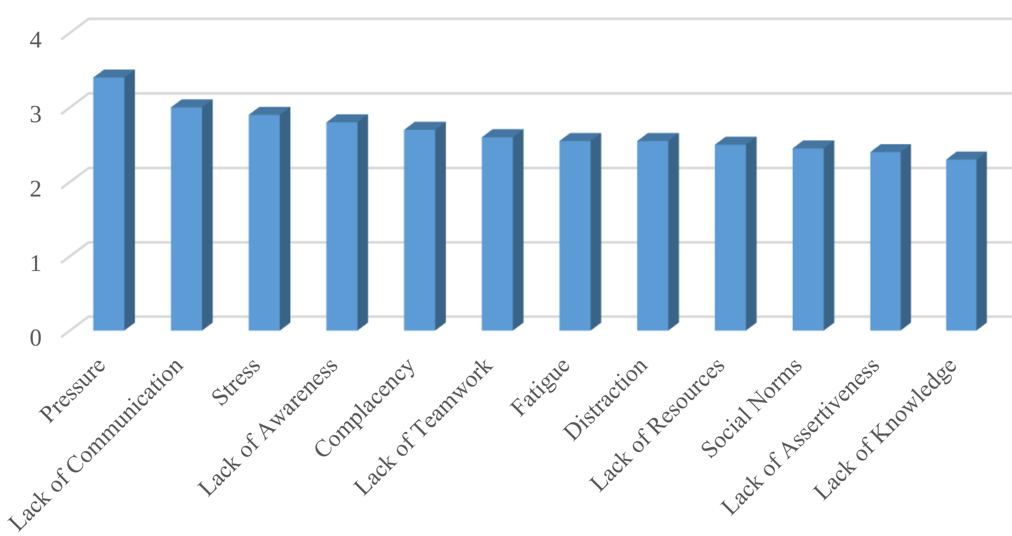

Figure 3. Dirty dozen categories of medical events in the operating room. Adapted from Marquardt et al., 2015.

Only one other system developed during this timeframe attempted to incorporate preconditions or contributing factors into its process. Boeing worked with nine domestic and foreign carriers to develop the Maintenance Event Decision Aid (MEDA). MEDA provides a “structured process for investigating the causes of errors made by maintenance technicians and inspectors” (Rankin, 2007, p. 1). Built into this process is an identification of contributing factors to the event. MEDA’s ten overarching contributing factors categories are (Boeing, 2013, p. 31):

- Information
- Ground support equipment, tools, and safety equipment
- Aircraft design, configuration, parts, equipment, and consumables
- Job or task
- Knowledge and skills
- Individual factors
- Environment and facilities
- Organizational factors
- Leadership and supervision
- Communication

While a few of the Dirty Dozen appear in the MEDA list, most of them are not represented. Moreover, MEDA is a reactive system. Like similar systems, it can only be used after-the-fact, once incidents have already manifested. Therefore, it has no inherent predictive capability, nor is it useful in proactive safety endeavors.

Summary

Dupont’s original analysis of maintenance human factors-related accidents was never published by Transport Canada, but the resultant preconditions for maintenance error known as the Dirty Dozen certainly was. While lacking scientific evidence in the peer-reviewed literature, the acceptance and appeal of the Dirty Dozen to the aviation industry worldwide is undeniable. Research exists in the medical field to support the Dirty Dozen’s general applicability to complex, highly technical occupations as well as its robust representation of most of the obstacles to performance (preconditions for error).

Additionally, on more than one occasion, researchers have likened aircraft maintenance to elements of the medical profession and have even gone so far as to associate certain cultural attributes between aircraft mechanics and surgeons. One possible, albeit simplistic explanation for the popularity and proliferation of the Dirty Dozen framework is simply that it makes sense to aviation maintenance professionals. That is, on some cognitive level, they recognize most or all of the 12 preconditions for maintenance errors and identify with them based on personal experience. Whatever the reason, the Dirty Dozen is firmly ensconced in the aviation maintenance culture around the globe.

CHAPTER III

METHODOLOGY

Due to the narrative nature of much of the data provided by the PA, a qualitative research approach was proposed. Archival data were examined for the presence of the preconditions for maintenance error known as the Dirty Dozen in order to answer the research questions below:

1. How does the reactive data (MER) analysis compare to the proactive (MOSA) analysis in terms of the Dirty Dozen? Do they echo similar Dirty Dozen categories, or do they seem to reflect different aspects of the Dirty Dozen?
2. What other preconditions for maintenance error become apparent from the analyses? What do they have in common, or are any of them similar to the additional preconditions suggested by Ma and Grower (2016)? In terms of typical preconditions for maintenance error, how complete is the Dirty Dozen?
3. What insights can be gleaned from the subjective report data (MCAS) with regard to maintenance personnel's perceptions of the organization's safety culture?

The research was performed in two phases. The first phase used subject matter experts (SMEs) to code two different types of reports (MER and MOSA) from the same airline within the construct of the Dirty Dozen (see Figure 4). The second phase of the research examined the PA's most recent Maintenance Climate Awareness Survey for insights on the organization's safety culture. The results illustrated the overall presence (frequency) of Dirty Dozen elements as well as measured their prevalence (intensity) within the maintenance culture of the PA. This allowed for recommendations to the PA to focus their safety efforts on the most prevalent preconditions for maintenance error. The examination and coding of these incident reports by SMEs was thought to holistically characterize events and behaviors with special attention to nuance, interdependencies and complexities, and context making a qualitative approach most appropriate (Patton, 1990).

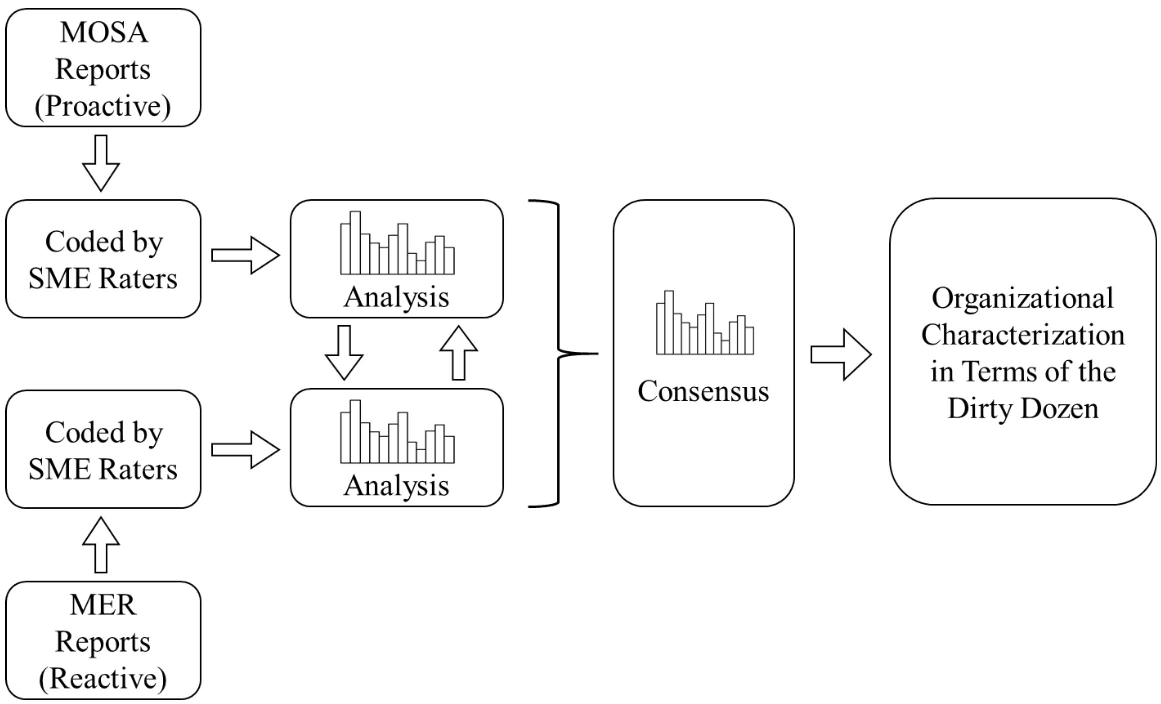

Figure 4. Process flow for proactive (MOSA) and reactive (MERs) reports.

The reports provided by the PA created certain challenges. To begin, while all the reports examined were from 2017, they were generated from data collected at three different time frames within that year. In addition, the study analyzed all available reports (25 MER reports and 60 MOSA reports) while assuring inter-rater reliability through repeated use of Krippendorff's alpha. Descriptive statistics were run to test normality of distributions. However, none of Dupont's previous work suggest an assumption of normality in terms of the distribution of the Dirty Dozen in any given organization. Thus, the limited number of reports and the nature of the data precluded conducting certain inferential statistical analyses. Accordingly, most of the exploration and comparisons in the current research relied on descriptive statistics and parametric statistical analyses where appropriate (e.g., Cronbach's alpha and Multivariate Analysis of Variance or MANOVA). A discussion of potential impacts to reliability and validity can be found at the end of this chapter.

Data Collection and Treatment

The first phase of the current research used aircraft maintenance SMEs to examine and code two different sets of reports from the PA. These reports were Maintenance Event Reports (MER) and Maintenance Operations Safety Assessments (MOSA). The airline provided a total of 25 MERs collected between January and May 2017, and 60 MOSA reports collected between September and November 2017. Results from the airline's Maintenance Climate Awareness Survey (MCAS) conducted between February and April 2017 were also provided (see Table 4).

Table 4

Report Descriptions

Report Name and Description	Number	Date Range
Maintenance Event Reports (MER): Reactive reports voluntarily filed by maintenance personnel documenting events or conditions found that did or could have caused an incident or accident.	25	Jun – May 2017
Maintenance Operations Safety Assessment (MOSA):	60	Sep – Nov 2017

Proactive reports generated by periodic internal MOSA team assessments during which trained MOSA auditors observe a variety of maintenance tasks. Specific categories of observations can be found in Appendix E.		
Maintenance Climate Awareness Survey (MCAS): Results of an anonymous survey (subjective) to which 1,246 maintenance related personnel responded. The four categories of the survey included organizational processes, organization climate, resources, and supervision. The survey also included five additional open-response questions.	26	Feb – Apr 2017

The MERs are an incident reporting system internal to the participant airline. Most of the 25 MERs received were short narratives of maintenance-related events that did or could have resulted in injury or damage to an aircraft similar to the FAA's Aviation Safety Action Program (ASAP). However, some reports simply indicated an overarching issue, such as fatigue, that the submitter felt could precipitate an event resulting in injury or damage to an aircraft. As such, MERs were voluntary, reactive reports thought to be illustrative of the airline's maintenance climate once they were coded in terms of the Dirty Dozen. Figure 5 shows an example of a MER report, with identifying information redacted.

Occurrence ID	Type	Risk	Date and Time UTC	Occurrence Title	Registered On/By	Tail Number	Aircraft Type	Location
0212-17	MNT GRH1	Medium	Jan 10 2017 00:30	Refueling	Jan 11 2017 10:00 [redacted] [redacted]			[redacted]

DESCRIPTION OF OCCURRENCE

Description: Flight [redacted] on Jan 10th 2016, tail number [redacted], originally going to [redacted] had to divert to [redacted] due to weather. The flight proceeded with no abnormalities whatsoever. When arriving at [redacted] the aircraft was instructed to stop at a GA parking position, and a mechanic greeted us saying he was the only one working that shift; he said he had to go dispatch another aircraft bound to [redacted] and would be right back. As soon as I got the paperwork for the flight I called [redacted] Dispatch, advising them we had to hurry up with refueling because we were almost reaching our duty time limit; the person on the radio also informed us there was only one mechanic available that night and we would have to wait for him to dispatch that other flight. After a few minutes, however, I noticed the fuel quantity on the displays going up. I tried contacting the mechanic over the interphone system, but there was no response. I came downstairs to see who was refueling the plane and it shook me to see the fuel truck driver performing the refuel all by himself; I instantly told him to stop. I asked the mechanic what was going on and he answered he did not request refueling the aircraft. I then questioned the Orange Cap, who said he only told the driver what fuel quantity they needed. I left [redacted] without knowing who was responsible for this mishap. I am writing this report with the intents of making people aware of what happened and to help such violations from taking place again.

Figure 5. Illustrative example of MER report.

The 60 MOSA reports conformed essentially to the format presented in AC 120-90 (FAA, 2006) for MOSA reports. Like MERs, MOSA reports also contained narratives. However, MOSA reports were the result of a proactive surveillance program aimed at identifying potentially hazardous behavior before it could manifest as an incident or accident. Nevertheless, the MOSA reports were thought to be similarly illustrative of the airline's maintenance climate, once coded. A comparison of the two sets of reports and an analysis of the categories within are discussed below in the Data Analysis Process section.

The MCAS provided by the participant airline were the results of a survey conducted between February and April 2017. The survey was administered to a total of 2,054 employees directly or indirectly associated with the airline's maintenance operation, of which 1,246 responded (60.6% response rate). This comprehensive survey consists of a total of 63 questions covering aspects of organizational processes, organizational climate, resources, and supervision. Five open questions were posed at the end of the survey, one of which was deemed relevant and was examined as well.

While not every category of the Dirty Dozen was reflected in the survey, many of them were. Moreover, some categories of the Dirty Dozen were often represented by multiple survey questions, making the MCAS a robust portrayal of the maintenance climate at the PA as viewed by its maintenance personnel.

Report Data

The MERs and MOSA reports were coded by two qualified aircraft maintenance professionals (see Appendix A). The coding scheme called for each rater to examine each event report within the context of the Dirty Dozen. An initial training session of approximately 90 minutes was held for the raters. Since some preconditions for maintenance error may not be represented in the current Dirty Dozen framework, an additional category labeled *other* was added for a total of 13 categories. The raters then allocated percentages (0% to 100%) to each of the categories based on their assessment of how much each precondition for error contributed to the event (see Figure 6).

<table>
<tr><th>Event</th><th>Occurrence ID</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></tr>
<tr><td>8</td><td>01088-17</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="14">Description of Occurance:
I asked the maintenance technician over the radio if everything was ready and set on the ground for the pushback and engine startup; the technician replied saying everything was OK around the aircraft and the hazard zones were clear and ready for startup. I then turned on the strobe lights and lit the ignition on engine #2. I noticed the ground crew was taking too long to push the plane and still had not linked the tow truck to the nose landing gear. Oddly enough, I was able to see the reflection of ground crew walking away from the aircraft with wheel chocks in hands on the glass of terminal building around the plane; in other words, not only there was personnel in hazard zones but there were people around the engine that was spooling up. I inquired the maintenance technician why he stated things were good to go and hazard zones were clear when that was clearly not the case. He replied it was just a matter of connecting the tow bar. After the ground crew left the surroundings of the aircraft the personnel continued the pushback and we proceeded with the startup.</td></tr>
<tr><td>50</td><td>10</td><td></td><td></td><td>20</td><td></td><td></td><td></td><td></td><td></td><td>20</td><td></td><td></td><td>100</td></tr>
<tr><td>Lack of Communication</td><td>Complacency</td><td>Lack of Knowledge</td><td>Distraction</td><td>Lack of Teamwork</td><td>Fatigue</td><td>Lack of Resources</td><td>Pressure</td><td>Lack of Assertiveness</td><td>Stress</td><td>Lack of Awareness</td><td>Norms</td><td>Other</td><td>Total</td></tr>
</table>

Figure 6. Sample coding form. Shows the event number, description of the event, and Dirty Dozen. Notional scores for Rater A shown in yellow.

When complete, the rater's scores for each event totaled 100, representing a characterization of 100% of the event expressed in terms of the Dirty Dozen. See Figure

7 for an example of this comparison. Since the minimum and maximum rating values were known (0-100), and the distance between each value is equal, the scores were considered interval measures for the purpose of determining inter-rater reliability (Hayes & Krippendorff, 2007). Following the first evaluation of the reports by the raters, inter-rater reliability was calculated using Krippendorff's alpha protocol for interval measures. A Krippendorff's alpha value of less than .80 would prompt further training on the application of the categorization scheme. Another inter-rater reliability check was conducted after the re-evaluation of the reports. This process was to continue until the minimum desired inter-rater reliability level (> .80) had been achieved.

8		RATER A	RATER B
DEFICIT	Lack of Communication	30	25
	Lack of Knowledge	20	15
	Lack of Teamwork	10	20
	Lack of Resources	0	0
	Lack of Assertiveness	0	0
	Lack of Awareness	10	10
SURPLUS	Complacency	20	20
	Distraction	0	0
	Fatigue	0	0
	Pressure	0	0
	Stress	0	0
	Norms	10	10
	Other	0	0

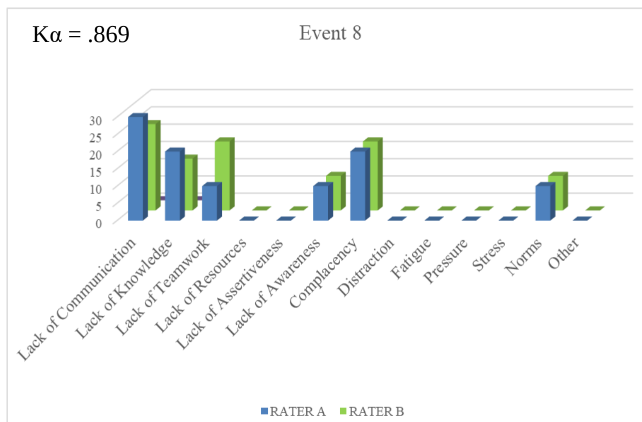

Figure 7. Example rater scores. Consolidated and reordered according to their influence on the event as a surplus or deficit (left). Rater agreement is characterized by the 3-D chart on the right and the actual Krippendorff's alpha value (center).

The order of the Dirty Dozen shown on the rater's sheet is in the same order it typically appears in textbooks and training media to avoid introducing bias. However, the categories were reordered in the summary table (Figure 7). This reorder helped visually underscore that half of the Dirty Dozen represented a deficit of a desirable attribute or condition such as a lack of teamwork, while the other half represented a surplus of an undesirable attribute or condition such as pressure. It was not known if this distinction would be meaningful or not but was thought to be a useful descriptor.

In the event the *other* category was used, the raters were instructed to highlight the text they felt represented a precondition for error not listed in the Dirty Dozen. If present, these would be examined later for any common themes that could suggest the presence of a definable precondition for maintenance error such as those suggested by Ma and Grower (2016).

For each of the 25 MER reports, once the necessary IRR was achieved (Figure 7), the rater's scores were averaged to create a single set of scores for comparison to the MOSA reports. This process was not necessary for the MOSA coding since each rater only evaluated half of the 60 MOSA reports[1]. However, certain additional steps were taken to ensure IRR for the MOSA reports. These steps are described in detail in the Reliability and Validity section. A one-way MANOVA was then conducted to compare and contrast the results of the MER and MOSA coded and scored by the SMEs.

Survey Data

The format of the Maintenance Climate Awareness Survey (MCAS) results required a somewhat different approach in terms of analysis. The survey consisted of 58 questions grouped under four headings: organizational processes, organizational climate, resources, and supervision. These questions were presented in a five-way Likert scale format providing for responses of totally agree, agree, disagree, totally disagree, and neutral. To augment the Likert scale questions, five open-response questions were posed

[1] See Reliability and Validity section on pp. 43-44 for details on measures taken to ensure inter-rater reliability.

at the end of the survey for a total of 63 questions. Of the base 58 MCAS questions, 26 of them could be mapped to six of the Dirty Dozen categories, as seen in Table 5. The mapping was presented to the SMEs for discussion and then grouped by consensus by the SMEs. The order of the table was determined by the number of survey questions related to a particular Dirty Dozen category.

Table 5

Six Dirty Dozen Categories Represented Within the 58 Base MCAS

Dirty Dozen Category	Number	Dirty Dozen Category	Number
Lack of Communication	9	Fatigue	2
Lack of Resources	8	Stress	2
Lack of Knowledge	3	Pressure	2

Note: Number = number of related survey questions.

The results of the 2017 MCAS suggest one of the five open-response questions at the end of the survey would be instrumental in further characterizing the maintenance climate at the PA. This question asked, "If there is a maintenance error, it will be due to (fill in the blank)?" (MCAS survey, 2017, p. 10). According to the PA, the 2010 MCAS indicated almost 20% of the respondents felt a maintenance error of this sort would likely be caused by pressure to release the aircraft back to service, suggesting a relatively high-pressure environment may have existed in 2010. From the same 2010 survey question, the combined scores for unskilled labor and insufficient training were over 17%, suggesting the presence of a lack of knowledge. Additionally, respondents cited a lack of tools and support equipment, lack of repair parts, and lack of personnel comprised 24.7%, suggesting the significant presence of a lack of resources. Information like this, gleaned from the relevant open-response question on the 2017 MCAS, was combined with the characterization derived from the analysis of the other 58 survey questions to synthesize and illustrate the organizational character in terms of the Dirty Dozen.

The three-pronged analysis of proactive data (MOSA), reactive data (MERs), and subjective data (MCAS) in this study was thought to yield an insightful report with actionable components within the Dirty Dozen construct despite the paucity of certain data. These components were then prioritized to recommend maintenance error mitigation strategies for the PA.

Rater Selection

The two raters were selected based on the following criteria established a priori. The candidates must be FAA certificated Airframe & Power Plant (A&P) mechanics, preferably certificated for 20 years or more. The candidates must have knowledge and experience with the Dirty Dozen, preferably in a training and/or human factors environment. The use of raters with such specific qualifications was thought to enhance overall reliability and validity of the study. Biographies of the raters can be found in Appendix A.

Reliability and Validity

Since the data used in the current research had been collected previously, certain issues had to be addressed in order to improve aspects of reliability and validity throughout the study. A variety of steps were taken to address these issues including frequent use of Krippendorff's alpha to ensure inter-rater reliability for MER and MOSA reports as well as Crohnbach's alpha to quantify the internal consistency of the MCAS survey.

Reliability. Statistical reliability, as it applies to the current research, concerns itself with the consistency of the data used. Of particular concern was the reliability of the raters as they coded the MER and MOSA reports, as well as the reliability of the MCAS as a survey instrument. To enhance reliability of the coding process, the SMEs underwent approximately 90 minutes of initial training. The training was conducted by the researcher and covered report types (reactive: MER vs. proactive: MOSA), scoring each event in the reports, and the importance of inter-rater reliability (IRR) and how it was to be calculated using a Krippendorff's alpha protocol. Although many ways exist to calculate IRR, Krippendorff's alpha lends itself to this study particularly well since it is a robust calculation tolerant of differing sample sizes, missing data, number of coders, and most metrics (e.g., nominal, ordinal, interval, and ratio). Since the minimum and maximum rating values were known (0-100) and the distance between each value is equal, the scores were considered interval measures for the purpose of calculating IRR. In accordance with Krippendorff's (2007) suggestion, the minimum alpha level for the study was established as $\alpha \geq 0.80$. Any alpha values calculated lower than .80 constituted grounds for retraining of the raters. Reliability, in terms of the MCAS survey, was characterized by calculating its internal consistency using Cronbach's alpha calculation with a minimal acceptable value of $\alpha \geq 0.70$.

Validity. The validity of the data is likewise of statistical concern as it is important to know the methods used actually demonstrate what the researcher claims they will demonstrate. Since the validity of the coding process for the MER and MOSA reports depended so heavily on the experience of the raters selected, certain qualifications became mandatory such as the raters must be (a) FAA rated A&P mechanics, (b) have more than 20 years in said rating, and (c) be intimately familiar with Dupont's Dirty Dozen, preferably from experience gained in a teaching capacity. The codes used by the SMEs are considered valid since the codes, or categories, used by the raters are Dupont's Dirty Dozen preconditions being sought. However, since the literature suggests that other preconditions may exist, a thirteenth category (other) was added to the initial 12 codes to account for this possibility.

Prior to being issued the entire set of reports, a calibration set was sent to each rater. For the MERs, the calibration set consisted of three reports (≈10%) randomly selected from the 25 cases provided by the PA. Since each rater was to evaluate all 25 reports, any disparity between them would be easily identified. For the 60 MOSA reports, six reports (10%) were randomly selected and sent to the raters for calibration. Once satisfied with an IRR $\alpha \geq 0.80$, reports 1-30 were sent to Rater A and 31-60 to Rater B. In addition, Rater A received three randomly selected reports from the 30 sent to Rater B, and Rater B was sent three randomly selected reports from the 30 sent to Rater A. Again, the Krippendorff's alpha calculation was applied to verify IRR in the final MOSA analysis.

During a separate meeting, the SMEs were asked to review the MCAS questions to establish which Dirty Dozen category, if any, was represented by that question. It was apparent that not all of the Dirty Dozen categories would be well represented, particularly in a survey not consciously designed with the Dirty Dozen in mind. However, a consensus was reached, and the raters agreed that nine questions related to a lack of communication, eight questions related to a lack of resources, three questions related to a lack of knowledge, and two questions each related to fatigue, pressure, and stress. The characterization of these six categories were expected to agree, to some extent, with the characterization developed in the analysis of the MER and MOSA reports. In this sense, although all 12 of the Dirty Dozen are not represented, the MCAS analysis was to serve as a confirmatory evaluation of relationships found to exist between the MER and MOSA reports. Also, in accordance with the findings of Johnson (1997) and Golafshani (2003), the use of two raters with such specific qualifications coupled with a third document type (MCAS) was thought to enhance overall validity, a technique called *triangulation*.

Ethical Considerations

This research relied on three types of reports provided by the PA. While these data are not publicly available, the data are archival in nature, and all references to personnel names and employee numbers were expunged from the data prior to being delivered to the researcher for analysis. Nevertheless, in accordance with university policy, an application for Institutional Review Board (IRB) for Exempt Determination was submitted on January 2nd, 2018. Since the researcher, committee members, and raters had signed non-disclosure agreements with the PA and there was no way to trace report results back to airline personnel, the research was granted exempt status by the IRB on January 5th, 2018.

Data Analysis Process

Once the 25 MER reports were coded by the SMEs and IRR was assured as described in the previous section, a single set of Dirty Dozen scores were needed to enable a comparison to the MOSA reports. Considering the lowest IRR value was .918, any disparate scores between raters were averaged to create a single score for that Dirty Dozen category in that particular case. This process was not needed for the MOSA scores since each rater coded half of the MOSA reports, resulting in a single set of 60 scores (see Appendices C and D). Since the sample sizes were not equal (25 vs. 60) and the variances were significantly different between the groups, the two data sets were analyzed by conducting a one-way, between-groups multiple analysis of variance (MANOVA), and the Brown-Forsythe test was used for the univariate analysis. For this analysis, the report type (MER vs. MOSA) was the independent variable, and the percentages reported for each of the Dirty Dozen categories by the SMEs comprised the dependent variable. Multivariate analysis statistics are reported using Wilks' Lambda, and an alpha level of .05 was used for all statistical analyses. Descriptive statistics were calculated for the MCAS data, including measures of normality (skewness and kurtosis).

Summary

The current study used subject matter experts to examine reports from the PA for evidence suggesting the presence of one or more of the Dirty Dozen preconditions for maintenance error as described by Gordon Dupont. Examined as a whole, the three types of report (proactive, reactive, and subjective) were expected to illustrate the PA's maintenance culture in terms of the Dirty Dozen, revealing the presence and frequency of the various preconditions for error via descriptive statistics and analysis. Once revealed, the frequency of the noted preconditions was calculated to assist the PA in targeting the most prevalent preconditions in its ongoing effort to enhance organizational safety.

CHAPTER IV

RESULTS

As discussed in Chapter I, the aviation industry has recognized the Dirty Dozen as the 12 most common preconditions for maintenance error for over twenty years. The current research used the Dirty Dozen construct to examine three types of reports provided by the PA in order to answer the following research questions:

1. How does the reactive data (MER) analysis compare to the proactive (MOSA) analysis in terms of the Dirty Dozen? Do they echo similar Dirty Dozen categories, or do they seem to reflect different aspects of the Dirty Dozen?
2. What other preconditions for maintenance error become apparent from the analyses? What do they have in common, or are any of them similar to the additional preconditions suggested by Ma and Grower (2016)? In terms of typical preconditions for maintenance error, how complete is the Dirty Dozen?
3. What insights can be gleaned from the subjective report data (MCAS) with regard to maintenance personnel's perceptions of the organization's safety culture?

The results of the various analyses are presented in this chapter. A discussion and interpretation of these results are found in Chapter V.

Maintenance Event Reports

The PA provided a total of 25 maintenance event reports (MERs) collected between January and May 2017. MERs are reactive in that they report on events that have already manifested. These reports comprised a broad variety of adverse events from simple miscommunications, to pointing out procedural issues, to understaffing, to a host of other safety issues. As discussed in Chapter III, the minimum and maximum rating values are known (0-100), and the distance between each value is equal, thus the scores were considered interval measures for the purpose of calculating inter-rater reliability. A Krippendorff's alpha value of .80 was established as the minimum acceptable value. After an initial 90-minute training session, the raters each examined and scored a sample of the MERs (six, or ≈ 20%). Inter-rater reliability (IRR) was calculated at .55. Since a minimum desired score was .80, the raters received additional training on the application of the Dirty Dozen categorization scheme discussed in Chapter III. Six new MERs were selected and given to the raters to evaluate, and another IRR test was conducted. This time the lowest Krippendorff's alpha value was .92. With IRR well above the minimum level, each rater was given the remainder of the 25 MERs to assess. Reliability was calculated one last time resulting in a mean value of .97. The results for report number 5 are shown in Figure 8 as an example. The summary results for all 25 reports can be found in Appendix C. The 25 MER results were then combined to show the contribution of each Dirty Dozen element to the overarching characterization created by the MERs (see Figure 9).

5		RATER A	RATER B
DEFICIT	Lack of Communication	0	0
	Lack of Knowledge	0	0
	Lack of Teamwork	0	0
	Lack of Resources	0	0
	Lack of Assertiveness	0	0
	Lack of Awareness	20	30
SURPLUS	Complacency	20	20
	Distraction	20	20
	Fatigue	20	20
	Pressure	20	10
	Stress	0	0
	Norms	0	0
	Other	0	0

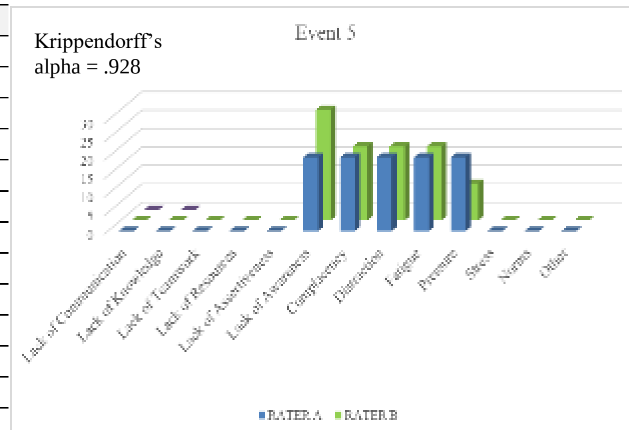

Figure 8. MER report 5 results.. Includes Krippendorff's alpha value.

Combined MER Values	
Lack of Communication	428
Lack of Knowledge	223
Lack of Teamwork	260
Lack of Resources	338
Lack of Assertiveness	78
Lack of Awareness	233
Complacency	293
Distraction	45
Fatigue	158
Pressure	133
Stress	38
Norms	278
Other	0

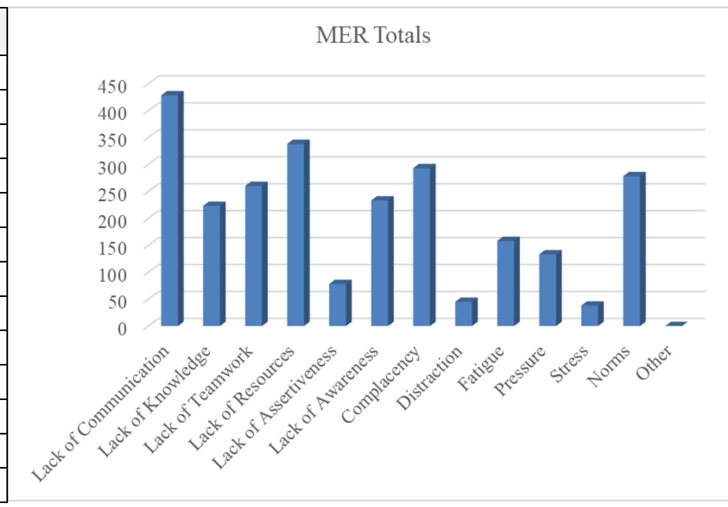

Figure 9. Frequency of Dirty Dozen categories from MERs.

As posited in Chapter III, each category of the Dirty Dozen can be thought of as either a surplus of an undesirable trait, such as *distraction* or *fatigue*, or a deficit of a desirable trait, such as *knowledge* or *resources*. To characterize the relationship between these two factors, the categories were re-ordered by frequency, as shown in Figure 10.

Category	Freq.
Lack of Communication	428
Lack of Resources	338
Complacency	293
Norms	278
Lack of Teamwork	260
Lack of Awareness	233
Lack of Knowledge	223
Fatigue	158
Pressure	133
Lack of Assertiveness	78
Distraction	45
Stress	38
Other	0

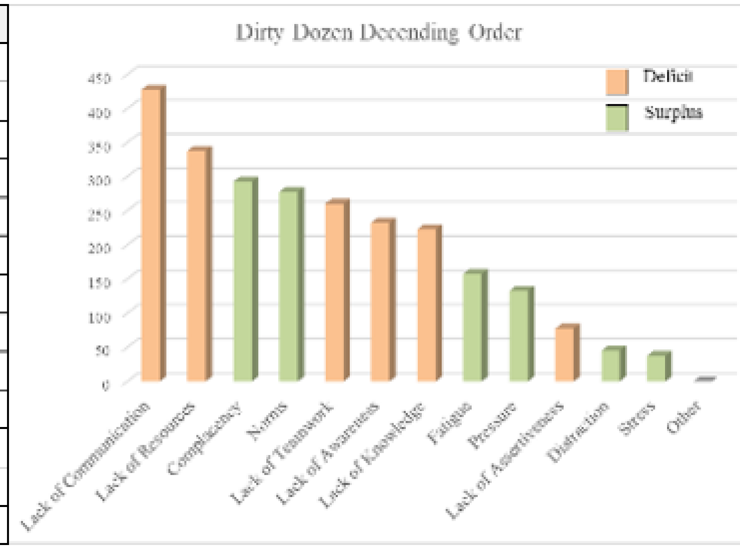

Figure 10. Dirty Dozen categories re-ordered. They are ordered by frequency and identified as a surplus of an undesirable trait or the deficit of a desirable trait.

It should be noted here that, while not shown in Figure 10, the raters expressed an interest in employing the *other* category for MER case #18. Although they were reluctant to actually score it as such, the raters felt that an argument could potentially be made for a *lack of operational integrity* as described in the works of Ma and Grower (2016) in this one case.

Maintenance Operations Safety Assessment (MOSA) Reports

A total of 60 MOSA reports reports collected between September and November 2017 were made available by the PA for examination. As with the MERs, the raters were asked to examine each MOSA report and record their assessment of how much of a role each Dirty Dozen category played in the manifestation of deficiencies documented in the report. For calibration purposes, each rater was assigned to evaluate six cases (10%), three randomly selected from cases 1-30, and three from cases 31-60. The IRR was calculated again using a Krippendorff's alpha protocol. As before, the desired minimum value was .80. The six calibration cases yielded a Krippendorff's alpha value of .97.

Assured that the IRR was satisfactory, the remaining MOSA reports were divided between the two raters. To ensure IRR, each rater received three additional cases that were also being evaluated by the other rater. These six cases were used to confirm IRR for the final analysis, and the calculated value was .88.

The MOSA reports themselves are a comprehensive form filled out by the assigned observer (see Appendix E). The form contains five areas that apply specifically to Dirty Dozen categories such as communication, fatigue, knowledge, pressure, and norms. Other areas address Dirty Dozen categories in a less direct fashion. For example, comments and indications made by the observer regarding tools, calibration, and technical manuals all relate to the Dirty Dozen category of Lack of Resources. Thus, the raters were able to apply scores for Dirty Dozen categories not specifically mentioned by inferring from context.

In coding the MOSA reports, the raters scored the Dirty Dozen category *Lack of Resources* far more often than any other category. As a result, graphing the combined raters results became problematic in that the relatively high frequency of *Lack of Resources* modulated-down the apparent distribution of the other categories. This was rectified by applying a base-10 logarithmic scale to the results, shown in Figure 11. Figure 12's scale was similarly modified but shows the categories in descending order.

Combined MOSA Values	
Lack of Communication	80
Lack of Knowledge	295
Lack of Teamwork	20
Lack of Resources	3148
Lack of Assertiveness	35
Lack of Awareness	160
Complacency	930
Distraction	150
Fatigue	325
Pressure	355
Stress	100
Norms	522
Other	0

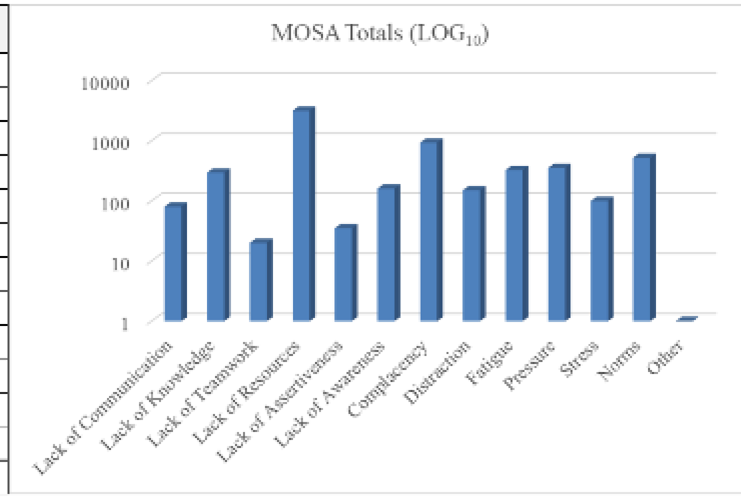

Figure 11. Combined scores showing frequency for Dirty Dozen categories. These results are from the examination of 60 MOSA reports provided by the PA.

MOSA Values Descending	
Lack of Resources	3148
Complacency	930
Norms	522
Pressure	355
Fatigue	325
Lack of Knowledge	295
Lack of Awareness	160
Distraction	150
Stress	100
Lack of Communication	80
Lack of Assertiveness	35
Lack of Teamwork	20
Other	0

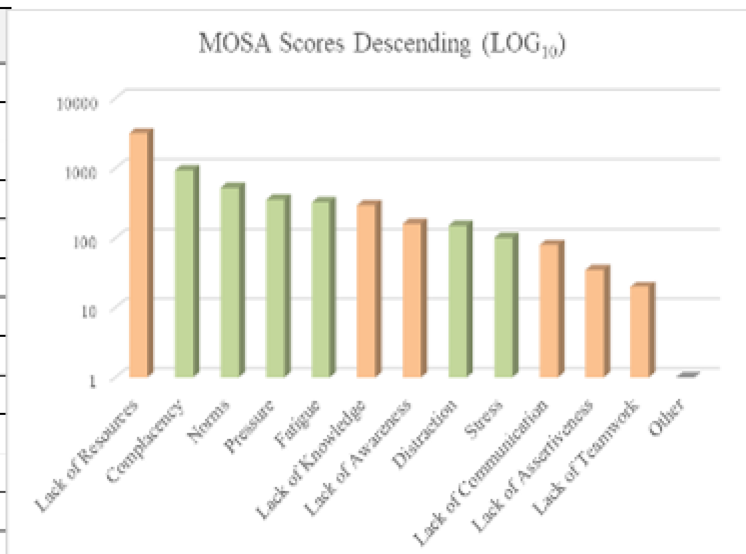

Figure 12. MOSA score totals. Values are arranged in descending order and identified as a surplus of an undesirable trait, or the deficit of a desirable trait.

MER – MOSA SME Ratings Comparison

To quantify the comparison between the MER and MOSA reports, a one-way between-groups MANOVA was conducted, with report type (MER vs. MOSA) as the independent variable. The dependent variables were the percentages reported by the raters for each of the 12 Dirty Dozen categories. Nine assumptions for the MANOVA were examined, following the guidance provided in Hair, Black, Babin, and Anderson (2010). These assumptions are discussed in turn.

- *Assumption #1: Two or more dependent variables measured at the interval or ratio level*. Assumption met since the ratings were continuous variables, measured from 0 to 100.
- *Assumption #2: Independent variable consisted of two or more categorical, independent groups*. Assumption met since report type consisted of two groups (MER and MOSA).
- *Assumption #3: Independence of observations*. Assumption met since the two types of reports (MER, MOSA) were independent.
- *Assumption #4: Adequate sample size*. Assumption met since more cases were in each group (MER = 25; MOSA = 60) than the number of dependent variables (Dirty Dozen categories = 12) analyzed.
- *Assumption #5: No multivariate outliers*. Assumption partially met. Four of the 95 cases showed multivariate outliers, as assessed by Mahalanobis distance ($p < .001$).
- *Assumption #6: Multivariate and univariate normality*. Assumption not met. The Shapiro-Wilk test of normality was significant ($p < .001$) across all dependent variables. However, as noted earlier, the relatively high frequency of *Lack of Resource*s modulated down the apparent distribution of the other categories. With regard to univariate normality, the ratio of both skewness and kurtosis to their respective standard error can be used as a test for normality of a distribution. A distribution can be considered normal so long as the absolute value of skewness

or kurtosis does not exceed two times their respective standard error. As shown in Tables 6 and 7, the only Dirty Dozen category to meet the normality criteria for both skewness and kurtosis among the MER reports was *Lack of Knowledge*. The only Dirty Dozen category to meet the normality criteria for both skewness and kurtosis among the MOSA reports was *Lack of Resources*.

- *Assumption #7: Linear relationship between each pair of dependent variables for each group of the independent variable*. Assumption not met. Examination of the scatterplot matrix for each group of the independent variable (report type) revealed the absence of a linear relationship between each variable pair. However, this was not unusual given the uniqueness of each Dirty Dozen category and no expectation these categories were linearly related.
- *Assumption #8: Homogeneity of variance and variance-covariance matrices*. Assumption not met. The Levene's Test of Equality of Error Variances was significant for several of the dependent variables (see Table 8). Further, Box's M Test revealed the covariance matrices were significantly different, F (78, 7258.60) = 4.41, $p < .001$. Accordingly, the Brown-Forsythe test was used for the univariate analysis since this test is appropriate when groups are unequal in size, and this test does not assume homogeneity of variance.
- *Assumption #9: No multicollinearity*. Assumption met. The correlation matrix of the 12 Dirty Dozen categories revealed no significant high correlations (greater than .9). The significant correlations identified in the correlation matrix ranged from .22 to .37.

Table 6

Descriptive Statistics for Ratings on Dirty Dozen Categories for MER

Dependent Variable	Mean	Std Dev	Skewness	Kurtosis
Lack of Communication	17.16	22.33	1.05	-0.14
Complacency	8.92	16.41	1.83	2.18
Lack of Knowledge	10.44	10.84	0.62	-0.28
Distraction	13.52	21.12	1.35	0.52
Lack of Teamwork	3.12	9.58	3.17	9.36
Fatigue	9.32	15.60	1.91	2.91
Lack of Resources	11.76	17.60	1.42	1.17
Pressure	1.80	6.27	3.37	10.41
Lack of Assertiveness	6.32	11.82	2.46	7.05
Stress	5.32	8.47	1.24	0.07
Lack of Awareness	1.52	4.41	2.97	8.53
Norms	11.12	16.26	1.92	4.05

Note. Std Dev = standard deviations. Standard error for skewness = 0.46. Standard error for kurtosis = 0.90.

Table 7

Descriptive Statistics for Ratings on Dirty Dozen Categories for MOSA

Dependent Variable	Mean	Std Dev	Skewness	Kurtosis
Lack of Communication	1.33	5.03	3.56	11.07
Complacency	15.50	21.93	1.77	3.58
Lack of Knowledge	4.92	12.13	2.47	5.17
Distraction	2.50	6.54	2.70	6.69
Lack of Teamwork	0.33	2.58	7.75	60.00
Fatigue	5.42	15.38	4.46	24.46
Lack of Resources	51.05	32.23	-0.07	-0.98
Pressure	5.92	11.52	1.77	1.78
Lack of Assertiveness	0.58	4.52	7.75	60.00
Stress	1.67	6.42	3.81	13.56
Lack of Awareness	2.67	9.13	3.73	14.30
Norms	8.45	11.81	1.24	1.05

Note. Std Dev = standard deviations. Standard error for skewness = 0.31. Standard error for kurtosis = 0.61.

Table 8

Levene's Test of Equality of Error Variances for MER and MOSA Data

Dependent Variable	F	df1	df2	Sig.
Lack of Communication	90.175	1	83	.000
Complacency	2.578	1	83	.112
Lack of Knowledge	0.333	1	83	.565
Distraction	53.593	1	83	.000
Lack of Teamwork	18.877	1	83	.000
Fatigue	0.668	1	83	.416
Lack of Resources	9.555	1	83	.003
Pressure	12.267	1	83	.001
Lack of Assertiveness	30.845	1	83	.000
Stress	10.997	1	83	.001
Lack of Awareness	1.727	1	83	.192
Norms	0.856	1	83	.358

Note. Tests the null hypothesis that the error variance of the dependent variable is equal across groups. F = test statistic. df = degrees of freedom. Sig. = significance (*p* value).

Multivariate analysis statistics are reported using Wilks' Lambda. An alpha level of .05 was used for all statistical analyses. Multivariate analysis revealed a significant effect of report type on the SME ratings for the Dirty Dozen categories, F (12, 72) = 9.10, p = .0001, η_p^2 = .603. Estimated marginal means and standard errors along with the test statistics are reported in Table 9.

Table 9

Estimated Marginal Means, Standard Errors, and Brown-Forsythe Test Results for Ratings on Dirty Dozen Categories by Report Type

Dependent Variable	MER	MOSA	Statistic	df	Sig.
Lack of Communication	17.16 (2.55)	1.33 (1.64)	12.30	1, 25.02	.002
Complacency	8.92 (4.10)	15.50 (2.65)	2.31	1, 59.61	.134
Lack of Knowledge	10.44 (2.35)	4.92 (1.52)	4.27	1, 50.04	.044
Distraction	13.52 (2.53)	2.50 (1.63)	6.55	1, 25.94	.017
Lack of Teamwork	3.12 (1.12)	0.33 (0.72)	2.06	1, 25.47	.164
Fatigue	9.32 (3.09)	5.42 (1.99)	1.11	1, 44.44	.297
Lack of Resources	11.76 (5.76)	51.05 (3.72)	51.96	1, 76.88	.001
Pressure	1.80 (2.06)	5.92 (1.33)	4.48	1, 76.99	.038
Lack of Assertiveness	6.32 (1.48)	0.58 (0.96)	5.55	1, 26.97	.026
Stress	5.32 (1.42)	1.67 (0.91)	3.75	1, 36.04	.061
Lack of Awareness	1.52 (1.61)	2.67 (1.04)	0.61	1, 81.11	.438
Norms	11.12 (2.65)	8.45 (1.71)	0.55	1, 35.04	.462

Note. MER = Maintenance Event Report. MOSA = Maintenance Operations Safety Assessment. Standard errors presented in parentheses following means. df = degrees of freedom. Sig. = significance (*p* value).

Univariate tests revealed a significant effect of report type on six Dirty Dozen categories: *Lack of Communication*, *Lack of Knowledge*, *Distraction*, *Lack of Resources*, *Pressure*, and *Lack of Assertiveness*. *Lack of Communication*, *Lack of Knowledge*, *Distraction*, and *Lack of Assertiveness* were rated significantly higher on the MER than the MOSA. *Lack of Resources* and *Pressure* were rated significantly higher on the MOSA than the MER. No significant differences were found on the other six Dirty Dozen categories: *Complacency*, *Lack of Teamwork*, *Fatigue*, *Stress*, *Lack of Awareness*, and *Norms*.

Maintenance Climate Assessment Survey (MCAS) Report

The MCAS report provided by the PA was from a survey conducted between February and April 2017. Of the 2,054 maintenance or maintenance-related personnel given the survey, 1,246 responded (60.66 response rate). The general demographics of the 1,246 respondents can be seen in Table 10. Of the respondents, 49% indicated they worked the day shift, 22% at night, and 30% mixed (day and night).

Table 10

MCAS Respondent Demographics

Position	Number	%	Maintenance Experience	Number	%
Maintenance Technician	759	61	0 – 5 years	258	21
Maintenance Inspector	105	8	5- 10 years	378	30
Maintenance Supervisor	31	2	10 – 20 years	358	29
Engineering Personnel	45	4	over 20 years	252	20
General Services	60	5		1246	100
Other Functions	246	20			
Total	1246	100			

The survey comprised 58 questions in four categories, a) organizational processes (18 questions), b) organizational climate (17 questions), c) resources (10 questions), and d) supervision (13 questions). The response options used a 5-point Likert scale format with the following possible bipolar responses: (1) totally disagree, (2) disagree, (3) agree, (4) totally agree, and (5) no opinion. Since one of the purposes of the current study was to look for the presence or absence of Dirty Dozen factors, the noncommittal “no opinion” response was not used in the analyses, leaving four relevant responses ranked ordinally as shown above (1 = totally disagree to 4 = totally agree). A test of the survey’s internal consistency was conducted using Crohnbach’s alpha. The calculated value was

.93 indicating a high degree of internal consistency. The survey also included five open-ended questions at the end, at least one of which offered a unique insight to the safety culture of the PA's maintenance department.

Survey Mapping. The full text of the questions can be found in Appendix F. Of the 58 Likert-scale questions, 26 of them could readily be mapped back to one of the Dirty Dozen categories. All survey questions were provided to the SMEs along with an initial draft of 28 survey questions and the Dirty Dozen category to which they were most closely associated (mapped). These materials were discussed and vetted, and 26 were finally agreed upon. Table 11 shows the question numbers and which category of the Dirty Dozen is most associated with them as grouped by consensus by the SMEs. Table 11 also shows the results of a Cronbach's alpha test used to measure the internal consistency of the associations made by the SMEs. The low internal consistency values for three groupings of the MCAS (*Lack of Knowledge*, *Stress*, and *Pressure*) limit the interpretation of the responses to these survey questions.

Table 11

Dirty Dozen Category and Associated MCAS Questions

Dirty Dozen Category	Associate MCAS Questions	TDP	Alpha
Lack of Communication (9)	8, 14, 15, 16, 17, 18, 21, 24, 52	9,840	.77
Lack of Resources (8)	36, 39, 40, 41, 43, 44, 45, 53	8,736	.74
Lack of Knowledge (3)	1, 6, 13	3,396	.55
Fatigue (2)	30, 38	2,264	.71
Stress (2)	32, 51	2,066	.13
Pressure (2)	42, 47	2,191	.49

Note. Raw data for questions 6, 38, and 41 (underlined) were transposed for agreement. TDP = Total Data Points. Alpha = Cronbach's coefficient alpha value.

The majority of the questions (55) ask the respondents to indicate their level of agreement to an affirmative statement. For example, question number one reads “The PA satisfactorily trains its maintenance personnel for safe performance of their tasks”. Answering this question with the “I totally agree” response indicates the respondent strongly agrees that some *desirable* characteristic exists within the PA. In this case, that the organization trains its personnel well for their appointed tasks. However, three questions, numbers 6, 38, and 41, ask the respondent to comment on an undesirable characteristic. For example, question number 6 reads “The PA promotes maintenance employees without appropriate experience or skill”. In this case, the “I totally agree” response would indicate the perceived presence of an *undesirable* condition or characteristic.

This is an important distinction to make when mapping the survey responses back to the Dirty Dozen categories since half of the Dirty Dozen categories represent the deficit of a desirable characteristic and the other half represent a surplus of a undesirable characteristic. In order to make accurate comparisons, especially when adding MCAS question responses together, the raw data for questions 6, 30, and 41 were transposed to make them agree with the other 23 questions. Using question six as an example again, transposing the response data makes it as though the question reads “The PA does not promote maintenance employees without appropriate experience or skill”, emphasizing the desirable condition thus creating agreement across all 26 questions used.

The summary data and histogram for each question used are found in Appendix G. Figures 13 through 18 show the summary statistics and histogram for the six Dirty Dozen categories shown in Table 12. Since Likert scale data tend to be normally distributed, the degree of skewness and kurtosis was used in each case to characterize the normality, or lack thereof, of each curve. Skewness indicates how symmetrically the data are distributed, and kurtosis indicates how closely data points are distributed relative to the mean. A value of zero for both skewness and kurtosis indicates a perfect, normal distribution.

For the current research, the distribution was considered normal so long as the absolute value of the skewness or kurtosis did not exceed two times their respective standard errors. The standard error for skewness was calculated using Equation 1:

$$(1) \quad \sqrt{\frac{6}{n}}$$

The standard error for kurtosis was calculated using Equation 2:

$$(2) \quad \sqrt{\frac{24}{n}}$$

In Figures 13 through 18, *Normality*$_1$ represents two times the standard error for skewness, and *Normality*$_2$ represents two times the standard error for kurtosis. These are presented for ease of comparison to the skewness and kurtosis values to assess normality. Normality values appearing in red text in Figures 13 through 18 denote a distribution that is not normal. Thus it can be seen that only one category, *Lack of Knowledge*, appears normally distributed. Using Bulmer's (1979) general criteria for skewness, the *Lack of Communication*, *Lack of Resources*, and *Pressure* distributions were only moderately skewed left (negatively), while *Fatigue* and *Stress* were moderately skewed right (positively). The categories of *Lack of Resources*, *Lack of Knowledge*, *Fatigue*, *Pressure*, and *Stress* exhibited negative kurtosis values (platykurtic) suggesting the collective data points comprising these categories were somewhat less clustered around the mean and contained more outliers than would be found in a normal distribution. Only one category, *Lack of Communication*, demonstrated a positive (leptokurtic) kurtosis suggesting the data points comprising this distribution were more tightly clustered around the mean with fewer outliers than would be found in a normal distribution.

Lack of communication. The histograms for the responses of all nine survey questions related to *Lack of Communication* were negatively skewed to varying degrees (see Appendix G), so, unsurprisingly, the histogram representing the aggregated totals in Figure 13 was also negatively skewed. The skewness (-0.48) and kurtosis (0.49) were well beyond two-times the standard error for their respective values indicating the data comprising the distribution curve are not normal in terms of the symmetry of its tails nor its tendency to hover near the mean.

Lack of Communication	
n	9,840
Mean	2.8097
Variance	0.4625
Std. Dev.	0.6801
Std. Error	0.0069
Skewness	-0.4824
Std. Error (Skewness)	0.0247
Normality_1	0.0494
Kurtosis	0.4890
Std. Error (Kurtosis)	0.0494
Normality_2	0.0988

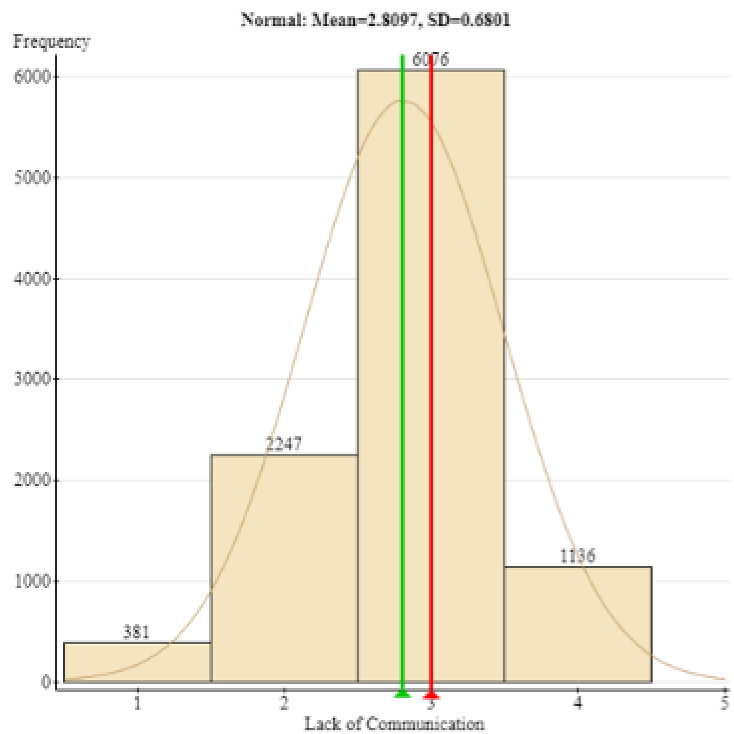

Figure 13. Summary statistics and histogram for MCAS items 8, 14-18, 21, 24, 52. The normal curve overlay, mean (green), and median (red) are also shown.

Lack of resources. Of the eight questions related to *Lack of Resources*, five were negatively skewed, two were positively skewed, and one was approximately normal. The histogram representing the aggregate totals (Figure 14) was negatively skewed (-0.30). The kurtosis value was also negatively skewed (-0.29), and both values were too high to be considered a normal distribution. The ratio of affirmative responses (5226) to negative responses (3500) was approximately 1.5:1.

Lack of Resources	
n	8,736
Mean	2.6108
Variance	0.6137
Std. Dev.	0.7834
Std. Error	0.0084
Skewness	-0.2982
Std. Error (Skewness)	0.0262
$Normality_1$	0.0524
Kurtosis	-0.2895
St. Error (Kurtosis)	0.0524
$Normality_2$	0.1048

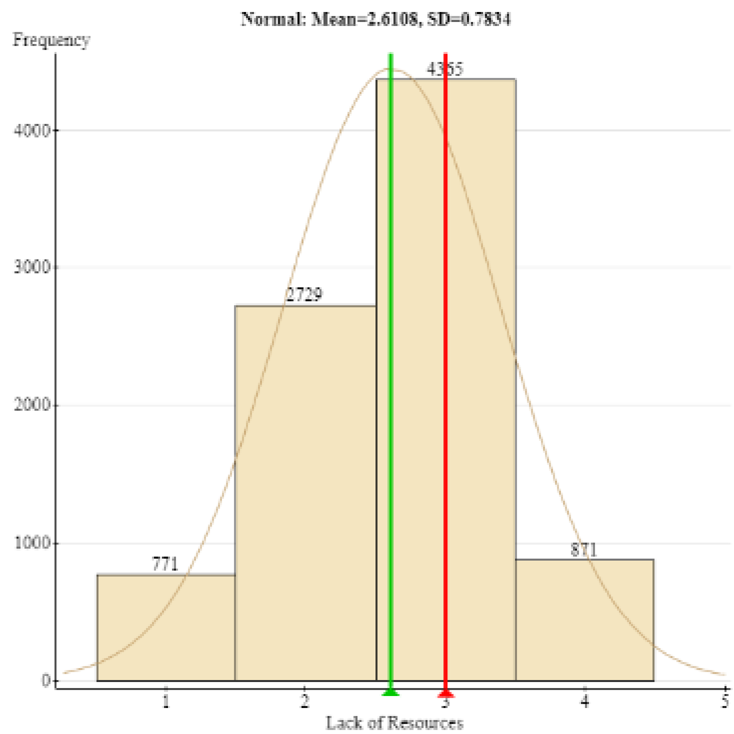

Figure 14. Summary statistics and histogram for MCAS Items 36, 39-41, 43-45, 53. The normal curve overlay, mean (green) and median (red) are also shown. Underline denotes data that were transposed for agreement.

Lack of knowledge. The aggregate distribution for the three survey questions related to *Lack of Knowledge* (1, 6, and 13) yielded skewness and kurtosis values signifying the distribution was normal (-0.39 and -0.10, respectively) indicating it was similar to traditional Likert scale responses (Figure 15). The ratio of affirmative to negative responses was greater than 2:1.

Lack of Knowledge	
n	3,396
Mean	2.7715
Variance	0.6040
Std. Dev.	0.7772
Std. Error	0.0133
Skewness	-0.0385
Std. Error (Skewness)	0.0420
Normality$_1$	0.0841
Kurtosis	-0.1046
St. Error (Kurtosis)	0.0841
Normality$_2$	0.1681

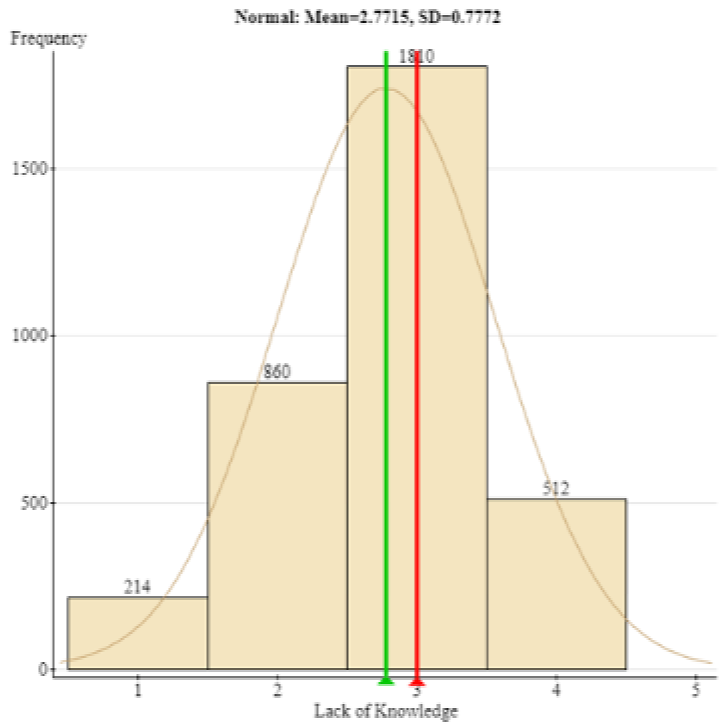

Figure 15. Summary statistics and histogram for MCAS items 1, 6, 13. The normal curve overlay, mean (green), and median (red) are also shown.

Fatigue. While both of the distributions for the questions related to *Fatigue* were negatively skewed with a high kurtosis value, the results were quite different. Question 30 asked if the frequency and duration of rest periods during the work shift were generally respected, to which personnel overwhelmingly affirmed at a ratio of over 4:1. However, question 38 asks if the general level of fatigue is impairing the performance of maintenance tasks at the PA, to which the respondents were split nearly equally (agree vs. disagree).

Fatigue	
n	2,191
Mean	2.3688
Variance	0.6694
Std. Dev.	0.8182
Std. Error	0.0175
Skewness	0.4007
Std. Error (Skewness)	0.0523
Normality$_1$	0.1047
Kurtosis	-0.3201
St. Error (Kurtosis)	0.1047
Normality$_2$	0.2093

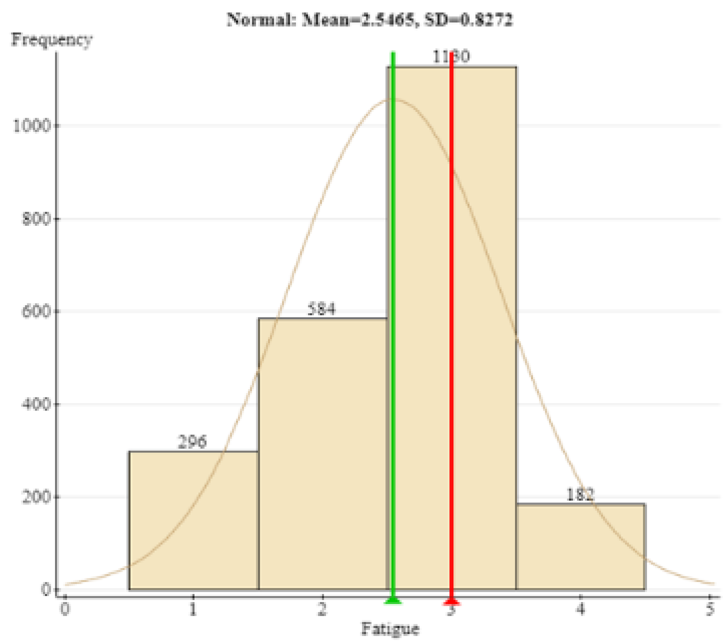

Figure 16. Summary statistics and histogram for MCAS Items 30, 38. The normal curve overlay, mean (green), and median (red) are also shown.

Pressure. While the two questions' aggregate distribution again showed a negative skew and kurtosis too high to be considered normal (Figure 17), an examination of the individual question's distributions shows disparate results. Question 32 asks if maintenance personnel are pressured to deviate from approved procedures in order to complete tasks. The respondents denied this possibility by a ratio of 2:1. However, question 51 asks if other departments (e.g., Operations) ever seek alternative means to release aircraft back to service, and the respondents overwhelmingly agreed (85%).

Stress. Figure 18 shows the aggregate distribution for the two stress-related questions to be positively skewed. The skewness value (0.13) and kurtosis (-0.70) are, again, too large for the distribution to be considered normal.

Pressure	
n	2,066
Mean	2.5416
Variance	0.6726
Std. Dev.	0.8201
Std. Error	0.0180
Skewness	-0.2866
Std. Error (Skewness)	0.0539
$Normality_1$	0.1078
Kurtosis	-0.4719
St. Error (Kurtosis)	0.1078
$Normality_2$	0.2156

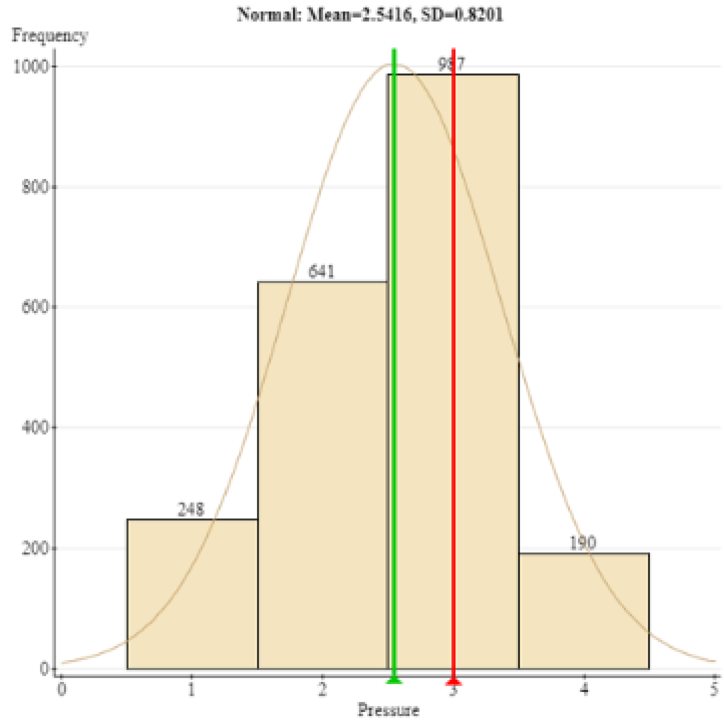

Figure 17. Summary statistics and histogram for MCAS items 42, 47. The normal curve overlay, mean (green), and median (red) are shown.

Stress	
n	2,264
Mean	2.5093
Variance	0.7662
Std. Dev.	0.8753
Std. Error	0.0184
Skewness	0.1260
Std. Error (Skewness)	0.0515
$Normality_1$	0.1030
Kurtosis	-0.6992
St. Error (Kurtosis)	0.1030
$Normality_2$	0.2059

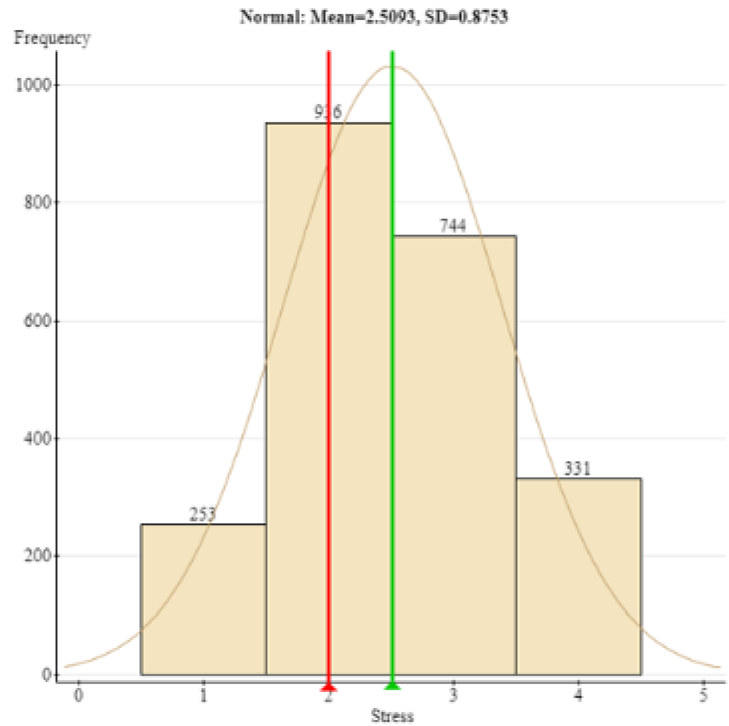

Figure 18. Summary statistics and histogram for MCAS items 32, 51. The normal curve overlay, mean (green), and median (red) are also shown.

There is a noticeable lack of normality typical of Likert scale response data in all but the *Lack of Knowledge* category. While not conclusive, this result has implications on the interpretation, design, and/or execution of the survey and any preconditions they might suggest. The significance of the presence or absence of these preconditions is discussed in Chapter V.

Open-Ended Questions. Five open-ended questions were presented at the end of the survey. Three of them were not relevant in terms of the current research, and one of them was simply too general to be of value. However, one of these questions was very telling, and the most popular responses contribute to the understanding of some of the responses discussed earlier in this chapter. Each of the five was a statement, and the survey instructions asked the 1,246 respondents to select the most appropriate response from 15 possible answers. However, personnel often marked multiple responses. The relevant question states: If there is a maintenance error at the PA, it will be due to __________. The possible responses were:

1) pressure to release the aircraft
2) unskilled labor
3) lack of tools or support equipment
4) lack of parts or material
5) lack of attention/employee commitment
6) insufficient training
7) work overload (multi-tasking), including bureaucracy
8) too few employees to perform the tasks
9) failure of procedures or non-adherence to procedures
10) insufficient supervision
11) demotivation due to organizational policies
12) fatigue/work schedule
13) planning error
14) relationship issues with leadership
15) difficulty/lack of communication between the maintenance sections

Of the personnel who answered this question, response option number four “lack of parts or material” was selected 947 times, and response option five “lack of attention/employee commitment” was selected 916 times. The third most common response was number three “pressure to release aircraft” selected 311 times, though the margin between the second and third place response was considerable. A chart showing the frequency of the 15 possible responses across question 60 can be seen in Figure 19.

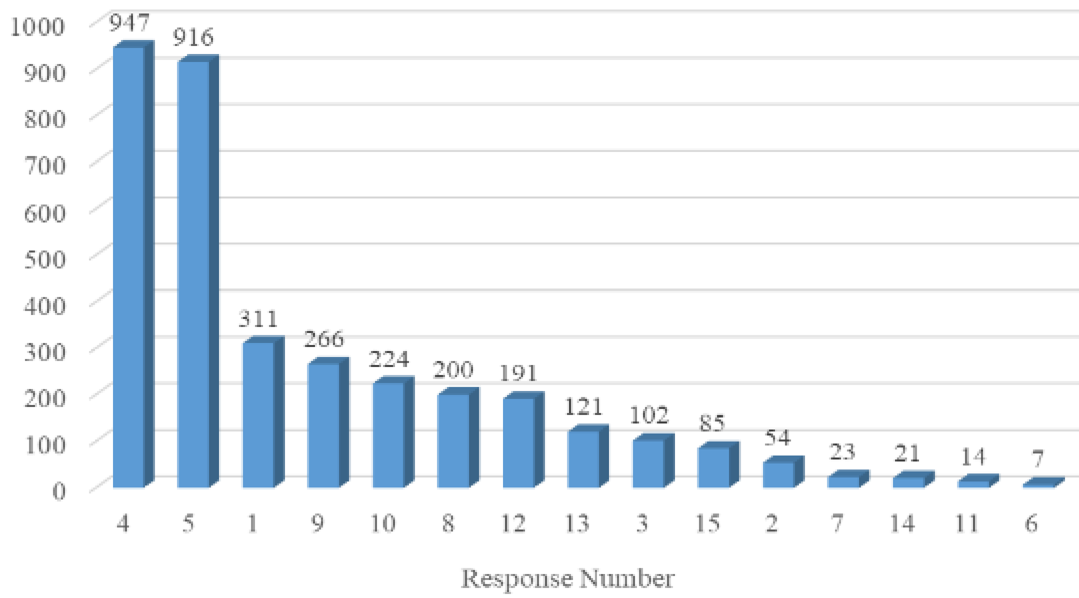

Figure 19. Frequency of responses to relevant MCAS open item. The 15 possible responses to the five open-ended MCAS questions are arranged in descending order.

Summary

All 25 reactive MERs provided by the PA were examined and coded by two SMEs for the presence of preconditions for maintenance error known as the Dirty Dozen. A Krippendorff's alpha protocol was used throughout the coding process to assure inter-rater reliability (IRR) remained at or above .80. The raters then each examined 30 proactive MOSA reports in a similar fashion (60 total). Again, Krippendorff's alpha was employed frequently to assure IRR. The concensus of the MER analysis was then compared to the MOSA analysis using a one-way MANOVA. Additional tests for MANOVA assumptions were conducted including those for normality of the distribution, linearity, homogeneity of variances, and homogeneity of variances and covariances. The overall results of the MCAS were examined for internal consistency using Cronbach's alpha (.93). Additionally, 26 of the 58 survey questions were mapped to six Dirty Dozen categories and grouped by consensus by the SMEs. Cronbach's alpha was again used to assess the internal consistency of the questions within each of these six Dirty Dozen categories. Finally, of the five open-response questions at the end of the MCAS, one was thought to be particularly relevant to the current research. An examination of the responses indicated respondents felt a lack of parts or material, and a lack of attention / employee commitment were a significant concern.

CHAPTER V

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

The crux of the literature review for the current research (Chapter II) is, despite the aviation industry's broad acceptance of the Dirty Dozen as the 12 primary preconditions for aircraft maintenance errors, no research has been conducted that leverages this broadly accepted framework for its potential analytical value. As stated in Chapter I, the research problem is more effective analytical methodologies are needed to continue to drive maintenance errors down. To address this problem, it is posited that an examination of an organization's maintenance culture through the construct of the Dirty Dozen will yield useful information identifying the presence of preconditions for maintenance errors. It is further posited that maintenance-related reports and surveys can be coded and analyzed using SMEs in such a way as to illustrate the organization's maintenance culture and reveal the presence of these preconditions for maintenance errors. Once revealed, a mitigating strategy can be devised to address the specific preconditions that are present, thereby reducing the total number of incidents and accidents that are able to manifest as a result.

The reports used were Maintenance Event Reports (MERs), which are reactive in nature; Maintenance Operations Safety Assessments (MOSAs), which are proactive in nature; and the results of the PA's 2017 Maintenance Climate Awareness Survey (MCAS), a subjective approach comprising survey responses from PA employees performing maintenance-related functions. The 25 MERs and 60 MOSA reports were coded by aviation maintenance SMEs looking for evidence of one or more Dirty Dozen elements, while the responses to 26 of the MCAS survey questions were mapped to Dirty

Dozen categories and grouped by consensus by the SMEs. Examined as a whole, the three types of report (proactive, reactive, and subjective) were expected to illustrate the PA's maintenance culture in terms of the Dirty Dozen, revealing the presence and frequency of the various preconditions for error.

Discussion

MER – MOSA Comparison

The first research question asked - How does the reactive data (MER) analysis compare to the proactive (MOSA) analysis in terms of the Dirty Dozen? Do they echo similar Dirty Dozen categories, or do they seem to reflect different aspects of the Dirty Dozen? Results showed significant differences between the MER and MOSA in the SME ratings of the Dirty Dozen categories, as discussed next.

To begin, the categories of *Complacency*, *Lack of Teamwork*, *Fatigue*, *Stress*, *Lack of Awareness*, and *Norms* were not significantly different between the two types of report. However, *Lack of Communication*, *Lack of Knowledge*, *Distraction*, *Lack of Resources*, *Pressure*, and *Lack of Assertiven*ess were rated significantly higher on the MER than the MOSA, while *Lack of Resources* and *Pressure* were rated significantly higher on the MOSA than the MER. This suggests the two types of report seem to echo each other in terms of some Dirty Dozen categories (*Complacency*, *Lack of Teamwork*, *Fatigue*, *Stress*, *Lack of Awareness*, and *Norms*). In contrast, the data suggest MERs appear to have somewhat greater sensitivity when applied to situations in which the categories of *Lack of Communication*, *Lack of Knowledge*, *Distraction*, *Lack of Resources*, *Pressure*, and *Lack of Assertiven*ess are prevalent. Whereas, the MOSAs appear to be more sensitive when applied to situations in which *Lack of Resources* or *Pressure* are in evidence.

As stated previously, six of the Dirty Dozen represent the deficit of a desirable characteristic (e.g., teamwork), and the other six represent a surplus of an undesirable feature (e.g., fatigue). The Dirty Dozen totals for both the MERs and MOSA reports were color coded for deficit (orange) and surplus (green), rearranged in descending order, and compared in Figure 19. A visible inspection of the two graphs shows no apparent relationship in terms of surplus versus deficit across the two types of reports. However, what can be seen is the prevalence of *Lack of Resources* across both reports, followed by *Complacency* and *Norms*.

Two notable issues became apparent in the examination of the MOSA reports. First, the *Lack of Resources* category was used so frequently by the raters that its total for the 60 MOSA cases was 3148. To put this into perspective, the next highest value was *Complacency* at 930, hence the use of a LOG_{10} algorithm to keep the other categories meaningful on the graph. Second, while *Lack of Communication* was the number one precondition revealed in the MER reports, it ranked tenth (of thirteen) on the MOSA reports. Being reactive in nature, the MER reports document events that have actually come to fruition, unlike the MOSA reports which speculate to a large degree what forces are at work during an observation by a third party and are heavily influenced by the specific items on the MOSA checklist. Therefore, for the purposes of the current research, the MERs are considered more directly grounded in reality and more representative of actual circumstances in the maintenance department. If this is indeed the case, it prompts the questions – why is *Lack of Communication* ranked so low on the

MOSA analysis? and, why was *Lack of Resources* disproportionately high in the MOSA analysis?

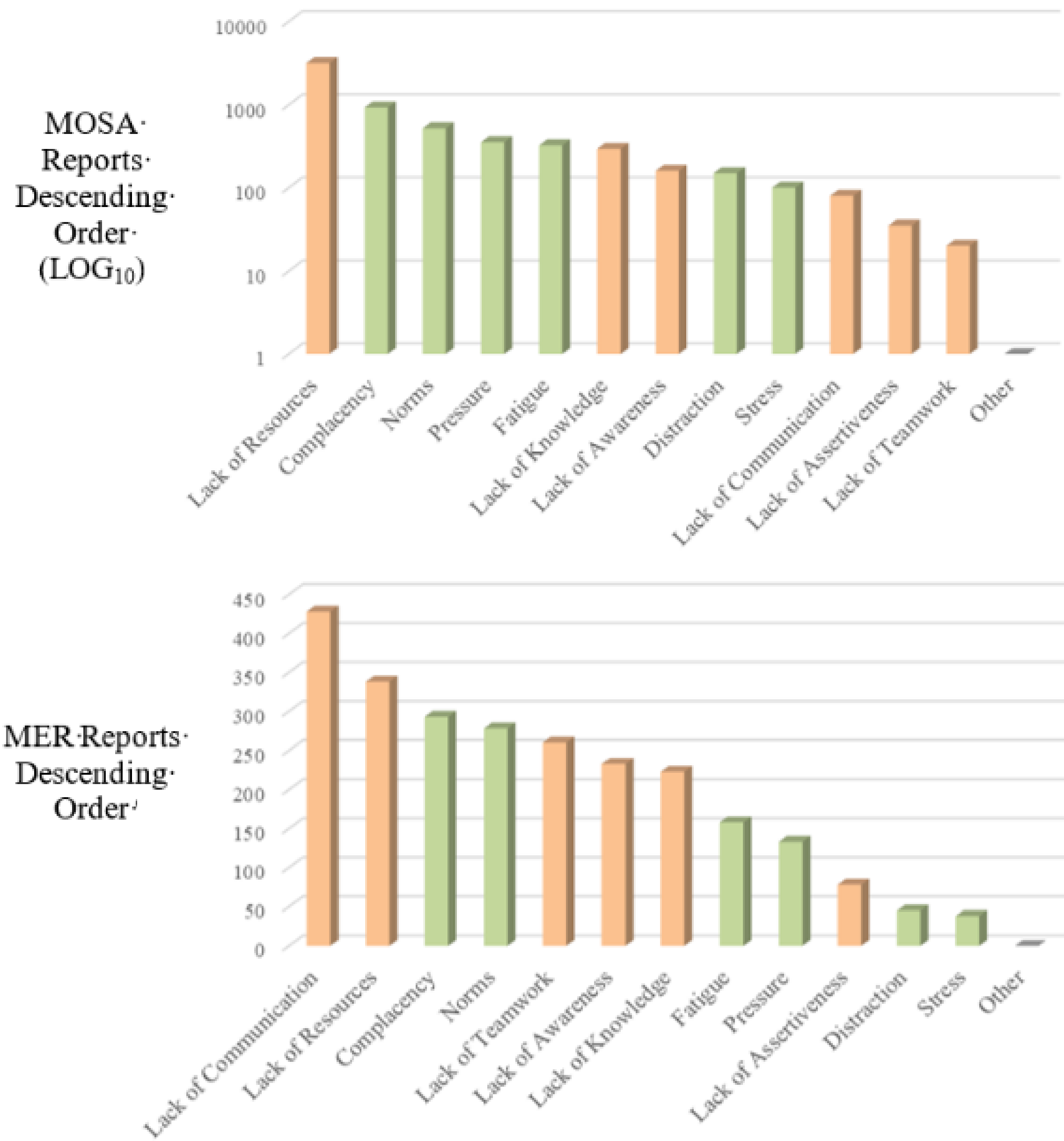

Figure 20. MOSA and MER reports arranged in descending order.

A possible answer to the first question can be found in the MOSA form itself (Appendix E). The last section of the MOSA form deals exclusively with communication. It asks the observer to assess six types of communication: communication between departments, between shifts, among technicians, between technicians and supervisors, technicians and inspectors, and between supervision and management. The observer is instructed to check one of three boxes next to each of the six types of communication labeled ‘Yes’, ‘No’, or ‘N/A’. *Lack of Communication* ranked low on the MOSA analysis since, more often than not, the ‘Yes’ box was checked for all six types of communication. However, even if it is assumed that communication is observed at all six levels, which seems unlikely given the MER analysis, there is no mechanism on the MOSA form for an observer to indicate the effectiveness of said communication. Thus, it can be seen that three possibilities exist to explain the disparity between the MER and MOSA report analyses: (a) communication is not, in fact, being observed at all six levels; (b) communication is being observed at all six levels, but the effectiveness of the communication is often poor; or (c) some combination of a and b. Since few matters involving human behavior are purely binary, odds favor ‘c’ as the more likely explanation. Therefore, the way in which ‘communication’ is handled in terms of both the construct of the MOSA form as well as training of the observers should be examined further by the PA.

An answer to the *Lack of Resources* question can also be found in the MOSA form itself (Appendix E). For maintenance personnel, the term *resources* is broadly defined. Maintenance manuals, tools, materials, parts, consumables, and more comprise a mechanic’s resources. With this in mind, an examination of the MOSA form shows that many of the headings (orange bars) contain several questions that can fairly be said to reflect ‘resources’; notably, 18 of the 60 questions (30%) on the form relate to resources in some way. Since no other precondition for maintenance error is so well represented, this sets up any analysis of the MOSA reports to be more sensitive to resources in general, and therefore creates a certain degree of bias in the results. However, given that *Lack of Resources* was coded by the raters more than the next highest category (complacency) by a ratio greater than 3:1, it seems likely that *Lack of Resources* would still rank very high in the MOSA analysis even if the bias were somehow accounted for.

The second research question concerns itself with how complete the Dirty Dozen framework seems to be and whether additional preconditions may have been encountered during coding and analysis, particularly those suggested by Ma and Grower (2016). During one of the training events conducted with the SME raters, MER event #18 was brought up. One of the raters felt the case could possibly be a candidate for a precondition for maintenance error referred to by Ma and Grower (2016) as *Lack of Personal Integrity*. While it was a compelling argument, that assessment required inferences that the team agreed could not be made with the limited information at hand. Thus, the current research seems to support the notion that the Dirty Dozen is robust and complete in its current state. However, future researchers should remain vigilant for other preconditions for maintenance error, particularly those suggested by Ma and Grower (2016).

Insights from Maintenance Climate Assessment Survey

Of the 58 survey questions, 26 could be mapped back directly to a Dirty Dozen category: nine questions for *Lack of Communication*, eight for *Lack of Resources*, three for *Lack of Knowledge*, and two each for *Fatigue*, *Pressure*, and *Stress* (see Table 5 for a complete breakdown). Before attempting to answer the third research question, a detailed examination of each of these preconditions for maintenance error is warranted.

Lack of communication. The histograms for the responses of all nine survey questions related to *Lack of Communication* were negatively skewed to varying degrees (see Appendix G), so, unsurprisingly, the histogram representing the aggregated totals in Figure 13 was also negatively skewed. The skewness (-0.48) and kurtosis (0.49) were well beyond two-times the standard error for their respective values indicating the data comprising the distribution curve are not normal in terms of the symmetry of its tails, nor its tendency to hover near the mean. Since Likert scale data traditionally tend to be normally distributed, this would seem to call the results into question despite a Cronbach's alpha value of .77 indicating a generally acceptable level of internal consistency. Moreover, the overwhelming majority of respondents answered in the affirmative (agree or totally agree) to the nine questions comprising *Lack of Communication*-related questions indicating they felt communication on nearly every level of the PA was well within what they considered to be acceptable limits.

Lack of resources. Of the eight questions related to *Lack of Resources*, five were negatively skewed, two were positively skewed, and one was approximately normal. The internal consistency was within acceptable limits with a Cronbach's alpha value of .75. The histogram representing the aggregate totals (Figure 14) was negatively skewed (-0.30). The kurtosis value was also negatively skewed (-0.29), and both values were too high to be considered a normal distribution. The ratio of affirmative responses (5226) to negative responses (3500) was approximately 1.5:1 suggesting the bulk of respondents felt the PA's resourcing of the maintenance department was within acceptable limits.

However, a close examination of the distributions of specific questions (Appendix G) related to resources associated with technical publications and tools and equipment (questions 44 and 45) suggests the respondents felt the PA was doing an exceptional job of resourcing maintenance in these areas. The less enthusiastic (but still positive) results were associated with questions 36, 39, 40, 43, and 53 which concern themselves with the adequacy of time, personnel, and materials other than tools and equipment.

Lack of knowledge. The aggregate distribution for the three survey questions related to *Lack of Knowledge* (1, 6, and 13) yielded skewness and kurtosis values signifying the distribution was normal (-0.39 and -0.11, respectively) indicating it was similar to traditional Likert scale responses (Figure 15). Despite its apparent conformity to typical Likert scale distributions, a low level of internal consitency was indicated by the Cronbach's alpha value of .55. The ratio of affirmative to negative responses was greater than 2:1 suggesting the respondents felt strongly that the maintenance department was adequately skilled and properly trained for the tasks they performed.

Fatigue. While the distributions for both of the questions related to *Fatigue* were negatively skewed with a high kurtosis value, the results were quite different. Question 30 asked if the frequency and duration of rest periods during the work shift were generally respected, to which personnel overwhelmingly affirmed at a ratio of over 4:1. However, question 38 asks if the general level of fatigue is impairing the performance of maintenance tasks at the PA, to which the respondents were split nearly equally (agree vs. disagree) suggesting that fatigue not mitigated by rest periods may be a concern. Despite this seeming disparity, the measured level of internal consistency using Cronbach's alpha was acceptable at $\alpha = .71$. Again, it can be seen that the aggregate distribution for

Fatigue (Figure 16) is not normal, and the positive responses outnumbered negative responses by approximately 1.5:1.

Pressure. While the two questions' aggregate distribution again showed a negative skew and kurtosis too high to be considered normal (Figure 17), an examination of the individual question's distributions shows disparate results. Question 32 asks if maintenance personnel are pressured to deviate from approved procedures in order to complete tasks. The respondents denied this possibility by a ratio of 2:1. However, question 51 asks if other departments (e.g., Operations) ever seek alternative means to release aircraft back to service, and the respondents overwhelmingly agreed (85%). This suggests that while maintenance personnel do not feel unduly pressured to return aircraft to service, there looms an ever-present possibility that Operations may defer certain maintenance tasks and order the aircraft back to service at any moment. Intuitively, these two concepts seem to conflict with one another which may help explain the Cronbach's alpha value of only .13.

Stress. Figure 18 shows the aggregate distribution for the two stress-related questions to be positively skewed. The skewness value (0.13) and kurtosis (-0.70) are again too large for the distribution to be considered normal. As with some of the previous Dirty Dozen categories, an examination of the individual questions reveals an interesting dichotomy underscored by an internal consistency of $\alpha = .49$. Question 47 asks if the PA's maintenance coordinators are more concerned with releasing aircraft back to service than with safe maintenance. Again, this concept was roundly rejected by nearly 70% of respondents. However, question 42 asks if personnel consider an excessive workload to be part of their normal routine, to which approximately 66% of respondents agreed. So while the majority of personnel felt significant stress in terms of their workload, they did not feel that management valued production over safety as a component of that stress.

Additional findings. Examination of the responses to the MCAS open-ended question, "If there is a maintenance error at the PA, it will be due to __________", provided additional insights into the PA's maintenance climate. The most frequently selected response was "lack of parts or material" selected 947 times. The relatively high frequency of this response option seems to contradict the sentiments expressed in the responses to the questions associated with *Lack of Resources*. Questions 36, 39, 40, 43, and 53 concern themselves with the adequacy of time, personnel, and materials other than tools and equipment. The respondents indicated these elements were reasonably well resourced by the PA. However, it is interesting to note that the responses to the two questions that most directly address availability of resources, question 36 "I have adequate resources to accomplish the tasks" and 43 "The aeronautical materials to carry out the maintenance tasks are always available and sufficient" have distributions that are nearly perfectly split in terms of agreement. Since MER and MOSA evidence discussed earlier in this chapter strongly suggests the presence of certain resource-related issues, such a split would seem to indicate the presence of acquiescense bias.

"Pressure to release aircraft" was the third most frequent response option selected for this open-ended question, though the margin between the second and third place response was considerable. Notably, "pressure to release aircraft" ranked number one in the 2010 MCAS survey, so it was included here simply to illustrate perceived change amongst employees. Again, it can be seen that responses to questions 32 and 51 in the body of the survey do not support this assertion. Respondents rejected question 32's assertion that personnel were pressured to deviate from approved procedures 2:1. However, in answering question 51, respondents overwhelmingly agreed (85%) that other departments (like Operations) were ready and willing to defer certain maintenance tasks in order to get the aircraft back in service. The disparity between responses to question 32 and the 311 times "pressure to release aircraft" was selected could also be a result of acquiescence bias. Examined as a whole, it seems reasonable to assume that while respondents deny their supervisors and immediate management personnel would ever suggest deviating from established processes and no small amount of pressure exists to return aircraft to service, the survey results suggest it comes from outside the maintenance department.

This conflict, as well as other seeming irregularities in the survey data, are not uncommon when using a Likert scale survey instrument. Acquiescence bias is the tendency for a respondent to agree with a statement in order to avoid attracting attention or being seen as dissident (Allen, 2007; Gross, 2018), even when respondents are assured their anonymity. The positive or negative wording of questions has also been seen to contribute to acquiescence bias (Colosi, 2005) as has culture (Lee, 2002). The conflict mentioned above as well as a number of apparent discrepencies noted in the specific discussion of the six Dirty Dozen categories earlier in this chapter could be accounted for by the presence of acquiescence bias. A literature review was conducted looking for ways to correct for this type of bias. Unfortunately, none were found that might help after the survey questions are written and after the data have been collected.

Prevalence of Dirty Dozen Categories

Coding and subsequent analyses of the MERs and the MOSA reports showed the presence of all twelve Dirty Dozen preconditions for maintenance error to one degree or another. It also demonstrated that while there are some Dirty Dozen categories that were revealed equally by both types of report, MERs were more sensitive to some categories and MOSA to others. *Lack of Resources* ranked second most frequent in the MER analysis and the most frequent in the MOSA analysis. Notably, *Lack of Resources* was disproportionately high in the MOSA analysis for reasons already discussed. While the responses to the questions in the body of the MCAS survey generally refuted this, the responses to the relevant open question confirmed this finding (see Additional Findings). So while the collective analyses of these proactive, reactive, and subjective reports suggest a notable lack of resources, that should not be construed to mean the PA is knowingly under-resourcing the maintenance department. In a recent article for *Director of Maintenance* magazine (2018), Gordon Dupont described traits exhibited consistently by maintenance personnel, including “doesn’t like to ask for help, tends to be self-sufficient, tends to think things through on their own and not share thoughts too frequently or thoroughly” (Dupont, 2018, p. 14). Dupont goes on to say that, because of these and other traits, mechanics often do not ask for the resources they need. Therefore, it is entirely possible that the PA is unaware of much of the under-resourcing experienced in the maintenance department.

Being reactive in nature, the MERs document events that have already occurred and thus are considered somewhat more reliable than their proactive (MOSA) counterpart. As such, it is difficult to ignore the most frequent Dirty Dozen category found in the MER analysis. In first place, *Lack of Communication* ranked approximately 25% higher than the second-place category (*Lack of Resources*). However, the MOSA analysis did not confirm a lack of communication was present. Given the issue in documenting the quality of communication present in the MOSA forms, a distinct issue with communication could well exist, but would be difficult to detect given these limitations.

Norms and *Complacency* were the last categories prevalent in the top of the MER and MOSA analyses. It seems worth noting that *Norms* was the fourth most prevalent category in the MER analysis and third in the MOSA, while *Complacency* ranked third in the MER analysis and second in the MOSA analysis. This suggests both *Norms* and *Complacency* as preconditions for maintenance error are present and active in the PA's maintenance department as well.

The presence of *Lack of Resources* was discovered in the MER and MOSA analyses, and, to some extent, in the insights gleaned from examining the MCAS responses. However, it should be noted that the insights from the MCAS were not so much due to the responses to the base survey questions, which were essentially split, but to the responses to the relevant open question which strongly indicated a lack of resources, specifically parts and materials. The skewness and kurtosis values of five of the six aggregate distributions were too high to be considered normal, calling their accuracy into question to some degree since Likert scale results tend to be normally distributed. Only the aggregate distribution for *Lack of Knowledge* was normal and thus within traditional Likert scale bounds despite poor internal consistency.

Conclusions

The current research sought to examine three types of commercial airline reports for signs of Dupont's Dirty Dozen. The Dirty Dozen are widely accepted to be the 12 most common preconditions for maintenance error in the aviation industry. The assumption being that if preconditions for maintenance error are found to exist, the errors themselves are likely not far behind. The reports documented the PA's maintenance activities from three points-of-view: reactive (MERs), proactive (MOSA), and subjective (MCAS). It was posited that a detailed examination of these maintenance-related reports through the framework of the Dirty Dozen would illustrate and highlight these preconditions, thus helping the PA understand where best to allocate resources to reduce these preconditons, thereby reducing the chance for errors to come to fruition.

The first research question asks – "How does the reactive data (MER) analysis compare to the proactive (MOSA) analysis in terms of the Dirty Dozen? And, do they echo similar Dirty Dozen categories, or do they seem to reflect different aspects of the Dirty Dozen?" The results from the analysis show the difference between the MER and MOSA reports is complex, with the MER reports detecting certain Dirty Dozen categories better than the MOSA and vice-versa. There also seems to be a subset of categories that the MER and MOSA reports detect equally well.

The second research question addresses the completeness of Dupont's Dirty Dozen and asks if other preconditions for maintenance error become apparent from these analyses. While discussion among the raters gave creedence to *Lack of Organizational Integrity* as posited by Ma and Grower (2016) as a legitimate precondition for error, it was ultimately decided the case information lacked sufficient granularity to make this assertion. So, it is difficult to state with any certainty that, as a list of common preconditions for maintenance error, the Dirty Dozen is complete based on the data at hand. Additionally, the literature makes a compelling case to remain vigilant for possible new preconditions as organizations, cultures, and technology change.

The third research question asks what insights can be gleaned from the subjective report data (MCAS) with regard to maintenance personnel's perceptions of the organization's safety culture. Oddly enough, the MCAS report data offered more insight to the maintenance organization based on what it did <u>not</u> say, rather than any assertions it may have made. For example, the results of the survey deny the existence of certain Dirty Dozen categories that the MER and/or MOSA analysis strongly suggests are present to some extent. This is difficult to accept given the clear presence of these categories revealed, particulary by the MER analysis. Also, the lack of normality of so many of the MCAS response distributions, whether grouped by Dirty Dozen category or examined on their own, suggests a potential problem with either the design or execution of the survey, possibly an artifact of the acquiescence bias noted. In addition, the low internal consistency coefficients for the MCAS question groupings for *Lack of Knowledge*, *Pressure*, and *Stress* suggest a reexamination of the construction of the survey may be in order as well since they were also the categories with the fewest survey questions associated with them (only three for *Lack of Knowledge* and only two each for *Pressure* and *Stress*). In its present state, the survey only reflects six of the twelve Dirty Dozen categories; this should also be addressed in future research.

Study Limitations

Although the findings are promising, conclusions drawn from these results are limited by the following notable issues identified in this study. First, the data derived from the three reports were collected during different time frames, which could introduce the possibility of events occurring that might have influenced one of the reports. Ideally, the data should be collected during the exact same timeframe. A second constraint was the limited number of reports provided by the PA. A larger data set would enable a more robust evaluation of the prevalence of the Dirty Dozen categories. Third, the low internal consistency values for three groupings of the MCAS limit the interpretation of the responses to these survey questions. Finally, this study focused on reports provided by one specific airline, limiting the generalizability of the findings to other airlines, that is, each airline has a unique maintenance climate, influenced by a broad range of organizational and ethnographic variables. Nevertheless, the methodology itself employed in this study would be applicable to other airlines.

Recommendations for Practice

Given the findings above, the basic concept of using the Dirty Dozen as a diagnostic tool for maintenance organizations seems to have merit. Although, more work needs to be done in terms of coordinating these three differing views of a maintenance organization and maintaining better control over the data source and other noted variables. Since the MER and MOSA reports seem to have a sensitivity to certain Dirty Dozen categories, how would the use of more controlled data affect the MER - MOSA relationship? It seems intuitive that more data collected (25 MERs was a rather modest quantity) and data gathered from identical timeframes might well impact this relationship. To this end, more research should be directed.

The PA should investigate further the suggested *Lack of Resources* that seems to be present in regards to maintenance. While the original data presented a variety of challenges, the triangulated results indicating a lack of resources is particularly compelling and warrants further investigation to develop a mitigation strategy. Although not as strong as the evidence supporting *Lack of Resources*, a case can be made for the presence of *Lack of Communication*, *Norms*, and *Complacency* as well. Therefore, a mitigation strategy for these preconditions should also be examined.

The majority of MOSA forms had checked boxes indicating that communication between various personnel was occuring. However, if the communication being observed does not relate to the task at hand, or if it is not interpreted correctly or not received at all by the receipient, this tends to confound the performance of tasks such as noted in the MER analysis. Since the MER analysis suggested *Lack of Communication* was prevalent in events that had come to fruition, it would be worthwhile for the PA to revisit this section of the MOSA form to see how it can be improved.

Finally, the evidence suggesting the presence of acquiescence bias in the responses to the MCAS is worth noting. As such, a thorough review of the questions in the survey instrument seems warranted. The literature concerning itself with acquiescence bias as well as other possible Likert scale distortions is sufficient to allow the PA to identify possible causes for this bias. The literature also includes various methods to ensure respondents' perception of anonymity.

Recommendations for Future Research

The apparent relationship of proactive reports (MOSA) to reactive reports (MER) in terms of their sensitivity to certain preconditions for maintenance error is intriguing and lends itself to a host of additional questions. For example, are the results found here typical, or do they tend to vary from one organization to another based on variables not considered in this study? If these results are typical, could reactive and proactive reports or their supporting documentation be improved in a manner that enhances their sensitivity to certain Dirty Dozen categories? Taking this idea a step further, could survey data such as the MCAS be enhanced and adapted similarly to create a systematic, triangulated approach (reactive/proactive/subjective) to reveal and mitigate preconditions for error?

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APPENDIX A

Rater Biographies

Rater Biographies

David Castellar - Born and raised in New York City, Mr. Castellar attended Aviation High school in Long Island City where he graduated in 1980 with his Airframe & Powerplant certificates. He graduated in June of 1980 and started working for Lockheed in July of that same year. He worked the L1011 line for a few months before he was moved into the manufacturing of the first seven F-117 Night Hawks where he remained for three years. Mr. Castellar also worked sheet metal, rigging, and hydraulics on American Airlines' DC-10 aircraft until he ultimately found his way to United Airlines in San Francisco. He began working as a structural mechanic and quickly found he had a gift for repairing composite structures. By 1991, he was teaching composite repair for United Airlines' maintenance workforce worldwide. In addition, he helped develop United's composite repair training program.

In 1993, Mr. Castellar became a member of the Commercial Aircraft Composite Repair Committee (CACRC); he was a participating member to help the Commercial industry try to set standards in the composite world. He was chairman of the Composite task group for several years and is still very active with this committee. Mr. Castellar is also a member of the Advanced Materials for Transport Aircraft Structures (AMTAS). In 2005, Mr. Castellar left United Airlines to go work for Abaris Training Resources Inc. in Reno, Nevada, and became the chief instructor for Abaris Training. He has taught for many different companies and has worked closely with the FAA to help set standards. His 30 plus years of composite experience has helped train people from all over the world.

Jose (Joe) Escobar – Mr. Escobar is the editorial director and co-founder of D. O. M. magazine and has worked in the aviation industry for almost 30 years. Escobar started working as a mechanic's helper in 1988 at NAS Corpus Christi, TX. Quickly working his way up the ranks maintaining Navy T-34s and T-44s, he earned his A&P certificate in 1993. In 1997, after earning his Inspection Authorization (I.A.), Mr. Escobar was promoted to the Quality Assurance department as a QA inspector. He was instrumental in developing and writing work instructions for the company in conjunction with receiving ISO 9000 certification in 1998. As part of his QA duties, he performed regular audits of the maintenance operations. He also helped the maintenance team perform root cause analysis whenever incidents or accidents occurred in order to develop appropriate corrective actions to prevent future occurrences. As part of his interest in root cause analysis, Mr. Escobar started to research Human Factors in 1998. His intent was not only to learn more about Human Factors, but also to develop a Human Factors training program for the company to use, especially for Inspection Authorization renewal requirements for company employees who were stationed in remote sites.

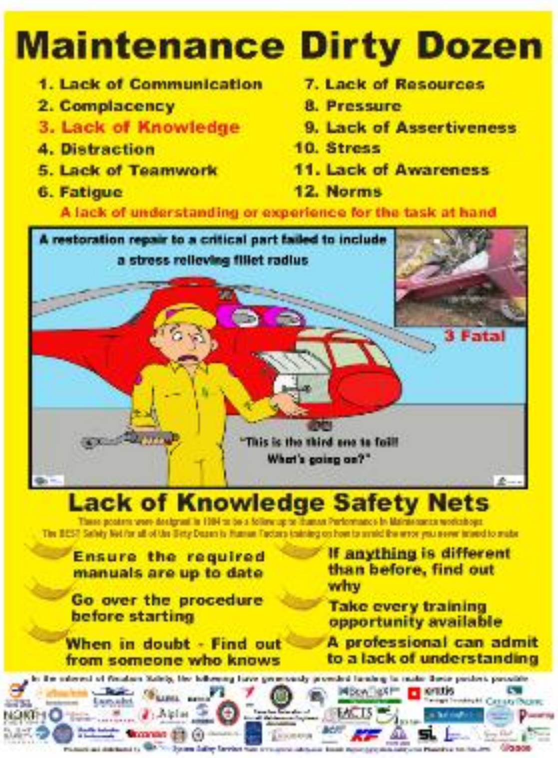
In 1999, Mr. Escobar was selected as editor of Aircraft Maintenance Technology (AMT) magazine. While at AMT, he researched topics on all areas of aircraft maintenance in order to write technical articles for the magazine. After eight years of working at AMT magazine, Mr. Escobar and two other colleagues had an idea of launching a new publication. In April 2008, he left AMT magazine and launched Director of Maintenance (D.O.M.) magazine with two business partners. The magazine covers leadership and management subjects that help educate both current and future aviation maintenance leaders. Mr. Escobar continues to promote Human Factors education to this date. Gordon Dupont, the “father of the dirty dozen,” is a regular contributor to D.O.M. magazine.

APPENDIX B

The Dirty Dozen Posters

The Dirty Dozen Posters

(Used by permission of Gordon Dupont, System Safety Services)




Maintenance Dirty Dozen
1. Lack of Communication
2. Complacency
3. Lack of Knowledge
4. Distraction
5. Lack of Teamwork
6. Fatigue
7. Lack of Resources
8. Pressure
9. Lack of Assertiveness
10. Stress
11. Lack of Awareness
12. Norms
A failure to seek and consider the input of others
Among the many contributing factors was the lack of teamwork between the persons doing the work and the person signing for it who did not know that a tire was very low on pressure
261 Fatal
"I thought you wanted him to turn left right here!"
Lack of Teamwork Safety Nets
Ensure that everyone has the same "Mental Picture" by discussing the job to be done
Recognize a common goal and all agree to work together towards it
Recognize that the team is EVERYONE in the company
Respect all your colleagues and their opinions
TEAM Together Everyone Accomplishes More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8. Pressure
9. Lack of Assertiveness
10. Stress
11. Lack of Awareness
12. Norms
A loss of alertness and a feeling of tiredness that eventually ends in sleep
Between 3 & 5 am, two experienced inspectors missed 140 cracks when inspecting 1,300 rivets
1 Fatal
95 Potential
"I'm sure glad this double shift is finally over"
Fatigue Safety Nets
Develop a routine for enough sleep & exercise
Know the symptoms & look for them in yourself & others
Use coffee or tea 30 minutes before needed
Watch for the circadian rhythm low (3 to 5 am)
Take the "Power Nap" when possible
Drink lots of water


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6. Fatigue
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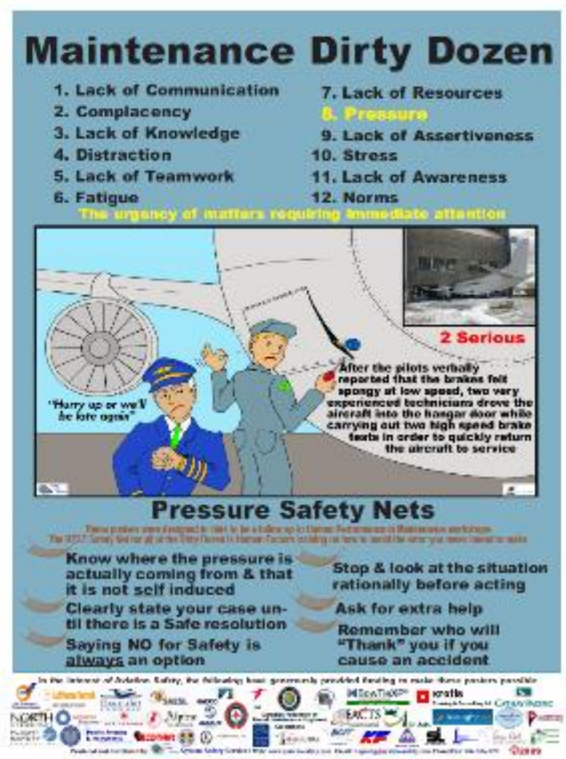
8. Pressure
9. Lack of Assertiveness
10. Stress
11. Lack of Awareness
12. Norms
A lack of material or support to Safely carry out the task at hand
Five cents worth of unavailable 1/8 inch shrink-wrap (Spaghetti) would have prevented the short circuit that lead to the accident
4 Serious
"We have all stock of left shink so this will have to do!"
Lack of Resources Safety Nets
If you even think it could compromise Safety, find the resource
Maintain a standard and if in doubt ground the aircraft
Order and stock parts before they are required
Know all available parts sources and arrange for pooling or loaning
Think of what the consequences would be if anything goes wrong
Practice Risk Management (Worst Case vs. Your Benefit)


Maintenance Dirty Dozen
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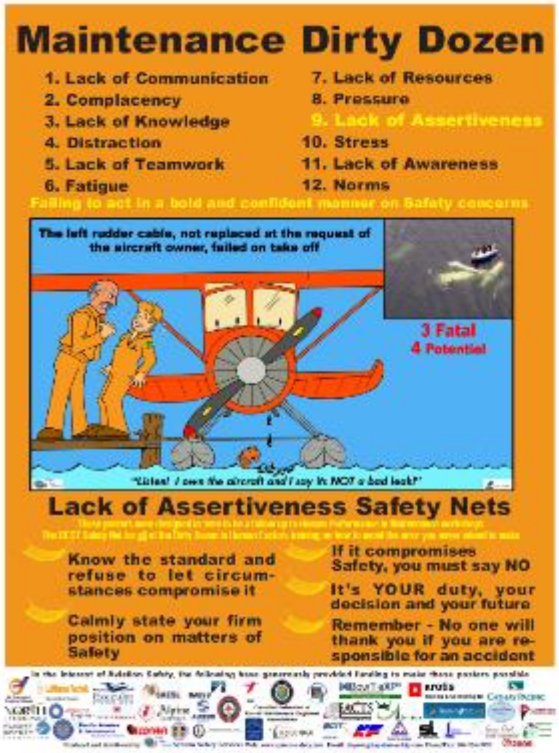
8. Pressure
9. Lack of Assertiveness
10. Stress
11. Lack of Awareness
12. Norms
The urgency of matters requiring immediate attention
2 Serious
"Hurry up or we'll be late again"
After the pilots verbally reported that the brakes felt spongy at low speed, two very experienced technicians drove the aircraft into the hangar door while carrying out two high speed brake tests in order to quickly return the aircraft to service
Pressure Safety Nets
Know where the pressure is actually coming from & that it is not self induced
Clearly state your case until there is a Safe resolution
Saying NO for Safety is always an option
Stop & look at the situation rationally before acting
Ask for extra help
Remember who will "Thank" you if you cause an accident



Maintenance Dirty Dozen
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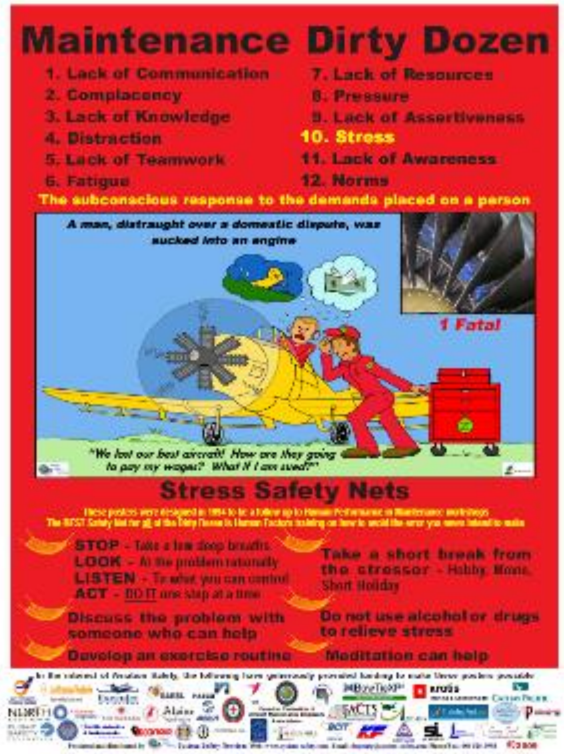
6. Fatigue
7. Lack of Resources
8. Pressure
9. Lack of Assertiveness
10. Stress
11. Lack of Awareness
12. Norms
Failing to act in a bold and confident manner on Safety concerns
The left rudder cable, not replaced at the request of the aircraft owner, failed on take off
3 Fatal
4 Potential
"Listen! I own the aircraft and I say it's NOT a bad look!"
Lack of Assertiveness Safety Nets
Know the standard and refuse to let circumstances compromise it
Calmly state your firm position on matters of Safety
If it compromises Safety, you must say NO
It's YOUR duty, your decision and your future
Remember - No one will thank you if you are responsible for an accident



Maintenance Dirty Dozen
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4. Distraction
5. Lack of Teamwork
6. Fatigue
7. Lack of Resources
8. Pressure
9. Lack of Assertiveness
10. Stress
11. Lack of Awareness
12. Norms
The subconscious response to the demands placed on a person
A man, distraught over a domestic dispute, was sucked into an engine
1 Fatal
"We lost our best aircraft! How are they going to pay my wages? What if I am sued?"
Stress Safety Nets
STOP - Take a few deep breaths
LOOK - At the problem rationally
LISTEN - To what you can control
ACT - DO IT one step at a time
Discuss the problem with someone who can help
Develop an exercise routine
Take a short break from the stressor - Hobby, Movie, Short Holiday
Do not use alcohol or drugs to relieve stress
Meditation can help

Maintenance Dirty Dozen
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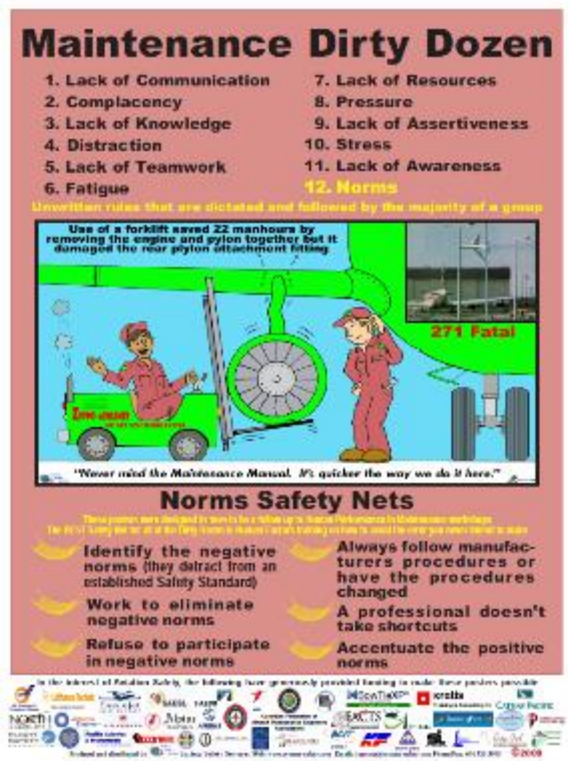
3. Lack of Knowledge
4. Distraction
5. Lack of Teamwork
6. Fatigue
7. Lack of Resources
8. Pressure
9. Lack of Assertiveness
10. Stress
11. Lack of Awareness
12. Norms
A lack of alertness and vigilance in observing
1 Serious Injured
A very experienced AME installed a fire extinguisher on a front bulkhead in the passenger compartment. In a later accident, a passenger removed it with his face
"All the regulations said was to install where it is easily accessible."
Lack of Awareness Safety Nets
Ask yourself - "What future problems could this task create?"
Ask others if they see any problems with the task at hand
Don't disregard conflicting information
Check to ensure there is no conflict with an existing repair or modification
Think of what can occur in an accident
System knowledge and experience promotes awareness



Maintenance Dirty Dozen
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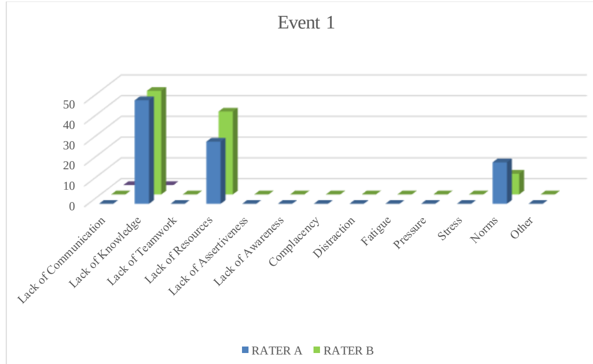
3. Lack of Knowledge
4. Distraction
5. Lack of Teamwork
6. Fatigue
7. Lack of Resources
8. Pressure
9. Lack of Assertiveness
10. Stress
11. Lack of Awareness
12. Norms
Unwritten rules that are dictated and followed by the majority of a group
Use of a forklift saved 22 manhours by removing the engine and pylon together but it damaged the rear pylon attachment fitting
271 Fatal
"Never mind the Maintenance Manual. It's quicker the way we do it here."
Norms Safety Nets
Identify the negative norms (they detract from an established Safety Standard)
Work to eliminate negative norms
Refuse to participate in negative norms
Always follow manufacturers procedures or have the procedures changed
A professional doesn't take shortcuts
Accentuate the positive norms

APPENDIX C

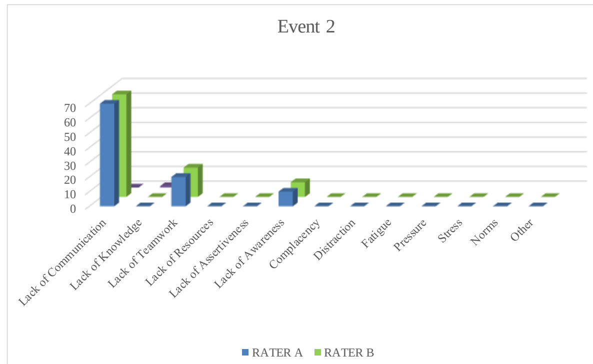
MER Scores for Raters A and B

MER Scores

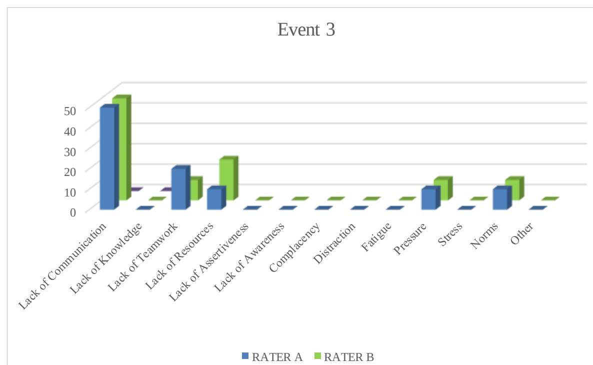
1		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	0	0	(Interval)
	Lack of Knowledge	50	50	.97
	Lack of Teamwork	0	0	
	Lack of Resources	30	40	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	20	10	
	Other	0	0	



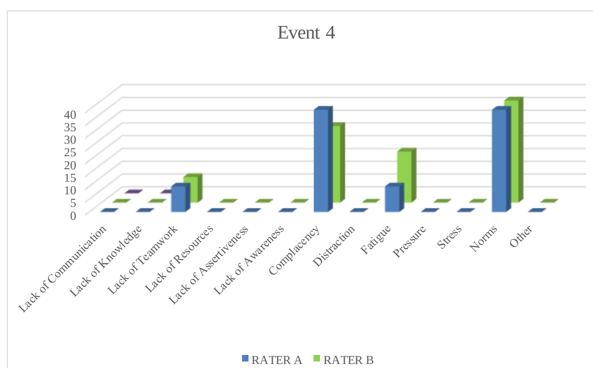
2		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	70	70	(Interval)
	Lack of Knowledge	0	0	1.0
	Lack of Teamwork	20	20	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	10	10	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



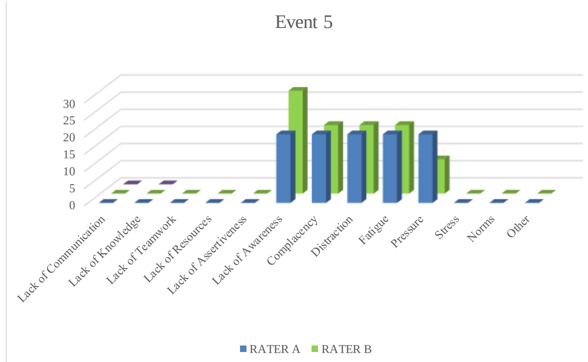
3		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	50	50	(Interval)
	Lack of Knowledge	0	0	.96
	Lack of Teamwork	20	10	
	Lack of Resources	10	20	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	10	10	
	Stress	0	0	
	Norms	10	10	
	Other	0	0	



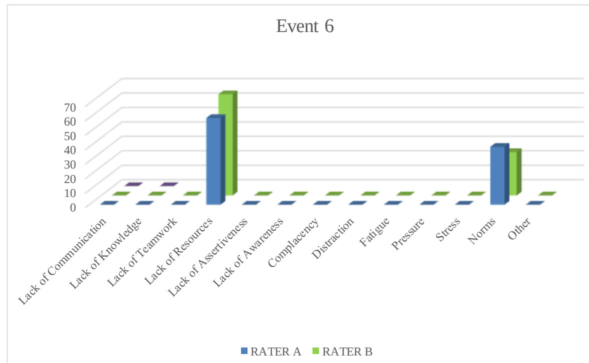
4		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	0	0	(Interval)
	Lack of Knowledge	0	0	.96
	Lack of Teamwork	10	10	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	40	30	
	Distraction	0	0	
	Fatigue	10	20	
	Pressure	0	0	
	Stress	0	0	
	Norms	40	40	
	Other	0	0	



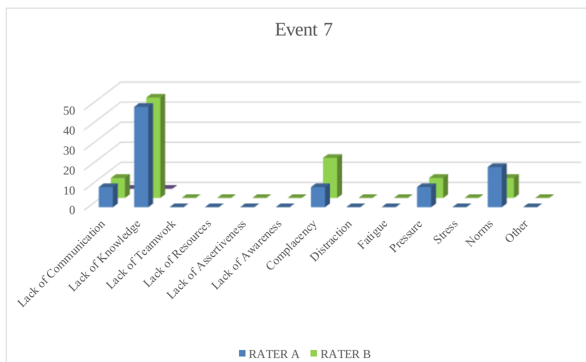
5		RATER A	RATER B	Krippendorff's α (Interval)
DEFICIT	Lack of Communication	0	0	.928
	Lack of Knowledge	0	0	
	Lack of Teamwork	0	0	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	20	30	
SURPLUS	Complacency	20	20	
	Distraction	20	20	
	Fatigue	20	20	
	Pressure	20	10	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



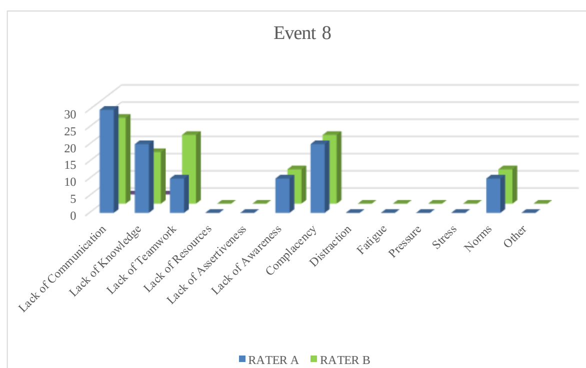
6		RATER A	RATER B	Krippendorff's α (Interval)
DEFICIT	Lack of Communication	0	0	.98
	Lack of Knowledge	0	0	
	Lack of Teamwork	0	0	
	Lack of Resources	60	70	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	40	30	
	Other	0	0	



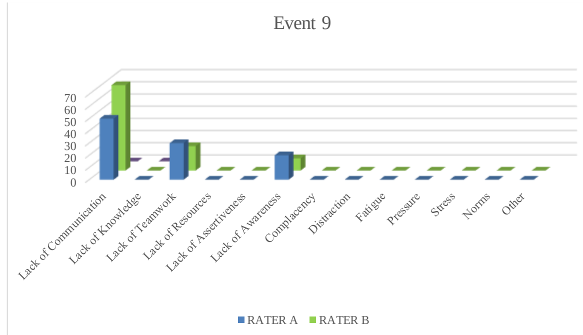
7		RATER A	RATER B	Krippendorff's α (Interval)
DEFICIT	Lack of Communication	10	10	.96
	Lack of Knowledge	50	50	
	Lack of Teamwork	0	0	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	10	20	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	10	10	
	Stress	0	0	
	Norms	20	10	
	Other	0	0	



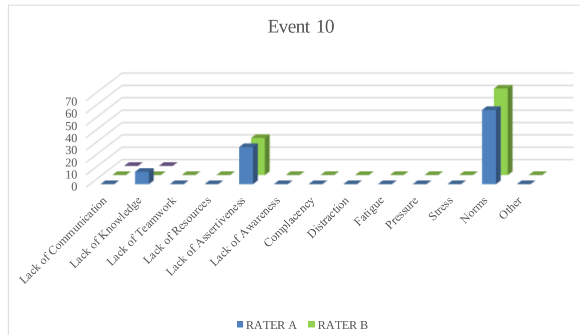
8		RATER A	RATER B	Krippendorff's α (Interval)
DEFICIT	Lack of Communication	30	25	.938
	Lack of Knowledge	20	15	
	Lack of Teamwork	10	20	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	10	10	
SURPLUS	Complacency	20	20	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	10	10	
	Other	0	0	



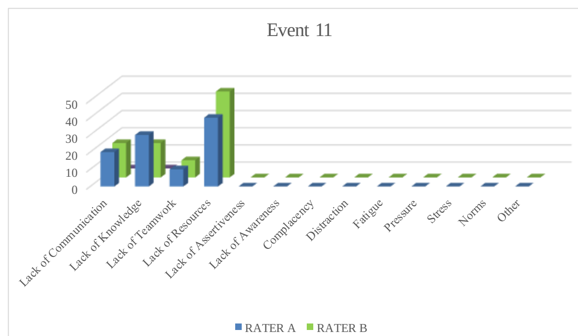
9		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	50	70	(Interval)
	Lack of Knowledge	0	0	.925
	Lack of Teamwork	30	20	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	20	10	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



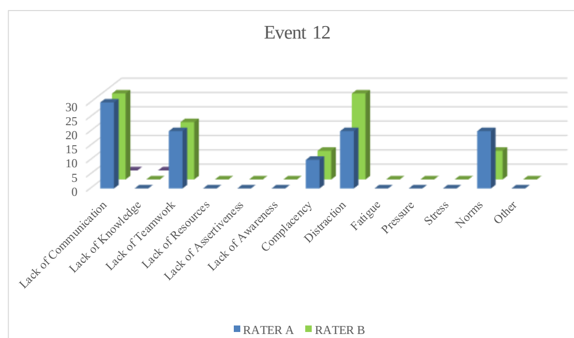
10		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	0	0	(Interval)
	Lack of Knowledge	10	0	.978
	Lack of Teamwork	0	0	
	Lack of Resources	0	0	
	Lack of Assertiveness	30	30	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	60	70	
	Other	0	0	



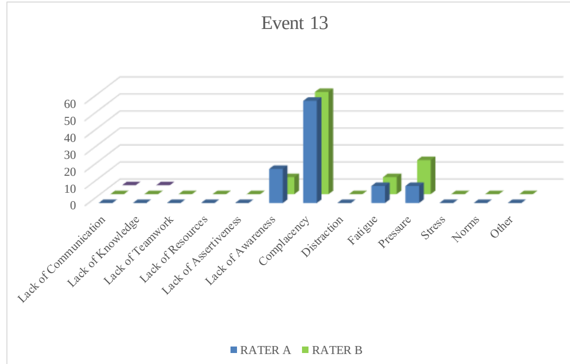
11		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	20	20	(Interval)
	Lack of Knowledge	30	20	.96
	Lack of Teamwork	10	10	
	Lack of Resources	40	50	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



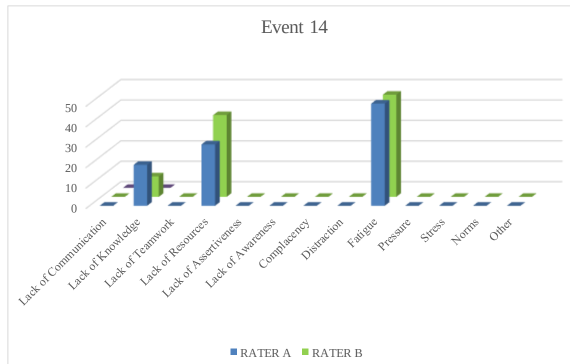
12		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	30	30	(Interval)
	Lack of Knowledge	0	0	.937
	Lack of Teamwork	20	20	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	10	10	
	Distraction	20	30	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	20	10	
	Other	0	0	



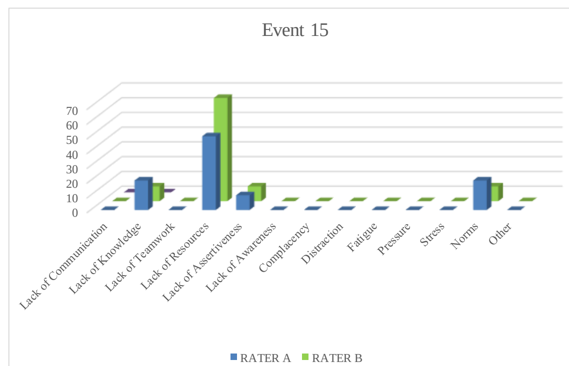
13		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	0	0	(Interval)
	Lack of Knowledge	0	0	.972
	Lack of Teamwork	0	0	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	20	10	
SURPLUS	Complacency	60	60	
	Distraction	0	0	
	Fatigue	10	10	
	Pressure	10	20	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



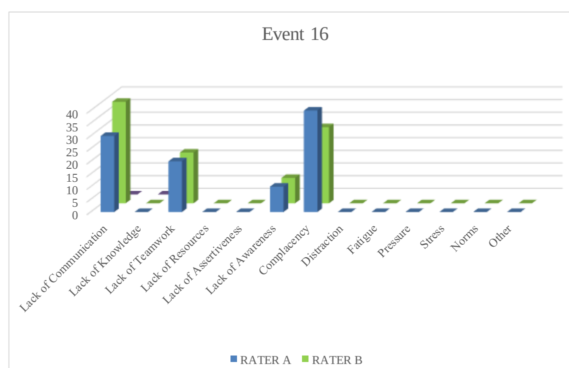
14		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	0	0	(Interval)
	Lack of Knowledge	20	10	.97
	Lack of Teamwork	0	0	
	Lack of Resources	30	40	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	50	50	
	Pressure	0	0	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



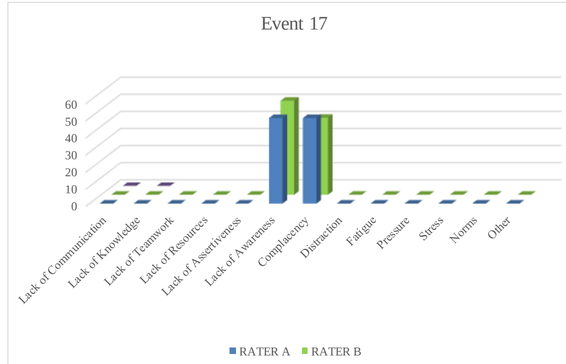
15		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	0	0	(Interval)
	Lack of Knowledge	20	10	.918
	Lack of Teamwork	0	0	
	Lack of Resources	50	70	
	Lack of Assertiveness	10	10	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	20	10	
	Other	0	0	



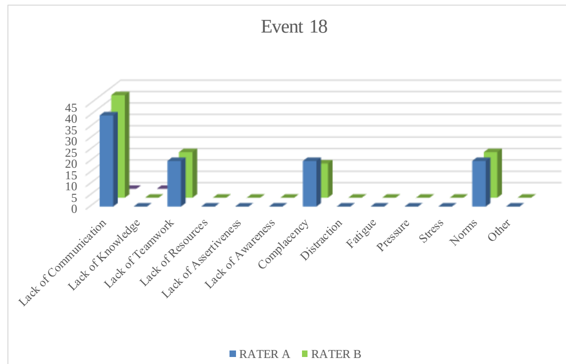
16		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	30	40	(Interval)
	Lack of Knowledge	0	0	.957
	Lack of Teamwork	20	20	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	10	10	
SURPLUS	Complacency	40	30	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



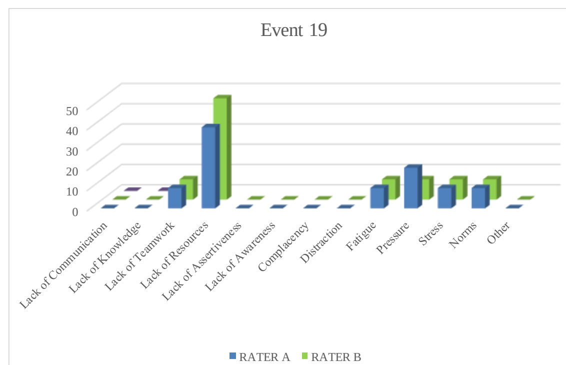
17		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	0	0	(Interval)
	Lack of Knowledge	0	0	.994
	Lack of Teamwork	0	0	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	50	55	
SURPLUS	Complacency	50	45	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



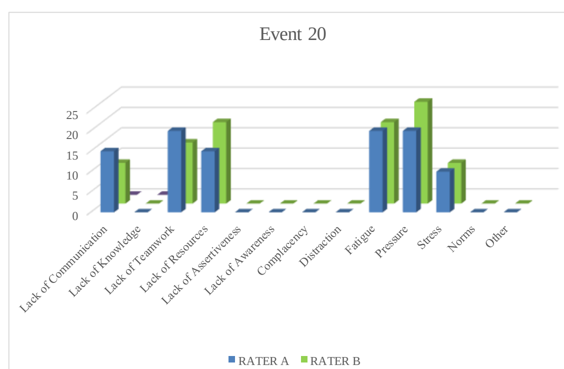
18		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	40	45	(Interval)
	Lack of Knowledge	0	0	.989
	Lack of Teamwork	20	20	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	20	15	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	20	20	
	Other	0	0	



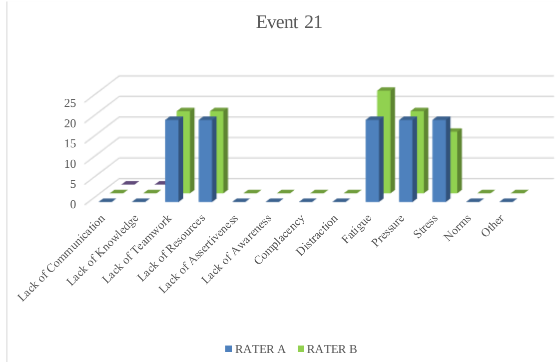
19		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	0	0	(Interval)
	Lack of Knowledge	0	0	.95
	Lack of Teamwork	10	10	
	Lack of Resources	40	50	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	10	10	
	Pressure	20	10	
	Stress	10	10	
	Norms	10	10	
	Other	0	0	



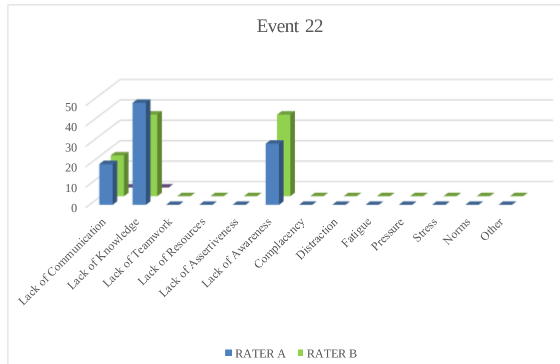
20		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	15	10	(Interval)
	Lack of Knowledge	0	0	.953
	Lack of Teamwork	20	15	
	Lack of Resources	15	20	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	20	20	
	Pressure	20	25	
	Stress	10	10	
	Norms	0	0	
	Other	0	0	



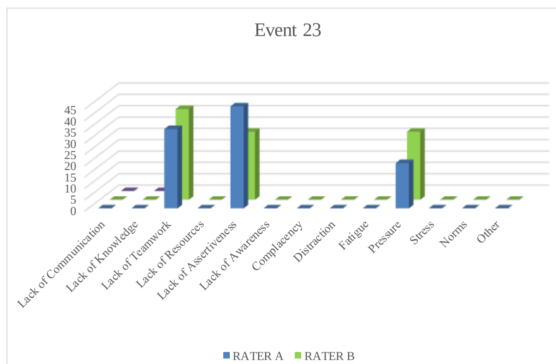
21		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	0	0	(Interval)
	Lack of Knowledge	0	0	.981
	Lack of Teamwork	20	20	
	Lack of Resources	20	20	
	Lack of Assertiveness	0	0	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	20	25	
	Pressure	20	20	
	Stress	20	15	
	Norms	0	0	
	Other	0	0	



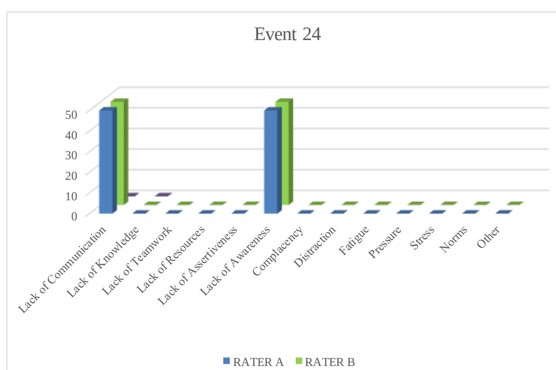
22		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	20	20	(Interval)
	Lack of Knowledge	50	40	.967
	Lack of Teamwork	0	0	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	30	40	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



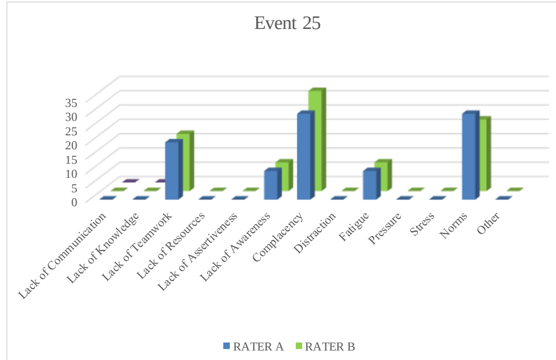
23		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	0	0	(Interval)
	Lack of Knowledge	0	0	.939
	Lack of Teamwork	35	40	
	Lack of Resources	0	0	
	Lack of Assertiveness	45	30	
	Lack of Awareness	0	0	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	20	30	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



24		RATER A	RATER B	Krippendorff's α
DEFICIT	Lack of Communication	50	50	(Interval)
	Lack of Knowledge	0	0	1.0
	Lack of Teamwork	0	0	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	50	50	
SURPLUS	Complacency	0	0	
	Distraction	0	0	
	Fatigue	0	0	
	Pressure	0	0	
	Stress	0	0	
	Norms	0	0	
	Other	0	0	



25		RATER A	RATER B	Krippendorff's α (Interval)
DEFICIT	Lack of Communication	0	0	
	Lack of Knowledge	0	0	.985
	Lack of Teamwork	20	20	
	Lack of Resources	0	0	
	Lack of Assertiveness	0	0	
	Lack of Awareness	10	10	
SURPLUS	Complacency	30	35	
	Distraction	0	0	
	Fatigue	10	10	
	Pressure	0	0	
	Stress	0	0	
	Norms	30	25	
	Other	0	0	



APPENDIX D

MOSA Scores for Raters A and B

MOSA Scores for Raters A and B

MOSA CASE NUMBER													
1													
0	0	0	0	0	0	30	40	0	0	0	30	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
2													
0	20	0	0	0	30	0	0	0	30	0	20	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
3													
20	0	0	0	0	30	0	0	0	30	0	20	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
4													
0	0	0	0	0	0	100	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
5													
0	0	30	0	0	0	50	0	0	0	0	20	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
6													
0	30	0	0	0	0	40	0	0	0	0	30	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
7													
0	50	0	0	0	0	30	0	0	0	0	20	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
8													
0	0	0	0	0	0	100	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

9													
0	0	0	0	0	0	100	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

10													
0	0	0	0	0	0	60	20	0	0	0	20	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

11													
0	0	0	0	0	0	75	0	0	0	0	25	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

12													
0	0	0	0	0	0	88	0	0	0	0	12	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

13													
0	0	0	0	0	40	60	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

14													
0	0	0	0	0	0	100	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

15													
0	0	0	0	0	0	60	40	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

16													
0	30	50	0	0	0	0	0	0	0	0	20	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

17													
0	100	0	0	0	0	0	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

18													
0	0	0	0	0	0	85	0	0	0	0	15	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
						85					15		100
19													
0	30	0	30	0	0	40	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
20													
0	0	0	0	0	100	0	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
21													
0	30	0	20	0	0	30	0	0	0	0	20	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
22													
0	40	40	0	0	0	20	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
23													
0	80	10	10	0	0	0	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
24													
0	20	20	0	20	0	20	0	0	0	0	20	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
25													
0	0	0	10	0	0	90	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
26													
0	40	30	0	0	0	20	0	0	0	0	10	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

27													
0	35	0	0	0	0	55	0	0	0	0	10	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

28													
0	0	0	0	0	0	100	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

29													
0	5	0	0	0	0	65	30	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

30													
0	20	20	0	0	0	40	10	0	0	0	10	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

31													
0	20	0	0	0	0	80	20	0	0	0	0	0	120
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

32													
0	20	0	0	0	0	60	0	0	0	0	20	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

33													
0	0	0	0	0	0	95	5	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

34													
0	0	20	0	0	0	70	0	0	0	0	10	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

35													
0	0	30	0	0	0	20	0	0	0	0	50	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

36

Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
0	25	0	0	0	20	0	0	0	0	25	30	0	100

37

Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
0	70	0	0	0	0	0	0	0	0	0	30	0	100

38

Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
20	0	0	0	0	0	30	30	0	0	0	20	0	100

39

Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
0	20	0	0	0	20	30	10	0	0	0	20	0	100

40

Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
0	0	0	0	0	0	75	0	0	0	0	25	0	100

41

Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
0	0	0	0	0	0	100	0	0	0	0	0	0	100

42

Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
0	0	0	20	0	0	80	0	0	0	0	0	0	100

43

Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
0	0	0	10	0	10	50	30	0	0	0	0	0	100

44

Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total
20	30	0	0	0	0	50	0	0	0	0	0	0	100

45													
0	0	0	0	0	20	50	30	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

46													
0	0	0	0	0	0	100	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

47													
0	0	0	20	0	20	40	20	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

48													
0	10	0	0	0	0	70	20	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

49													
0	30	0	0	0	0	70	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

50													
0	0	0	20	0	0	60	0	0	20	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

51													
0	0	0	0	0	0	100	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

52													
0	20	0	0	0	0	50	0	0	0	30	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

53													
20	10	0	0	0	15	15	0	35	0	5	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

54													
0	50	0	0	0	0	0	0	0	0	50	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

55													
0	30	0	0	0	0	40	0	0	0	30	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

56													
0	30	0	0	0	0	50	0	0	0	20	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

57													
0	0	0	0	0	0	50	30	0	20	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

58													
0	0	0	10	0	20	50	20	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

59	*												
0	35	0	0	0	0	65	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

60	*												
0	0	45	0	0	0	55	0	0	0	0	0	0	100
Lack of Communication	Complacency	Lack of Knowledge	Distraction	Lack of Teamwork	Fatigue	Lack of Resources	Pressure	Lack of Assertiveness	Stress	Lack of Awareness	Norms	Other (Highlighted)	Total

APPENDIX E

PA Maintenance Operations Safety Assessment (MOSA)

MOSA - MAINTENANCE OPERATIONS SAFETY AUDIT

General Information

Month and year: ____________________ Local: Start ____________________

time: ____________________ End time: ____________________

Model aircraft: ____________________ Engine model: ____________________

Number of personnel: ____________________ Number of inspectors: ____________________

H/H planned: ____________________ H/H available: ____________________

Observed task: ____________________

Manual reference number: ____________________

Technical Information

	Answer?		
	Yes	No	N/A
Was the technical manual available and current?			
Did the employee use it correctly?			
Do you have skill in using the manual?			

Comments:

Supporting Equipment / Tools / Materials

	Answer?		
	Yes	No	N/A
Equipment and/or tools required for the task were available?			
Equipment and/or tool was calibrated?			
Equipment and/or tool was in servicable condition?			
Equipment and/or tools were used correctly?			
Were the materials/parts available?			
Were the parts/materials in servicable condition?			
Materials/parts came with proper documentation?			

Comments:

Work / Task

	Answer?		
	Yes	No	N/A
Is the work complex or confusing?			
Is the work monotonous or repetitive?			
New or recently reviewed task?			
Did you follow all the steps in the task?			
Identified good practices?			
Identified deviations?			
Did you use the referenced tasks throughout the execution?			
Did you use the required tools and materials in the referenced task?			

Comments:

Aircraft Design / Configuration / Components

	Answer?		
	Yes	No	N/A
Area/components easy to access?			
Components with error-proofing systems (poka-yoke)?			

Comments:

Technical Knowledge / Skills / Qualification

	Answer?		
	Yes	No	N/A
Do you have knowledge of the task?			
Do you have knowledge of the aircraft systems?			
Knowledge of the process / procedures of the company?			
Do you have the necessary technical skills?			
Do you have linguistic proficiency?			
Do you have the required training?			
Do you have the required technical qualification?			
Is it properly designated (on the roster)?			

Comments:

Individual Aspects

	Answer?		
	Yes	No	N/A
Compliance (acceptance and tolerance of deviations)?			
Signs of fatigue?			
Limitations / time pressure?			
Group pressure?			
Physical health?			
Forgetfulness?			
Ergonomic Viability (Size / Body Strength / Tool)?			
Distractions / interruptions?			
Signs of alcohol / drug use?			
Psychsocial problems?			
Demotivation?			

Comments:

Surroundings

	Answer?		
	Yes	No	N/A
High noise levels?			
Weather conditions?			
Lighting?			
Cleaning?			
Ventilation?			
Signaling?			
Presence of F.O.			

Comments:

Organizational Factors

	Answer?		
	Yes	No	N/A
Quality of technical support.			
Company security policy			
Restructuring / corporate change			
Normal group practices			

Comments:

Leadership / Supervision

	Answer?		
	Yes	No	N/A
Prioritizing work			
Delegation of assignments			
Leadership pressure on task completion			
Trust in the team from supervision			

Comments:

Communication

	Answer?		
	Yes	No	N/A
Between departments			
Between shifts			
Among technicians			
Between technicians and supervisors			
Between technicians and inspectors			
Between supervision and management			

Comments:

Other Observations

Describe in Detail Any Non-Conformities Found

APPENDIX F

MCAS Questions Used in Analysis

Note: Underscored question numbers indicate data that were transposed for agreement.

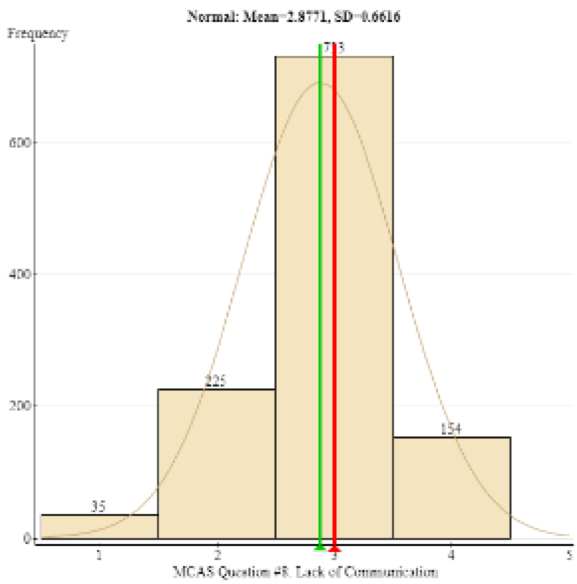
MCAS Question Number	MCAS Question	Dirty Dozen Category
8	PA Maintenance workers are routinely informed about the potential hazards associated with their tasks.	Lack of Communication
14	The PA's Maintenance department effectively conducts transitions between the shifts.	Lack of Communication
15	The PA's Operational Safety Executive Management keeps the Maintenance staff informed of all identified hazards and risks.	Lack of Communication
16	Communication channels with other departments within the PA and the Maintenance department are effective.	Lack of Communication
17	Within PA Maintenance, communication channels are effective.	Lack of Communication
18	PA maintenance workers (all levels) identify and report risk conditions in their daily activities.	Lack of Communication
21	PA Maintenance reports all adverse events.	Lack of Communication
24	PA Maintenance employees are willing to report operational deviations, unsafe behavior, or dangerous conditions.	Lack of Communication
52	The PA Maintenance planning coordinates its actions effectively with O.S.T./M.O.C.	Lack of Communication
36	I have adequate resources to accomplish my assigned tasks (e.g., time, personnel and budget).	Lack of Resources
39	The number of employees for the activities of their job is sufficient to carry out the tasks.	Lack of Resources
40	The number of supervisors/inspectors for the activities of their job is sufficient for the accomplishment of the tasks.	Lack of Resources
41	Additional temporary services or off-base tasks create operational safety issues in the maintenance department.	Lack of Resources

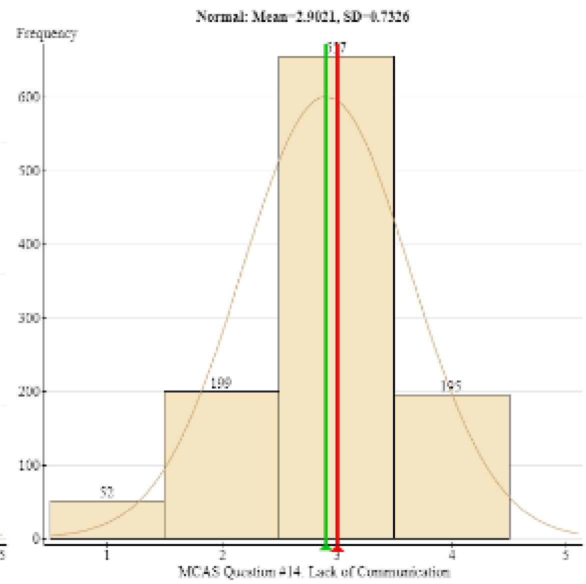
43	The aeronautical materials to carry out the maintenance tasks are always available and sufficient.	Lack of Resources
44	The tools and equipment necessary for the accomplishment of tasks are available and I use them.	Lack of Resources
45	The technical publications of PA Maintenance are up-to-date and I use them regularly.	Lack of Resources
53	The Maintenance Planning of PA is effective in making resources available for Maintenance.	Lack of Resources
1	PA satisfactorily trains its maintenance personnel for safe performance of their tasks.	Lack of Knowledge
6	PA promotes Maintenance employees without appropriate experience or skill.	Lack of Knowledge
13	The qualifications of PA Maintenance employees are constantly improved by the managers.	Lack of Knowledge
30	The rest periods during the work shifts are (not) respected in GOL Maintenance.	Fatigue
38	Fatigue, as a function of daily activities, is impairing the quality of Maintenance tasks in GOL.	Fatigue
32	GOL Maintenance employees are pressured to make deviations to fulfill their tasks.	Pressure
51	The O.S.T / M.O.C seek alternative means to release aircraft back to service.	Pressure
42	An excessive workload is part of my work routine.	Stress
47	GOL Maintenance Coordinators are more concerned with the release of aircraft than with Safe Maintenance.	Stress

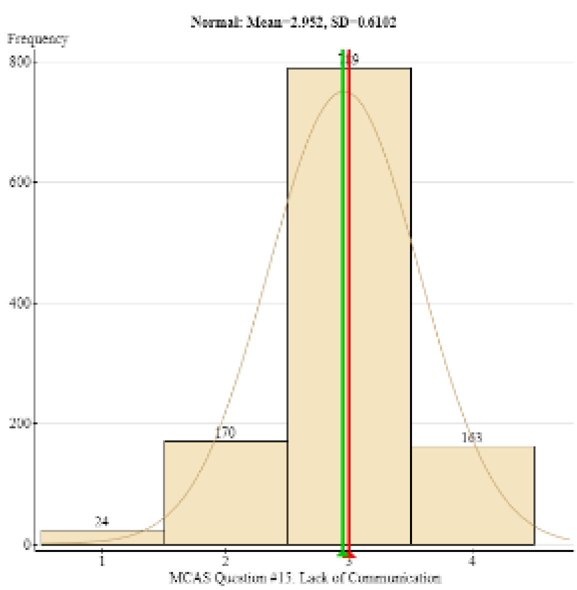
APPENDIX G

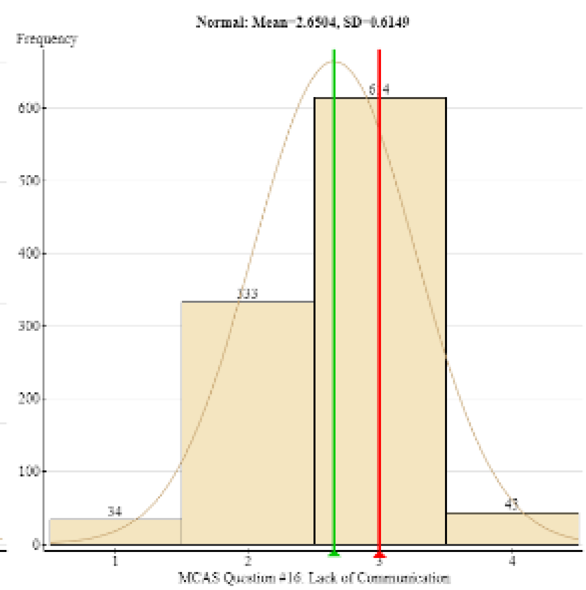
Histograms for MCAS Questions

Lack of Communication

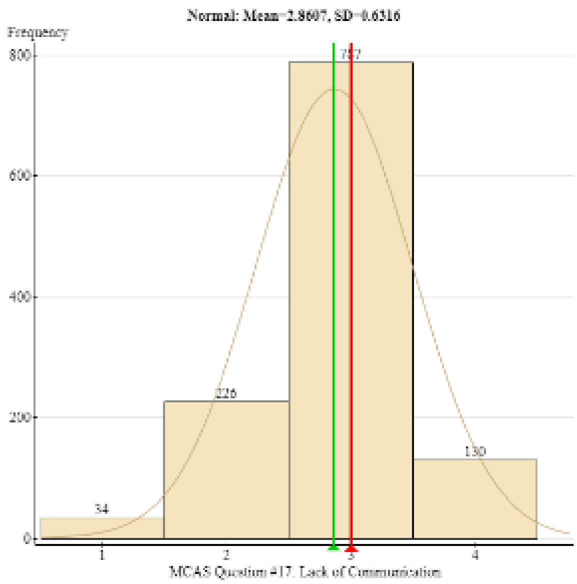


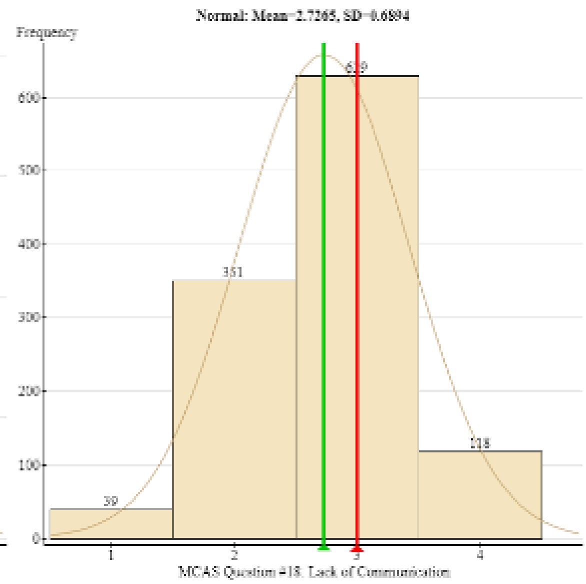


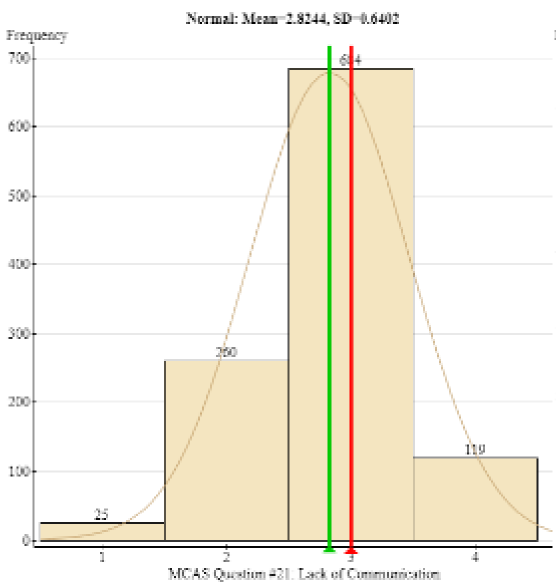


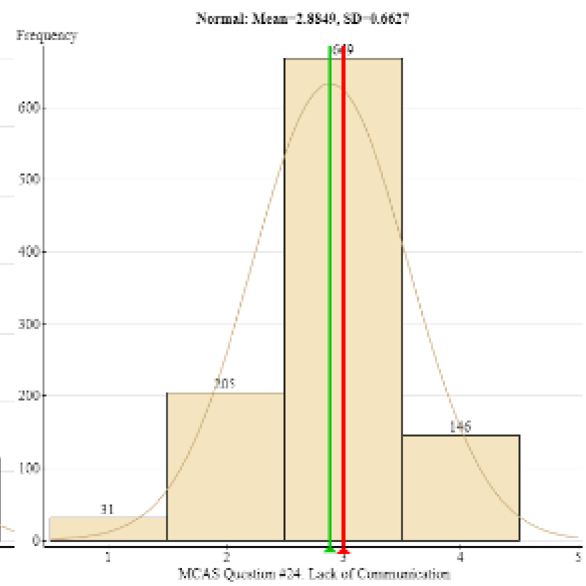


Lack of Communication (cont.)

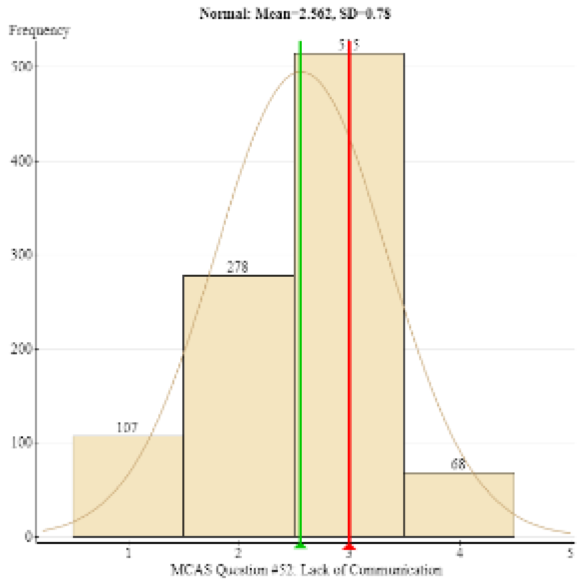




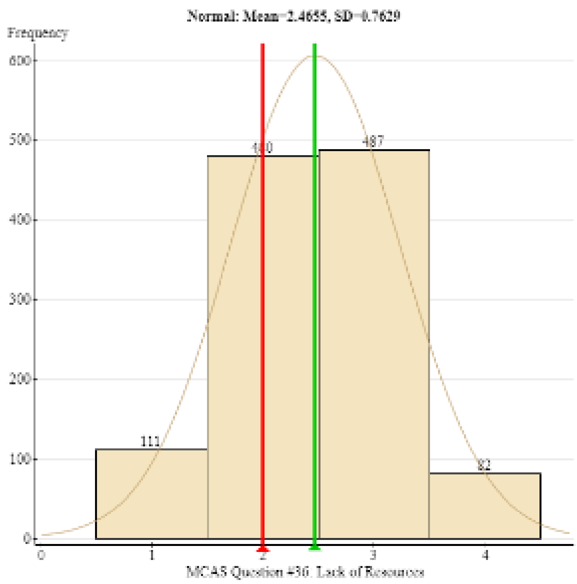


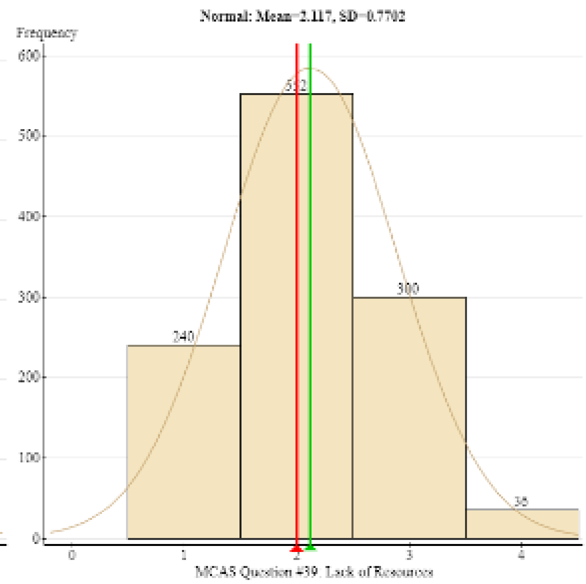


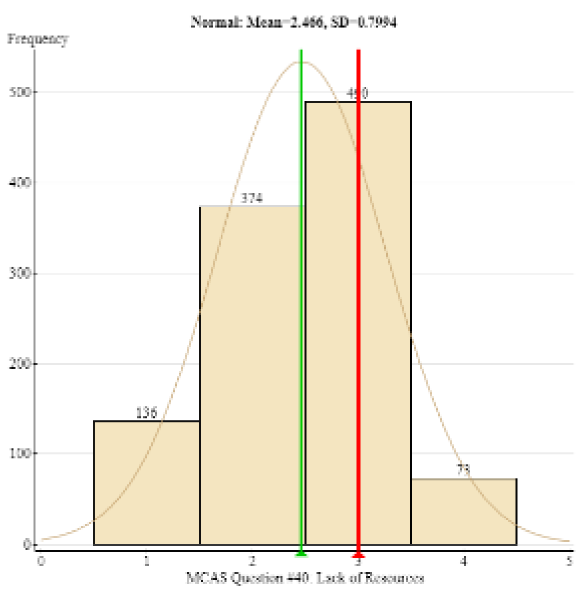
Lack of Communication (cont.)

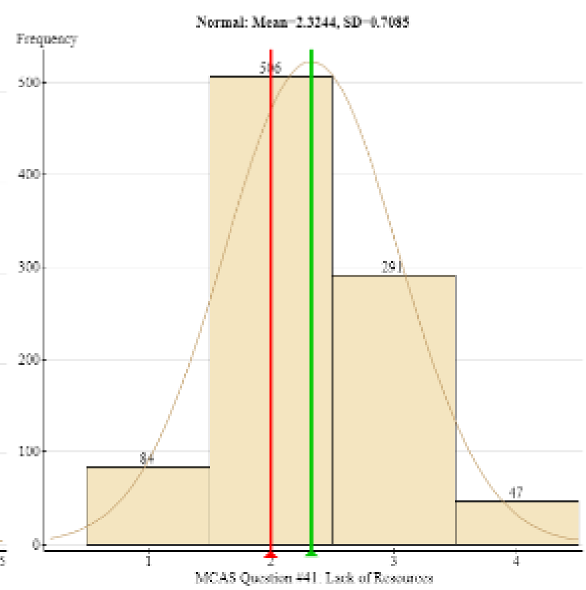


Lack of Resources

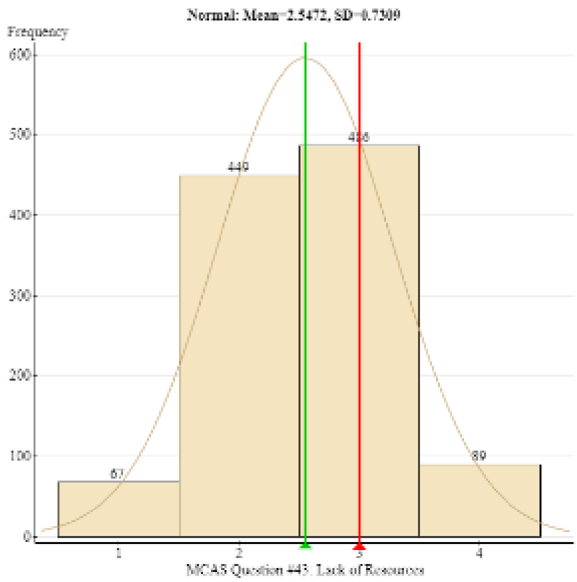


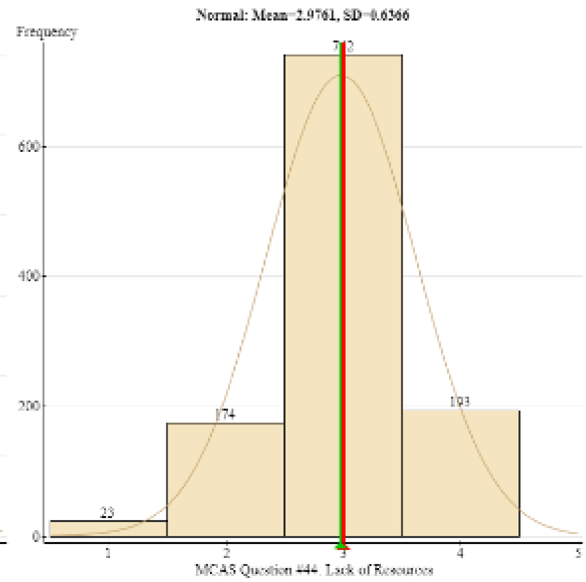


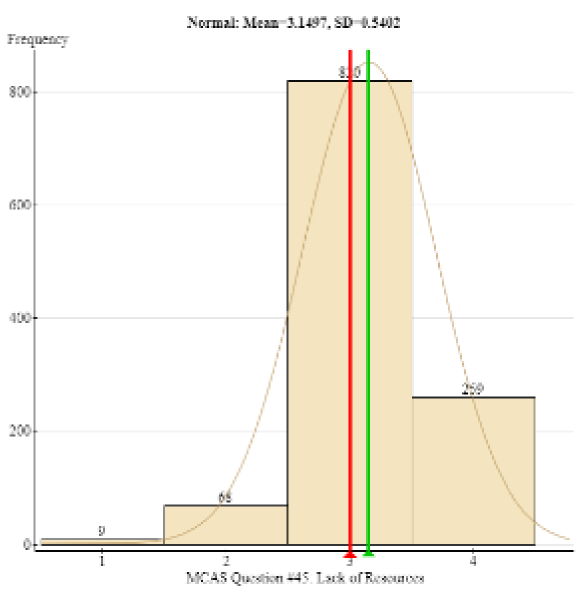


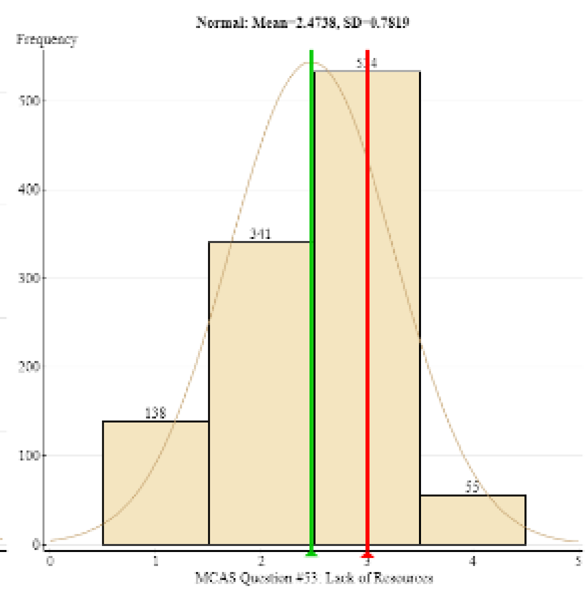


Lack of Resources (cont.)

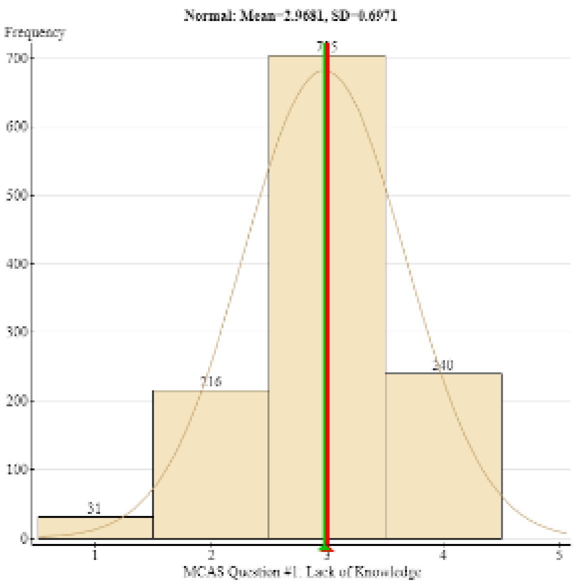


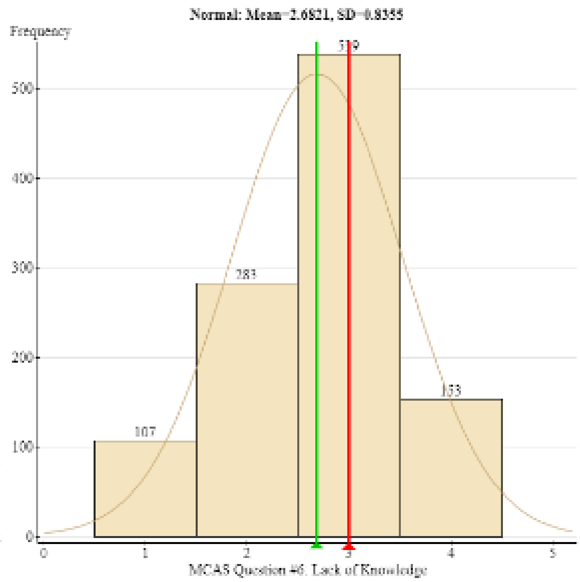


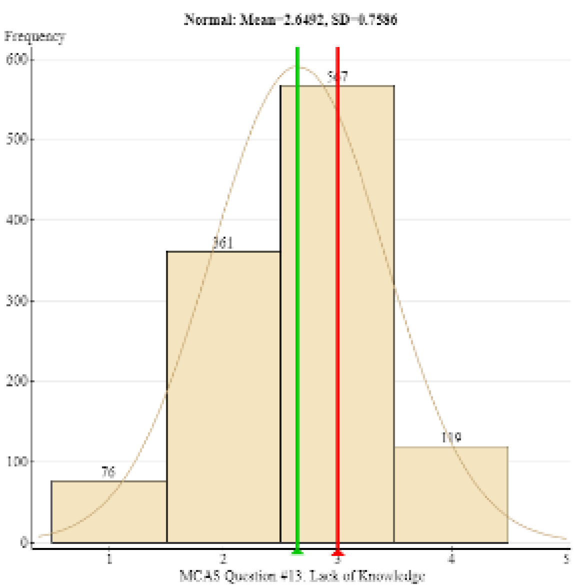




Lack of Knowledge







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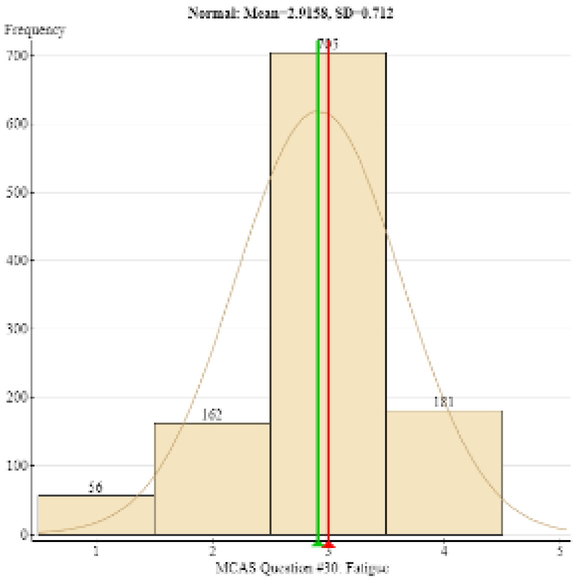

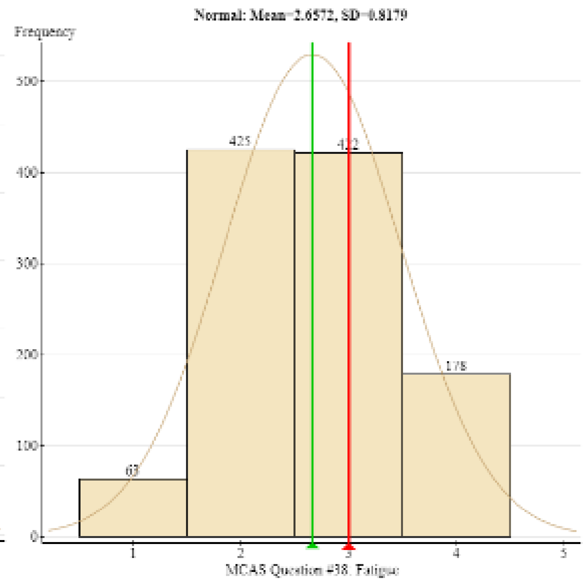

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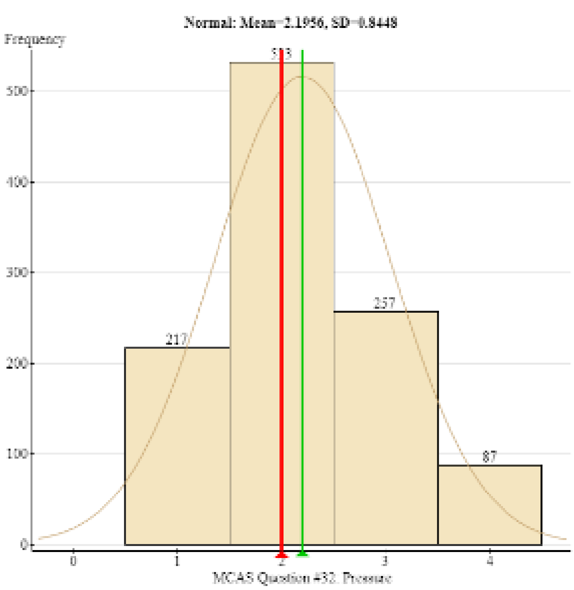
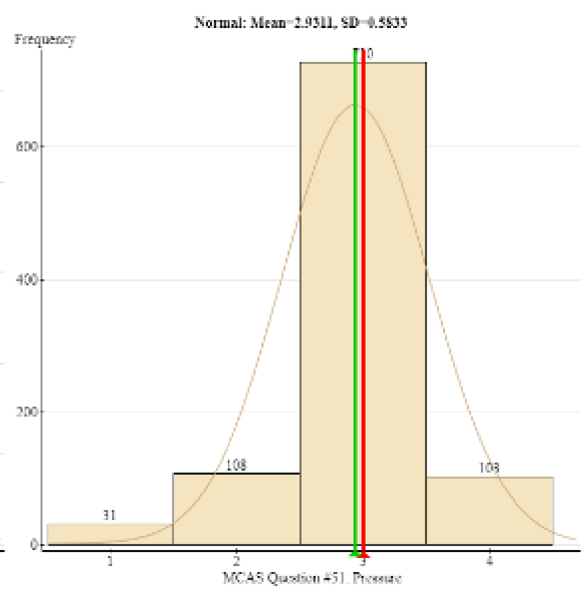
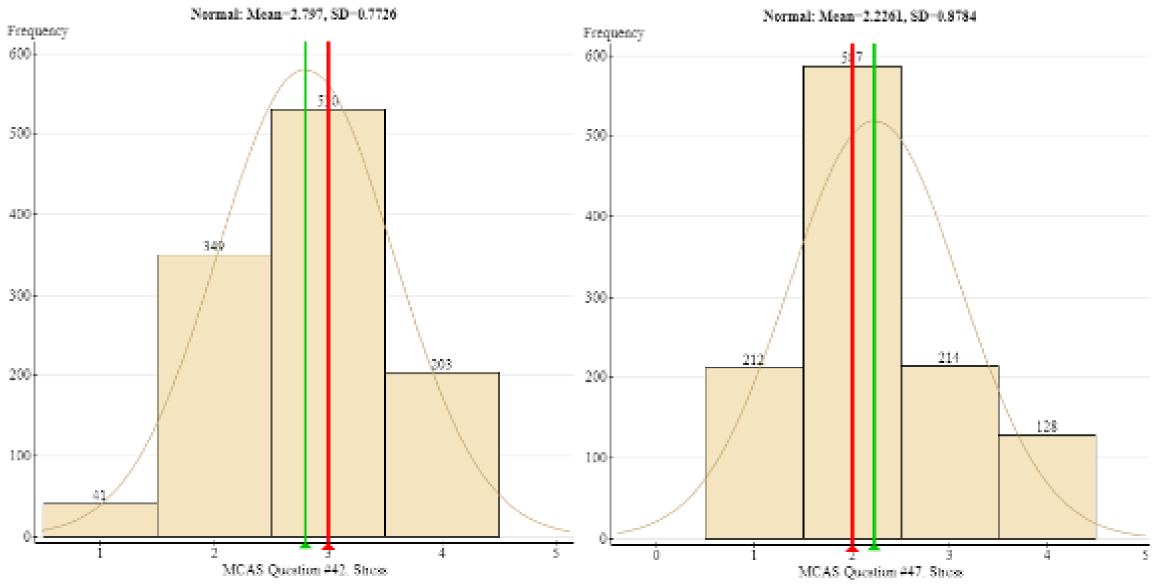




Stress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Frequency
MCAS Question #42. Stress
41
349
203
Normal: Mean=2.2261, SD=0.8784
Frequency
MCAS Question #47. Stress
212
214
128