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Human Error in Commercial Fishing Vessel Accidents: An Investigation Using the Human Factors Analysis and Classification System

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HUMAN ERROR IN COMMERCIAL FISHING VESSEL ACCIDENTS: AN INVESTIGATION USING THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM

by

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ABSTRACT

HUMAN ERROR IN COMMERCIAL FISHING VESSEL ACCIDENTS: AN INVESTIGATION USING THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM

Peter J. Zohorsky
Old Dominion University, 2020
Director: Dr. Holly Handley

The commercial fishing industry is frequently described as one of the most hazardous occupations in the United States. The objective, to maximize the catch, is routinely challenged by a variety of elements due to the environment, the vessel, the crew, and several external considerations and how they interact with each other. The analysis of fishing vessel accidents can be complicated due to the diverse nature of the industry, including the species caught, the type and size of boat that is employed, how far travelled from their homeport, and the adequacy of the support organizations ensuring safe and uninterrupted operations. This study will develop and evaluate a version of Wiegmann and Shappell's (2003) Human Factors Analysis and Classification System (HFACS), specifically for commercial fishing industry vessels (HFACS-FV), using ten years of data documenting the causes of fatal accidents in the commercial fishing industry. For this study, the accident investigation information will be converted into the HFACS-FV format by independent raters and measured for inter-rater reliability. The results will be analyzed for the frequency of the causal factors identified by the raters, and causal factors will also be evaluated for their relationship with vessel demographic information. Based on the results, the conclusion of the study will determine the efficacy of the HFACS-FV model.

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With gratitude, it is essential to express my sincere appreciation for those who provided direct and indirect support for this dissertation. Numerous family members, friends, and colleagues unknowingly provided motivation throughout the process by inquiring about a status update. Informal discussions with several co-workers assisted in understanding various issues and perspectives. A special note of thanks is necessary for the four raters who volunteered their time to learn the HFACS rating process and evaluate each incident. The analysis and conclusions of this research were based on their dedicated and attentive efforts.

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Most importantly, I would like to thank my wonderful wife, Stephanie, for her continual patience and understanding during this entire undertaking. I am deeply indebted to her for her kind tolerance of the years it took to complete this dissertation. I look forward to spending more time together. Thank you, my love!

NOMENCLATURE

AcciMap – Accident Mapping

AEB – Accident Evolution and Barrier Analysis

AIPA – Accident Initiation and Progression Analysis

ANP – Analytic Network Process

APJ – Absolute Probability Judgment

ASEP – Accident Sequence Evaluation Program

ATHEANA – A Technique for Human Error Analysis

BA – Barrier Analysis

CA – Change Analysis

CADA – Critical Action and Decision Approach

CARA – Controller Action Reliability Assessment

CAHR – Connectionism Assessment of Human Reliability

CBDTM – Cause Based Decision Tree Method

CES – Cognitive Environment Simulator

CESA – Commission Errors Search and Assessment

CODA – Conclusions from Occurrences by Descriptions of Actions

COGENT – Cognitive Event Tree System

CREAM – Cognitive Reliability and Error Analysis Method

ECFC – Events and Causal Factors Charting

ECFCA – Events and Causal Factors Charting and Analysis

ETA – Event Tree Analysis

FRAM – Functional Resonance Accident Model

FTA – Fault Tree Analysis

GEMS – Generic Error Modelling System

HAZOP – Hazard and Operability Study

HCR – Human Cognitive Reliability

HEART – Human Error Assessment and Reduction Technique

HEI – Human Error Identification

HEIST – Human Error Identification in System Tools

HERA – Human Error and Recovery Assistant Framework

HET – Human Error Template

HFACS – Human Factors Analysis and Classification System

HFIT – Human Factors Investigation Tool

HPES – Human Performance Enhancement System

HRA – Human Reliability Analysis

HRMS – Human Reliability and Management System

IDAC – Information, Decision, and Action in Crew Context

IDHEAS – Integrated Decision Tree Human Error Analysis Systems

IMAS – Influence Modelling and Assessment System

ISM – International Safety Management Code

JHEDI – Justified Human Error Data Information

K-HRA – Korean Human Reliability Method

MERMOS – Méthode de Evaluation de la Réalisation des Missions Operateur pour la Sûreté

MTO – Människa-Teknologi-Organisation

NARA – Nuclear Action Reliability Assessment

NIOSH – National Institute for Occupational Safety and Health

OATS – Operator Action Tree System

PC – Paired Comparisons

PEAT – Procedural Event Analysis Tool

PHECA – Potential Human Error Cause Analysis

RARA – Railroad Action Reliability Assessment

RCA – Root Cause Analysis

SCAT – Systematic Cause Analysis Technique

SHERPA – Systematic Human Error Reduction and Prediction Approach

SLIM – Success Likelihood Index Methodology

SLIM-MAUD – Success Likelihood Index Methodology, Multi-attribute Utility Decomposition

SMoC – Simple Model of Cognition

SOLAS – Safety of Life at Sea

SPAR-H – Standardized Plant Analysis Risk-Human Reliability Analysis

SRK – Skill, Rule, and Knowledge Model

STAMP – Systems Theoretic Accident Model and Process

STCW – International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers

STEP – Sequential Time Events Plotting

TESEO – Tecnica Empirica Stima Errori Operatori

THERP – Technique for Human Error Rate Prediction

TRACEr – Technique for Retrospective and Predictive Analysis of Cognitive Errors

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CHAPTER 1

INTRODUCTION

1.1 Problem statement

The hazards and tragic results associated with a commercial fishing vessel accident while operating in severe weather conditions are discussed by Junger (1997). Junger detailed the challenges of a fishing voyage in the North Atlantic Ocean. He described the importance of both teamwork and sustained physically demanding work in an environment of rotating deck equipment and moving fishing gear while working with dangerous tools on wet and slippery decks in a variety of weather and sea conditions. Commercial fishing is consistently ranked as one of the most hazardous occupations in the United States (Drudi, 1998; U.S Coast Guard, 1999). According to data from the Bureau of Labor Statistics, workers in the commercial fishing industry had the second-highest occupational death rate for the year 2018, as shown in Table 1 (U.S. Department of Labor, 2019). Commercial fishing is a unique maritime industry where the vessels transit to their fishing grounds and back to port to offload their catch rather than carrying passengers or cargo from one port to another. Safety within the commercial fishing industry is dependent upon the boats, their operators, and several external factors, all interacting dynamically and simultaneously (National Research Council, 1991).

Transportation and industrial accidents that cause physical injury, economic impact, or environmental damage are common occurrences, as shown in Table 2 (U.S. Department of Labor, 2017; U.S. Department of Transportation, 2017; Kuhlman, 1977). Investigations of accidents to determine their cause are conducted for various reasons including: the owner's concern for economic damage, the safety of workers and customers, to assess damages for

Table 1. Highest fatal work injury rates for civilian occupations for 2018, per 100,000 full-time equivalent workers (U.S. Department of Labor, 2019).

Occupation	Fatal work injury rate
Logging workers	97.6
Fishers and related fishing workers	77.4
Aircraft pilots and flight engineers	58.9
Roofers	51.5
Refuse and recyclable material collectors	44.3
Driver/sales workers and truck drivers	26.0
Farmers, ranchers, and agricultural managers	24.7
Structural iron and steelworkers	23.6
Supervisors of construction/extraction workers	21.0
Supervisors of landscaping workers	20.2

potential liability, to examine the impact to work processes, the interest of labor organizations about workplace safety, concerns of the public, and governmental assessment of regulatory standards. Investigations examine all aspects of the accident to understand the mechanisms and circumstances present, as well as the interaction of the persons, machinery, and working conditions that contributed to the accident (Kuhlman, 1977). An analysis of the accident should consider ways or actions necessary to preclude a similar accident in the future. Dekker (2006) stated that “the ultimate goal of an investigation is to learn from failure” (p. 5).

Table 2. Transportation-related fatalities in the U.S. for 2000, 2010, 2015 (U.S. Department of Transportation, 2017).

Mode	2000	2010	2015
Air	764	477	404
Highway	41,945	32,999	35,485
Railroad	937	735	751
Transit Rail	197	120	151
Water	701	821	700
Pipeline	38	19	10
TOTAL	44,582	35,171	37,501

Luo and Shin (2019) separated maritime accident causes into six groups: vessel and equipment, environment, traffic, navigation and operation, market factors, and human factors. Human factors is the broad multi-disciplinary area of study focused on the optimization of interactions of humans and machines in a system (Proctor and Van Zandt, 2008). Human factors are widely considered to contribute to most shipping accidents (Talley, 2000; Sulaiman et al., 2011). The contribution of human factors to accidents was explored by Reason (1990, 1997), who was studying accidents in the nuclear power industry. His resulting "Swiss cheese model" compared accidents as the failed layers of defenses to the holes lining up in slices of Swiss cheese. The Human Factors Analysis and Classification System (HFACS) model, initially developed by Wiegmann and Shappell (2001) to categorize the various causes of military aviation accidents, has its roots in the human error studies completed by Reason (1990, 1997). Wiegmann and Shappell (2003) estimated that human factors contribute to 70 - 80 percent of aviation accidents. Studies using HFACS have examined accident data across the transportation, industrial, and healthcare sectors (Shappell et al., 2007; Baysari et al., 2009; Lenne et al., 2012; Cohen et al., 2018).

1.2 Research objective

This study will adapt the framework provided by HFACS for the commercial fishing industry to investigate the role of human factors in fatal commercial fishing accidents. It will establish HFACS as an appropriate model to classify the causal factors that contribute to these accidents. The resulting data will then be analyzed for patterns or trends that determine the human factors causes in maritime accidents and to evaluate if mitigations can be proposed to prevent future accidents.

1.3 Research questions

The investigation into the contribution of human factors in commercial fishing accidents will use a modified HFACS framework. The accident data organized in this way allows for the overall analysis and categorization of the causal factors of these commercial fishing accidents. To support this study, several research questions will be investigated:

Question 1: Is HFACS an appropriate tool for analyzing accidents caused by human factors in the commercial fishing industry?

Question 2: Does the use of the HFACS-FV framework identify any pattern or consistent distribution of the various human error categories that contribute to commercial fishing vessel accidents in the United States?

Question 3: Does the data suggest that organizational factors have less impact on commercial fishing vessel accidents in the United States than supervisory or non-supervisory issues?

Question 4: Does the data suggest that latent conditions have less impact on commercial fishing vessel accidents in the United States than active conditions?

Question 5: Is there any relationship to reliability estimates for identified human factors and the quality of the information provided in the investigation?

1.4 Research background

Like many complex socio-technical systems, commercial fishing vessel operations represent a wide variety of individuals and groups that work within their organizational structures with their own goals, constraints, and procedures. Interactions within this socio-technical system, whether on the boats, the businesses who buy their product, the companies who support them, or those who regulate them, is a dynamic of their daily operation with numerous outside factors to consider like weather or sea conditions (National Research Council, 1991). Commercial fishing vessels operate in extreme diversity. Their targeted catch is the driver for the waters they will fish and the gear they need, their hull construction, and their crew requirements. While many of the vessels are owned corporately, a substantial number are individually owned and operated (National Research Council, 1991). Because of this complexity, an accident analysis tool for this domain must have the ability to identify a variety of causal factors; the numerous HFACS subdivisions demonstrate the complexity of categorizing accident causes (Wiegmann and Shappell, 2003). The diversified factors selected in this process that contribute to these accidents represent the first step toward the goal of improving safety and minimizing accidents. This HFACS evaluation of commercial fishing vessel accidents will provide useful insights into the various entities and conditions, directly or indirectly, involved in this industry to protect human lives, property and the environment in the future.

1.5 Research challenges

This study depends on the accuracy of the causal factors in the data that will be directly exported for the application of HFACS. The data utilized for this study originated from marine accident reports and their subsequent investigations. While human error is recognized as a cause of all accidents, including commercial fishing vessel accidents, the way all investigators collect and code the data may not be directly applicable to the HFACS framework. While detailed investigations are expected to reveal causal factors accurately, depending on the training, experience, and workload of the assigned investigator, the investigation may not account for human error properly. Dekker (2006) described the terms “old view” and “new view” as related to human error. The old view is that accidents are due to mistakes made by the operator. The new view is that systems contain inherent vulnerabilities and weak spots with operators who are trying to do a good job. Investigators are assumed to be unbiased and to consider not only mistakes made by the operator but the defects within the system that may have had an impact on the operator. The concern about the inconsistent quality of the information provided in commercial fishing vessel accident investigations was previously identified by Lincoln (2006).

Evaluation and assignment of causal factors using the HFACS categories require familiarization and experience (Wiegmann and Shappell, 2003). From the HFACS perspective, an investigation is necessary before HFACS can be applied and evaluated. The investigation needs to be thorough and impartial. The results of the investigation are essential to prevent similar events but are also critical for an accurate HFACS utilization.

Any data set being evaluated for statistical purposes depends on the completeness of the data to provide meaningful analysis. While accidents that require notifications may be subject to under-reporting for several reasons, including responsibility for damages and employment consequences, it is reasonable to believe that accidents involving fatalities and the necessary documentation for the various public, private, and family interests would minimize this issue.

This study considers that all HFACS causative factors may not apply to all commercial fishing vessels and the accidents represented in the data. Companies that own or operate commercial fishing vessels vary considerably in their size and scope. A company may consist of one boat owned and operated by one person or may be part of a regional, national, or international company. Regardless of the size of the company, it is valuable and significant to study the impact of human error on accidents affecting commercial fishing vessels in this dangerous and minimally regulated industry using HFACS. “Self-employed” fishing industry personnel, which account for nearly half of all industry fatalities on vessels, may not be as likely to have the full representation of data in the fields for management and supervision (U.S Bureau of Labor Statistics, 2012). This is different from previous maritime HFACS studies that have considered oceangoing ships with a fully developed management and support structure onshore. It could also be a reason that HFACS has not been previously applied to commercial fishing vessels.

1.6 Research contributions

The direct contribution of this study to the body of knowledge will be to adapt the HFACS for commercial fishing vessel accidents and evaluate accident data with this version. This technique will identify the various causative human factors that contributed to commercial fishing vessel accidents using the modified HFACS. The indirect contribution will be providing a methodology for the HFACS modification for application to other types of vessels, as well as other transportation or industrial sectors. In addition, the identification of the human factors that contribute to these fatal accidents is critical to vessel owners, operators, and regulators to evaluate the current practices and initiate safer procedures in an effort to minimize injury and loss of life in this industry.

CHAPTER 2

BACKGROUND OF THE STUDY

Several topics will be explored in this section to provide the theoretical basis for this study. A discussion of the development of modern human factors and human error will be followed by descriptions of human reliability analysis, human error identification, and accident analysis, including representative methods of these topics. This will lead to an explanation of the Human Factors Analysis and Classification System (HFACS), including a review of the literature applying the method in a variety of applications. Concluding this chapter, the common hazards and safety concerns within the commercial fishing industry will be examined.

2.1 Historical foundation of human error study

Human error as a causative factor in industrial accidents began after Watt's steam engine and Whitney's cotton gin inventions saw their early application within the textile industry in the late eighteenth century. Heinrich (1931) detailed how industrial safety improvements occurred at a much slower rate than industrial development and expansion. He described dangerous working conditions, including overcrowded factories with poor lighting and ventilation. Employees, including children, worked more than twelve hours each day, and injuries and fatalities were commonplace. Advances in safety were slow to develop and slower to be implemented. In 1833, factory inspections were initiated in England (Heinrich, 1931). Even as the pace of innovation within the industrial and transportation sectors increased, safety hazards and their impact on people were accepted in the quest for progress.

As the nineteenth century concluded and the twentieth century began, safety advancements were made due to a variety of employers' liability and workers' compensation laws, the advent of numerous safety organizations, a prospering insurance market, the publishing of industry-specific periodicals, and governmental agencies examining the causes and preventative measures of accidents (Heinrich, 1931). These ventures still could not surpass the rapid growth and diversification in the manufacturing, mining, railroad, and maritime industries. As populations increased in urban centers around the world, concepts like more, better, bigger, and faster were instrumental in enhancing the divide between technology and safety. Heinrich (1931) also produced research regarding the causes of industrial accidents. He analyzed 75,000 industrial accidents and concluded that unsafe acts primarily caused 88%, unsafe physical or mechanical conditions caused 10%, and 2% of the accidents were unpreventable. Figure 1 represents his findings. Heinrich (1931) also proposed a model that compared ratios of accidents causing injuries. Based on data from 5,000 accidents, Heinrich developed the theory of the 300-29-1 ratio. These numbers represented the seriousness of injuries from 330 accidents where 300 would result in no injury, 29 would result in minor injury, and one would result in a major injury, as shown in Figure 2. This model showed the importance of evaluating and learning from "near misses" that result in no injury or minor injury. Identifying and resolving unsafe conditions provides an opportunity to prevent a more severe accident that may impact life, property, or the environment. These two representations of accidents and their causes have remained valuable to the examination of human error and the progression of safety improvements within the industrial and transportation sectors. Significant opportunities to study human error became available with global military conflicts and the maturation of aviation in the first part of the twentieth century. An important work in human error and ergonomics was completed shortly after World War II by surveying hundreds of military pilots. Fitts and Jones (1947) studied the perception and interpretation error of aviation instruments. Their categorization of nine recurring error types,

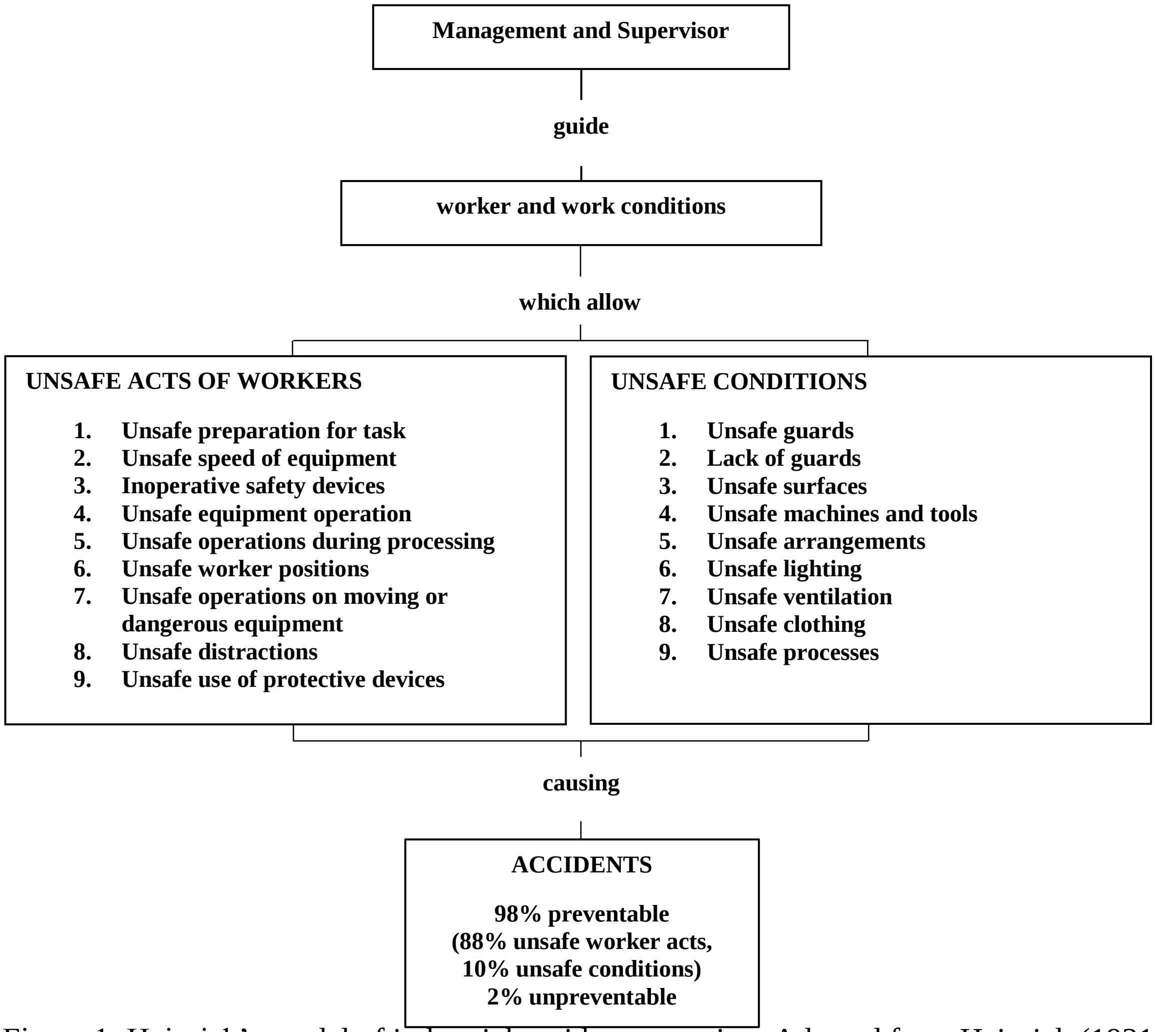

Figure 1: Heinrich’s model of industrial accident causation. Adapted from Heinrich (1931).

including incorrectly reading multi-revolution instruments and improperly applying instrument scales, provided a direct connection between cognitive functioning, equipment design, and operational error. Their foundational research provided insight into daily hazards encountered by aviators that had previously not been collected and analyzed.

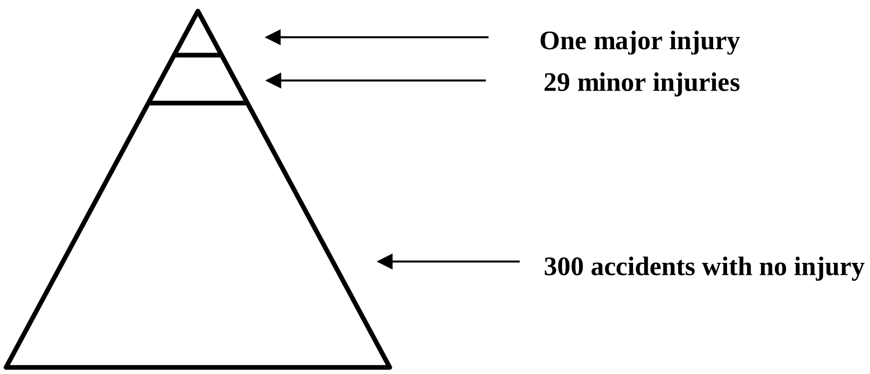

Figure 2: Heinrich’s 300-29-1 ratio foundation of a major injury. Adapted from Heinrich, (1931).

2.2 Safety and human reliability

The modern study of human error was sparked by accelerated technological innovation and a series of unfortunate accidents in the 1970s and 1980s across the transportation and industrial sectors. Accidents including the crash of an Eastern Air Lines flight in Florida in 1972, the runway collision of Pan Am and KLM jets in the Canary Islands in 1977, the Three Mile Island partial meltdown in 1979, the Hyatt Regency skyway collapse in Kansas City, Missouri in 1981, the *Ocean Ranger* sinking in the Atlantic Ocean in 1982, the methyl isocyanate release in Bhopal, India in 1984, the Challenger explosion in 1986, the Chernobyl explosions in 1986, the *Herald of Free Enterprise* capsizing in 1987, and the *Piper Alpha* fire in the North Sea in 1988 demonstrated the impact of human error across various applications and are summarized in Table 3 (Reason, 1990; Chiles, 2002).

These tragic accidents highlight the complexity of modern technology in these diverse industries. Transportation and industrial workers are often most at risk from these accidents. The impacts of unsafe work environments are far-reaching. Though generally described as lost

Table 3: Significant accidents of the 1970s and 1980's and their impact (Kemeny, 1979; Zeller, 1981; Sheen, 1987; Reason, 1990; Chiles, 2002).

Event	Impact
Eastern Airlines crash in Florida (1972)	101 deaths
Canary Islands runway collision (1977)	583 deaths
Three Mile Island partial meltdown (1979)	voluntary evacuation of 140,000 residents
Hyatt Regency skyway collapse (1981)	114 deaths
Ocean Ranger sinking (1982)	84 deaths
Bhopal gas release (1984)	estimated 7,000 deaths
Challenger explosion (1986)	7 deaths
Chernobyl explosions (1986)	estimated 5,000 – 10,000 deaths; government evacuated 135,000 residents
Herald of Free Enterprise capsizing (1987)	193 deaths
Piper Alpha fire (1988)	167 deaths

time and lost revenue, Petersen (1971) included specific effects of lost time from the employee injuries, retraining and supervisory losses, repair of damaged equipment, and lost income to the employee's family, delays to operations, and employee retention. These unsafe environments are prone to accidents. Johnson (1973) provided a comprehensive definition of the word *accident* in this manner:

1. An accident is an unwanted transfer of energy,
2. Because of lack of barriers and/or controls,
3. Producing injury to persons, property or process,
4. Proceeded by sequences of planning and operational errors which:
    a. Failed to adjust to changes in physical or human factors,
    b. And produced unsafe conditions and/or unsafe acts,
5. Arising out of the risk in an activity,
6. And interrupting or degrading the activity (p. 25).

Accidents and unsafe operations are symptoms of a system with low reliability, according to Kelly and Boring (2009). Human reliability refers to how likely a person or persons can adequately complete an assignment within a specified time criterion (Meister, 1966; Swain and Guttmann, 1983). However, Leveson (2004) pointed out that this relationship between safety and reliability was not without exception and that systems existed that were unsafe with high reliability and safe with low reliability.

Singleton (1972) highlighted the concern associated with evaluating human error. Due to the wide variety of factors connected with errors involved and the objectives of the analysis, the sorting and classifying of errors is a primary issue to resolve. Singleton (1972) described human error classifications, including errors of commission and omission, reversible and irreversible, systematic and random, and formal and substantive. Throughout the review of relevant literature, there are varying taxonomies referred to as human reliability analysis (HRA) techniques, human error identification (HEI) techniques, or accident analysis techniques. While all are important for the reduction of accidents, and specific methods may be more appropriate for applications within a particular industry or transportation sector, it is challenging to infer consensus regarding the categorization of these techniques without an understanding of the author's perspective. The various methods can prove troublesome during comparisons when attempting to evaluate appropriate methods to analyze the specific data.

Calvo Olivares et al. (2018) described a human error classification scheme with four significant divisions, including taxonomies based on the task, taxonomies of information processing, taxonomies and models of symbolic processing, and HRA techniques of quantification. Taxonomies based on the task categorize various human error modes or system errors. Taxonomies of information processing utilize input and output actions in the evaluation of human performance. Taxonomies and models of symbolic processing are a diverse grouping that use physical and cognitive theories to represent a systematic analysis of error. HRA techniques for quantification are comprised of first generation, second generation, third generation, and expert judgment methods.

2.3 Human Reliability Analysis (HRA) methods

Kirwan (1997) characterized HRAs as methods to evaluate risks within a system to avoid accidents. HRA methods can be retrospective or prospective, according to Cacciabue (2010). Retrospective HRA occurs after the accident or incident and uses information from the actual event to uncover the cause of the event. Prospective HRA involves the modeling of human-machine interactions to predict and evaluate the possible impacts of the system.

Kelly and Boring (2009) delineate three steps in HRA as error identification, modeling, and quantification. The error identification phase includes deconstructing the system into tasks and sub-tasks and establishing actual or likely sources of error. The next stage is modeling, which assesses overall risk through the use of event trees, fault trees, or other methods to evaluate the sequence of human actions in the system. The final phase is quantification, where human error probabilities are determined.

First generation HRA methods are characterized by Cacciabue (2004) as concentrating on the quantitative probability of success or failure of the operation or performance. However, evaluation related to the factors directly associated with system failures or errors is lacking, and ultimately first generation HRA methods may prove ineffective in preventing subsequent accidents. Examples of first generation HRA are described in the following paragraphs.

The Accident Initiation and Progression Analysis (AIPA) originated in the nuclear energy industry during the 1970s (Kirwan, 1992a). This probabilistic method was intended to determine if the operator’s responses during plant operation were effective or not. It was expected to encourage rapid and accurate responses by the operator but provided no insight regarding how decisions were made or what factors contributed to incorrect decisions (Hollnagel, 1996). Bell and Holroyd (2009) noted that this method was no longer in use.

The Technique for Human Error Rate Prediction (THERP) was developed during the 1960s and 1970s and is based on event tree analysis. It is meant to identify system boundaries and failures, human error events and probabilities, evaluate system failures, and provide recommendations for change to prevent a similar failure in the future. A fundamental concept within THERP determining if the error was caused by an act of omission or an act of commission. This "action" element is similar to AIPA, which attempted to link the recognition of a system abnormality with a suitable response. THERP provides an expanded analysis of the probabilities associated with the system, its operation, and its weaknesses (Swain and Guttmann, 1983).

The Human Error Assessment and Reduction Technique (HEART) was developed by Williams (1985) and has been influential in the creation of other HRAs. The method is based on the relationship between reliability and the task being considered. It is known for its relatively easy application, including a task analysis using generic task types and error producing conditions to calculate human error probabilities. HEART has been applied in various industries and requires minimal outside resources to arrive at a nominal likelihood of failure (Bell and Holroyd, 2009).

The Operator Action Tree System (OATS) was formulated by Wreathall (1982). This technique consists of the following segments: generation of event trees covering plant safety functions, necessary actions for plant safety, applicable alarms and expected response time, and production of event trees or fault trees for the human reliability analysis of the revealed errors and approximate error probabilities. Similar to AIPA, operator actions will be termed as success or failure (Hollnagel, 1996).

The Human Cognitive Reliability (HCR) model was created in the 1980s (Hannaman and Worledge, 1988) and is grounded in the skill-based, rule-based, and knowledge-based framework (Rasmussen, 1983). The critical portions of this model include: establish which actions will be evaluated, categorize the necessary cognitive processing mechanisms, decide median time for operator's response, modify the median time for relevant performance factors, estimate the system time window for each action to be performed, and calculate the normalized time value by dividing the system time window by the median response time. The HCR model utilizes no response in addition to actions classified as success or failure (Bell and Holroyd, 2009).

Drawbacks of first generation HRA methods were incorporated into the changes that resulted in second generation HRA methods when they were introduced in the 1990s as described by Bowo et al. (2017). These methods examine the system background, cognitive, and human behaviors that led to the error (Bell and Holroyd, 2009; Calvo Olivares et al., 2018). Summaries of selected second generation HRA methods are provided below.

The Cognitive Environment Simulator (CES) utilized artificial intelligence and computer simulation to model operator response and was initially developed for the nuclear power industry. CES provides a virtual operational plant control panel for the operator and produces accurate scenarios that an operator is likely to encounter. CES is a valuable tool to catalog operator responses to resolve critical system troubles but has seen limited application since the 1980s (Bell and Holroyd, 2009).

The Cognitive Reliability and Error Analysis Method (CREAM) is a qualitative method, suitable for prospective or retrospective analysis that utilizes cognitive processes to evaluate operator response reactions. CREAM starts with a task analysis and then generates categorized tables of errors and actions. Error modes, organizational, and general system operations are evaluated as part of the analysis. The system is examined using these nine common performance conditions: organizational adequacy, working environment, suitability of human-machine interface and support of operations, procedure availability, number of simultaneous objectives, necessary time for operations, time the operation occurs, training and proficiency assessment, and the degree of crew cooperation (Hollnagel, 1998).

A Technique for Human Error Analysis (ATHEANA) was produced for the nuclear power industry as a qualitative and quantitative technique that can be used for retrospective and prospective HRA evaluations. It was developed using a team of industry and reliability experts for the U.S. Nuclear Regulatory Commission (1996). ATHEANA is a method consisting of ten elements but essentially is comprised of a task analysis, error identification, linking relevant failures to error producing conditions, and calculating error probability of these events. Bell and Holroyd (2009) describe the highly detailed process as productive but also complicated and inefficient.

Third generation HRA methods are a minor division and represent a blending of first and second generation methods (Flaus, 2013; Hogenboom, 2018). The Nuclear Action Reliability Assessment (NARA) was developed by Kirwan et al. (2005) and is based on HEART to estimate human error in the nuclear power industry. NARA utilizes generic type and error producing conditions in conjunction with a human error database to quantify error probabilities (Bell and Holroyd, 2009).

Expert judgment methods are unique approaches that utilize the demonstrated mastery and opinions of those recognized for their specific knowledge to analyze and estimate error probabilities of a system (Bell and Holroyd, 2009; Calvo Olivares et al., 2018). The Success Likelihood Index Method using the Multi-Attribute Utility Decomposition (SLIM-MAUD) technique is an expert judgment, the computer-aided analysis described by Embry et al. (1984) and initially developed for the nuclear power industry. A group of experts is utilized to assess the priority and weighting of performance shaping factors and their effect on system reliability. The sum of weighted performance shaping factors becomes the success likelihood index, which is then converted into human error probability estimates. SLIM-MAUD is versatile but subject to the biases and time demands of the team of experts (Bell and Holroyd, 2009).

2.4 Human error theory development

Accidents in the industrial, transportation, and medical sectors are attributed mainly to human error (Kirwan, 1987; Pennie et al., 2007; Uğurlu et al., 2013; Cohen, 2017; Ung, 2018). Reason (1997) defines human error as “the failure of planned actions to achieve their desired ends” (p. 71). Human error is common in all human endeavors, and it is most troubling when those persons taking action believe that their years of experience make them exempt from accidents (Allnut, 2002). Kirwan (1992b) provided the essential criteria by which human error identification (HEI) methods should be assessed; these include thoroughness, ability to produce correct results, and practical applicability to the data or event being evaluated. HEI methods are beneficial in that they identify the external error type as well as the mechanism behind the error. Performance shaping factors, those categories of various human errors that may be present in the event, are common to most HEI methods.

The Systematic Human Error Reduction and Prediction Approach (SHERPA) method evaluates the various tasks within a system, and qualitatively assesses their priority to the risk posed to the system (Flaus, 2013). The technique involves a task-by-task analysis and classification, error identification, evaluation of consequences and error recovery, error probability frequency, error consequence, and possible error reduction mechanisms (Embry, 1986). The resulting analysis, according to Flaus (2013), is comprehensive but demanding with no regard for cognitive errors.

The System Theoretic Accident Model and Processes (STAMP) was developed by Leveson (2004). This system-based method proposed that accidents are the result of interacting organizational, environmental, and technical elements of the system. Accidents occur when system limitations are not recognized, are improperly implemented, or are exceeded (Grant et al., 2018). STAMP uses system development and operations models to determine and constrain the interaction between system elements.

Rasmussen (1983) proposed the Skill-Rule-Knowledge (SRK) classification method to categorize human behavior and ultimately explain human error. Skill-based behavior refers to automatic actions and responses. This learned behavior becomes intuitive with minimal mental exertion. Rule-based behavior is based on procedures and specifically whether a procedure is being followed or not. Knowledge-based behavior involves cognitive effort. Making decisions and solving problems are common applications of knowledge-based behavior. Skill-based errors are least probable and knowledge-based errors are most probable.

Causal modeling represents a number of techniques to sequentially diagram a process or system by examining how an accident occurred. Two standard methods in error analysis are fault tree and event tree analysis. Fault tree analysis can be employed qualitatively or quantitatively to break down an accident or event into progressively detailed causes. The presentation of a fault tree analysis shows the event at the top of the diagram with subsequent layers of causes beneath that and uses logic gates, including "AND" and "OR" to finally arrive at the root cause or causes (Lewis, 1996; Flaus, 2013). Event trees, often referred to as consequence trees, provide a quantitative probability estimate of the effects of the unwanted event. In this method, the tree is diagrammed in a left to right orientation, with the event being continuously subdivided, showing further impacts of the event in a binary decision manner leading to the consequences of each of the tree branches (Lewis, 1994; Flaus, 2013).

The Human Error Identification in System Tools (HEIST) developed by Kirwan (1994) uses pre-identified performance shaping factors that represent the various errors likely to be encountered in a system. Then each performance shaping factor is evaluated in a table with four categories: error identification question, external error mode, system cause/psychological error mechanism, and error reduction guidelines (Doytchev and Szwillus, 2009).

The Technique for the Retrospective and predictive Analysis of Cognitive Errors (TRACEr) was initially intended as a technique to specifically consider air traffic control hazards and preventative measures (Shorrock and Kirwan, 2002). TRACEr employs numerous taxonomies in the analysis of the cognitive factors affecting the operator’s performance and the work environment (Schröder-Hinrichs et al., 2017). The method's design for use as a retrospective and prospective tool provides comprehensive analysis with a variety of applications but may also be overly complicated and time-consuming in practice.

The Generic Error Modelling System (GEMS) established by Reason (1990) is based on the works of Rouse (1981) and Rasmussen (1983). Using Rasmussen's (1983) SRK model, GEMS utilizes a sequential analysis of these behaviors to describe the error modes of the system (Reason, 1990). The method examines the behaviors before and after the event happens. Errors occurring before the problem has been noticed are classified as monitoring errors. Those errors occurring after that are known as problem-solving errors. Reason (1990) further divides skill-based errors into those resulting from inattention and over attention. Rule-based errors can develop from misapplication of proper rules and the application of bad rules. Knowledge-based errors proceed from the following categories: selectivity, workspace limitations, out of sight out of mind, confirmation bias, overconfidence, biased reviewing, illusory correlation, halo effects, problems with causality, and problems with complexity.

The AcciMap approach was developed by Rasmussen (1997) to examine events considering the complicated interactions in socio-technical systems. The method presents a multi-level diagram showing how causal factors are related to physical events, conditions, or processes, and organizational or external elements contributed to the accident. Then these factors are connected based on their dependence on other layers of factors and ultimately with the outcome. AcciMap provides a comprehensive examination of the factors involved in an accident, as well as how they are linked with other factors (Branford et al., 2011).

The Functional Resonance Analysis Method (FRAM) created by Hollnagel (2004) studies accidents based on performance probability and how system factors occurring together can result in conditions that surpass limitations for normal operations. FRAM is dependent on the ability to provide the likelihood of system functions as well as the insight to establish functional resonance limitations. This method also offers the opportunity to introduce preventative measures and how they would prospectively influence the functional resonance of the system (Hollnagel, 2012).

A Failure Mode and Effects Analysis (FMEA) is a prospective method to examine the various potential manners of system failure and their impacts. It is similar to the retrospective root cause analysis method of conducting investigations to determine their cause or causes of an accident. FMEA is a structured, qualitative risk assessment tool that aims to identify, evaluate, and mitigate potential failures proactively. The origins of FMEA are attributed to United States military procedures, and it is widely applied within the Unites States National Aeronautics and Space Administration (Sheridan, 2008). FMEA is also an important part of the Lean Six Sigma method of product and performance improvement (Mekki, 2006).

A Hazard and Operability (HAZOP) study is beneficial for the identification of hazards and risks in an industrial plant or environment (Kletz, 1974). HAZOP studies are prospective methods that are generally conducted with a specialized team of four to eight experienced personnel familiar with the proposed operations. Each subsystem is analyzed in a detailed fashion with regard to design intent and deviations from the specified operating parameters. Guide words appropriate to the system or process are utilized to ensure the team considers overall objectives. Although the method provides substantial insight into system processes and operations, HAZOP studies are generally expensive and time-intensive (Gould et al., 2000).

The Potential Human Error and Cause Analysis (PHECA) was developed by Whalley (1987) for the chemical processing industry. This method uses performance shaping factors or error categories similar to THERP and SHERPA. Process, personnel, and ergonomic groups are typical performance shaping factors. PHECA involves the analysis of various operational data, including accident reports, medical and operational records, and logbooks combined with the use of computer analysis in the identification of human errors contributing to accidents (Grozdanovic, 2001; Kim and Jung, 2003).

2.5 Accident analysis

After an accident occurs, a systematic and objective investigation is conducted to determine the cause or causes of the accident. Though accident analysis may, at times, be considered a portion of the accident investigation, it may also be utilized to evaluate recommendations and trends supported by the investigation (Hollnagel and Speziali, 2008). As industries and transportation methods involve greater use of technology, the complexity surrounding accidents and socio-technical systems has required innovative approaches to investigate and analyze these accidents (Underwood and Waterson, 2013a). Hollnagel and Goteman (2004) proposed three divisions to classify accident analysis methods: sequential techniques, epidemiological techniques, and systemic techniques. Sequential techniques include fault tree analysis, event/consequence tree analysis, and root cause analysis (Hollnagel and Speziali, 2008; Bowo et al., 2017) that evaluate linear, cause-and-effect type accidents (Underwood and Waterson, 2013). Epidemiological techniques consider latent and active contributions to accidents and were named for their similarities to the distribution of illness and disease as compared to how latent factors negatively impact organizational and supervisory conditions within the system (Qureshi, 2007; Underwood and Waterson, 2013a). Examples of epidemiological techniques are the Swiss cheese model (Reason, 1990) and the Human Factors Analysis and Classification System (Wiegmann and Shappell, 2003). Systemic methods evaluate the interactions between system components as critical to the understanding of how a system operates or fails (Underwood and Waterson, 2013a). Techniques such as AcciMap (Rasmussen, 1997), FRAM (Hollnagel, 2004), and STAMP (Leveson, 2004) provide an enhanced level of system comprehension and dependency on control limitations when analyzing an accident (Underwood and Waterson, 2013a).

Hollnagel (2008) outlined various theories for comparing accident investigation and analysis methods. Benner (1985) proposed ten criteria to compare methods of accident investigation, including encouragement, independence, initiatives, discovery, competence, standards, enforcement, states, accuracy, and closed-loop. Hollnagel (1998) produced six criteria to classify and compare accident methods, namely analytic capability, technical basis, relation to existing taxonomies, practicality, and cost-effectiveness. Perrow (1984), in his discussion of socio-technical systems and motivated by the Three Mile Island accident, presented a model with two criteria: interactions and coupling. Interactions are described on a scale from linear to complex. Linear system interactions are described as having flexibility and freedom in components and personnel assignments: linear systems have thoroughly known operations and responses. Complex system interactions, by contrast, are optimized by design. While component design and integration are finely tuned, there may not be complete comprehension of how the system may respond under certain conditions or when various subsystems interact. Coupling is a measure of system and subsystem dependency; while loose coupling may be indicated by variability in the system, tight coupling is more specific regarding built-in redundancy, critical logistical support, and necessary timelines. Using the combinations of linear and complex interactions with loose and tight coupling results in Perrow’s (1984) four quadrant interactions/coupling chart, as shown in Figure 3.

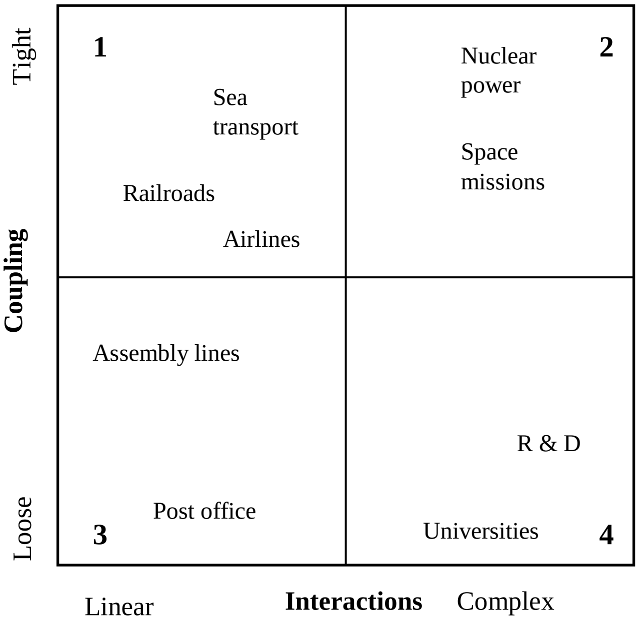

Figure 3: Perrow’s interactions/coupling chart. Adapted from Perrow (1984).

The chart includes numerous industries, transportation modes, governmental, and educational organizations. Maritime and rail transportation are examples of quadrant one enterprises. While the operation of these modes is very complicated and timeliness is critical to performance, component isolation and response knowledge are high. Quadrant two represents complex interactions and tight coupling activities, including nuclear power plants. Nuclear power plants are characterized by a large number of radiological, mechanical, electronic, and personnel subsystems operating and interacting with each other. System interactions and responses may be unpredictable or unstable. Personnel are assigned to very specialized positions, and operations rely, at times, on incomplete information sources and system understanding. Further, the system is dependent on proper procedures that must be followed, designed redundancies, with little room for time variations or delays. Factories, especially assembly plants, are typical quadrant three applications because of separate production activities with minimal unexpected system feedback. While production delays are not desired, system safety is not affected by these delays. Also, excess parts, supplies, and personnel can ensure that production continues as intended. Universities are model quadrant four organizations, as their loose coupling is shown through their capacity to withstand delays, changing sequences, and varying personnel. They also pursue the simultaneous objectives of education, research, and public information. Furthermore, their large number of students, faculty, different colleges, and numerous fields of study lead to complex interactions between these various systems (Perrow, 1984).

Hollnagel and Speziali (2008) use Perrow's (1984) interactions/coupling quadrant numbers to match accident analysis technique groupings. Quadrant one activities, associated with linear interactions and tight coupling, are best suited for epidemiological techniques. Enterprises identified with tight coupling and complex interactions, located in quadrant two, are appropriate for systemic techniques. Loose coupling and linear interaction operations in quadrant three fit the sequential techniques (Hollnagel and Speziali, 2008).

2.6 Method summary and selection consideration for the current study

The variety of HRA, HEI, and accident analysis techniques raises obvious questions of how to select a proper method for a particular research topic or the most effective method for a subject. The literature contains many examples comparing these methods, as noted in Table 4. Several methods are considered to be representatives of more than one of the categories as HRA, HEI, or accident analysis. This complicates the manner of selection of a particular method. While some studies describe the differences between methods within their specific area of HRA, HEI, or accident analysis (Kirwan, 1992b; Hollnagel and Speziali, 2008; Bell and Holroyd, 2009), others may compare and contrast these methods across the areas. Most of the methods in Table 4 appear in only one of the three categories. However, several methods are listed in two of

Table 4. List of various techniques associated in the literature under the categories of human reliability assessment, human error identification, or accident analysis methods (Kirwan, 1992b; Hollnagel, 1996; Kirwan, 1997; Rantanen et al., 2006; Hollnagel and Speziali, 2008; Bell and Holroyd, 2009; Doytchev and Szwillus, 2009; Cheng et al., 2013; Underwood and Waterson, 2013a, Underwood and Waterson, 2013b; Alvarenga et al., 2014; Cheng and Hwang, 2015; Akyuz, 2015; Akyuz and Celik, 2015a; Akyuz and Celik, 2015b; Ung, 2015; Akyuz et al., 2016; Akyuz and Celik, 2016; Bowo et al., 2017; Islam et al., 2017; Kim et al., 2017; Calvo Olivares et al., 2018; Grant et al., 2018; Ung, 2018).

Human Reliability Analysis	Human Error Identification	Accident Analysis
AcciMap	ATHEANA	AcciMap
AIPA	CADA	AEB
APJ	CBDTM	ANP
ASEP	CES	BA
ATHEANA	CREAM	CA
CAHR	FMEA	Critical Path
CARA	GEMS	CREAM
CES	HAZOP	Drift into Failure Model
CESA	HEART	Domino Model
CODA	HEIST	ECFC
COGENT	HERA	ECFCA
CREAM	HET	ETA
FRAM	HFACS	Five Whys
HCR	HRMS	FRAM
HEART	IMAS	FTA
HRMS	K-HRA	HERA
IDAC	NARA	HFACS
IDHEAS	PHECA	HFIT
INTENT	SHERPA	HPES
JHEDI	SLIM	MTO
MERMOS	SLIM-MAUD	Normal Accident Theory
NARA	SPAR-H	PEAT
OATS	SRK	RCA
PC	THERP	Risk Management Framework
RARA	TRACEr	SCAT
SLIM		STAMP
SLIM-MAUD		STEP
SMoC		Swiss Cheese Model
SPAR-H		TRACEr
STAMP		
TESEO		
THERP		

the categories. CREAM is a recognized method appearing in the literature as an appropriate technique for HRA, HEI, and accident analysis. This apparent dilemma is a reminder of Singleton's (1972) comments regarding the classification of methods used to evaluate human error. As Bell and Holroyd (2009) pointed out, several of the HRA methods were devised specifically for the nuclear power industry and may not be adaptable for other applications or may not be publicly available. This statement can be generalized to stipulate that the modification of any HRA, HEI, or accident analysis methods for an application other than what it was developed for may not be successful. This is the first consideration in the method selection process.

Despite the extensive use and dependency on maritime commerce, available statistics to support human error probability calculations are generally lacking. Kirwan (1997) describes human error probability as the ratio of error observations compared to error opportunities. Ung (2018) identified the challenge of quantifying human error analysis due to the extreme absence of necessary data associated with maritime accidents. The National Research Council (1991) discussed the inherent data challenges in the commercial fishing industry. Issues that contribute to the less than optimal data include accident reporting rates, accident investigation thoroughness, unclear national and state accident reporting and vessel registration requirements, full time and part-time employment, and a lack of insurance covering vessels and employees. These statistical issues indicate that quantitative HRA and HEI methods may be difficult to substantiate for use in the study of human error in the maritime transportation and specifically the commercial fishing domain. This is the second consideration in the method selection process.

Recalling the works of Perrow (1984), Hollnagel and Speziali (2008), and Underwood and Waterson (2013a) is beneficial to the selection of an appropriate human error analysis method for the current study. The accident analysis technique for a specific industry should be applied appropriately for an effective examination of an accident and future prevention efforts. Maritime transportation is identified in quadrant one indicating tight coupling and linear interactions. Hollnagel and Speziali (2008) and Underwood and Waterson (2013a) proposed that epidemiological techniques such as the Swiss cheese model and HFACS are best suited for quadrant one activities due to the influence of active and latent causal factors involved in these accidents. This is the third consideration in the method selection process. Combining these three considerations provides the ideal way to proceed. The elimination of those techniques not adaptable for maritime transportation and those techniques which include quantification, together with Hollnagel and Speziali's (2008) implementation of Perrow's (1984) interactions/coupling, indicates that the Swiss cheese model and HFACS are best suited for this study.

CHAPTER 3

Human Factors Analysis and Classification System (HFACS)

3.1 Reason's Swiss cheese model

Reason (1990, 1997, 2000, and 2003) argued that the causes of accidents attributed to human error are the result of latent failures and active failures. Latent failures are those often hidden conditions that present the real risk for accidents. These latent failures are generally due to priorities, culture, procedures, and decisions within an organization that may have been in place for a considerable time before the accident occurred. Latent failures are built into the system either intentionally or inadvertently. They may have been present in the system for days or decades. They may represent a disguised hazard that was never envisioned to cause an accident or one that was not thoroughly evaluated as a potential risk. While active failures may serve the final initiating event for accidents due to some error in judgment or decision making on the part of the operator and may be listed as the cause of the accident, the latent failures are generally more to blame. Operators may be the final link of an accident chain, but as Reason (1990) notes:

> Rather than being the main instigators of an accident, operators tend to be inheritors of system defects created by poor design, incorrect installation, faulty maintenance, and bad management decisions. Their part is usually that of adding the final garnish to a lethal brew whose ingredients have already been long in the cooking (p. 173).

These active and latent failures are evident in the groupings of organizational factors, supervisory factors, preconditions for the unsafe act, and unsafe acts. Causal factors associated with organizational influences, unsafe supervision, and preconditions for unsafe acts are latent failures. Those related to unsafe acts are active failures (Reason, 1990; Akyuz et al., 2016; Cohen, 2017). Reason's (1990, 1997) Swiss cheese model is shown in Figure 4.

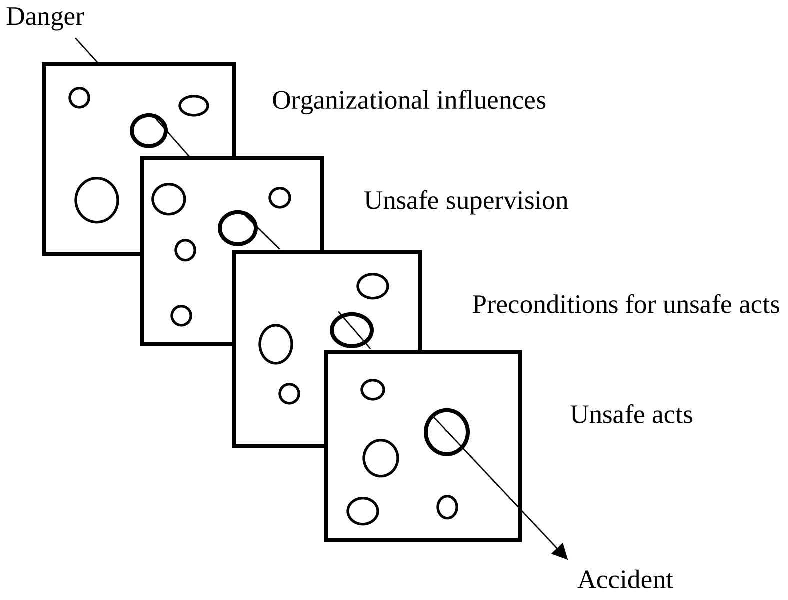

Figure 4. Swiss cheese model showing the role of layered defenses that cause or prevent accidents. Adapted from Reason (1990, 1997).

Human error is commonly expressed as having a sharp or pointy end and a blunt end. The sharp end represents the operator, whether it is a ship's captain, pilot, physician, or others, as an active failure. The blunt end represents latent failures and refers to the organization, administration, suppliers, or regulators (Reason, 1990). Rasmussen (1990) wrote that accidents are generally not due to some intentionally improper decision but through some breakdown in the system, which caused a loss of control or a flawed decision by the operator. The Swiss cheese model provides the foundation for HFACS.

3.2 HFACS development

The Human Factors Analysis and Classification System (HFACS) model was created to understand the causes of naval aviation accidents (Shappell and Wiegmann, 2001). The factors that contribute to these accidents, often occurring at high speed with significant personnel and mission impact, were critical in determining how to avoid repeating known and tragic circumstances. The HFACS shows the importance of human factors on these accidents and makes corrective actions more likely. For the proper application of HFACS, a detailed investigation and database are necessary to correctly document all causal factors, including human error in an accident. Historically, accident investigations focused on the last actions of the operator or the final minutes before the accident without examining and categorizing all of the organizational, supervisory, and pre-conditional factors that put the operator in the position for the accident to occur (Dekker, 2006). While organizations and management will tend to blame the operators for accidents, Dekker (2017) disputes that in the following:

> Its four basic assumptions were that people have a clearly defined utility function that allows them to index alternatives, according to their desirability, that they have an exhaustive view of decision alternatives, that they can foresee the probability of each alternative scenario, and that they can choose among these to achieve the highest subjective utility (p. 554).

Where aviation has rapidly and dramatically changed its technology and its importance in society during the last century, maritime transportation has existed for millennia but has not experienced the same rapid innovation as aviation. The maritime sector is comprised of numerous vessel types based on the commodity they carry and the waters they need to transit for the delivery of the product. Vessels often operate in challenging environments and weather conditions. Their size, function, and capabilities all contribute to how they successfully interact with each other. In addition, although 90% of worldwide trade is carried by commercial vessels (Sulaiman et al., 2011), maritime accidents generally tend to lack the ability to capture public interest and are seen as less newsworthy than aviation accidents as presented in Table 5. Maritime applications of HFACS show considerable potential to prevent accidents that result in loss of life and property.

Table 5: Top ten aviation and maritime disasters since 1900 not caused by terrorism or military conflict (Watson, 1995; Chiles, 2002; Republic of Senegal, 2002; Panama Maritime Authority, 2006; Pike, 2008; Eyers, 2013; Gero, 2017).

Aviation accidents	Fatalities	Maritime accidents	Fatalities
Canary Islands runway collision (1977)	583	*Doña Paz* collision and sinking (1987)	4386
Japan Airlines flight 123 crash (1985)	520	*Mont-Blanc* collision and explosion (1917)	2000 (estimated)
Mid-air collision near Charkhi Dadri (1996)	349	*LeJoola* capsizing (2002)	1863
Turkish Airlines flight 981 crash (1974)	346	*Titanic* iceberg collision and sinking (1912)	1513
Saudi Arabian flight 163 runway fire (1980)	301	*Taiping* collision and sinking (1949)	1500 (estimated)
Iranian military flight crash (2003)	275	*Salem Express* grounding and sinking (1991)	1400 (estimated)
American Airlines flight 191 crash (1979)	273	*Toyu Maru* sinking (1954)	1153 (estimated)
American Airlines flight 587 crash (2001)	265	*Al Salam Boccaccio 98* sinking (2006)	1031
China Airlines flight 140 crash (1994)	264	*Empress of Ireland* collision and sinking (1914)	1012
Nigeria Airways flight 2120 crash (1991)	261	*General Slocum* fire and sinking (1904)	1000 (estimated)

Wiegmann and Shappell (2003) used the four tiers suggested by Reason (1990, 1997) of organizational influences, unsafe supervision, preconditions for unsafe acts, and unsafe acts as the basis for HFACS. Then they expanded the tiers into categories and subcategories that were based on six psychological theories of human error that contributed to HFACS (Wiegmann and Shappell, 2003): cognitive, ergonomic, behavioral, aeromedical, psychosocial, and organizational. The cognitive perspective refers to how the operator processes the information as part of a stimulus/response or input/output. Rasmussen (1983) and Wickens and Flach (1988) describe a process where stimuli are received, mentally processed and evaluated for the assessment and recognition of a known pattern to form a decision and finally lead to a response or action taken. The ergonomic perspective has to do with the human, machine, and environment interface. Edwards' (1988) SHEL model is a systems-based approach to coordinate software, hardware, environment, and liveware for effective design and operation. The behavioral perspective is related to the motivation and punishment or reward system of the operator. Peterson (1971) and Skinner (1974) theorized that performance is optimized through proper motivation, rewards, and satisfaction. The aeromedical perspective considers the medical and psychological condition of the operator that may have contributed to the accident. Though initially envisioned for aviation, Wiegmann and Shappell's (2003) explanation of the aeromedical perspective is relevant to all accident types where non-optimal physical or mental conditions may contribute to operator error. The psychosocial perspective examines the interactions between the various members associated with the operation. For example, in maritime applications, the different crew positions, port and facility support services, shoreside maintenance contractors, and others all contribute to the safe operation of the vessel. The organizational perspective models accidents as an uninterrupted succession of factors and incidents that the various management levels must identify and control. The domino theories of accident causation, originally proposed by Heinrich (1931) and modified by Bird (1974), refer to a progression of factors that lead to incidents. Heinrich's (1931) model included: ancestry and

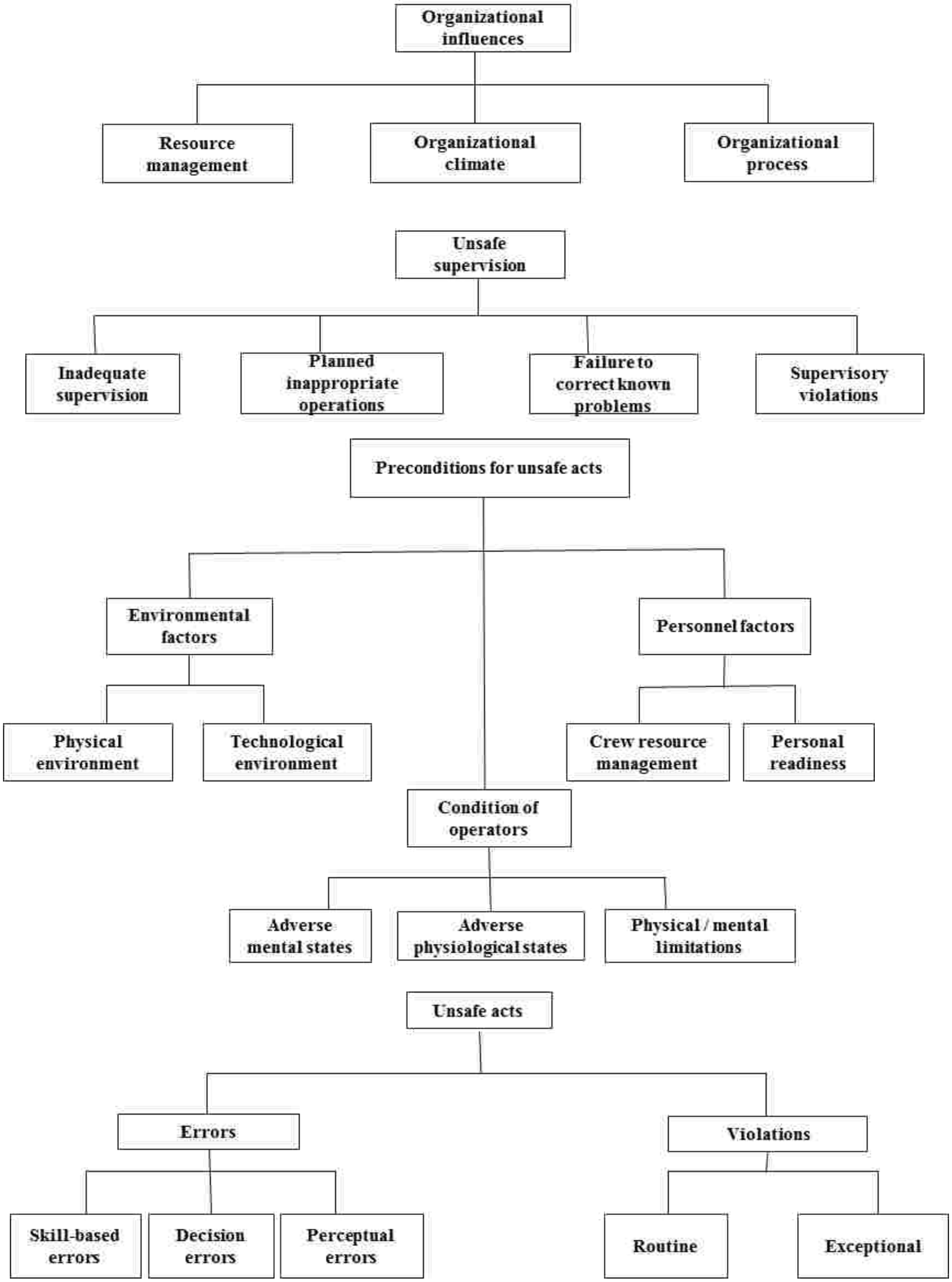

Figure 5. The Human Factors Analysis and Classification System. Adapted from Wiegmann and Shappell (2003).

social environment, fault of the person, unsafe act and mechanical or physical hazard, accident, and resulting injuries. Bird (1974) discussed failures within the organization in the factors of safety/loss of control, basic causes, intermediate causes, accident, and resulting injuries.

3.3 HFACS model

The HFACS model is comprised of tiers, categories, and subcategories, as shown in Figure 5 and briefly described in Table 6. The highest tier in HFACS is organizational influences (Wiegmann and Shappell, 2003). In both large and small organizations, upper management has specific policies and expectations for work processes and logistical support for the organization. In addition to written procedures, there may be an unwritten manner of doing business. Although top management may feel they are not responsible when an accident occurs with one of their assets, that may be removed from them geographically or administratively, these organizational factors and subfactors are likely to have some influence on the accident. Corporately, a mindset regarding safety is established, either directly or inferentially. This mindset may also be concluded from maintenance and acquisition budgets or the tolerated safety risks that are taken to remain profitable. Funding for repair, maintenance, or acquiring a new asset represents a commitment by the organization to reliable and safe equipment that will maximize operations and minimize accidents. In the absence of specific guidance provided by the organization, operators may make decisions based on their opinions of corporate strategy and culture. A recent example of an accident that occurred due to latent organizational influences demonstrates the dangers associated with confined space entry. A crewmember was killed, and two others were injured, after entering an empty refrigerated saltwater tank that was nearly

Table 6. HFACS category descriptions. Adapted from Wiegmann and Shappell (2003) and Shappell et al. (2007).

Organizational influences	
	Resource management: Acquisition, allocation, and utilization of equipment and personnel
	Organizational climate: Informal, often undocumented, but reality-based considerations of how decisions are made and how operations are conducted
	Organizational process: Documented procedures of operations, risk, and quality management oversight
Unsafe Supervision	
	Inadequate supervision: Management to ensure technical and professional personnel and equipment readiness for operations
	Planned inappropriate operations: Assessment of mission to ensure success considering risk factors, personnel assignment, and equipment limitations
	Failure to correct known problems: Operational authorization despite previously identified unresolved personnel and equipment shortcomings
	Supervisory violations: Intentional non-compliance of management overseeing operation with applicable standards and procedures
Preconditions for unsafe acts	
Environmental factors	Physical environment: Natural and atmospheric conditions and their impact on the operator
	Technological environment: Design, installation, and function of equipment and its interaction with operators
Condition of operators	Adverse mental states: Psychological or cognitive impairment that impacts operator performance
	Adverse physiological states: Medical or physical impairment that impacts operator performance
	Physical/mental limitations: Medical or cognitive obstacles or restrictions that impact the operators' abilities and mission performance
Personnel factors	Crew resource management: Ineffective interactions between crew members and their impact on operations
	Personnel readiness: Lack of preparedness for operation due to inattention to standard off-duty protocol
Unsafe acts	
Errors	Skill-based errors: Faulty actions based on inattention to a process or technique
	Decision errors: Intentional actions inappropriate for the situation due to poor choices
	Perceptual errors: Improper actions based on defective sensory input and evaluation
Violations	Routine: Deliberate actions that may be common practice and viewed as relatively minor but are against standard procedures
	Exceptional: Deliberate atypical actions that are a substantial deviation from standard procedures

depleted of all oxygen on the fishing vessel *Sunbeam* during a maintenance period (Marine Accident Investigations Branch, 2018a). While factors from other HFACS tiers contributed to this accident as well, the lack of procedures for this risky operation, the lack of equipment and professional services necessary to ensure safe entry into the tank, and the culture to proceed without assessing all of the threats all show a lack of organizational involvement in this case.

Unsafe supervision is the second tier in the HFACS model and occurs at a level above the operator, where decisions could be made to assist the operator or terminate the operation altogether (Wiegmann and Shappell, 2003). Inadequate supervision also includes items such as failure to provide proper training and failure to ensure sufficient rest for the operators. Examples of planned inappropriate operations also include proper crew selection. Failure to correct a known problem can also be seen in knowingly operating a vessel with a leaking hull or inadequate fire protection. It may also be observed by not learning from or documenting near misses or unsafe tendencies. Unsafe supervision has active and passive components. Supervisors have a responsibility for the operations being conducted with matters in their purview that are directly evident as well as those that may require some degree of analysis. Regardless, a supervisor's communication, or lack thereof, further impacts the operator’s decisions and actions. A fatal fishing vessel accident illustrates unsafe supervision. A crewmember was killed aboard the fishing vessel *Enterprise* when his leg was caught in a rope while the fishing gear was being set. He was dragged overboard, pulled underwater, and drowned (Marine Accident Investigations Branch, 2018b). Among the HFACS factors concluded from the investigation were the unsafe supervision categories of inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations. In this case, the supervisor failed to ensure that the crewmember stayed in the designated safe location on the main deck while the fishing gear was being set. In addition, there was a failure to correct a known problem since the deceased crewmember had done this previously despite warnings from other crewmembers.

The preconditions of unsafe acts level examine the operator's background conditions that may influence unsafe acts (Wiegmann and Shappell, 2003). The physical environment refers to weather conditions, time of day (including nighttime or sun glare). The technological environment considers ergonomic concerns and the ease of using controls. The condition of operators includes physiological and psychological factors in accidents. Adverse mental states include many factors that lead to a loss of concentration, whether due to stress, distraction, and complacency, among others. Adverse physiological states consider illness, fatigue, prescription medication, as well as others. Physical/mental limitations may address a lack of operator experience that may cause an operator to be overwhelmed and can also address limited reaction time due to visibility factors. Personnel factors include crew resource management and personnel readiness factors. Crew resource management considers a variety of factors, including poor communications within the operational team as well as a lack of teamwork. Personal readiness covers poor physical preparation, including improper rest and inadequate nutrition. A recent accident occurred and was investigated that highlights the category of personnel factors. A crew of 44 was forced to abandon the fishing vessel *American Eagle* after a fire started due to oxy-acetylene cutting operations to replace a valve. Although no injuries were reported, firefighting efforts were negatively impacted due to a lack of a common language of the crewmembers from seven countries (National Transportation Safety Board, 2017). This communication problem emphasized the importance of team coordination in an emergency. This situation also exposes the supervisory issue regarding crew selection.

The final tier of HFACS is unsafe acts (Wiegmann and Shappell, 2003). Errors are operational breakdowns that may still be within organizational rules and procedures. Violations indicate a disregard for these rules. Skill-based errors may include missed checklist items, missed procedures, or improper actions. Decision errors may be honest mistakes or cases where the operator did not have sufficient experience for the conditions encountered. Perceptual errors consider illusions, disorientation, or judgment errors affecting distance, speed, and other operational characteristics. Routine violations may indicate a regular practice of not following the rules that were thought inconsequential. Exceptional violations include severe departures from accepted standards, including exceeding safe operational parameters and intentional dangerous operations. Skill-based errors, decision errors, and perception errors all contributed to a collision between the motor vessel *Jag Amov* and the motor vessel *Total Response* that occurred off of the coast of Australia when both vessels failed to maintain a proper lookout (Australian Transport Safety Bureau, 2018). Furthermore, crewmembers failed to use the information from their electronic navigational equipment, and the mate on watch on the *Jag Amov* improperly assessed the situation and failed to take avoidance actions after concluding that they would not collide with the *Total Response*.

3.4 HFACS application

Previous analysis of maritime accident investigations using HFACS generally focused on specific incidents or accident types but employed a variety of analysis methods. Celik and Cebi (2008) applied HFACS in conjunction with a fuzzy analytic process to study the role of human factors in a boiler explosion. This study was conducted on a dry bulk carrier and produced weighted contributing factors of the accident. Schröder-Hinrichs et al. (2011) examined human error in 41 machinery space fires using an adapted HFACS model. This study focused on causal organizational factors and utilized an additional tier for outside factors. Chauvin et al. (2013) addressed the HFACS framework tailored to ship collision accident investigations. They also considered a fifth tier of outside factors in this HFACS adaptation. Akhtar and Utne (2013) combined HFACS and the risk associated with ship groundings. Data were collected from 93 ship groundings and specifically explored the link between crew fatigue and groundings. Chen et al. (2013) proposed an HFACS–Maritime Accidents (MA) model in their review of the *Herald of Free Enterprise* accident. This study concentrated its analysis on human and organizational factors of this maritime tragedy. Mazaheri et al. (2015) created HFACS–Ground in their review of accident investigations of ship groundings. Their examination combined human error and risk analysis. Soner et al. (2015) used an HFACS and a fuzzy cognitive mapping approach to identify the causes of fire safety issues. This HFACS modification analyzed fire safety deficiencies to improve prevention efforts. Ozdemir et al. (2015) employed HFACS and multiple criteria decision-making to study human error in maritime accidents. Their resulting analysis identified and ranked the contributing factors in the maritime accidents they considered. Zhang et al. (2016) focused on collisions between ships as they examined HFACS data with a risk analysis model. This study used interval probability and Bayesian network modeling to evaluate the accident data. Akyuz (2016) proposed a model to assess HFACS with the analytic network process in the investigation of a liquefied petroleum gas leak aboard a liquefied gas carrier. The resulting model produced weighted causal factors of the accident. Yildirim (2017) applied the HFACS-MA framework with chi-square and correspondence analysis to examine ship collisions and groundings. This study utilized data from specific accident types to generalize the human error analysis for all types of maritime accidents.

These studies offer valuable tools, processes, and analyses to investigate serious casualties on oceangoing international tank ships and freight ships. Oceangoing ships, subject to international Safety of Life at Sea (SOLAS) requirements, classification society standards, and the various national regulations of every country they visit, generally have robust corporations to deal with these complexities. These corporations know that to be successful and profitable businesses they must hire a workforce that is able to satisfy all portions of maritime operations management. That includes providing crews for their ships that have appropriate documentation attesting to their compliance with the International Maritime Organization’s convention on Standards of Training, Certification, and Watchkeeping (STCW). These professional requirements ensure consistent levels of competence covering all mandatory shipboard positions as described by Chauvin et al. (2013). The International Safety Management (ISM) Code is another example of maritime requirements that a shipping company must support within their organization. The ISM Code is a quality management system where the company’s leadership provides expectations for organizational responsibility, personnel support, and the operation and maintenance of ships as noted by Batalen and Sydnes (2014). If implemented correctly, the company’s safety management system should address many of the categories within HFACS.

Commercial fishing vessels, on the other hand, usually do not have the same level of organizational support. STCW and ISM represent two major guidelines that took effect in 1998 that are applicable to oceangoing commercial ships (Chauvin et al., 2013) but generally not to commercial fishing vessels. The need for personnel qualification and safety management systems were noted by the National Research Council (1991) and NIOSH (1994) and constitute vulnerabilities that still exist. These two areas are challenging to most commercial fishing companies that do not have the financial resources to hire personnel to address them voluntarily. However, as Chauvin et al. (2013) expressed, the organizational and human factors that they represent pose significant hazards to their vessels’ operations.

The actual distribution of human factors contributing to commercial fishing vessel accidents will be unique and not previously documented in the research. The resulting HFACS adaptation will be generalizable to all maritime accidents but should be especially valuable to commercial maritime accidents involving small business operations.

3.5 Commercial fishing vessel safety

Safety issues have always been present in the commercial fishing industry. Junger (1997) wrote that approximately 10,000 commercial fishermen have died since 1650 from Gloucester, Massachusetts, the renowned center of the fishing industry in New England. The historic fishing industry did not have the technological tools that are available in the present day. The vessels were more susceptible to flooding and sinking, long-range weather forecasting was an unimaginable concept, and the setting and retrieving of fishing gear was done by hand. The harvests of cod and mackerel were plentiful and ensured the continuity of the industry despite the inherent safety risks and the recognized loss of life in the community (Junger, 1997).

Safety considerations in the fishing industry today are divided into the components of the vessel, the crew, and external factors (National Research Council, 1991). The vessel category includes how a ship is built, maintained, and equipped. Crew factors include the competencies of the mariners to navigate and operate the vessel and the skills needed for their fishery. External factors consider wide-ranging topics covering regulatory compliance, including management of the fishery, business economics of bringing the catch to market, and environmental conditions such as weather and sea state.

The design of a fishing vessel is directly related to the type of aquatic species being harvested. In turn, this species will determine where the vessel will operate and what equipment is necessary for the fishery (U.S. Department of Commerce, 2016; Alaska Department of Fish and Game Division of Commercial Fisheries, 2005). Fishery operations conducted on inland sounds and bays generally utilize smaller vessels with smaller crews. Fisheries conducted offshore have larger boats and larger crews (U.S. Coast Guard, 2008). It is essential to understand the financial implications of vessel design, maintenance, and outfitting. As with any business, funding priorities influence many decisions. Decisions regarding the expected useful life of a vessel, maintenance frequency, and the state and age of the technology utilized in the fishery represent business risk variables that may be evaluated differently based on their attitudes as risk-averse, risk-neutral, or risk-seeking (Pinto and Garvey, 2013). Greenlaw (1999) described a regimen of regular engine maintenance to minimize costly, unplanned repairs. Conversely, Wang et al. (2005) concluded that many fishing vessel accidents showed very minimal maintenance which was directly related to mechanical failures.

The equipment related to the fishery harvest is a significant safety hazard to crew members on a commercial fishing vessel. Accidents involving rotating winches and heavy loads, throwing gear over the side of the boat and retrieving it, or being struck by any moving object or apparatus are among some of the ways that deck machinery represents a considerable hazard for the crew. The extent to which the vessel is equipped with the most technologically available protective devices, including remote stops and machinery guards, is another factor to consider (Jaleel and Grewal, 2017).

The crew aboard fishing vessels faces numerous hazards. Greenlaw (1999) described the fatiguing schedule of a long-liner sword fishing voyage with an average of three to four hours of sleep per night after each physically grueling workday. This schedule could last for two weeks or two months until the fish hold was full. The work requires concentration in the midst of repetitive motions and actions while working on slippery decks in various weather and ocean conditions (U.S. Bureau of Labor Statistics, 2012). Injuries due to fishing hooks and gaffs or landed fish before they are safely stowed in the fish hold, represent common hazards that after a long day of work and without a trained medical professional aboard, can quickly become life-threatening (Junger, 1997; Greenlaw, 1999).

External factors, though possibly viewed as less important than the vessel or the crew with regard to safety, play an important role in fishing vessel accidents. The goal of commercial fishing, like any business, is to make a profit. Receiving a high price for the catch onboard the boat is dependent upon the size of the catch and its price per pound. The price per pound depends on the supply of the catch in the marketplace and consumer demand. As Greenlaw (1999) wrote, a fishing trip that produced a large amount of fish could show a disappointing profit due to a low market price. The commercial fishing industry aims to get a catch to market as soon as possible, not only for maximum freshness but to beat competitors for a better market price (Junger, 1997; National Research Council, 1991).

Another significant external safety factor is fishery management. Fishery management is closely related to the business side of fishing and is meant to promote conservation by preventing overfishing of a species (National Research Council, 1991). The fishing industry, in an effort to maximize profits while minimizing expenses, found it advantageous to fish in one location, preferably close to the home port, to catch as many fish as possible and get them quickly to market. The resulting problem is taking more fish than can be replenished naturally. Fishery management can cover who can catch the fish, what species they can catch, where they can catch the fish, when they can catch the fish, how they can catch the fish, and why these efforts are necessary (National Research Council, 1991; Junger, 1997; U.S. Department of Health and Human Services, 1994). The Magnuson Fishery Conservation and Management Act of 1976 established national sovereignty over aquatic species within 200 miles of the coasts of the United States. The intent was to limit foreign fishing vessels from operating and harvesting fish adjacent to the United States' shoreline. The act also provides for regional fisheries management councils (Junger, 1997). Fishery management is not a popular topic in the commercial fishing industry. While preserving or rebuilding fish stocks, fishery management may mean that vessel crews need to travel further to catch their fish or be time-constrained within a fishery area with the unintended consequence of safety risks due to exposure to poor weather conditions (National Research Council, 1991; U.S. Department of Health and Human Services, 1994; Jin et al., 2001). These decisions made by regulators or other external parties can impact the safety of fishing vessels.

3.6 Conclusion

HFACS progressive application, from its initial development as a tool to analyze military aviation accidents, through various other commercial and military transportation segments, as well as industrial and healthcare settings, demonstrates its robust design and flexibility. Modifying HFACS for the commercial fishing industry must incorporate organizations of all sizes where frequently crewmembers are "self-employed" and work for shares of the profit (Drudi, 1998; Greenlaw, 1999; Lincoln, 2006). In a competitive and dangerous industry that minimizes organizational overhead, the obstacles of hiring and retaining competent and capable personnel as well as a systematic method for companies to assess and respond to operational risks and hazards will need to be considered and reflected in this new model. Table 7 shows a comparison between Wiegmann and Shappell's (2003) model and the HFACS-Fishing Vessel (FV) showing tiers, categories, and subcategories that will be discussed in more depth in the next chapter. Tiers are noted in bold font, categories are in normal font, and subcategories are in italics.

Table 7: Comparison between Wiegmann and Shappell's (2003) model and the HFACS-FV.

Wiegmann and Shappell (2003)	HFACS-FV
Organizational influences	**Organizational influences**
Resource management	Resource management
	Human resources
	Equipment acquisition and support
Organizational climate	Climate
	Structure
	Safety culture
Organizational process	Process
	Procedures
	Risk/systems management
Unsafe supervision	**Unsafe management**
Inadequate supervision	Poor supervision
	Technical readiness of crew
	Supervisory competency
Planned inappropriate operations	Improper operational risk assessment
Failure to correct known problems	Allowing unsafe operations
Supervisory violations	Supervisory violations
Preconditions for unsafe acts	**Preconditions for unsafe acts**
Environmental factors	Environmental factors
Physical environment	*Physical environment*
Technological environment	*Technological environment*
Condition of operators	Crew condition
Adverse mental states	*Mental readiness*
Adverse physiological states	*Physical readiness*
Physical/mental limitations	
Personnel factors	Personnel factors
Crew resource management	*Crew communication*
Personal readiness	*Personal readiness*
Unsafe acts	**Unsafe acts**
Errors	Errors
Skill-based errors	*Skill-based errors*
Decision errors	*Decision errors*
Perceptual errors	*Perceptual errors*
Violations	Violation
Routine	*Routine*
Exceptional	*Exceptional*

CHAPTER 4

METHODOLOGY

4.1 Overview

This chapter will detail the modification of the HFACS model for fishing vessel accidents, the data that will be considered for this study, and how raters will employ the modified HFACS version using this data. The stepwise research methodology is enumerated here as well as shown in Figure 6.

1. Review existing HFACS model and identify which categories need to be updated to reflect organizations and operations on commercial fishing industry vessels. Make initial modifications to create HFACS-FV.
2. Identify an appropriate fishing vessel accident data set. Evaluate HFACS-FV with a subset of data of ten cases to confirm that the modified HFACS version adequately represents and categorizes investigation information.
3. Execute the HFACS-FV version, after selecting and training multiple raters, to code the entire fishing vessel accident data set.
4. Evaluate the suitability of the HFACS-FV model through a variety of reliability measures in response to Question 1.
5. Perform quantitative analysis of the output data to identify the most common causal factors for mitigation strategies in response to Questions 2 through 5.

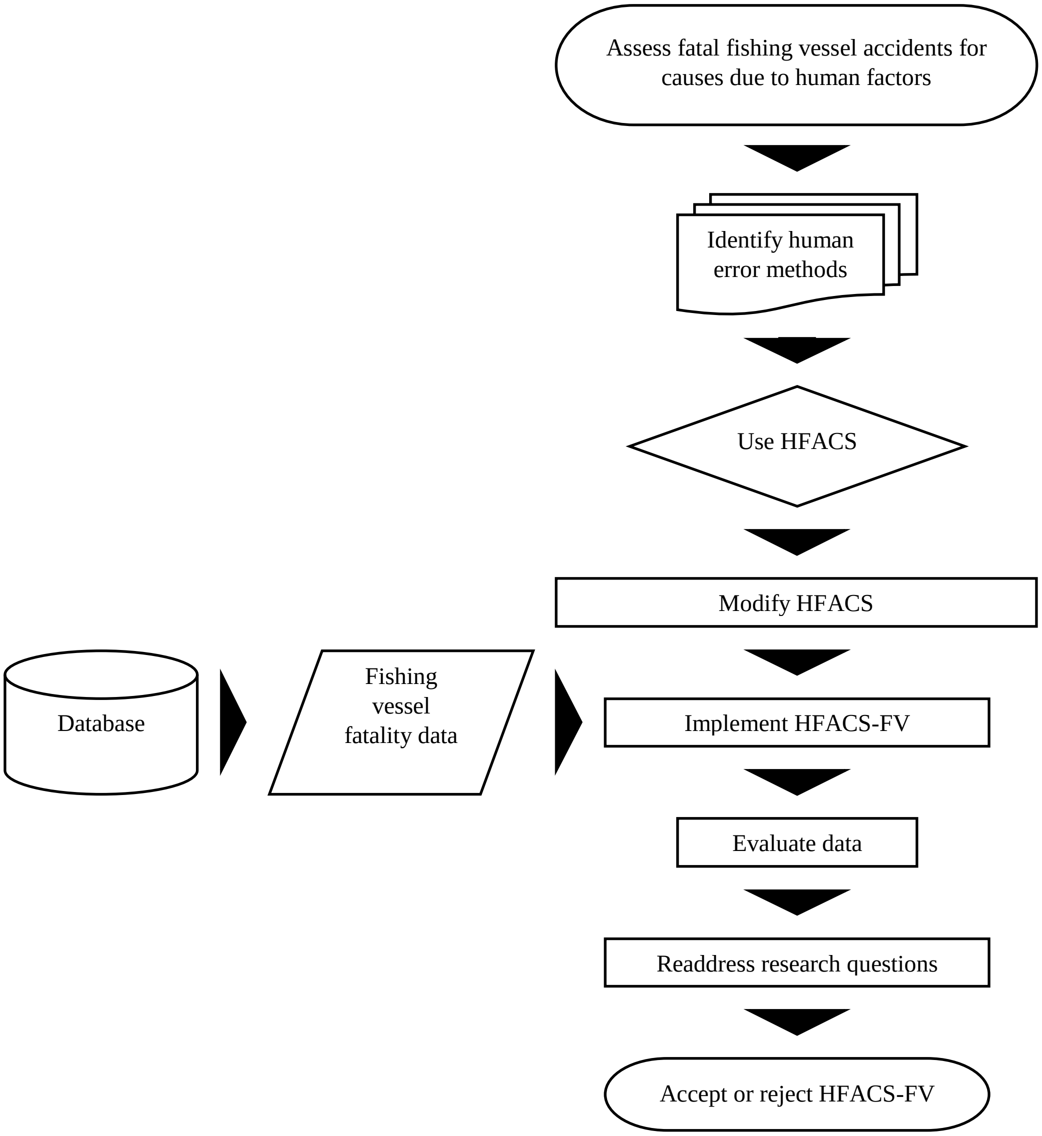

Figure 6: Procedural framework of the study.

4.2 Modify HFACS

Wiegmann and Shappell's (2003) HFACS model has been modified and adapted for various applications. Numerous versions have been developed for a specific industry or specific accident type, as shown in Table 8. These model adjustments were meant to provide insight for researchers into particular work areas and allow for more relevant data collection and evaluation that would produce more direct areas of emphasis to prevent future accidents. They all offer alterations to Wiegmann and Shappell's (2001) model initially developed for naval aviation accidents.

Table 8. Named HFACS variation examples.

HFACS version	Application	Developer
HFACS-ATC	Air traffic control accidents	Scarborough and Ponds, 2001
HFACS-ME	Helicopter maintenance error	Krulak, 2004
DoD HFACS	U.S. Department of Defense mishaps	U.S. Department of Defense, 2005
HFACS-RR	Railroad accidents	Reinach and Viale, 2006
HFACS-ADF	Australian Defense Force aviation safety	Australia Government Department of Defense, 2008
HFACS-MI	Mining accidents	Patterson and Shappell, 2010
HFACS-MSS	Maritime machinery space fire and explosion	Schröder-Hinrichs et al., 2011
HFACS-Coll	Maritime collisions	Chauvin et al., 2013
HFACS-MA	Maritime accidents	Chen et al., 2013
HFACS-Ground	Maritime groundings	Mazaheri et al., 2015
HFACS-FCM	Maritime fire prevention	Soner et al., 2015
HFACS-Healthcare	Surgery-related incidents	Cohen et al., 2018

The commercial fishing industry offers a challenge where the tiers of organizational influence and unsafe supervision can vary substantially due to the size of the company. That does not make these divisions less important but requires thoughtful consideration to address this distinction and accurately classify causal factors. An evaluation of fatal fishing vessel accidents in the United States from 1992-2007 concluded that 55% of all deaths were caused by flooding, sinking, or capsizing. Also, most of the deaths occurred while the vessels were transiting either from a port or back to port rather than during fishing operations (U.S. Coast Guard, 2008).

These statistics indicate that underlying hull integrity issues contributed significantly to these fatalities. These latent factors suggest a lack of maintenance, a failure to adequately monitor flooding concerns with the hull and piping systems connected to the hull, or ignoring conditions previously identified without completing effective repairs. These conditions also imply of lack of financial support from the company. Except for major corporations involved in the commercial fishing industry, the majority of companies have substantially fewer employees with less defined organizational procedures and documented policies and procedures. HFACS-FV, the HFACS model customized for fishing vessel accidents, is meant to identify the inherent differences of the commercial fishing industry and its workforce with its unique characteristics.

HFACS-FV addresses hazards specific to commercial fishing. The National Research Council (1991) detailed human factor threats in the industry including: the lack of any professional crew certification prior to hiring, the lack of any assessment of physical well-being prior to hiring, the lack of professional standards for operating the vessel and fishing gear, the absence of human factors consideration in the design and operation of the vessel and fishing apparatus, the lack of standardized safety systems, the nearly constant dangers associated with vessel and fishing operations, excessive work hours in all weather and sea conditions, and the enormous economic pressures that drive daily operations. These threats are reflected in modifications to several HFACS categories and subcategories. Changes within HFACS-FV were made in the following headings: equipment acquisition and support, safety culture, risk/systems management, technical readiness of the crew, allowing unsafe operations, mental readiness, and physical readiness.

Equipment acquisition and support is a subcategory under the operational influences tier. As previously discussed, organizations within the commercial fishing industry vary considerably.

Commercial fishing organizations are generally smaller and more compressed in their structure than other transportation or industrial applications. This means that multiple organization responsibilities may be assigned to one person. In a small organization, where economic pressures may not be able to be spread to other vessels, resources, or assets, the decision to support new vessels or new equipment or scheduled maintenance represents substantial financial expenditures that must be weighed against the likelihood that hazards or delayed operations would be encountered. The reliability of a fishing boat to transit to and from the fishing grounds and effectively harvest fish is paramount to any fishing organization. The recognition of a preventative maintenance schedule acknowledges the time and money spent before an accident or mishap occurs ensures a safer vessel with minimal operational delays (Marine Accident Investigation Branch, 2008). It also helps to provide an opportunity to address modifications that can result in dangerous loading conditions (National Research Council, 1991). These maintenance priorities also must address the life cycle of the vessel or its equipment to determine when it is no longer economically feasible to support and when replacement is necessary.

Safety culture is another subcategory in HFACS-FV under the organizational influences tier. Essentially, robust or effective safety culture is how management prioritizes safety in comparison to operations and economic influences (Jaleel and Grewal, 2017; Marine Accident Investigation Branch, 2008). The attitudes of management, either communicated directly or understood indirectly, reveal their expectations, and are interpreted by the workers by how they perform their jobs. Marine Accident Investigation Branch (2008) has documented that management's positive concerns for the safety of their crews result in more responsible operations and actions. This is necessary since many fishing industry personnel are generally not supported with health insurance, work hour monitoring, or onboard medical assistance except in life-threatening situations (National Research Council, 1991). Håvold (2010) noted that commitment to a positive safety culture by management can be observed by the orientation that new crew members receive detailing the company's values.

The subcategory of risk/systems management, also under the organizational influence tier, refers to the establishment of management procedures in the same manner that operational procedures exist. It is the recognition that risks must be acknowledged and minimized before they impact productivity and profit. Marine Accident Investigation Branch (2008) observed the considerable effect that financial matters had on commercial fishing, and management's commitment to safety offered long term benefits as opposed to unplanned and preventable mechanical failures and injuries. Håvold (2010) proposed that the contentment of commercial fishing personnel produced a higher standard of job performance and ultimately led to safer operations. Further, Håvold (2010) wrote that the most important influence on a safety management plan is the attitude that management portrayed with respect to safety. Marine Accident Investigation Branch (2008) also pointed out that although many fishing personnel demonstrated the ability to perform risk evaluations in the course of their daily operations, there was room for improvement in documenting these risk processes in the form of a risk or safety management plan.

The technical readiness of the crew is a subcategory of the unsafe management tier. This is an important factor in the commercial fishing industry since there are no established standards for professional competency related to the safe operation and navigation of vessels (National Research Council, 1991). Also, due to smaller-scale operations than other maritime transportation segments, crewmembers are expected to be skilled in a variety of professions besides vessel and fishing operations, including engine mechanic, electronics expert, hull repair technician, and safety equipment specialist (National Research Council, 1991). However, the rate of crew turnover can be high depending on the fishery, and this has a negative effect on safety (Håvold, 2010). Jaleel and Grewal (2017) wrote that unsafe operations during ordinary and emergency situations on commercial fishing operations are negatively impacted by the crew’s lack of training.

Improper operational risk assessment is a category in the unsafe management tier. While this category is related to risk/systems management, improper operational risk assessment refers to the inability of management to provide meaningful and appropriate oversight of expected operations with an analysis of the risks that are present rather than having an effective system to manage risks. Håvold (2010) and Zytoon and Basahel (2017) provide statistics from the commercial fishing industry that demonstrate the high injury rate of younger workers in the industry as opposed to older workers who have more experience, more patience, more skill, and are better able to estimate risks during operations. Marine Accident Investigation Branch (2008) stated that the risk-taking environments onboard fishing vessels could be self-perpetuating until an accident occurs, which causes the management of this behavior to be corrected. Improper operational risk assessment may also be identified during times of financial hardship when vessels and crews are pushed harder and longer regardless of the weather and sea conditions or the productivity of the fishery (Marine Accident Investigation Branch, 2008).

The category of allowing unsafe operations under the unsafe management tier is similar to the term “failure to correct known problems” in other HFACS variations. It can involve sending a boat to sea that is not structurally sufficient for the sea conditions it is likely to encounter or that the boat's ability to pump its bilges and prevent dangerous accumulations of seawater within the hull and possible loss of stability. Where "allowing unsafe operations" differs, though, may be seen when modifications to the boat are conducted without a complete evaluation of their impact on the stability characteristics of the boat. Structures that are added high on the boat or other changes that increase the center of gravity of the boat may be overlooked or minimized because of the expense or time delays that may result (Marine Accident Investigation Branch, 2008).

HFACS-FV utilizes the categories of mental readiness and physical readiness under the tier of preconditions for unsafe acts to describe how these crew conditions may contribute to commercial fishing accidents. Zytoon and Basahel (2017) commented on the importance of the physical readiness of fishing personnel due to hazardous weather conditions combined with rotating and moving deck machinery and lifting heavy loads. Fatigue among workers in the commercial fishing industry is routinely documented and frequently cited as a significant factor in many accidents (Jaleel and Grewal, 2017). Work periods of up to 96 hours were documented by the National Research Council (1991). Another major issue of concern affecting the crew's condition is stress. Steiner (1987) noted stress in the commercial fishing industry could be caused by work conditions, lack of sleep, or the uncertainty of the catch, and resulting income could cause distractions that could lead to accidents. These are just a few of the many conditions that represent the importance of the physical and mental readiness of fishing industry personnel. The subcategory of physical/mental limitations in HFACS is included in the HFACS-FV subcategories of mental and physical readiness. This does not infer the unsuitability of this former subcategory in the original model, but it is meant to simplify the mental and physical readiness subcategories where raters may find it difficult to differentiate between an adverse state and a limitation. Table 9 updates the HFACS category descriptions with modifications for HFACS-FV.

Table 9. HFACS-FV category and subcategory descriptions.

Organizational influences	
Resource management	Human resources: Staffing, support, and administration of personnel
	Equipment acquisition and support: Procurement of new vessels and equipment and maintenance of existing vessels and equipment
Climate	Structure: Established leadership and authority and the expected communications of managers
	Safety culture: Relative priority of employee safety expressed by management through documentation or actions compared to other organizational priorities
Process	Procedures: Defined objectives, methods, and/or policies for personnel and operational matters
	Risk/systems management: Formalized method to consistently evaluate how risks and quality are assessed
Unsafe Supervision	
Poor supervision	Technical readiness of the crew: Strategies, practices, and assessments of crew training to ensure their readiness for daily and emergent operations
	Supervisory competency: Management to ensure personnel and equipment readiness for operations
Improper operational risk assessment	Appraisal of current and projected vessel, crew, environmental and fishing conditions, and operational limitations
Allowing unsafe operations	Authorization to commence or continue operations despite full awareness of vessel, personnel, or equipment issues present or likely to develop which would endanger the vessel or crew
Supervisory violations	Intentional non-compliance of management overseeing operation with applicable standards and procedures
Preconditions for unsafe acts	
Environmental factors	Physical environment: Natural and atmospheric conditions and their impact on the operator
	Technological environment: Design, installation, and function of equipment and its interaction with operators
Crew condition	Mental readiness: A temporary or permanent psychological or intellectual disability or condition that influences a crew members' execution of duties
	Physical readiness: A temporary or permanent medical or physical disability or condition that influences a crew members' execution of duties
Personnel factors	Crew communication: Ineffective interactions between crew members and their impact on operations
	Personal readiness: Lack of preparedness for operation due to inattention to standard off-duty protocol
Unsafe acts	
Errors	Skill-based errors: Faulty actions based on inattention to a process or technique
	Decision errors: Intentional actions inappropriate for the situation due to poor choices
	Perceptual errors: Improper actions based on defective sensory input and evaluation
Violations	Routine: Deliberate actions that may be common practice and viewed as relatively minor but are against standard procedures
	Exceptional: Deliberate atypical actions that are a substantial deviation from standard procedures

Table 10 is a comparison of different models comparing tiers, categories, and subcategories. Tiers are noted in bold font, categories are in normal font, and subcategories are in italics. The progression of HFACS variations is observed including the motivation for HFACS in Reason (1990), the HFACS version created for naval aviation mishaps in Wiegmann and Shappell (2003), the Department of Defense (2005) HFACS model for all accident types, the Schröder-Hinrichs et al. (2011) HFACS-MSS adaptation for shipboard machinery space fires, and the model of Yildirum et al. (2017) HFACS-MA proposed for all types of maritime accidents. The table shows the stability of the original models of Reason (1990) and Wiegmann and Shappell (2003) especially in the tier of unsafe acts which is relatively unchanged across all of these models.

4.3 Identify fishing vessel fatality data

Data for this study was collected from the U.S. Coast Guard's Marine Information for Safety and Law Enforcement (MISLE) database. The focus will be on significant accidents classified by the Coast Guard as serious marine incidents involving commercial fishing vessels. The regulatory term “serious marine incident” is defined in Title 46 Code of Federal Regulations § 4.03-2. It represents a higher degree of severity from the general term of “marine casualty or accident” and includes accidents that result in at least one fatality, injuries requiring medical treatment, property damage more than $200,000, the loss of a vessel, and the discharge of more than 10,000 gallons of oil or an equivalent amount of hazardous materials. Agency procedures require drug and alcohol testing of all individuals involved in the accident and causal factor analysis to be completed as part of the investigation. This level of accident investigation will ensure that the data available to determine causal factors were thoroughly examined and documented. All personal identifying information is eliminated before analysis. The data for this study will analyze all commercial fishing vessel accidents in the United States for the ten year period 2008-2017. A total of 577 incidents were identified in this query. Of those, 117 incidents resulted in one or more fatalities. These are the incidents that will be considered for this study using HFACS-FV. Data fields from the investigations identify vessel details, geographic locations, incident timeline, personnel injuries or fatalities, vessel impact (fire, grounding, flooding, sinking), and accident analysis. Data fields are also provided for narrative descriptions of the accident and the accident causes. All investigations were completed by personnel designated under agency procedures and guidelines. The database and the investigation did not identify the accident causes with the standard HFACS tiers, categories, and

Table 10. Comparison of selected HFACS variations.

Reason (1990)	Wiegmann and Shappell (2003)	Department of Defense HFACS (2005)	Schröder-Hinrichs et al. HFACS-MSS (2011)	Yildirum et al. HFACS-MA (2017)	HFACS-FV
			Outside factors Statutory *International standards* *Flag state implementation*	**External factors** Regulations *Administration (Port Authorities)* *Design flaws* *Others*	
Fallible decisions	**Organizational influences**	**Organizational influences**	**Organizational influences**	**Organizational influences**	**Organizational influences**
	Resource management	Resource / acquisition management	Resources *Human resources* *Technological resources* *Equipment/facility resources*	Organizational asset management	Resource management *Human resources* *Equipment acquisition and support*
	Organizational climate	Organizational climate	Organizational climate *Structure* *Policy* *Culture*	Organizational environment	Climate *Structure* *Safety culture*
	Organizational process	Organizational process	Organizational process *Operations* *Procedures* *Oversight*	Organizational process	Process *Procedures* *Risk/systems management*

Table 10. (continued)

Reason (1990)	Wiegmann and Shappell (2003)	Department of Defense HFACS (2005)	Schröder-Hinrichs et al. HFACS-MSS (2011)	Yildirum et al. HFACS-MA (2017)	HFACS-FV
Line management deficiencies	**Unsafe supervision**	**Supervision**	**Unsafe supervision / workplace factors**	**Unsafe management**	**Unsafe management**
	Inadequate supervision	Inadequate supervision	Inadequate supervision	Poor management	Poor supervision
			Shipborne and shore supervision		*Technical readiness of crew*
					Supervisory competency
	Planned inappropriate operations	Planned inappropriate operations	Planned inappropriate operations	Inadequate work planning	Improper operational risk assessment
			Shipborne operations		
	Failure to correct known problems	Failure to correct known problems	Failed to correct known problems	Failure to fix known problems	Allowing unsafe operations
			Shipborne related shortcomings		
	Supervisory violations	Supervisory violations	Supervisory violations	Violations of management	Supervisory violations
			Shipborne violations		
Psychological precursors for unsafe acts	**Preconditions for unsafe acts**	**Preconditions**	**Preconditions for unsafe acts**	**Preconditions for unsafe acts**	**Preconditions for unsafe acts**
	Environmental factors	Environmental factors	Environmental factors	Environmental factors	Environmental factors
	Physical environment	*Physical environment*	*Physical environment*	*Physical environment*	*Physical environment*
	Technological environment	*Technological environment*	*Technological environment*	*Technological environment*	*Technological environment*
	Condition of operators	Condition of individuals	Crew condition	Condition of individual	Crew condition
	Adverse mental states	*Cognitive factors*	*Cognitive factors*	*Adverse mental state*	*Mental readiness*
		Psycho-behavioral factors			
	Adverse physiological states	*Adverse physiological states*	*Physiological state*	*Adverse physiological states*	*Physical readiness*
	Physical/mental limitations	*Physical/mental limitations*		*Physical/mental limitations*	
		Perceptual factors			
	Personnel factors	Personnel factors	Personnel factors	Personnel factors	Personnel factors
	Crew resource management	*Coordination / communication / planning factors*	*Crew interaction*	*Communications*	*Crew communication*
				Resource management	
	Personal readiness	*Self-imposed stress*	*Personal readiness*	*Readiness for task*	*Personal readiness*
Unsafe acts	**Unsafe acts**	**Acts**	**Unsafe acts**	**Unsafe acts**	**Unsafe acts**
Unintended action	Errors	Errors	Errors	Errors	Errors
Slip	*Skill-based errors*	*Skill-based errors*	*Skill-based errors*	*Skill-based errors*	*Skill-based errors*
Lapse	*Decision errors*	*Decision and judgment errors*	*Decision and judgment errors*	*Decision errors*	*Decision errors*
Mistake	*Perceptual errors*	*Misperception errors*	*Perceptual errors*	*Perceptual errors*	*Perceptual errors*
Intended action	Violations	Violations	Violation	Violation	Violation
Violation	*Routine*		*Routine*	*Routine*	*Routine*
	Exceptional		*Exceptional*	*Exceptional*	*Exceptional*

subcategories. Therefore, the information that will be analyzed will come directly from the database and will be assessed by four reviewers for HFACS-FV conversion. The dependent variables are represented by the consequences of the accidents in the database. The independent variables will consider the accident causes.

4.4 Implement HFACS-FV

After the suitability of the HFACS-FV model has been confirmed through a small data set evaluation, it can be used to identify the causal factors of the full data set of fishing vessel accidents. All classification efforts will be based on the database; no attempts will be made by the co-raters or the researcher to introduce outside information for consideration in coding or to alter conclusions of the investigation. After the data is categorized, it will be assessed for inter-rater reliability. Following that, the data will be evaluated statistically for trends and distributions.

The actual coding will be conducted independently by four raters. A discussion regarding the number of raters in various HFACS research is presented in the following section. The raters will be chosen based on their previous experience with investigating marine accidents as well as their experience inspecting and examining commercial vessels. The raters will be trained by the author in the theory and application of HFACS. In addition, several test cases will be used from the data set during the training of the raters as examples in the rating process and also to provide sufficient familiarization with HFACS-FV prior to rating the remaining data set. The raters will each be given a copy of the database extracts for each fatal incident and a form, as shown in Figure 7, that will allow the entry of a "0" if the causal factor was absent from the investigation or a "1" if the causal factor was present in the investigation. The co-raters will be evaluating the causal factors for the applicable HFACS tiers and categories or subcategories. A

HFACS-FV rating sheet

Rater Number:_____________ **Incident number:_____________**

Data quality: 1 – Very poor 2 - Poor 3 – Fair 4 – Good 5 - Excellent

Tier	Category	Rating	Notes
Organizational influences			
	Resource Management		
	Human Resources		
	Equipment Acquisition/Support		
	Climate		
	Structure		
	Safety Culture		
	Process		
	Procedures		
	Risk/Systems Management		
Unsafe Management			
	Poor Supervision		
	Technical Readiness of Crew		
	Supervisory Competency		
	Improper Operational Risk Management		
	Allowing Unsafe Operations		
	Supervisory Violations		
Preconditions for Unsafe Acts			
	Environmental Factors		
	Physical Environment		
	Technological Environment		
	Crew Condition		
	Mental Readiness		
	Physical Readiness		
	Personnel Factors		
	Crew Resource Management		
	Personal Readiness		
Unsafe Acts			
	Errors		
	Skill-based Errors		
	Decision Errors		
	Perceptual Errors		
	Violation		
	Routine		
	Exceptional		

Figure 7: Sample HFACS-FV rating sheet.

particular causal factor will only be marked in a positive manner, as a "1", a maximum of one time per incident. In addition to the review of each incident for relevant HFACS causal factors, each incident will also be evaluated for the investigation information provided to the reviewers. A five-point Likert scale will be utilized to examine the HFACS causal factor rating, given the information available to make those decisions. The Likert scale will be "1" for very poor, "2" for poor, "3" for fair, "4" for good, "5" for excellent. The concern is that specific incident investigations provide more information than others and may provide a higher level of confidence in the HFACS rating. For general comparison, a “1” on this scale will indicate that the information available is insufficient to make decisions for causal factors. A “3” will indicate that the information was sufficient to make rating decisions of casual factors and a “5” will indicate exceptional information quality. The most common reasons that may affect information availability may be related to the thoroughness of the investigation and entry into the database, an extreme lack of evidence when a boat disappears with no survivors or witnesses, or a particularly notable incident with multiple fatalities which may allow for additional investigation resources, support, and analysis. This measure of information quality will be valuable to compare with inter-rater reliability of the reviewers. This data will be used to determine the relationship between investigation and information quality compared to co-rater reliability.

Wiegmann and Shappell (2003) describe the beginning of their analysis procedure to be the time of the accident with the actions of the operator. If unsafe acts of the operator were determined to contribute to the accident, the raters would examine the categories of errors and violations to determine if they were factors in the accident. The next step would be to consider the sub-categories, including skill-based error, decision error, perception error, routine violations, and exceptional violations. After that, the raters would proceed through the tiers of preconditions for unsafe acts, unsafe management, and organizational influences. At each tier, the rater would assess any potential causal factors and then proceed through each category and subcategory, fully evaluating the contributing causal factors.

Olsen and Shorrock (2010) showed that co-rater reliability proved to be a concern because of the lack of an applied familiarity with HFACS. Co-raters involved with this study have a suitable background and capability to apply the HFACS categorization properly. Co-raters will be provided with specialized instruction on the theory and application of HFACS. In order to ensure each accident is assessed correctly and consistently, it will be essential to have co-raters who have experience and qualifications reach a consensus on these factors or to document any disagreement (Shoufan and Damiani, 2017).

Cohen et al. (2018) highlight the importance of providing training for co-raters. Hallgren (2012) confirmed that the more training co-raters receive, the better their reliability, thereby producing more robust conclusions. Studies have shown differences in training regimes from two hours to two days. They are generally a combination of instruction and practice exercises. The co-raters who participated in this study have a background in maritime laws and regulations and vessel examination. Also, they have been investigators of maritime accidents who are currently teaching courses in maritime accident investigation. Before evaluating the data for the HFACS-FV conversion, the co-raters will receive training. The training will include lecture-type sessions on Reason's human error theory and HFACS development, structure, and applications. This will be followed by general HFACS coding principles and practical, interactive, and supervised HFACS coding examples.

4.5 Reliability and validity

Credible research depends on the fundamental concepts of measurement, reliability, and validity. Carmines and Zeller (1979) discuss these terms and define measurement as the "process of linking abstract concepts to empirical indicants” (p. 10). Reliability is concerned with the "repeatability" of the measurement, while validity relates to the accurate representation of the intended measurement. A simple example is a bathroom scale to enable the user to know their weight. A user expects the scale to read the correct weight whenever they use it. If the scale is always 10 pounds off of the true weight, then statistically, it may be reliable but is not valid. This research is dependent upon co-raters' ability to accurately and consistently apply the HFACS criteria to fatal fishing vessel accident investigations and produce sound conclusions regarding the use of HFACS-FV.

Where physical measurement leaves little room for critical review, provided adequate attention is provided to equipment calibration and conventional sources of error, HFACS causal factor codification requires subjective interpretations of the data and categories. Reliability estimates are used in a variety of fields of study where data interpretation and the resulting statistics necessary for conclusions are utilized in research. Judges or raters evaluate and convert the information of one type and align it with a suitable scale or paradigm. Rater reliability estimates personal evaluations, and coding is consistent and leads to proper conclusions. Rater reliability can be further specified as inter-rater reliability, the agreement between raters, or intra-rater reliability, agreement by the same rater at different times. Krippendorff (2004) discusses the differences between inter-rater and intra-rater reliability in this manner. Inter-rater reliability was summarized as “reproducibility” and intra-rater reliability was described as “stability.” Reproducibility, Krippendorff (2004) concluded, was more powerful and easier to examine than stability. Intra-rater reliability requires additional research time and control measures so that the coder does not recall previous scenarios, answers, or decisions. Inter-rater reliability should produce consistent results among a variety of coders who have been provided the same information and similar instructions while completing their evaluations separately.

Similar to Dekker's (2006) theory of the old view and the new view of human error, Deming proposed that 94 percent of problems within an organization are due to the systems or processes, and six percent are due to the workers themselves (Boardman, 1994). Deming, as a statistician, recognized that variation was a reality in any company and that managers needed to be aware of the sources of the variation and minimize its impact. Likewise, reliability in research is linked to consistency and the obligation to identify and decrease or eliminate those aspects leading to undependable data and conclusions. Among the recurrent errors in the evaluation and documentation of inter-rater reliability, Hallgren (2012) included the failure to note which method was used, the utilization of an inappropriate method based on the type of data and number of raters, and an explanation of the inter-rater reliability estimates concerning the study.

A survey of the literature contained in 28 HFACS related studies regarding reliability methods shows a significant disparity. Nearly half of these studies provide no mention of any reliability assessment that was performed after the coders conducted their HFACS conversion. This does not presume that an evaluation of the coders’ interpretation was not completed for reliability purposes; it merely means that it was not part of the report. However, it does raise the question whether any reliability analysis was completed in conjunction with these studies. The remainder of these 28 studies employed a wide variety of reliability measures including percent agreement, Cohen’s kappa, multi-rater kappa free, Krippendorff’s alpha, Cronbach’s alpha, and other correlation coefficients. Table 11 provides an inter-rater reliability summary, as reported in a sampling of HFACS studies.

Table 11. Reported inter-rater reliability in various HFACS studies. Adapted from Cohen et al. (2015).

Study	Number of raters	Reliability Method	Reported inter-rater reliability
Gaur (2005)	2	Percent agreement (PA)	PA=87.0%
Li and Harris (2006)	2	PA and Cohen's kappa (k)	$PA_{average}$=88.8%, $k_{average}$=0.67
Li et al. (2008)	2	PA and k	$PA_{average}$=85.1%, $k_{average}$=0.38
O'Connor (2008)	123	PA	PA $fixed_{average}$=77.8%, PA $rotary_{average}$=78.8%
Baysari et al. (2009)	3	PA	$PA_{average}$=79.0%
Rashid et al. (2010)	2	PA and k	$PA_{average}$=94.8%, $k_{average}$=0.77
O'Connor (2010)	2	Multi-rater kappa free (k_{free})	$k_{free(average)}$=0.76
Olson and Shorrock (2010)	Study 1- 11, Study 2- 1	PA	Study 1- PA=40.0% Study 2- PA=40.1%
O'Connor and Walker (2011)	204	k_{free}	$k_{free\ helicopter}$=0.58, $k_{free\ tacair}$=0.69
Olson (2011)	7	PA	PA_{ATCO}=36.1%, PA_{HF}=34.5%
Zhou et a. (2013)	Not reported	Cronbach's alpha (CA)	CA=0.92
Madigan et al. (2016)	2	PA	$PA_{average}$=91.2%
Ergai (2016)	125	Krippendorff alpha (KA)	$KA_{average}$=0.67

Percent agreement is an intuitive measure for two raters that can easily compare their number of agreements and disagreements as a percentage from zero to 100. This method presents the specific categories being rated that show disagreement (McHugh, 2012) and is frequently used in research projects (Hallgren, 2012). Cohen et al. (2015) observed that percent agreement is more reliable as the number of items to be rated increases and is less reliable as the possible categories for the rater increases. The primary concern for percent agreement arises from those agreements that happen where the raters come to the same decision randomly (Hallgren, 2012). This is mainly an issue with a small number of categories. Krippendorff (2011) argues that percent agreement is only usable for two coders and infers inaccurate conclusions for very low and very high percent agreement. Hayes and Krippendorff (2007) stated that the percent agreement is "flawed in nearly all important respects" (p. 80). Wallace and Ross (2006) considered 70% agreement as a minimum figure to determine rater reliability.

Scott (1955) and Cohen (1960) presented methods that considered the chance agreement in their studies. Cohen (1960) referred to his measure as the "coefficient of agreement," which described "the proportion of chance-related disagreements" among the raters and identified it as kappa. Cohen's (1960) kappa is calculated as:

$$\kappa = \frac{p_0 - p_c}{1 - p_c}$$

where p_0 is the proportion of agreed ratings and p_c is the proportion of chance agreed ratings. The scale of the kappa statistic ranges from -1 to +1 and is a type of correlation coefficient suitable for only two coders (McHugh, 2012). Primavera et al. (1996) discussed the nine commonly used reliability measures at that time and endorsed Cohen’s kappa for the use of two raters with nominal data. Also, Cohen's kappa was noted for its known standard error leading to confidence intervals and significance testing of its values. Although the complexity of calculations completed manually could be challenging, Primavera et al. (1996) concluded, "we know of no major disadvantages of kappa” (p. 64). Wiegmann and Shappell (2003) opted to use Cohen's kappa as a "conservative” reliability indicator in their research. Landis and Koch (1977) proposed a graduated kappa scale that ranged from less than zero indicating poor reliability to values above 0.81 indicating almost perfect reliability.

However, differing opinions about Cohen’s kappa appear in the literature. The use of percent agreement, under the name index of concordance, was favored over Cohen’s kappa in several HFACS studies (Olsen and Shorrock, 2010; Olsen, 2011; Madigan et al., 2016). They substantiate their perspective based on Davies et al. (2003), Ross et al. (2004), and Wallace and Ross (2006), which discount Cohen's (1960) point of view on chance agreement with truly independent raters. The index of concordance noted above was attributed to Martin and Bateson

(1986) and is represented as A/(A + D), where A is the number, percent, or proportion of rater agreements, and D is the number, percent, or proportion of rater disagreements.

Hallgren (2012) claimed that two adverse results are possible with the use of Cohen's kappa. "Prevalence problems" can occur when raters are more inclined to select various categories, which can lead to inaccurate low kappa estimates. "Bias problems" suggest differing category selection distributions that may lead to distorted kappa figures on the high side. Krippendorff (2011) concluded, "that kappa's expected agreement is entirely inadequate for assessing the reliability of coding" (p. 98).

Krippendorff's (1970) alpha is recognized as a flexible and consistent measure of reliability. As Hayes and Krippendorff (2007) explain the agreement coefficient, "…it generalizes across scales of measurement; can be used with any number of observers, with or without missing data; and it satisfies all of the important criteria for a good measure of reliability" (p. 78). Hayes and Krippendorff (2007) suggested that alpha values higher than 0.8 demonstrated reliability and values less than 0.667 indicated unreliable agreement.

Krippendorff's alpha, as expressed by Gwet (2014), is calculated by:

$$\alpha = \frac{p'_a - p_e}{1 - p_e}$$

where $p'_a = (1 - \varepsilon_n)p_a + \varepsilon_n$, $p_a = \sum_{k=1}^{n} p_{kk}$, and $p_e = \sum_{k=1}^{q} \pi_k^2$

In addition, $\varepsilon_n = \frac{1}{2n}$ and $\pi_k = (p_{k+} + p_{+k})/2$.

Here p'_a is the percent of rater agreement and p_e is the percent of chance rater agreement. The form of the calculation for Cohen's kappa, Scott's pi, and Krippendorff alpha are very similar, but the method each of them use to estimate the chance agreement of the raters is different (Gwet, 2014). Hayes and Krippendorff (2007) state that with two raters with nominal data that "α is asymptotically equal to Scott's π" (p. 82).

This study will utilize percent agreement, Cohen's kappa, and Krippendorff's alpha to compare inter-rater reliability for the HFACS tiers and categories. A comparison of the reliability estimates will provide a measure of confidence if there is agreement and lack of confidence if there is not agreement. This is similar to the approach of Jacinto et al. (2016) that used percent agreement, Scott's pi, and Krippendorff's alpha. Their study examined workplace accidents using the European Statistics of Accidents at Work system and employed inter-rater and intra-rater reliability among different groups of raters. Their results showed strong agreement with all three measures, although percent agreement was consistently the highest. Ergai (2013) applied percent agreement, Cohen's kappa, and Krippendorff's alpha for intra-rater reliability and percent agreement, Fleiss' kappa, and Krippendorff's alpha for inter-rater reliability. These measures demonstrated strong consensus within the intra-rater and inter-rater reliability estimates.

CHAPTER 5

ANALYSIS

5.1 Rater process and observations

Four raters were selected for converting the data from the Coast Guard accident investigations into the HFACS-FV framework. The raters were experienced in vessel examinations and inspections and were very familiar with the various maritime and industry standards applicable to commercial vessels. They also were knowledgeable in maritime accident investigation, including the response to investigation scenes. Before agreeing to participate in the HFACS-FV rating of accidents for this research, none of the raters had any familiarity with the HFACS model or applying a similar framework to accident investigation. A total of four hours of human factors and HFACS instruction, directed and self-paced examples, and a discussion of their ratings of selected accidents conducted individually prepared the raters for their independent rating of 73 accidents. The raters spent significant time in providing ratings for this study. They spent an average of four hours rating the 12 training cases and 12 hours rating the remaining 73 investigations. With limited exposure to human factors principles, the interpretation of the various categories and subcategories required additional description to allow for a more consistent evaluation by the raters. Discussions between raters explaining their rationale for a decision of one factor as opposed to another factor during the training sessions increased mutual understanding of the categories by the raters. Complicating the rating process was the number of cases with smaller organizations that virtually eliminated the major tiers, although the categories and subcategories remained valid. This indicates a significant departure from the standard HFACS regime but establishes the HFACS-FV model for applications involving small businesses and organizations. As an example, an investigation can identify whether the factor of equipment acquisition and support contributed to the accident. However, as a subcategory under the organizational tier it may seem an unreasonable selection for a small organization with a limited number of employees. This meant that the raters focused on the categories and subcategories and not the major tier under which they were organized.

Raters were challenged by limiting their decisions to the conclusions found in the accident reports when their subject matter knowledge could easily lead them to infer other factors. The raters were instructed to base their decisions only on the conclusions stated and not make deductions based on additional information that may have been presented in the investigation report.

Each of the four raters examined 73 accident investigation reports and used the investigation conclusions to convert these findings into the 22 factors of the HFACS-FV framework. All raters worked independently and provided their results directly to the researcher. The raters examined the human factors that led to the initiating cause of the accident rather than the subsequent actions. For example, if a fishing boat sank due to a flooding issue and a crewmember died after abandoning the boat without wearing a personal flotation device, only the conclusions relating to the flooding were considered for the HFACS-FV conversion and not the proper use of lifesaving equipment. This emphasized the event which was most responsible for the fatality and helped to clarify expectations for the raters.

5.2 Data analysis

Data was gathered on 117 accidents from their investigation reports. A review of the raw data from these accidents showed that the top five initiating events were capsizing (32 accidents), flooding (26 accidents), falls overboard (16 accidents), crew injury (15 accidents), and collision (11 accidents). The location of all accidents is shown in Figure 8.

Figure 8: Locations of all reported fatal fishing vessel accidents involving vessels registered in the United States, 2008-2017.

Of these 117 accidents, 32 were excluded from the analysis. The exclusions were comprised of 26 accidents where all crewmembers aboard died without other witnesses; five accidents where the decedent had a diagnosed, pre-existing medical condition; and one accident that was improperly categorized as a fishing vessel when it was not.

After removing these excluded accidents from consideration, 85 accident investigations remained. These 85 accidents were reviewed to produce a consensus rating and assessed for the human factors involved in the accidents, geographic (regional) evaluation of the human factors that were present, and accident location in relation to its distance from shore and the human factors that were revealed, the vessel length, and any correlation of these human factors with other accidents in similar locations. These analyses are summarized in Table 15 and will be described below.

The consensus rating was produced from the four raters' assessments into one combined rating for each HFACS-FV category. This rating compared the judgments of the raters and required the agreement for each factor by at least three of the raters. An example of the consensus rating process is from incident number 3145673. Raters one and two identified improper operational risk assessment and physical environment as contributing factors. Rater number three concluded that improper operational risk assessment, physical environment, and decision error were factors. Rater number four identified physical environment as a contributing factor. The consensus ratings from this incident were the categories of improper operational risk assessment and physical environment. The results from all of the raters and the consensus ratings for all categories of all accidents in this study are provided in Appendix A.

These consensus ratings established the human factors for statistical analysis and identified 108 human factors present in these 85 accidents for a mean 1.24 factors per accident. The top five human factors discerned from the consensus HFACS-FV rating were physical environment (20), equipment acquisition and support (18), decision error (13), technical readiness of the crew (12), and allowing unsafe operations (9). The complete consensus rating of the HFACS-FV human factors by category is shown in Figure 9. The list of categories is ordered using the standard HFACS arrangement of tiers but without showing those separations. Thus, the categories under the organizational influences are listed first, followed by the categories of unsafe management, then the categories for preconditions for unsafe acts, and finally, the categories for unsafe acts. This order also represents how these categories are characterized as latent and active failures. The distinction between latent and active failures occurs between the tiers of preconditions for unsafe acts and unsafe acts. In Figure 9, this happens between the categories of personal readiness and skill-based errors. The diagram without the tier designations depicts actual HFACS-FV application to small organizations which may show minor personnel changes between the four tiers.

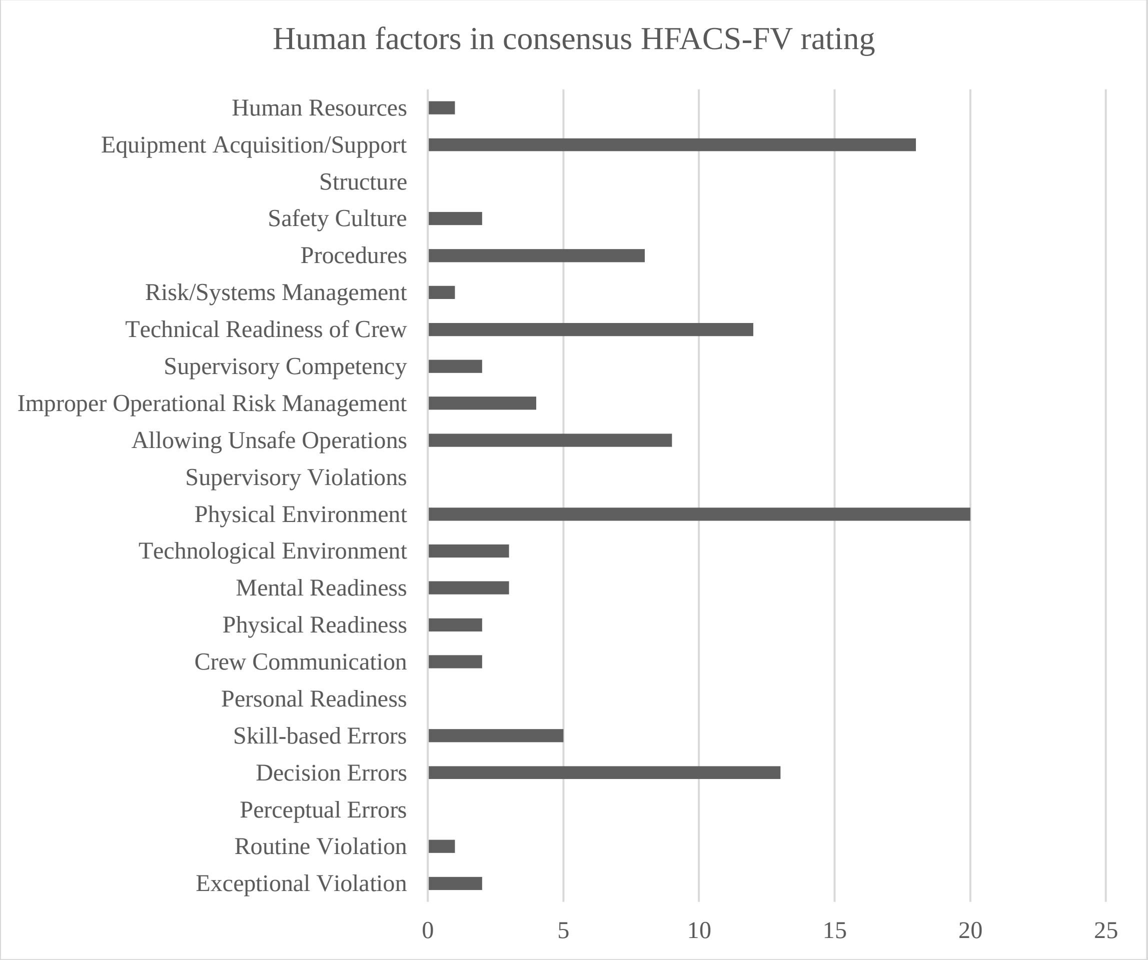

Figure 9: Human factors by categories in consensus HFACS-FV rating of incidents.

The data from these 85 accidents were assessed for human factor trends based on the accidents' geographical location and whether the accident occurred on inland, coastal, or offshore waters. The six geographic divisions for analysis were the Atlantic Ocean and connecting waters from Maine to New Jersey, the Atlantic Ocean and connecting waters from Delaware to Florida, the Gulf of Mexico and connecting waters, the Pacific Ocean from Washington to California and connecting waters, the waters of Alaska, the Central Pacific Ocean including Hawaii and United States territories. Another analysis was conducted with different geographic groupings. The description of inland waters refers to harbors, rivers, and sounds that minimize exposure to adverse weather and sea conditions. Coastal waters are less protected than inland waters and considered bays or inlets at the entrance to or immediately adjacent to oceans or seas. Offshore waters are oceans, seas, and the Gulf of Mexico that maximize the vulnerability of mariners and vessels. Table 12 provides the top human factor categories by these locations.

The data were also examined for vessels of different lengths. Length measurements were available for 81 out of 85 of these accidents. The length grouping was for vessels less than 25 feet long, between 25 and 40 feet long, between 40 and 60 feet long, between 60 and 100 feet long, and greater than 100 feet long. The data are summarized below in Table 13.

Correlation calculations were performed to determine if statistically significant relationships existed between the human factors using IBM SPSS Statistics version 26 (SPSS). These calculations were performed for factors identified within these geographic and length separations. The Pearson Chi-Square test showed that the correlation between any of the human factors grouped by accident location or boat length was not statistically significant at a $p < 0.05$. That indicates the independence of human factors when evaluated by accident location. The lack

Table 12: Top human factors by accident location from consensus ratings.

Accident location	Top human factor categories
East Coast (north)	Decision error
	Physical environment
East Coast (south)	Physical environment
	Decision error
	Equipment acquisition/support
Gulf Coast	Equipment acquisition/support
	Physical environment
West Coast	Physical environment
	Decision error
Alaska	Equipment acquisition/support
	Physical environment
Pacific	Technical readiness of the crew
	Equipment acquisition/support
Inland waters	Equipment acquisition/support
	Physical environment
Coastal waters	Physical environment
	Decision error
Offshore waters	Equipment acquisition/support
	Allowing unsafe operations
	Technical readiness of the crew

of a statistical relationship between human factors provides insight into the complexity and variation of these fatal fishing vessel accidents' underlying causes.

From these 85 accidents, twelve were used for the raters' training and familiarity with the HFACS-FV model, leaving 73 cases to compute inter-rater reliability. Calculations for inter-rater reliability were made using Microsoft Excel 2013 (Excel) and SPSS. Inter-rater reliability was calculated using the methods of percent agreement, the kappa statistic, and Krippendorff’s Alpha. A summary of inter-rater reliability by the incident is displayed in Figure 10.

The mean percent agreement for all raters of all accidents was calculated as 89.26%. The mean kappa statistic was calculated to be 0.3966 and the mean Krippendorff’s alpha statistic was

Table 13: Statistical breakdown of the data by length groupings.

Vessel length	Number	Primary initiating events	Primary operating waters	Primary geographic location	Top human factor categories
Less than 25’	10	Capsize Flooding Collision	Inland Coastal	Alaska	Physical environment Decision error
Greater than 25’ and less than 40’	24	Capsize Diver death Flooding	Coastal	West Coast	Physical environment Decision error
40’ and less than 60’	21	Capsize Flooding	Coastal	West Coast	Physical environment Equipment, acquisition, and support
60’ and less than 100’	15	Flooding Crewmember injury	Offshore	East Coast (north) Gulf Coast Alaska	Equipment, acquisition, and support Technical readiness of the crew
Greater than 100’	11	Crewmember injury Collision	Offshore	Central Pacific Ocean	Procedures Equipment, acquisition, and support

calculated to be 0.3367. The differences between these methods' results were not consistent since they were calculated and because only two options were available for the raters; the factor was either present or not present. Since the kappa statistic and the Krippendorff’s alpha consider chance or random agreement, this binary choice can significantly differ with the percent agreement calculations. Calculations using percent agreement and the kappa statistic are limited to two raters at one time where the Krippendorff’s alpha calculations consider all four raters simultaneously. Accordingly, the reported percent agreement and kappa statistic are the mean of six rater comparisons (rater one to rater two, rater two to rater three, rater three to rater four, rater one to rater three, rater one to rater four, and rater two to rater four). A breakdown of the mean percent agreement of raters by the human factor category was also performed to determine if differences in agreement in these categories would highlight concerns that may have contributed

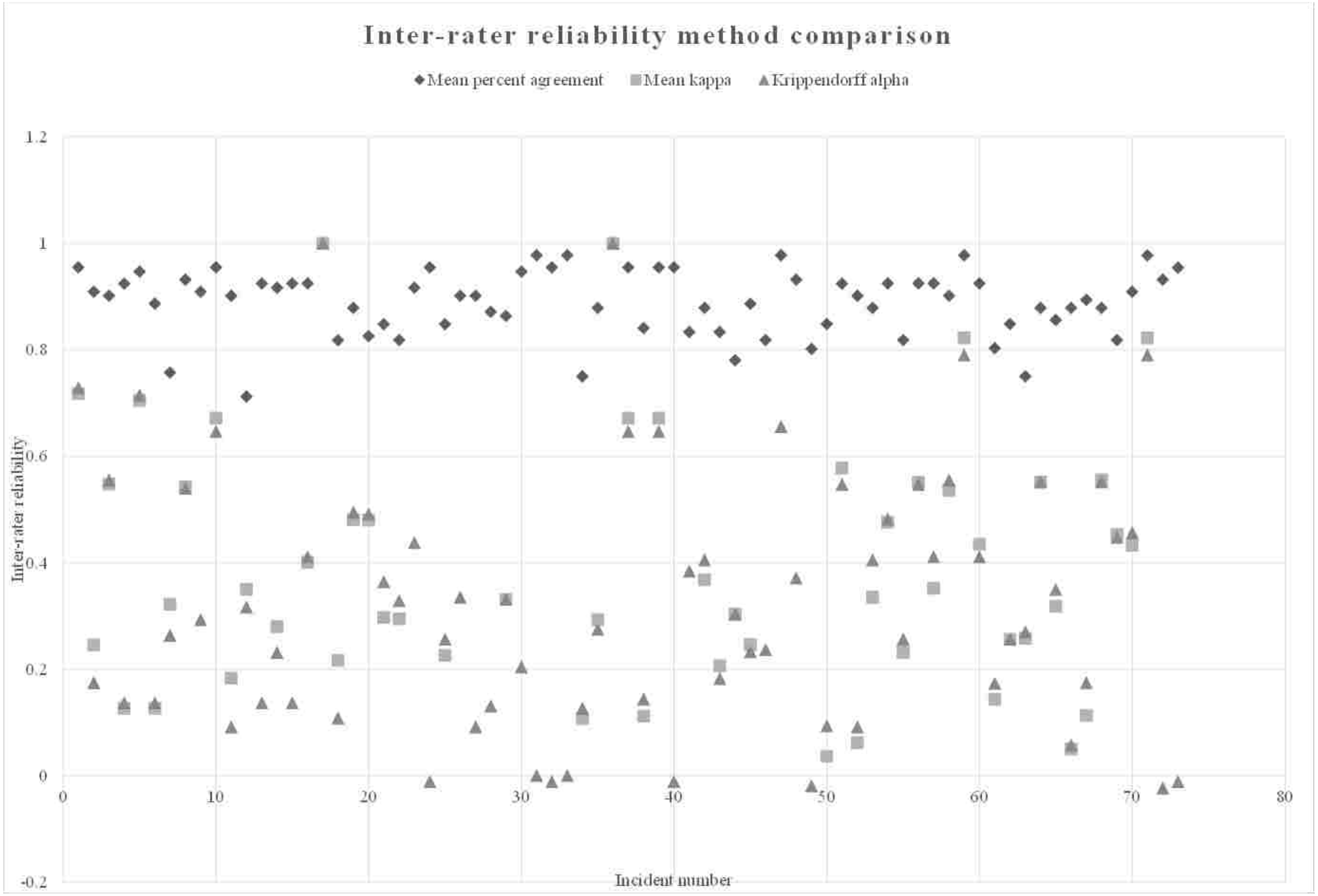

Figure 10: Comparison of inter-rater reliability methods

to lower inter-rater reliability values. The human factor categories with the lowest mean percent agreement were decision error, equipment acquisition and support, technical readiness of the crew, skill-based error, and procedures. Figure 11 summarizes the mean percent agreement of raters by the human factors category.

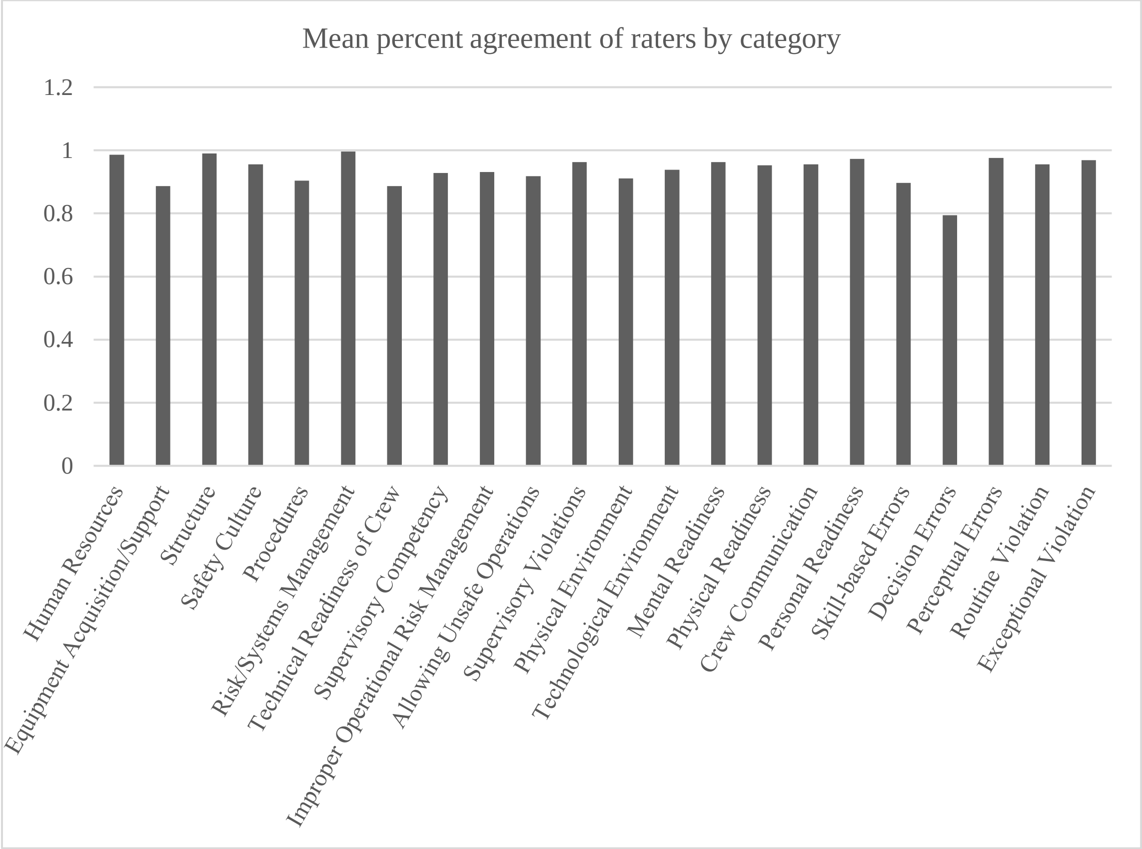

Figure 11: Mean percent agreement of raters by HFACS-FV category.

5.3 Discussion of results

This section will interpret the calculated results presented above. The exclusion of 26 cases or 22% of all of the 117 total accidents because there were no survivors and no witnesses was imposed due to lack of information from which the investigator could reasonably draw conclusions regarding the cause of the accident. Subsequently, the raters' data regarding the human factors selected would be suspect as well. More troubling than excluding these cases is the realization that 17 of these accidents involved only a single operator with no additional crewmembers. That means that the same person who is navigating the boat is also setting and retrieving the fishing gear and stowing the catch. It also means that there is no one available to help when an injury or fall overboard happens. In addition, it also means that there is no one to assist the operator with meals or when fatigued. This points to the thin economic margins of the business and the risks that these operators are willing to take.

5.3.1 HFACS-FV results

Twelve accidents out of these 85 were utilized for the training of the raters. The researcher chose these accidents for training purposes randomly, but ultimately they included straightforward cases, complex cases, cases with numerous human factors present, and those with few or no human factors present. Initially, ten cases were chosen for training purposes, but two additional cases were provided to increase the raters' confidence. The consensus rating, as noted previously, showed a mean of 1.24 human factors per accident. This statistic is valuable to understand the correlation between human factors and inter-rater reliability discussed later in this chapter. The top five categories of physical environment, equipment acquisition and support, decision error, technical readiness of the crew, and allowing unsafe operations account for 72 out of 108 (67%) of the human factors issues noted and provide a solid foundation for the underlying causes of these fatal accidents.

The physical environment category illuminates the impact of weather and sea conditions on the operator and the risks that operators take as part of their routine course of business. Equipment acquisition and support as a highly rated human factor indicates that the owner and/or operator utilized a boat that had known and unresolved issues related to the vessel or equipment before their voyage. It also indicates the economic constraints under which these businesses must operate. The risk of operating a boat that needed to be replaced or repaired produced significant consequences in these accidents. The identification of decision error as a category on this list is not surprising. An operator's direction to the crew under complex operating conditions or response to an accident scenario can understandably result in a regrettable decision. Furthermore, given the tendency to place responsibility for an accident on the operator, this active factor shows the complexity and dynamics of the business operations. The technical readiness of the crew resulting in fatalities refers to the training of the crew so that they are ready to respond to routine and emergent conditions. Although many fishing vessel operators have years of experience, their crews may be quite inexperienced. Also, without any licensing or professional certification requirements, it is difficult to attribute any minimum level of competence to the operators or crews. Further, issues such as vessel loading and stability may not be fully understood or assessed by the crew. Allowing unsafe operations indicates personnel were allowed to begin or continue operations with the full awareness of the dangers involved. This human factor has interesting parallels to the technical readiness of the crew. Both factors are considered to be supervisory, but the factor of allowing unsafe operations shows the bias in taking risks in dangerous situations. These five categories from fatality cases demonstrate how commercial fishing personnel have substantial economic constraints, are inclined to take risks, and would benefit from additional training.

The geographic distribution of accidents from the locations in Figure 8 indicates that 34% of these accidents occurred on the East Coast, 16% on the Gulf Coast, 19% on the West Coast, 17% in Alaska, and 13% in the Central Pacific Ocean. Without detailed data in each geographic area on the number of vessels engaged in fisheries, economic factors including market demand, cost to operate and repair vessels, crew availability and training, weather and sea conditions, and various other matters, it would be challenging to compare each region against the others for the rate of fatal accidents. For reference, Table 14 shows the top ten ports for fishery landings by value and quantity of their catch for 2015. While there are several ports on both lists, the ports on one list but not the other show the complexity of making any type of accident rate comparison; therefore, no insights or conclusions will be provided based solely on accident location.

Table 14: Top ports for fishery landings in the United States for 2015 (U.S. Department of Commerce, 2016).

Port	Value (Million dollars)	Port	Quantity (Million pounds)
New Bedford, MA	322	Dutch Harbor, AK	787
Dutch Harbor, AK	218	Kodiak, AK	514
Kodiak, AK	138	Aleutian Islands, AK	467
Aleutian Islands, AK	111	Intracoastal City, LA	428
Empire-Venice, LA	111	Empire-Venice, LA	379
Honolulu, HI	97	Reedville, VA	350
Alaskan Peninsula, AK	90	Pascagoula-Moss Point, MS	295
Bristol Bay, AK	90	Alaskan Peninsula, AK	268
Cape May-Wildwood, NJ	72	Naknek, AK	176
Key West, FL	71	Cordova, AK	162

The next portion of the analysis consisted of grouping these consensus ratings for 85 accidents geographically. The first grouping was based on the part of the country where the accident happened. The objective was to see if specific parts of the country may have similar vessels, fisheries, attitudes towards safety, attitudes towards risk, and other matters and their impact on fatal accidents. The number of accidents in this study on the East Coast from New Jersey through Maine was 12. The number on the East Coast from Delaware through Florida was 13. The number on the Gulf Coast was 15. There were 18 accidents on the West Coast from California to Washington, 18 accidents in Alaskan waters, and nine accidents in the Central Pacific Ocean. The top categories for human factor selection for all of these locations included physical environment for every location except the Central Pacific Ocean. Perhaps voyages in the Central Pacific Ocean led these operators to consider longer-term weather predictions or to ensure the vessel's condition was ready for these remote operating conditions. Decision error and equipment acquisition and support were also widely represented in most geographic groupings. The Central Pacific Ocean accidents showed that technical readiness of the crew was a significant human factor. This may be attributed to hiring crewmembers of multiple nationalities and languages.

Operations on inland, coastal and offshore waters indicate the time the boats will be underway until their return. The consensus ratings showed 21 of these accidents occurred on inland waters, 38 accidents happened on coastal waters, and 26 accidents on offshore waters. Boats on inland waters generally return the same day, boats on coastal waters return typically within days, and boats on offshore waters may be away from their homeport for weeks. This helps to explain how physical environment was not one of the leading human factor categories associated with accidents on offshore waters. Vessels operating on offshore waters, in all probability, are built to a higher standard and maintained better to withstand sustained operation in the expected weather and sea conditions. Represented in the category selection of the top human factors for accidents occurring on offshore waters includes allowing unsafe operations and the technical readiness of the crew. These two factors can be explained by the length of their voyage and the fatigue that is likely to develop and magnify any primary training deficit.

The length of fishing vessels covered in this accident data varied from 17' to 344', with most of the vessels measuring less than 60' in length. Capsizing was the leading initiating event in the length groupings less than 60' long. Examining the primary initiating event with the top human factor categories, one can theorize that these vessels were operating beyond the design limitations of their vessel for the specific weather conditions, possibly with unsafe loading that created stability issues on their vessels. Flooding is another commonly seen initiating event that indicates the economic concerns faced by this industry that lead to delaying hull maintenance or repairs and the tendency to embrace risk during operations. For vessel groupings of 60' or more, one can see the transition from capsizing to fatal crewmember injuries. This is not unexpected as these larger vessels have more crewmembers and significant mechanical equipment to handle and transfer their large volume of fish. The top human factors also support this accident causation by identifying training, procedures, and equipment issues. As one would expect, the primary operating waters show the smaller vessels operate on more protected waters and the larger vessels on less sheltered waters.

Correlation calculations were performed for all factors of accidents within the same geographic and length groupings. With a consensus mean human factor selection of 1.24 factors per accident, it is not surprising that no statistically significant correlations were found to indicate relationships between these human factor categories.

Table 15: Summary of completed analyses.

Relationship	Reference	Finding	Interpretation
Human factors by categories of all incidents	Figure 9	Top factors were physical environment, equipment acquisition and support, decision error, technical readiness of the crew, and allowing unsafe operations.	Risk-taking related to business profitability and associated with weather or sea conditions, economic factors affecting vessel readiness, and training contributed to these accidents.
Top human factors by location	Table 12	Physical environment was the top human factor for all locations except the Central Pacific Ocean and offshore waters where equipment acquisition and support and technical readiness of the crew were the top human factors.	Vessel operations close to shore and economic pressures may cause operators to accept hazardous environmental conditions.
Top human factors by length	Table 13	Physical environment was the top human factor for all vessels of less than 60' in length and equipment acquisition and support was the top human factor for vessels more than 60' in length.	Smaller vessels that operate closer to shore are willing to take more risk considering their relatively short time to return to their homeport.

5.3.2 Rater reliability results

As previously discussed, calculations were completed for percent agreement, Cohen’s kappa, and Krippendorff’s alpha. Calculations were initially conducted with Excel. Then calculations were performed with SPSS for percent agreement, the kappa statistic, and Krippendorff’s alpha. Krippendorff’s alpha statistic was not directly available in SPSS and required the separate Krippendorff’s alpha macro to be imported into SPSS for the calculation (Hayes and Krippendorff, 2007; Griffin). Table 16 shows pertinent characteristics for each of these inter-rater reliability measures. As addressed in Section 4.5, there is considerable academic discussion associated with inter-rater reliability methods, including their positive and negative aspects and researchers' preferences. Results for this study produced a mean percent agreement of 89.26% which indicates reliable agreement, a mean kappa statistic of 0.3966 shows a fair to moderate reliability, and a Krippendorff's alpha of 0.3367 indicates unreliable agreement.

Table 16: Comparison of inter-rater reliability methods used in this study (Landis and Koch, 1977; Wallace and Ross, 2006; Hayes and Krippendorff, 2007; Hallgren, 2012).

Inter-rater reliability method	Number of raters	Measurement scale	Reliability scale and interpretation	Results from this study
Percent agreement	2	0 to 100%	0 – 60% unreliable 60 – 70% moderately reliable 70 – 100% reliable	89.26%
Cohen’s kappa	2	-1 to 1	<0 unreliable 0 – 0.20 slight reliability 0.21 – 0.40 fair reliability 0.41 – 0.60 moderate reliability 0.61 – 0.80 substantial reliability 0.81 – 1.00 almost perfect	0.3966
Krippendorff’s alpha	2 or more	0 to 1	0 – 0.667 unreliable 0.667 – 0.80 acceptable reliability 0.80 – 1.00 reliable	0.3367

With these statistics providing conflicting impressions of the reliability of HFACS-FV, further examination is necessary. Ideally, the results of each of these inter-rater reliability methods would demonstrate reliable agreement. Olsen and Shorrock (2010) explored the challenges of inter-rater reliability with the HFACS framework. Issues such as the selection of rating participants from field experts rather than human factors experts, unclear or overlapping category descriptions that produce various interpretations and assessments by the raters, and the usage of inter-rater reliability statistics are a few of these issues. As previously noted, a significant portion of HFACS studies do not report reliability statistics. From the reliability analysis perspective, there are two major obstacles for the type of data provided by the raters. The data was widely characterized by 22 human factors that the raters showed were not present in the vast majority of the accidents. Also, the raters had two choices for each factor: present or not. Both of these challenges were noted by Kraemer et al. (2002):

> It is useful to note that κ = 0 indicates either that the heterogeneity of the patients in the population is not well detected by the raters or ratings, or that the patients in the population are homogeneous. Consequently, it is well known that it is very difficult to achieve high reliability of any measure (binary or not) in a very homogeneous population (P near 0 or 1 for binary measures). That is not a flaw in kappa or any other measure of reliability, or a paradox. It merely reflects the fact that it is difficult to make clear distinctions between the patients in a population in which those distinctions are very rare or fine. In such populations, 'noise' quickly overwhelms the 'signals' (p. 2114).

Another interesting characteristic of kappa calculations occurs when one or more raters select the same rating for each category, which results in a κ = 0, as noted above. SPSS would not perform a kappa calculation in these instances. Consider the following kappa configuration from sample data obtained from this study in Figure 12.

	0	1	
0	20	0	20
1	2	0	2
	22	0	22

Figure 12: Sample kappa configuration showing a rater selecting only one category

This shows the rater represented as the top of the figure selected “0” 20 times and “1” 0 times, while the rater represented at the left of the figure selected “0” 20 times and “1” 2 times. In other words, the first rater did not show that any of the 22 factors were present in the accident.

Recalling Cohen’s kappa equation, the kappa is calculated as:

$\kappa = (((20/22)+0) - ((20/22)*1)+(0*(20/22)))/(1 - (20/22)) = 0.$

Thus, although the percent agreement was 20/22 or 0.909, kappa was not reported for these two raters. Accordingly, Figure 10 does not show mean kappa for those accidents.

A sample of SPSS calculation output is provided in Appendix B. Output files for incident numbers 4709987 and 5940972 show the calculations for the six rating pairs for percent agreement, the kappa statistic, and the Krippendorff’s alpha statistic. These output files highlight the sensitivity of the kappa and Krippendorff’s alpha statistics to minor rating differences. A general observation with these two rating outputs reveals that a slightly reduced mean percent agreement from 90.17% for incident number 4709987 to 87.88% for incident number 5940972 resulted in dramatic increases to the kappa statistic from 0.0618 to 0.5558 and Krippendorff’s alpha from 0.0916 to 0.5521, respectively.

The data shows a degree of confusion of raters for critical factors. Certain factors showed interpretation differences that reduced inter-rater reliability. An analysis of the human factor categories with the lowest mean percent agreement by raters showed decision error, equipment acquisition and support, technical readiness of the crew, and skill-based error. Further, procedures were the most likely to produce disagreements among raters. A review of raters’ scoring sheets indicated inconsistent interpretation between the factors of decision error and skill-based error. While skill-based error relates to improper actions based on inattention to a process or a technique, decision error addresses intentional acts due to poor decisions. Both of the errors possess cognitive and action components, and the data shows that raters appeared to have different understandings of these factors. A mean percent agreement between raters of less than 80% for decision error most likely negatively impacted inter-rater reliability, especially since it was one of the leading consensus human factors. A similar concern exists for equipment acquisition and support as the second leading human factor category. While it is less clear from the data what may have caused the lack of agreement, this factor was also likely for reduced inter-rater reliability.

Overall, the inter-rater reliability shows the need for HFACS-FV method improvements to allow conclusive levels of reliability using the percent agreement, Cohen's kappa, and Krippendorff’s alpha statistics.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

The goal of this work was to establish HFACS-FV as an appropriate model to classify the causal factors that contribute to fishing vessel accidents. The collected data were analyzed for patterns or trends to determine human factors causes in fishing vessel accidents and evaluated to determine whether mitigations can be proposed to prevent future accidents. Overall, although the HFACS-FV variation shows significant potential, the results from this study produced marginal reliability and indicate additional modifications are necessary.

6.1 Support for research questions

In Chapter 1, several research questions were identified as objectives in this study. They are revisited below using the results and the analysis of this research.

Question 1: Is HFACS an appropriate tool for analyzing accidents caused by human factors in the commercial fishing industry?

The first research question was concerned with a discernable pattern or distribution of the human factor categories from the data. The consensus ratings clearly showed the leading categories: physical environment, equipment acquisition and support, decision error, technical readiness of the crew, and allowing unsafe operations. These categories indicate opportunities to reduce accidents that exist with enhanced risk assessment, additional funding for the procurement and maintenance of vessels, and a focus on professional training for the fishing personnel.

Question 2: Does the use of the HFACS framework identify any pattern or consistent distribution of the various human factor categories that contribute to commercial fishing vessel accidents in the United States?

Question 3: Does the data suggest that organizational factors have less impact on commercial fishing vessel accidents in the United States than supervisory or non-supervisory issues?

Question 4: Does the data suggest that latent conditions have less impact on commercial fishing vessel accidents in the United States than active conditions?

Questions two, three, and four are similar in that they attempt to ascertain the distribution of human factors in the consensus rating across the various HFACS tiers of organization, supervisory, preconditions, and unsafe actions by the operator and the degree to which they represent latent or active failures. In general, the data in Figure 9 shows a reasonable distribution across the tiers with unsafe acts as the tier least represented. The tiers of supervisory factors and preconditions are equally represented with the next highest tiers of consensus human factor ratings, followed by the organizational tier. The division of the human factors by tiers is provided in Table 17.

Table 17: Summary of human factors by HFACS-FV tier.

HFACS-FV tier	Total number of human factors from consensus ratings
Organizational influences	30
Unsafe management	27
Preconditions for unsafe acts	30
Unsafe acts	21

Considering the small business nature of the fishing industry, in general, one of the valuable points of this study is that the HFACS tiers are not nearly as important as the HFACS categories and subcategories. This is due to compression of the tiers that realistically eliminates one or more tiers. This also highlights latent and active failures in these accidents. The data overwhelmingly shows latent factors had a much more significant role in these accidents than active failures.

Question 5: Is there any relationship to reliability estimates for identified human factors and the quality of the information provided in the investigation?

The fifth question primarily concerns the degree to which the rater found the investigation to benefit their review for human factors selection. The data showed no relationship to the investigation report to the reliability that was produced. There was a general trend indicating that the investigations were more complete and more valuable to the raters as the length of the fishing vessel increased or the number of fatalities increased. It seems logical that there would be more scrutiny on the investigation report with more people impacted.

6.2 Conclusions

The HFACS-FV method presented in this study was shown to provide valuable information regarding the human factors involved in fatal fishing vessel accidents. Identifying the human factor categories of physical environment, equipment acquisition and support, decision error, technical readiness of the crew, and allowing unsafe operations in the consensus rating provide realistic opportunities for the improvement of safety throughout commercial fishing fleets. The inter-rater reliability measures did not indicate overall method reliability using percent agreement, Cohen's kappa, and Krippendorff’s alpha statistics. However, with method refinements and enhanced category descriptions, a modified HFACS-FV structure could produce sound inter-rater reliability statistics not only for fishing vessels but also provide a generalized tool to analyze accidents occurring in smaller organizations in the transportation and industrial sectors.

6.3 Future study

The process and knowledge obtained from this study provide significant potential for subsequent inquiry in the examination of human error. An analysis of the categories that are utilized and further clarification of their interpretation would be beneficial to any future adaptations and their raters. Also, consideration should be given to modifying the rating choices so that a Likert scale on the presence of a factor is available to the raters. Although this would complicate the rating process, it would provide a better idea of the influence of particular human factors and likely produce more consistent inter-rater reliability calculations.

Small businesses involved in transportation, construction, or other industries that have to balance several concerns, including maintaining a profitable and successful company with a safe workforce, face significant challenges with a smaller workforce. Their concerns, constraints, business models, and organizational structures differ from those of larger or multi-national corporations. A logical expectation that follows is that the accident analysis for these businesses would differ as well. In addition to commercial fishing vessels, small companies in the maritime industry include excursion passenger, charter boat, and towing services. In air transportation and trucking, there are also small businesses in the midst of large companies. This HFACS-FV model could be adapted to these industries and their regulators to examine the human factors involved in their accidents so that they could operate more safely and prevent injuries to operators, employees, or the public.

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APPENDIX A

RATING DATA

Rater 1 assessment:

	Organizational influences						Unsafe management					Preconditions for unsafe acts						Unsafe acts					
Case Number	Human Resources	Equipment Acquisition/Support	Structure	Safety Culture	Procedures	Risk/Systems Management	Technical Readiness of Crew	Supervisory Competency	Improper Operational Risk Management	Allowing Unsafe Operations	Supervisory Violations	Physical Environment	Technological Environment	Mental Readiness	Physical Readiness	Crew Communication	Personal Readiness	Skill-based Errors	Decision Errors	Perceptual Errors	Routine Violations	Exceptional Violations	Data quality (1-very poor, 3-fair, 5-excellent)
3145673	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	3
3146458	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
3170489*	0	1	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4
3205746	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	3
3232874	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
3245496	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	3
3277382	0	0	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	4
3351236	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	3
3362233*	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	4
3372195	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1
3379100	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3
3416568	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
3421895	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
3439089	0	1	0	0	0	0	1	1	0	1	0	0	0	1	0	0	0	0	1	0	1	1	5
3456731	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3481721*	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3
3493014	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3644393	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	2
3654862	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	3
3679151	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3704945	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	4
3709416	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	4
3721448	0	1	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	5
3723468	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	4
3766101*	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
3782157	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	1	1	1	0	4
3795920	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
3877897	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
3913657*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3921416	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	3
3933389	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2
3949541	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	3
3960797*	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	3
4015907*	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
4023152	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	3
4038101	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	4

4054537	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
4222885	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4228449	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4260959	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
4267048*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	4
4269696	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	1	0	0	0	0	0	0	3
4273017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
4308216	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4313311	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	3
4325704	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4
4366498	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2
4368797	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
4381219	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	4
4427722	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	4
4445311	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4452622	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	1	1	4
4486849	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	3
4544170	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	4
4562655*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4590591	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4631791	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3
4646452	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	4
4648308	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3
4668495	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	4
4709987	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3
4731665	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	4
4733433	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
4742290*	0	1	0	1	0	0	0	1	1	1	0	0	1	0	0	0	0	0	1	0	0	0	5
4801133	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	4
4815152	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
4879500	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4891737	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4899684	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
4933257	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2
4991451	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	3
5760341*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	4
5775162	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
5782541	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	4
5800732	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	3
5824759	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
5842397	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3
5865626	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
5940972	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	4
6077682	0	1	0	0	1	0	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	5
6106414*	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	4
6137302	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4
6198783	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
6199558	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
6243679	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4

Rater 2 assessment:

	Organizational influences						Unsafe management					Preconditions for unsafe acts						Unsafe acts					
Case Number	Human Resources	Equipment Acquisition/Support	Structure	Safety Culture	Procedures	Risk/Systems Management	Technical Readiness of Crew	Supervisory Competency	Improper Operational Risk Management	Allowing Unsafe Operations	Supervisory Violations	Physical Environment	Technological Environment	Mental Readiness	Physical Readiness	Crew Communication	Personal Readiness	Skill-based Errors	Decision Errors	Perceptual Errors	Routine Violations	Exceptional Violations	Data quality (1-very poor, 3-fair, 5-excellent)
3145673	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3146458	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	2
3170489*	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
3205746	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	3
3232874	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
3245496	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3277382	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	4
3351236	0	0	0	0	1	0	0	0	0	1	1	1	0	1	0	0	1	0	1	0	0	0	3
3362233*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	3
3372195	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2
3379100	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	2
3416568	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3421895	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2
3439089	0	1	0	0	0	0	1	1	0	1	0	1	0	0	1	1	0	0	1	0	1	1	5
3456731	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
3481721*	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3493014	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
3644393	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3654862	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	3
3679151	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3704945	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3709416	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	3
3721448	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	4
3723468	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	3
3766101*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	3
3782157	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	3
3795920	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3
3877897	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3913657*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3921416	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
3933389	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
3949541	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
3960797*	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	2
4015907*	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4
4023152	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4038101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	3
4054537	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
4222885	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
4228449	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1

4260959	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4267048*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	2
4269696	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	3
4273017	0	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	4
4308216	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4313311	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
4325704	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
4366498	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
4368797	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4381219	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	1	0	0	0	1	0	0	3
4427722	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	2
4445311	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
4452622	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	3
4486849	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4544170	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3
4562655*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4590591	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
4631791	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4646452	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0	0	3
4648308	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3
4668495	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
4709987	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2
4731665	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
4733433	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
4742290*	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	4
4801133	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	3
4815152	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4
4879500	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4891737	0	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4899684	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	3
4933257	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4991451	0	1	0	1	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	4
5760341*	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	3
5775162	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
5782541	0	1	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	3
5800732	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	4
5824759	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	3
5842397	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2
5865626	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
5940972	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
6077682	0	0	0	1	0	0	1	1	0	1	0	1	0	0	0	0	0	0	1	0	0	0	4
6106414*	0	1	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	5
6137302	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
6198783	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
6199558	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
6243679	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5

Rater 3 assessment:

	Organizational influences						Unsafe management					Preconditions for unsafe acts						Unsafe acts					
Case Number	Human Resources	Equipment Acquisition/Support	Structure	Safety Culture	Procedures	Risk/Systems Management	Technical Readiness of Crew	Supervisory Competency	Improper Operational Risk Management	Allowing Unsafe Operations	Supervisory Violations	Physical Environment	Technological Environment	Mental Readiness	Physical Readiness	Crew Communication	Personal Readiness	Skill-based Errors	Decision Errors	Perceptual Errors	Routine Violations	Exceptional Violations	Data quality (1-very poor, 3-fair, 5-excellent)
3145673	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	4
3146458	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	4
3170489*	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
3205746	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	3
3232874	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
3245496	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	3
3277382	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	5
3351236	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	5
3362233*	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	3
3372195	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	3
3379100	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	3
3416568	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	3
3421895	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
3439089	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	5
3456731	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	5
3481721*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
3493014	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2
3644393	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2
3654862	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
3679151	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
3704945	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	3
3709416	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	4
3721448	0	1	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	5
3723468	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	4
3766101*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
3782157	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	5
3795920	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
3877897	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3913657*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3921416	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3
3933389	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	3
3949541	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
3960797*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	2
4015907*	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4
4023152	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
4038101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	3
4054537	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4222885	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4228449	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1

4260959	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4267048*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	2
4269696	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	4
4273017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	3
4308216	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4313311	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
4325704	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	3
4366498	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
4368797	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
4381219	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	1	0	1	0	0	0	0	5
4427722	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	3
4445311	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4
4452622	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	4
4486849	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4
4544170	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	4
4562655*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4590591	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
4631791	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4646452	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	4
4648308	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
4668495	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
4709987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
4731665	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	4
4733433	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
4742290*	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	4
4801133	0	0	0	0	1	0	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	5
4815152	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	3
4879500	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
4891737	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
4899684	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
4933257	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4991451	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
5760341*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
5775162	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	3
5782541	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	1	0	0	0	4
5800732	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	4
5824759	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
5842397	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	4
5865626	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
5940972	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	4
6077682	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	4
6106414*	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	4
6137302	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4
6198783	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
6199558	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
6243679	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	5

Rater 4 assessment:

	Organizational influences						Unsafe management					Preconditions for unsafe acts						Unsafe acts					
Case Number	Human Resources	Equipment Acquisition/Support	Structure	Safety Culture	Procedures	Risk/Systems Management	Technical Readiness of Crew	Supervisory Competency	Improper Operational Risk Management	Allowing Unsafe Operations	Supervisory Violations	Physical Environment	Technological Environment	Mental Readiness	Physical Readiness	Crew Communication	Personal Readiness	Skill-based Errors	Decision Errors	Perceptual Errors	Routine Violations	Exceptional Violations	Data quality (1-very poor, 3-fair, 5-excellent)
3145673	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
3146458	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4
3170489*	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4
3205746	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	4
3232874	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3
3245496	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	2
3277382	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3351236	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2
3362233*	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	4
3372195	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
3379100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3416568	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3421895	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3439089	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	3
3456731	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
3481721*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
3493014	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
3644393	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3654862	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3679151	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
3704945	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2
3709416	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	3
3721448	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	3
3723468	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	2
3766101*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
3782157	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	3
3795920	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3877897	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3913657*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
3921416	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
3933389	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3949541	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2
3960797*	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	3
4015907*	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4
4023152	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4038101	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
4054537	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
4222885	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4228449	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

4260959	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4267048*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4269696	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	3
4273017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2
4308216	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4313311	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
4325704	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4366498	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
4368797	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4381219	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4427722	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	2
4445311	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4452622	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	4
4486849	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4544170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4562655*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4590591	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
4631791	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4646452	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4648308	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3
4668495	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
4709987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
4731665	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2
4733433	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
4742290*	0	1	0	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	4
4801133	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4815152	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
4879500	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4891737	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4899684	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
4933257	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4991451	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	2
5760341*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	2
5775162	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
5782541	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2
5800732	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	1	0	4
5824759	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
5842397	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3
5865626	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
5940972	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	3
6077682	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
6106414*	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	4
6137302	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	4
6198783	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
6199558	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
6243679	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5

Consensus rating:

	Organizational influences						Unsafe management					Preconditions for unsafe acts						Unsafe acts				
Case Number	Human Resources	Equipment Acquisition/Support	Structure	Safety Culture	Procedures	Risk/Systems Management	Technical Readiness of Crew	Supervisory Competency	Improper Operational Risk Management	Allowing Unsafe Operations	Supervisory Violations	Physical Environment	Technological Environment	Mental Readiness	Physical Readiness	Crew Communication	Personal Readiness	Skill-based Errors	Decision Errors	Perceptual Errors	Routine Violations	Exceptional Violations
3145673	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
3146458	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3170489*	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3205746	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
3232874	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3245496	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
3277382	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3351236	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
3362233*	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
3372195	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
3379100	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
3416568	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
3421895	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3439089	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
3456731	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3481721*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3493014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3644393	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3654862	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
3679151	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
3704945	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3709416	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
3721448	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3723468	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
3766101*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3782157	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
3795920	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3877897	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3913657*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3921416	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3933389	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
3949541	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3960797*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
4015907*	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
4023152	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4038101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
4054537	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4222885	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4228449	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4260959	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4267048*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
4269696	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4273017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
4308216	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4313311	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
4325704	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4366498	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
4368797	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4381219	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
4427722	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
4445311	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4452622	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
4486849	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4544170	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4562655*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4590591	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
4631791	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4646452	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4648308	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4668495	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
4709987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4731665	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
4733433	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
4742290*	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0
4801133	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4815152	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
4879500	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4891737	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4899684	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
4933257	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4991451	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5760341*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
5775162	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
5782541	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
5800732	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
5824759	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
5842397	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5865626	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5940972	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6077682	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
6106414*	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
6137302	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
6198783	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
6199558	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6243679	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: * indicates training cases

APPENDIX B

SAMPLE SPSS OUTPUT

SPSS output for accident # 4709987.

rater_diff12

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	1	4.5	4.5	4.5
	0	21	95.5	95.5	100.0
	Total	22	100.0	100.0	

rater_diff23

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	1	4.5	4.5	4.5
	0	19	86.4	86.4	90.9
	1	2	9.1	9.1	100.0
	Total	22	100.0	100.0	

rater_diff34

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	1	4.5	4.5	4.5
	0	20	90.9	90.9	95.5
	1	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

rater_diff41

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	1	4.5	4.5	4.5
	0	20	90.9	90.9	95.5
	1	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

rater_diff13

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	1	4.5	4.5	4.5
	0	20	90.9	90.9	95.5
	1	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

rater_diff24

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	1	4.5	4.5	4.5
	0	19	86.4	86.4	90.9
	1	2	9.1	9.1	100.0
	Total	22	100.0	100.0	

Rater1 * Rater2 Crosstabulation

		Rater2		
		Factor not present	Factor present	Total
Rater1	Factor not present	20	1	21
	Factor present	0	1	1
Total		20	2	22

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	.645	.324	3.237	.001
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Rater2 * Rater3 Crosstabulation

		Rater3		
		Factor not present	Factor present	Total
Rater2	Factor not present	19	1	20
	Factor present	2	0	2
Total		21	1	22

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	-.065	.046	-.324	.746
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Rater3 * Rater4 Crosstabulation

		Rater4		
		Factor not present	Factor present	Total
Rater3	Factor not present	20	1	21
	Factor present	1	0	1
Total		21	1	22

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	-.048	.034	-.223	.823
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Rater4 * Rater1 Crosstabulation

		Rater1		
		Factor not present	Factor present	Total
Rater4	Factor not present	20	1	21
	Factor present	1	0	1
Total		21	1	22

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	-.048	.034	-.223	.823
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Rater1 * Rater3 Crosstabulation

		Rater3		
		Factor not present	Factor present	Total
Rater1	Factor not present	20	1	21
	Factor present	1	0	1
Total		21	1	22

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	-.048	.034	-.223	.823
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Rater2 * Rater4 Crosstabulation

		Rater4		
		Factor not present	Factor present	Total
Rater2	Factor not present	19	1	20
	Factor present	2	0	2
Total		21	1	22

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	-.065	.046	-.324	.746
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

```
kalpha judges = Rater1 Rater2 Rater3 Rater4/level = 1/detail = 0/boot =
10000.

Run MATRIX procedure:

Krippendorff's Alpha Reliability Estimate


             Alpha    LL95%CI    UL95%CI      Units    Observrs      Pairs
Nominal      .0916     -.3976      .5108    22.0000      4.0000   132.0000

Probability (q) of failure to achieve an alpha of at least alphamin:
   alphamin         q
      .9000    1.0000
      .8000     .9999
      .7000     .9975
      .6700     .9975
      .6000     .9913
      .5000     .9521

Number of bootstrap samples:
  10000

Judges used in these computations:
 Rater1   Rater2   Rater3   Rater4

Examine output for SPSS errors and do not interpret if any are found

------ END MATRIX -----
```

SPSS output for accident # 5940972.

rater_diff12

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	1	4.5	4.5	4.5
	0	20	90.9	90.9	95.5
	1	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

rater_diff13

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	3	13.6	13.6	13.6
	0	18	81.8	81.8	95.5
	1	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

rater_diff23

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	2	9.1	9.1	9.1
	0	20	90.9	90.9	100.0
	Total	22	100.0	100.0	

rater_diff24

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	1	4.5	4.5	4.5
	0	20	90.9	90.9	95.5
	1	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

rater_diff34

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	1	4.5	4.5	4.5
	0	18	81.8	81.8	86.4
	1	3	13.6	13.6	100.0
	Total	22	100.0	100.0	

rater_diff41

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-1	1	4.5	4.5	4.5
	0	20	90.9	90.9	95.5
	1	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Rater1 * Rater2 Crosstabulation

		Rater2		
		Factor not present	Factor present	Total
Rater1	Factor not present	18	1	19
	Factor present	1	2	3
Total		19	3	22

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	.614	.249	2.880	.004
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Rater1 * Rater3 Crosstabulation

		Rater3		
		Factor not present	Factor present	Total
Rater1	Factor not present	16	3	19
	Factor present	1	2	3
Total		17	5	22

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	.397	.240	1.954	.051
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Rater2 * Rater3 Crosstabulation

		Rater3		
		Factor not present	Factor present	Total
Rater2	Factor not present	17	2	19
	Factor present	0	3	3
Total		17	5	22

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	.699	.194	3.437	.001
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Rater2 * Rater4 Crosstabulation

		Rater4		
		Factor not present	Factor present	Total
Rater2	Factor not present	18	1	19
	Factor present	1	2	3
Total		19	3	22

Symmetric Measures

		Value	Asymptotic Standard Error^a	Approximate T^b	Approximate Significance
Measure of Agreement	Kappa	.614	.249	2.880	.004
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Rater3 * Rater4 Crosstabulation

		Rater4		
		Factor not present	Factor present	Total
Rater3	Factor not present	16	1	17
	Factor present	3	2	5
Total		19	3	22

Symmetric Measures

		Value	Asymptotic Standard Error^a	Approximate T^b	Approximate Significance
Measure of Agreement	Kappa	.397	.240	1.954	.051
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Rater4 * Rater1 Crosstabulation

		Rater1		
		Factor not present	Factor present	Total
Rater4	Factor not present	18	1	19
	Factor present	1	2	3
Total		19	3	22

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	.614	.249	2.880	.004
N of Valid Cases		22			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

```
kalpha judges = Rater1 Rater2 Rater3 Rater4/level = 1/detail = 0/boot =
10000.



Run MATRIX procedure:

Krippendorff's Alpha Reliability Estimate


              Alpha      Units    Obsrvrs      Pairs
Nominal       .5521    22.0000     4.0000   132.0000

Judges used in these computations:
 Rater1   Rater2   Rater3   Rater4

Examine output for SPSS errors and do not interpret if any are found

------ END MATRIX -----
```

VITA

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