Identifying Opportunities of Tracking Major Human Factors Risks through Flight Data Monitoring

by

Jingru Yan

A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Applied Science

in

Systems Design Engineering

Waterloo, Ontario, Canada, 2014

AUTHOR'S DECLARATION

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

Material covered in Chapter 2 and Chapter 4 of this thesis has previously been published in:

Yan, J., & Histon, J. M. (2013) Flight Data Monitoring and Human Factors Risks Identification: A Review of Best Practices. *Canadian Aeronautics and Space Institute 60th Aeronautics Conference and Annual General Meeting*, April 30-May 2, 2013, Toronto, Ontario.

Statement of contributions of this paper:

Author	Statement of Contributions
Yan, J. (Candidate)	Conceptual design (80%) Model Development (70%) Writing and Editing (70%)
Histon, J.M.	Conceptual design (20%) Model Development (30%) Writing and Editing (30%)

Material covered in Chapter 3 of this thesis has previously been published in:

Yan. J., & Histon, J. M. (2014) Identifying Major Human Factors Risks in North American Airline Operations: A HFACS Analysis of Accident and Incident Investigation Reports. In *Proceedings* of *Human Factors and Ergonomics 2014 International Annual Meeting* (Vol. 58, No. 1, pp. 120-124), October 27-31, 2014, Chicago, Illinois.

Statement of contributions of this paper:

Author	Statement of Contributions
Yan, J. (Candidate)	Conceptual design (80%) Data Collection and Analysis (100%) Writing and Editing (80%)
Histon, J.M.	Conceptual design (20%) Writing and Editing (20%)

Abstract

It is widely believed that human factors risks contribute to more than half of the aviation accidents (Shappell et al., 2007). Thus, aviation safety risk identification, and in particular human factor risk identification, is one of the crucial components in today's aviation safety management systems. There is a need to identify examples of major human factors risks in recent years in the industry and track the exposure of these risks in an individual airline's own operation routinely. Flight Data Monitoring (FDM) is a systematic and proactive program (Civil Aviation Authority, 2013), which aims to improve aviation safety by collecting and analyzing digital flight data. Since the flight data is able to provide objective and up-to-date information of routine flight performance, this program has the potential to contribute to the identification of the existence and status of the some major human factors risks in airlines' routine operations. However, current FDM data is not widely used to proactively monitor and track human factors issues.

This thesis presents an initial analysis of the potential of using FDM data for identifying and tracking human factors risks. As a first step, in order to obtain insights into the current key human factors risks in the North American commercial aviation operations, the Human Factors Analysis and Classification System (HFACS) was used to categorize 267 accident and incident final reports from 2006 to 2010. Semi-structured interviews have also been conducted to identify and understand major and projected human factors issues from the airline operators' perspectives. By combining the results obtained from two methods, examples of perceived major human factors risks in current operations are determined. The current top risks of concern include Standard Operational Procedures (SOPs) noncompliance, fatigue, distraction, communication issues, inadequate situation awareness, training issues, pressure, and high workload.

In order to assess the potential opportunities of tracking these top human factors risks in airline operations through FDM, current FDM process, applications, best practices and recorded flight parameters were studied. A literature review, field observations, and interviews with experienced safety investigators and flight data analysts were conducted. Models of general FDM process, event setting process, and daily review workflow are presented and human performance related flight parameters are categorized into seven classes.

Finally, opportunities and two potential approaches of using FDM to track some major human factors risks have been identified. These two approaches have the potential of being embedded into current FDM processes are 1) setting up new human factors events (HF events) and 2) conducting specific human factors focused studies (HF studies). Implementation examples demonstrating how these two approaches can be applied to track some major human factors, including automation confusion, high workload, and on time pressure are provided. For example, a proposed "automation mode confusion event" is recommended especially for new type of aircrafts (e.g., the Boeing 787), where new pilots are interacting with new operational environments. Applications of the potential approaches, recommendations to commercial airlines, and future work of this study are also discussed.

Acknowledgements

I first would like to express my sincere gratitude to my supervisor, Dr. Jonathan Histon from the Department of Systems Design Engineering at the University of Waterloo. His guidance, support, and motivation not only helped me in pursuing my master study but also my future career in aviation safety management.

I would also like to express my sincere appreciation to all the aviation safety and flight data experts who have participated in my studies for their participation, guidance, and support in this research project. I was able to complete the studies because of their generous help.

I would like to thank Dr. Catherine Burns and Dr. Frank Saccomanno for being the readers of my thesis. Their comments and feedback were essential in completing this thesis.

I would like to thank my colleagues in the HCOM, CSL, and AIDL. Colin Dow, Xiaochen Yuan, Samuel Lien, and Meshael Alqahtani, I want to thank them all for their support, help, and encouragement during my master study.

I gratefully acknowledge the National Science and Engineering Research Council of Canada for funding this research project through the Engage Grant.

Dedication

To my family Dad, Mom, and Cheng:

I dedicate this thesis to you.

Thank you for bringing me to this wonderful world

and guiding me through all the difficulties.

I love you all forever.

Table of Contents

List of Figures

List of Tables

Chapter 1
Introduction

On February 12th, 2009, Colgan Air Flight 3407 lost control on its approach and crashed near Buffalo Airport in the United States of America. Fifty people died and four people on the ground were seriously injured in this crash. The investigation conducted by the National Transportation Safety Board (NTSB) indicated that the aircrew's failure to appropriately control the airplane system was the direct cause of the accident. In addition, a series of supervisory and organizational issues were also identified as underlying contributing factors to this tragedy, including inadequate training, inappropriate crew scheduling, and inadequate fatigue management (NTSB, 2010). Such risks are all examples of human factors risks, a known and common threat to aviation safety.

Similar issues have been cited as probable causes and contributing factors in many previous aviation occurrences. Research shows that approximately 60% to 80% of the aviation accidents today are related to human errors (Shappell et al., 2007). Although significant efforts have been made to prevent human errors, these risks still exist in today's airline operations. Moreover, projected increases in air traffic worldwide (ICAO, 2012), the development of increasingly sophisticated forms of automation (Sarter, Woods, & Billings, 1997), and changes in the operational environment have the potential to introduce new types of human factors risks. Because of the quick evolving operational environment, the traditional approach of identifying problems only after they have led to an accident cannot satisfy the needs of future risk management.

New ways of proactively identifying existing and emerging risks are needed. As a first step, it is useful to identify examples of major human factors risks in recent years in the industry and routinely track the exposure of these risks in an individual airline's own operation. A more accurate and comprehensive data source and a more proactive and systematic human factors risk identification method are needed for airlines to monitor the human factors risks, especially the current major issues, in routine operations.

Flight data, which records aircraft operations and performances through all phases of the flight, is often thought of primarily as a resource in accident investigation. However, advances in technology and processes have provided new opportunities to collect, analyze, and act on flight data as a part of routine flight safety operations. Flight data has now become one of the major information sources for line operational performance management due to the establishment of the Flight Data Monitoring (FDM) program in many countries and major airlines during the past decade. Since this program is able to provide objective and up-to-date information of aircraft and aircrew performance, there might be the potential for airlines to use flight data to track and analyze the major human factors issues in routine operations, and even identify the emerging issues. However, this has not been done yet. Research work is needed to explore the potential.

This thesis aims to identify the opportunity on how existing FDM processes could be modified to track human factors risks, particularly some major human factors risks of current concerns in order to improve airlines risk management.

1.1 The Challenge of Identifying Aviation Human Factors Risks

Studies of human factors related issues can be found from the earliest days of aviation. Those earliest studies mainly focused on the welfare of the operators and their capabilities to adapt to the systems (Koonce & Debons, 2011). Human factors concepts continue to evolve over time. In particular, the viewpoint that a complex system is more reliable than human operators is slowly decreasing (Dekker, 2000), being replaced by the recognition that the human operator is the center of complex system design and that human errors are indications of irreconcilable goals and pressures farther upstream (Dekker, 2000). Since the 1990s, the focus of identifying and mitigating human factors risks has shifted from making humans adapt to the system to understanding the root causes of human errors and modifying design, training, and procedures to help human operators perform better (Li & Harris, 2006).

However, a major challenge that current human factors risk identification is facing is the lack of an objective and comprehensive data source and a data driven identification method. Based on the literature review (Chapter 2), interviews, and field observations (Chapter 3 and Chapter 4) conducted in this thesis, traditional human factors risk management is usually conducted based on reported events and safety audits. Thus, human factors issues are only able to be detected through safety reports after the occurrences. This approach is limited because safety reports are descriptive data which describe the occurrences from the reporters' opinions. Also, some information might be lost or covered up if the reporters neglect it or choose not to report it. For example, pilots might narrate the event in their own understanding or they might omit one or two human factors related facts that they think are not important in the report, thereby causing self-reporting or self-selected bias (Leroux, Rizzo, & Sickles, 2012; Olsen, 2008). The bias of the reporters will inevitably influence the results of risk identification.

As discussed above, an FDM program collects accurate and up-to-date flight performance information which provides an opportunity for data driven identification of the human factors risks. However, based on the literature review, there are no practices or previous research on using FDM to proactively monitor the human factors issues in daily operations. Some related work has been done, but no systematic method has been developed. Challenges of exploring such opportunities and potential approaches include how to interpret human factors related information through the digital flight data and how to embed the method into current FDM activities. These are challenges this thesis aims to address in the following chapters.

1.2 Flight Data Monitoring

Flight data analysis has long been used to investigate aviation incidents and accidents. In recent years, it has been recognized that these same tools may be used to review routine data to reveal underlying trends and risks in operational line flying. FDM is a "systematic, proactive and non-punitive program" (Civil Aviation Authority, 2013), which aims to provide "greater insight into the total flight operations environment" (Transport Canada, 2001) to improve aviation safety by collecting and analyzing digital flight data generated from routine operations.

Since the 1990s, modern safety theories have started to view and manage aviation safety from a systematic and organizational perspective, which is the basis of the current Safety Management Systems (SMS). SMS include a series of documented processes that focus on proactive risk identification and continuous risk mitigation to ensure aviation safety in the industry. Safety oversight of daily operational performance is one of the important components in SMS. FDM, which serves as one of the "reporting nodes" for safety oversight in SMS (Transport Canada, 2004), has become a significant method of risk management in many airlines. FDM is now being employed globally to prevent accidents, improve flight safety enhance, and operational efficiency. In addition, it has the potential for tracking some of the human factors challenges since it provides objective information of aircraft and aircrew performances in daily operations.

1.3 Research Scope and Objectives

Aviation human factors risks include a wide range of issues from human capabilities, limitations, perceptions, and interactions with the complex system to organizational and environmental influences. Covering all these topics is beyond the scope of this research. The goal of this thesis is to identify potential opportunities and potential approaches to use FDM track some major human factors issues airlines are currently facing. To achieve the thesis goal, three specific objectives are defined and described as follows:

Objective 1—Identify examples of major human factors risks in current airline operations in North America.

The major human factors risks in current operations are the risks of interest that airlines wish to track through FDM. As well, understanding the current major risks will help identify and develop potential approaches. Thus, the first objective of the thesis is to identify examples of major human factors risks in current operations.

To identify the major human factor risks that need to be monitored through FDM, accident and incident data from North America in the most recent five years, for which relatively complete accident and incident investigations are available (2006 to 2010) was examined using the Human Factors Analysis and Classification System (HFACS). The data were collected from accident and incident investigation reports published by Canadian and US transportation safety boards. A literature review on previous research of HFACS analysis and application of accident investigations was done. Interviews with aviation safety experts were also conducted to obtain insights into airline operators' perceptions of current major and upcoming human factors issues. The results from two methods were compared and a list of examples of major human factors challenges is presented in Chapter 3.

Objective 2— Understand current FDM practices and flight parameters available in current FDM analyses.

Understanding current FDM practices is the basis of exploring new opportunities to track human factors risks. A literature review was done to develop insights into the backgrounds of digital flight data, flight data analysis tools, and current FDM practices and applications. To better understand the FDM process and event setting logic, field observations and semi-structured interviews were conducted through multiple visits to a major North American air carrier's FDM department. Flight data analysis software, data analysis procedures, and the event programming process were studied during the field observations. These software, tasks, and procedures are core components of the entire FDM process. The interviews with FDM experts also helped with understanding the current FDM activities. Questions with respect to the current FDM activities and event settings were asked and answers were collected. Based on the core components and findings identified from the field observations and interviews, as well as the literature review, three models, describing FDM processes, have been developed in Chapter 4.

In addition, a study of recorded flight parameters was done in order to identify parameters relevant to aircrew performance, which have the potential to reflect human factors relates issues during the flight. Regulations on digital flight data were also reviewed.

Objective 3—Identify potential approaches of using FDM to track some major human factors risks.

Based on the findings identified from Objectives 1 and 2, opportunities of tracking some example major human factors issues through FDM were identified. Two potential approaches based on the identified opportunities are proposed in Chapter 5. Detailed processes and application instructions of the two preliminary approaches are developed. Implementation examples of some major human factors risks are also presented to demonstrate how to apply the respective approaches.

These three objectives and the methods used to achieve them are captured in Figure 1.1:

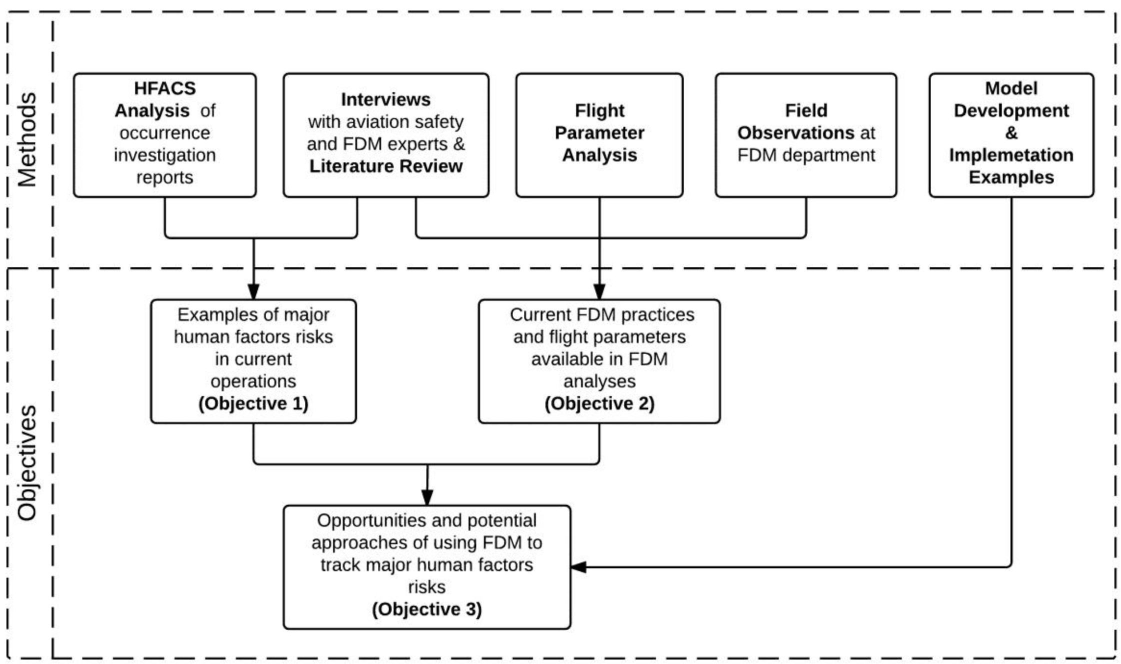


Figure 1.1 Research Methods and Objectives

1.4 Thesis Organization

The remainder of the thesis is organized as follows:

- **Chapter 2: Background** contains an introduction of basic concepts regarding the theme of this thesis and a review of previous research related to aviation human factors identification and FDM applications.
- **Chapter 3: Major Aviation Human Factors Risks** presents the research methods and findings of identifying major aviation human factors in current operations. HFACS analysis of past five years occurrences in North America and interviews with ten aviation safety experts with respect to major human factors risks are presented. The results obtained from two methods are compared and examples of major human factors risks of current concern are summarized in this chapter. Objective 1 of the research will be achieved through Chapter 3.
- **Chapter 4: Current FDM Processes and Flight Parameter Analysis** presents the methods and findings with respect to the current FDM processes and analysis of flight parameters. Three models describing general FDM process, event setting process and daily activities are presented in this chapter. Classification of the recorded flight parameters based on their relevance to aircrew's actions and awareness are also discussed. Objective 2 will be achieved through this chapter.
- **Chapter 5: Potential Approaches of Tracking Human Factors Risks through FDM** proposes the potential approaches of using FDM to monitor some major human factors risks. Detailed processes and potential implementation examples of applying the two approaches in tracking some of the major risks are provided. Limitations and concerns are also discussed. Objective 3 will be achieved through this Chapter.
- **Chapter 6: Conclusion** summarizes key findings of this thesis and proposes recommendations and future research opportunities.

Chapter 2
Background

This chapter presents a review of previous research related to the analyses of aviation human factors risk and the application of Flight Data Monitoring (FDM). The following sections of this chapter discuss the previous studies in the research areas of aviation human factors theory, human factors risk identification methods, FDM, and human factors focused FDM applications. This chapter also discusses the limitations of previous work in solving some human factors risk identification challenges discussed in Chapter 1. In addition, how previous research can be applied in this thesis to better achieve the research objectives is discussed.

The literature sources reviewed include books, prescriptive documents, reports, meeting proceedings, and research papers in the field of aviation human factors research and FDM. Examples of reviewed materials include the International Civil Aviation Organization (ICAO) regulations, Transport Canada and Federal Aviation Administration (FAA) publications, National Aeronautics and Space Administration (NASA) project reports, and research papers from academics.

2.1 Accident Causation Theory

An accident is “a short, sudden, and unexpected event or occurrence that results in an unwanted and undesirable outcome” (Hollnagel, 2004). In the aviation industry, ICAO defines accident as “an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which a person is fatally or serious injured, the aircraft sustains damage or structural failure, or the aircraft is missing or completely inaccessible” (ICAO, 2001).

The understanding of accident causations is essential to accident prevention. Various accident causation theories and models presenting different approaches of accident investigations and analysis exist such as the Reason Model (1990) and Heinrich’s Law (1950). The perception of accident causation has evolved over time from concentrating on hardwire failures to human factors viewpoints. Instead of simply blaming the operators, modern safety theories espouse that accidents are caused by a series of failures from organizational level to the operational level. It is now widely accepted that such failures arise from the interactions between human and operational systems. Reason’s Model, also known as the Swiss Cheese Model, which describes the dynamics of accident causations from “latent failures” to “active failures” (Reason, 1990), is the most common applied model of this accident causation theory (Salmon, 2011).

The Swiss Cheese Model likens human operational systems to four slices of swiss cheese, each representing a level of failure in the operational system—Unsafe Acts, Preconditions of Unsafe Acts, Unsafe Supervision, and Organizational Influences. Reason believes that unsafe acts are the direct cause of the accident; and when there are unsafe acts, there must be some preconditions that lead to the unsafe acts. In addition to these two levels of “active failures”, there are also “latent failures”, which refer to the supervisory and organizational level issues. The decisions and supervisions from upper level management are sometimes the underlying causes of unsafe acts and unsafe preconditions (Reason, 1990). However, supervisory and organizational level issues are latent because they are not as easy to discover as operator’s mistakes. This model shows that cumulative effects of the four levels of failure or absent defenses at any link (e.g., protective equipment, training, regulations and rules) will finally trigger mishaps.

The Swiss Cheese Model has driven the establishment of many significant human factors risk identification methods (Salmon, 2011). For example, the Human Factors Analysis and Classification System (HFACS) (Shappell & Wiegman, 2003), is used as a major method to identify the example key human factors risks in this research (Section 3.2).

2.2 Human Factors Risk Identification Methods

Various methods have been developed to identify and analyze human factors risks. Generally, there are two major types of methods to study human factors risks.

(1) Directly identify human factors risks through reports and events from daily routine operations using human factors analysis tools and models such as HFACS (Shappell & Wiegman, 2003), the SHEL Model (ICAO, 1989), and the PEAR Model (Johnson & Maddox, 2007). This kind of risk identification relies on data sources including safety reports, safety audits, and external information shared by other parties.

(2) Conduct human factors experiments. Recruit participants and measure participants’ physical and psychological data, as well as their performance using questionnaires and equipment in real operations or simulation scenarios. Based on the measurement results, human factors related issues such as fatigue and workload can be assessed and analyzed.

2.2.1 HFACS

The HFACS is expanded from the Swiss Cheese Model by Shappell and Wiegmann (2001). This classification system categorizes human operation failures into four levels, which are same as the four levels in the Swiss Cheese Model. The HFACS further divided the four levels of failure into 19 sub-categories (Table 1) (Shappell & Wiegmann, 2001). It bridges the gap between theory and practice (Shappell & Wiegmann, 2001) and provides a tool for the identification and classification of the underlying causes of operational errors in aviation accidents and incidents (Li & Harris, 2006). Each sub-category has detailed description and examples; however, detailed explanation of HFACS is beyond the scope of this thesis, a brief explanation and some examples for each category are listed in Appendix A.

Table 2-1 The HFACS Framework (adapted from Shappell & Wiegmann, 2001)

<table>
<tr><th colspan="7">Level 1 Unsafe Acts</th></tr>
<tr><th colspan="4">Errors</th><th colspan="3">Violations</th></tr>
<tr><td>Decision Errors</td><td colspan="2">Skill-Based Errors</td><td>Perceptual Errors</td><td>Routine Violations</td><td colspan="2">Exceptional Violations</td></tr>
<tr><th colspan="7">Level 2 Preconditions For Unsafe Acts</th></tr>
<tr><th colspan="2">Environmental Factors</th><th colspan="3">Condition of Operators</th><th colspan="2">Personnel Factors</th></tr>
<tr><td>Physical Environment</td><td>Technological Environment</td><td>Adverse Mental State</td><td>Adverse Physiological State</td><td>Physical/ Mental Limitations</td><td>Crew Resource Management</td><td>Personal Readiness</td></tr>
<tr><th colspan="7">Level 3 Unsafe Supervision</th></tr>
<tr><td colspan="2">Inadequate Supervision</td><td colspan="2">Planned Inappropriate Activates</td><td colspan="2">Failed to Correct Problem</td><td>Supervisory Violation</td></tr>
<tr><th colspan="7">Level 4 Organizational Influence</th></tr>
<tr><td colspan="3">Resource Management</td><td colspan="2">Organizational Climate</td><td colspan="2">Operational Process</td></tr>
</table>

The HFACS framework was first developed for aviation, and has been widely applied and evaluated in other domains, including road and maritime transportation (Celik & Er, 2007; Iden & Shappell, 2006), mining (Lenné, Salmon, Liu, & Trotter, 2012) and healthcare (Diller et al., 2013). Many studies using HFACS in aviation accident analyses show a common trend of Unsafe Acts (e.g., operator errors and violations) and Preconditions of Unsafe Acts (e.g., weather, technical environment, distractions, and fatigue) as the most prominent human factors risks (W. Li, Harris, & Yu, 2008; Shappell et al., 2007; Williams, 2011). However, organizational management inadequacies also proved crucial in safety management and accident prevention (Li & Harris, 2006). When

Shappell et al. (2007) analyzed the US commercial aviation accident data from 1990 to 2002, and they found that the majority of accident causal factors was attributed to aircrew errors and environment. Also, skill-based error and decision-error accidents were most prevalent. Shappell and Wiegmann (2004) also compared human factors risks between the North American military and civil accidents, as well as some specific types of accident analysis using HFACS (Shappell & Wiegman, 2003).

Williams (2011) found similar results to Shappell and Wiegmann's in his analysis of fatal and serious accidents in Alaska from 2004 to 2009. HFACS has also been adopted in other countries outside North America. Li, Hrris, & Yu (2008) analyzed 41 civil aviation accidents that happened during 1999 to 2006 in Taiwan. The results show statistically significant relationships between errors at the operational and organizational level. In Li and Harris (2006), the focus of HFACS application is more on the organizational level. Similar research has been done in several other countries (e.g., (Daramola, 2014)). These studies testify to HFACS's merits in identifying aviation human factors risks and provide valuable statistical results.

However, the North American accident data used in previous research was from 1990-2002. With the development of technology and world air traffic since then, the pattern of prominent human factors risks might change, and new types of risks might appear. Thus, updating the results to map with the rapidly changing operational environment is necessary. The most recent years' data are valuable information to airlines' safety management. The key issues identified from occurrences in recent years are the risks of interest that airlines need to keep track of in their daily operations. Thus, the development of potential approaches using FDM to track human factors risks will focus on these major issues.

Moreover, almost all the previous analyses concentrate only on accident data; whereas, incident data are equally valuable in providing risk information (Ward, 2012). Billings and Reynard (1984) conducted a seven-year study of human factors in aircraft incidents. Their results indicate that aviation incident reports are very important to safety supervision because incidents usually involve the same elements as accidents in causal factors analysis. Therefore, the first step of this research, as presented in Chapter 3 of this thesis, aims to determine some examples of major human factors risks that occurred most frequently during the recent 5-year time period (2006 to 2010) for which relatively complete both accident and incident investigations in North America are available.

2.2.2 Other Human Factors Model

Besides the HFACS framework, there are other human factors models, such as the SHEL Model and the PEAR Model. These two models are named after the initial letters of their components' names, and are introduced in the following paragraphs. These human factors models identify and examine the human factors issues within the interactions between the individual and other components of the system (Molloy & O'Boyle, 2005).

The SHEL Model, often presented as the form shown in figure 2.2 concentrates on the interactions between Liveware (the operator) and four other human factors components in the system: Software, Hardware, Environment, and other Liveware. This concept was first developed by Edwards (1973). It was proposed by the ICAO (1989) as a method of aviation human factors risk identification.

Figure 2.1 The SHEL Model (Image adapted from ICAO, 1989)

Liveware refers to the human operators in the system, such as flight crews, engineers, maintenance personnel, and administration people. This is the most critical component in the model. Other components need to match the operators in order to mitigate the risks. On the other hand, the operators are easily affected by external and internal influences. Software includes the rules, procedures, written documents, and regulations. Hardware refers to the functional systems including equipment, displays, and machines. Environment refers to the social and economic climate in which other parts of the system are operating, as well as the natural environment. It considers the features of each component and the task, and helps to identify the human factors issues and design the most appropriate software, hardware, environment and team to perform the task.

The PEAR Model is similar to the SHEL Model, but focuses on the aviation maintenance area. It has four considerations for assessing human factors risks in aviation maintenance: "People" who perform the task, “Environment” where the task is performed, “Actions” the operators perform, and “Resources” which are needed to complete the task (Johnson & Maddox, 2007). Each of the four factors is associated with different human factors issues such as operator’s physical and psychological status and organizational environment. These factors need to be considered as possible issues while applying this model in human factors risks identification.

These two human factors models have been used as tools to identify possible risks of operational tasks or risks in the operational system. Comparing to these two models, the HFACS framework is more detailed and systematic in classifying and statistical analyzing the human factors causations of existing problems. Thus, the HFACS framework is used to analyze the investigation reports of previous occurrence and identify the major human factors related causations in Chapter 3.

2.2.3 Human Performance Measurement

Human performance measurement is another approach to track human factors issues. This kind of testing requires experiment design, participant recruitment, data collecting, and analysis. Normally, the purpose of the experiment is to measure the participants’ physical and mental data and their performance when conducting the tasks in real working environment or simulation scenarios. The measurements can be done using questionnaires, equipment or other techniques. Based on the measurement results, human factors related issues such as fatigue and workload can be analyzed.

For example, numerous studies have been conducted to analyze fatigue issues using various measuring methods. These measurements include subjective self-evaluation reports, physiological measuring techniques such as actigraphy and polysomno-graphy, which collect objective indicators of fatigue (Lee, Bardwell, Ancoli-Israel, & Dimsdale, 2010). In the 1980s, a new objective fatigue assessing technique was introduced and has been developed gradually during the past decades, which is known as the Psychomotor Vigilance Task (PVT). Studies shown that the PVT is sensitive to sleep loss (Dinges & Powell, 1985) and subject performance in the PVT can also be a practical measurement of fatigue (Lee, Bardwell, Ancoli-Israel, & Dimsdale, 2010). Similar techniques, for example, self-evaluation questionnaires like the NASA Task Load Index (Hart & Staveland, 1988), physiological measurement of heart rate, eye movement (Klinger, Gregoire & Barta, 1973), as well as the Situation Awareness Global Assessment Techniques (SAGAT) (Endsley, 1988) are also used in measuring other popular human factors topics (e.g., workload and situation awareness).

This kind of measurement has merits in capturing real time human performance and physical data, which provide valuable information to understand human factors issues. However, the problem is that these measurements require extra experiments and tasks besides daily activities. Research shows that observation and physiological measurements may influence the task operators' performance in a long-term practical application, for example, wearing heart rate senor for the entire long haul flight (Tran et al., 2007). Therefore, considering the costs and influence on performance measurement, this kind of human factors risk identification method is hard to put in practical for use on a daily regular basis.

In sum, the two major types of human factors risk identification method discussed, either rely on reported events which already contain bias from the reports or require experiment participants. Therefore, an objective and practical human factors risk identification method is needed for routine monitoring purpose. Routine flight performance data collected by FDM offers a great opportunity satisfy this need. The following sections will introduce the background of digital flight data and FDM.

2.3 Digital Flight Data and FDM

2.3.1 Digital Flight Data and Flight Data Recorders

Digital flight data is consisted of parameters that provide flight performance information throughout all phases of flight. The parameters are recorded by devices installed on the aircraft. The number of collected parameters varies with different types of aircraft (ICAO, 2010). According to the FAA, there are 91 required parameter groups, including airspeed, altitude, acceleration, automation system data, and etc. (FAA, 2014). Recording intervals varies with different types of parameters from 0.125 second to 1 second (ICAO, 2010).

An aircraft can be equipped with several types of devices that collect flight data. A Flight Data Recorder (FDR) is a device required by the regulatory agencies to record digital flight data; it was originally mandated for accident investigation purposes. Digital FDR has replaced magnetic tape FDR since 1980s and greatly improved the number of the parameters that are recorded (Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA), 2005). Figure 2.3(a) shows a type of digital FDR used on modern airplanes (Zimmerman, 2013). Initially, the principal use of flight data was in accident investigations, especially those severe accidents with no survivors. The design requirement for the FDR is that it could sustain damages such as fire or impact in crashes. FDR records flight operation parameters that provide the real information of the accident to the investigators. Typically, accident investigators will follow the standard procedures to recover and readout the data from the FDR first, and then replay the situations when accidents happened, to investigate the causes and generate factual reports (NTSB, 2002).

Quick Access Recorder (QAR) is another type of onboard recording unit. Different from FDR, it provides quick and easy access to a removable medium and is able to record over 2,000 parameters, which is more accessible and accurate for ground analysis (FAA, 2004). Figure 2.3(b) shows a type of QAR produced by Teledyne Technologies Incorporated (Teledyne Technologies, 2013). It can acquire certain parameters with selected sampling frequency from data recording units. Generally, data needs to be downloaded from a removable disk regularly before the memory is full. The most recent technologies allow wireless data transmission from recorders to the ground station, which is more accessible for routine monitoring and research purposes.

(a) FDR

(b) QAR

Figure 2.2 FDR & QAR (Image adapted from Zimmerman, 2013; Teledyne Technologies, 2013)

Since the 1970s, the aviation industry began to realize the valuable insights provided by the flight data for daily routine performance measurement. By routinely accessing flight parameters through the secondary recorder QAR, much more information of operations performance and aircraft conditions could be collected, and risks could be detected to prevent the accidents or serious incidents from occurring. Flight data analysis tools developed by technical software development companies like Aerobytes Ltd. are able to assist analysts to replay and animate the digital flight data (Global Aviation Information Network (GAIN), 2003). Advanced data replay tools can provide different views of the flight performance during different flight phases. Relative high automation has been achieved by some of the analysis software, which greatly simplifies the data presentation method. Many flight data analysis tools are applied in the today's flight data analysis processes (GAIN, 2003) and more advanced analysis tools have been developed over the past decade (Ananda & Kumar, 2008; Harboe-Sorensen et al., 2012; Haverdings & Chan, 2010).

2.3.2 An FDM Program

FDM is a "proactive and non-punitive program for gathering and analyzing data recorded during routine flights to improve flight crew performance, operating procedures, flight training, air traffic control procedures, air navigation services, or aircraft maintenance and design" (ICAO, 2005). Early in the 1970s, the UK CAA's Safety Regulation Group started to develop a similar program to apply FDM information in safety tasks (Civil Aviation Authority, 2013). Before the 1990s, individual efforts were made by some large airlines that first integrated FDM into their systems to improve safety management. Transport Canada held the International FDM Meeting in Ottawa in 1997 and began to implement the prototype FDM system (Transport Canada & Software Kinetic Ltd., 1997). Since 2005, after ICAO introduced a requirement on all member states (Civil Aviation Authority, 2013), FDM has been accepted and established in more countries as a mandatory program. However, both the FDM program in Canada and the FOQA program in US are voluntary programs and they must use de-identified data (FAA, 2004; Transport Canada, 2001).

The general FDM process is that raw flight data are first recorded by data recording unit on the aircraft and transferred to the ground station. Analysts on the ground retrieve decoded flight data from FDM database and then replay and animate flight data via specific analysis tools and methods to find potential safety risks and events. These practices provide feedback and improvement suggestions to the entire airline's operations system. The risk mitigation actions taken in the relevant departments based on FDM feedback will finally improve the operations of the aircraft systems continuously.

Research has previously been done in the area of exceedance detection. Exceedance detection is looking for abnormal flight performance, in which some flight data exceeds a previously established safety boundary (Nehl & Schade, 2007). The statistical results of exceedance analysis could provide important and reliable information for predicting potential risks and improving training techniques (Nehl & Schade, 2007). Recent research conducted by researchers at MIT proposed a cluster analysis approach to flight data analysis. Compare to traditional exceedance detection, the cluster analysis aims to identify abnormal patterns in the data, which enlarges the investigation boundary to include underlying events that are within the threshold (L. Li, Gariel, Hansman, & Palacios, 2011).

In FDM, the unsafe performance event detection is based on event settings to the FDM software. However, the advisory circulars and related documents only described the basic rules and recommendations of how to set up the events that wish to detect by the software and the thresholds (FAA, 2004). In practice, the event sets are decided and customized by different airlines based on their safety goals and SOPs, which regulate the standard operations during each flight phase for the pilots. Detailed FDM activities are discussed in Chapter 4.

2.4 Other Related Programs and Systems

Other programs and systems related with digital flight data have also been designed and developed in the aviation industry. Some previous research on applying flight data in human factors related studies were conducted based on these programs. These programs or systems differ from each other on specific areas of focus, but they all aim try to take the advantages of routine flight data monitoring to identify safety risks and improve aviation safety.

2.4.1 Flight Operational Quality Assurance (FOQA)

FDM is also known as FOQA in the US. The aim of FOQA is to allow the FAA and carriers to cooperate with each other to identify and mitigate safety risks. FOQA allows commercial airline operators and pilots to share de-identified information with the FAA, so that the FAA can monitor trends in aircraft operations nationally and target its resources to address operational risks. The basic elements of the FOQA program include: airborne data recording systems, air/ground data transfers, and ground data analysis systems (FAA, 2004). The general process is similar to the FDM, which are presented in details in Chapter 4.

To further FOQA program toward the proactive safety risk management, NASA has collaborated with airlines in a project know as Aviation Performance Measuring System (APMS). The objectives of APMS are to develop advanced concepts and prototype software for routine flight data analysis and finally transferring these tools to practice (Chidester, 2003).

2.4.2 Aviation Safety Information Analysis and Sharing (ASIAS) System

The development of FDM or FOQA program in many airlines provides the aviation industry an opportunity to aggregate the data and share the information among different airlines. Aviation Safety Information Analysis and Sharing (ASIAS) system is a safety analysis and data sharing collaboration initiated by the FAA and the aviation community in the US. Today, ASIAS has at least 50 domestic and international airline members, (ASIAS, 2014). ASIAS collects various aviation data sources include air traffic management data, de-identified digital flight data (from FOQA), and safety reports from airlines. Analysts can access to these data sources via a secured communication network. The goal of this system is to proactively identify and manage safety issues and emerging risks by synthesizing and analyzing safety data from different sources (ASIAS, 2014). The results of these analyses are shared with the ASIAS participants.

2.4.3 Advanced Qualification Program (AQP)

AQP is a voluntary training program and was first built in the late 1980s by the FAA. Its initial motivation was the development of aircraft technology and training techniques. The aim is to reconstruct the content of training programs for crew members and dispatchers (FAA, 2006). Unlike conventional training, AQP emphasizes crew-oriented training and data-based instructions (Bresee, 1996). Generally, the AQP process involves analyzing job tasks and required knowledge for the operators and qualifying the standards and documents first, and then conducting training in small groups. Once initial performance data are collected and analyzed, the training program is evaluated and revised to achieve continuous improvement (FAA, 2006). The FAA, NASA and some researchers have been working on integrating FOQA data in AQP, to provide an objective measurement of flight performance. This will assist training programs to describe the qualified standards and support training program (Bresee, 1996; Callantine, 2001).

2.4.4 Fatigue Risks Management System (FRMS)

FRMS is a data-driven and scientific approach of identifying fatigue related safety risks in airline operations. Key components of the FRMS approach are access to fatigue related data, fatigue analysis methods, identification and management of fatigue drivers, and application of fatigue mitigation procedures. ICAO introduced FRMS to Annex 6 (Operation of Aircraft) in 2008 and several commercial airlines (e.g., Singapore Airline and EasyJet) have successfully implemented FRMS as part of their SMS (Srivastava & Barton, 2012).

2.5 Human Factors Focused FDM Practices

FDM events often contain a significant human factors element. In order to gain insight into human factors focused flight data applications, previous FDM research associated with human factors are discussed in this section. Current FDM practices that focus on human factors issues are mainly in the domains of training, crew performance measurement (e.g., SOPs noncompliance), and crew fatigue monitoring, as well as integrating FDM with other data sources. Many research projects have been done with the support of FDM/FOQA, AQP and other related programs.

Mitchell, Sholy & Stolzer (2007) have analyzed the benefits of FOQA data for training programs. Their research shows that replay of the flight data, for example, GPS data, can assist the instructors to critique whether the flight was following the right path. Research has also been conducted on integrating FDM data into the Crew Activity Tracking System (CATS) to identify training needs (Callantine, 2001). The CATS model compares state parameters obtained from real flight data with constraint parameters and pilot actions to identify unsafe operations. In addition, the researchers have worked on applying data obtained from FOQA programs into AQP to provide a solid base of training instructions (Bresee, 1996; Callantine, 2001). A FAA training manual also describes briefly the efforts of using crew performance trend data for training purpose (Seamster, Boehm-Davis, Holt, & Schultz, 1998).

The second area of applying FDM data to address human factors issues is measuring crew performance. Chidester (2003) has applied APMS tools to understand the crew performance during approach and runway assignment changes. The Japan Aerospace Exploration Agency has proposed an initial flight crew operation safety analysis tool designed to be used within an airline's FDM. This tool is designed to reconstruct flight crew activities, including SOPs tasks that can and cannot be directly detected from changes of parameters, using a human behavioral model (Muraoka & Tsuda, 2006). Research has also been conducted on applying FDM for crew fatigue monitoring. For instance, EasyJet has collaborated with NASA in implementing Human Factors Monitoring Program, which provides some examples of integrating FDM data in fatigue monitoring (Srivastava & Barton, 2012).

In addition, several studies have explored integrated safety analysis. In particular, Maille and Chaudron (2013) have worked on developing a new methodology, which combines the different feedback databases (e.g., safety reports and FDM) in safety management. This new safety management method uses the unique flight identifications (e.g., flight number and departure time) to link and match the human factors components in crew reports to the operational deviations detected by digital flight data from the same flight. They have successfully tested their method based on a small set of data provided by a cooperative airline. Walker and Strathie (2012) presented an approach of applying human factors methods to FDM data source. They note that current applications of flight data analysis lack a path to understand why the risks exist; they suggest that human factors methods, such as the signal detection theory and the mental model theory, can be used to analyze the information provided by digital data.

However, although many studies have been done in identifying human factors related issues based on flight data analysis, the human factors focused FDM applications are relatively limited, especially in routine risk identification practices. There is no systematic approach of tracking major human factors risks through FDM that can be embedded to current routine flight data analysis. Current challenges include interpreting human factors elements from flight data and identifying the relationship between human performance and certain flight parameters. These are the significant problems that need to be addressed in order to develop potential approaches to keep track of the major human factors issues via monitoring the digital flight data.

2.6 Chapter Summary

In summary, this chapter presented the basic aviation human factors risk identification methods and the background of flight data analysis. Previous work about FDM applications associated with human factors was reviewed. However, while human factors elements were proved to be existed in FDM information, none of these studies were focused on developing a systematic human factors risk identification approach through FDM on a routine monitoring basis. Current human factors risk identification practice mainly relies on prescriptive information data source such as safety reports. Researchers have realized the opportunities of investigating human factors issues through digital flight performance data, but there is a gap between human factors risk identification and current FDM process.

In order to bridge this gap and identify the potential approaches of using FDM to track major human factors concerns in today's airline operations, first, examples of major human factors issues in recent years need to be identified. Then, current FDM process and flight parameters need to be carefully studied to build a comprehensive understanding of the program and techniques. In the next chapter, the research of identifying current key human factors risks in North America is discussed.

Chapter 3
Major Aviation Human Factors Risks

This chapter aims to determine some examples of major human factors risks of concern in current airline operations. The human factors risks in this thesis refer to various factors, related to human errors as classified in the HFACS framework, which could cause or contribute to incidents or accidents. Due to available resources, the scope of this study was airline operations within North America aviation industry. Key risks that showed up most frequently were identified from accident and incident investigation reports using Human Factors Analysis and Classification System (HFACS) analysis and semi-structured interviews with aviation safety experts. Risks that become more prominent over the years and upcoming issues that might be introduced by changes in the airline operational environment are also discussed in this chapter.

The objective of the investigation report analysis and interview is to look for major general types of human factors issues that may exist in current operations. These top risks would be of most interest in airlines' proactive risk management. Identifying and understanding the current major risks will help explore the opportunities to use FDM to track exposures to these risks. In addition, the research findings in this chapter can provide insight into current concerns and will assist airlines in assessing their own operations and preventing future occurrences.

3.1 Methodology

As discussed in Chapter 2, previous research of human factors risks identification using HFACS focused only on accident data. In addition, the results of prominent human factors risks in North America was most recently updated in 2002. Thus, more recent data is needed to update this result. Moreover, this research includes not only accident but also incident data in North America to capture a wider scope of the risks. In order to identify the key human factors risks within current airline operations, an HFACS analysis (Shappell et al., 2007) was done of the final commercial occurrence investigation reports from 2006 to 2010 time period, for which relatively complete accident and incident investigations are available in the US and Canada. The commercial airline operations described here refers to the operations regulated under Federal Aviation Regulations (FARs), Part 121 Scheduled Air Carrier Operations. The Canadian data were selected under Canadian Aviation Regulations (CARs) Part VII, Subpart 705 Airline Operations.

In addition, semi-structured interviews have been conducted with ten safety experts and flight data analysis in order to collect two types of information: airline operators' perceptions of top human factors concerns and FDM data analysis process and activities. In this chapter, results obtained from human factors risk related interview questions are presented and used in complementing the HFACS analysis results. The second type of information collected from FDM related interview questions were used in developing FDM models, which are discussed in the next chapter.

The structure of a semi-structured interview is organized around the topics of interest and starts with a prepared list of questions. The set of prepared questions used in the interviews are listed in Appendix B. However, during the interviews, the actual questions asked are not limited to the prepared question list, making this form of interview more flexible and fluid. Based on participants' answers, additional or extended questions are asked. This method aims to ensure the flexibility in how and in what sequence questions are asked, and in what particular areas might be followed up and developed with different interviewees (Mason, 2004). Using semi-structured interviews also allows new viewpoints to emerge freely. The topics discussed in these ten interviews include major human factors risks the airline is facing, upcoming human factors related issues, and current FDM practices.

In the final part of the chapter, the HFACS analysis results are compared with airline operators' perceptions to obtain a more comprehensive and practical point of view of current major risks. The following sections in this chapter describe the methodologies and results of both HFACS analysis and interviews.

3.2 HFACS Analysis

The contents presented in this section are based on a paper (Yan & Histon, 2014) that has been submitted to and accepted by Human Factors and Ergonomics 2014 Annual Meeting in October, Chicago, Illinois (See Statement of Contribution).

3.2.1 Data

The HFACS analysis was conducted using 267 commercial aviation occurrences in the US and Canada from 2006 to 2010, for which relatively complete accident and incident investigations are available[1]. The commercial airline operation incident and accident final investigation reports were retrieved from two investigation report databases. First, the US data were obtained from the National Transportation Safety Board (NTSB) Aviation Accident and Incident Data System through the FAA's Aviation Safety Information Analysis and Sharing System (ASIAS) (FAA ASIAS, 2014). The

[1] Investigations take time and final investigation reports for some accidents and incidents may take years to complete.

Canadian final reports were retrieved from the Transportation Safety Board of Canada (TSB)'s aviation investigation report database (TSB, 2013). In total, 267 accident and incident final reports, including 230 US occurrences and 37 Canadian occurrences, have been analyzed. The final reports contain conclusions of findings as causal factors which indicate that the investigations for the occurrences are finalized.

3.2.2 HFACS Analysis Method

The report analysis process in this study is described in Figure 3.1. First, commercial operation accidents and incidents (for flights operated under FARs 121 and CARs 705) were selected from the investigation report databases. Whether human errors were involved in the occurrence as one of the causal factors is determined by the findings in the investigation reports.

An occurrence related to human errors was defined as one where the probable causes described human actions, or inactions, including operator errors and organizational issues, as contributing to the incident or accident. The investigation report normally provides information on whether human operators, including aircrew, ground crew, ATC or maintenance personnel were involved and whether their operation errors were the causes of, or contributing factors to, the occurrence. The errors made by these personnel could be anything that deviated from safe and standard operations. Occurrences not related to human errors were primarily caused or contributed by other factors including weather, mechanical system failures, and bird strikes.

Accidents and incidents involving human errors were then categorized by four types of personnel (ground crew, ATC, maintenance and aircrew) who had direct or indirect influence on the occurrences. Several types of personnel can be involved in a single accident/incident. Since this study is conducted from a commercial airline perspective, only accidents and incidents involving aircrew actions were considered in HFACS analysis.

The contributing factors of the occurrences were coded into HFACS categories based on the probable causes in each report. The coding started from higher levels of failure to sub-categories, mapping each causal factor mentioned in the report to the HFACS categories. For example, it was first determined which level of failure a cause belongs to (whether it is a violation or organizational issue), and the cause was then coded into subcategories. Since it is difficult to differentiate between routine and exceptional violations simply from the description of the investigation report for a single occurrence, violations are discussed together in the study. The customized HFACS framework used in this thesis has 18 categories (Table 3-1). Each HFACS category was counted a maximum of only once per accident/incident; thus, this count acted simply as an indicator of the presence or absence of each of the 18 categories under the four levels of human failure.

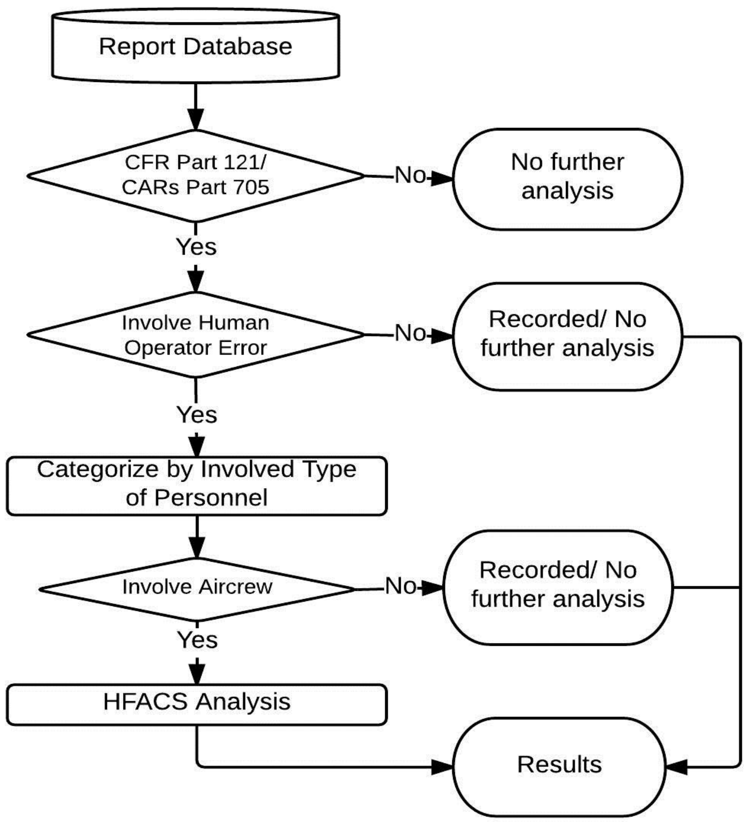


Figure 3.1 Investigation Report HFACS Analysis Process

Table 3-1 The Customized HFACS Framework (adapted from Shappell & Wiegmann, 2001)

<table>
<tr><th colspan="12">Level 1 Unsafe Acts</th></tr>
<tr><th colspan="7">Errors</th><th colspan="5">Violations</th></tr>
<tr><td colspan="2">Decision Errors</td><td colspan="2">Skill-Based Errors</td><td colspan="3">Perceptual Errors</td><td colspan="5">Routine and Exceptional Violations</td></tr>
<tr><th colspan="12">Level 2 Preconditions For Unsafe Acts</th></tr>
<tr><th colspan="3">Environmental Factors</th><th colspan="5">Condition of Operators</th><th colspan="4">Personnel Factors</th></tr>
<tr><td colspan="2">Physical Environment</td><td>Technological Environment</td><td>Adverse Mental State</td><td colspan="2">Adverse Physiological State</td><td colspan="2">Physical/ Mental Limitations</td><td colspan="2">Crew Resource Management</td><td colspan="2">Personal Readiness</td></tr>
<tr><th colspan="12">Level 3 Unsafe Supervision</th></tr>
<tr><td colspan="3">Inadequate Supervision</td><td colspan="3">Planned Inappropriate Activates</td><td colspan="3">Failed to Correct Problem</td><td colspan="3">Supervisory Violation</td></tr>
<tr><th colspan="12">Level 4 Organizational Influence</th></tr>
<tr><td colspan="4">Resource Management</td><td colspan="4">Organizational Climate</td><td colspan="4">Operational Process</td></tr>
</table>

3.2.3 Results

After filtering for FARs 121 and CARs 705 operations, there were 267 accidents and incidents, among these commercial occurrences, more than half (61%) were determined to be related to human errors (Table 3-2). This result accords well with the previous study that around 60%-80% aviation accidents are associated with human errors (Shappell et al., 2007). Among these human error associated occurrences, 85 were cited as being contributed by aircrew errors. That is, aircrew contributed 52% of the human error associated aviation occurrences, and 32% of the total 267 occurrence final reports, which indicates that aircrew errors are a significant concern (Table 3-3). Concentrating on the airline perspective, this chapter focuses on the aircrew errors. For the 85 aircrew error associated occurrences which have been examined using HFACS, the frequency count and percentage of each HFACS category are shown in Figure 3.2.

Table 3-2 Frequency Count for Occurrence Type

Occurrence Type	Frequency	Percentage
Related to Human Errors	162	61%
Not Related to Human Errors	105	39%

Table 3-3 Frequency Counts for Each Type of Personnel Involved in Human Operator Error Related Occurrences

Personnel	Frequency	Percentage
Aircrew	85	52%
Ground Crew	34	21%
ATC	33	20%
Maintenance	26	16%

Note that the percentages in the table will not add to 100%, because in some cases more than one type of personnel was associated with an occurrence.

The HFACS analysis results show that Level 1, Unsafe Acts and Level 2, Preconditions of Unsafe Acts are the two most prominent failures described in the investigation reports, a finding which is in accordance with results in previous studies (Li et al., 2008; Shappell et al., 2007). "Active failures" including unsafe acts (Level 1) and preconditions of unsafe acts (Level 2) are more prominent than "latent failures" in the supervisory (Level 3) and organizational environment level (Level 4), because unsafe acts are the most easily recognized types of failures. Most times, unsafe acts are the direct causes or contributing factors of the occurrence, such as incorrect usage of controls/equipment on the aircraft and failure in following the SOPs. Level 2 Preconditions of Unsafe Acts as the direct trigger of unsafe acts are commonly cited as contributing factors in most of the occurrences. Among these preconditions, physical environment issues, including weather, ATC services, and adverse mental states such as distraction and lack of situation awareness can easily affect human performance. Another possible reason for the pattern observed in the results is that incident reports were also included in this study in order to capture a wider scope of risks. However, since incidents are less severe than accidents, sometimes there were no cues of “latent failures”, pointing to supervision and organizational level problems or even no need for deep diving into the upper level issues due to time and financial expenses.

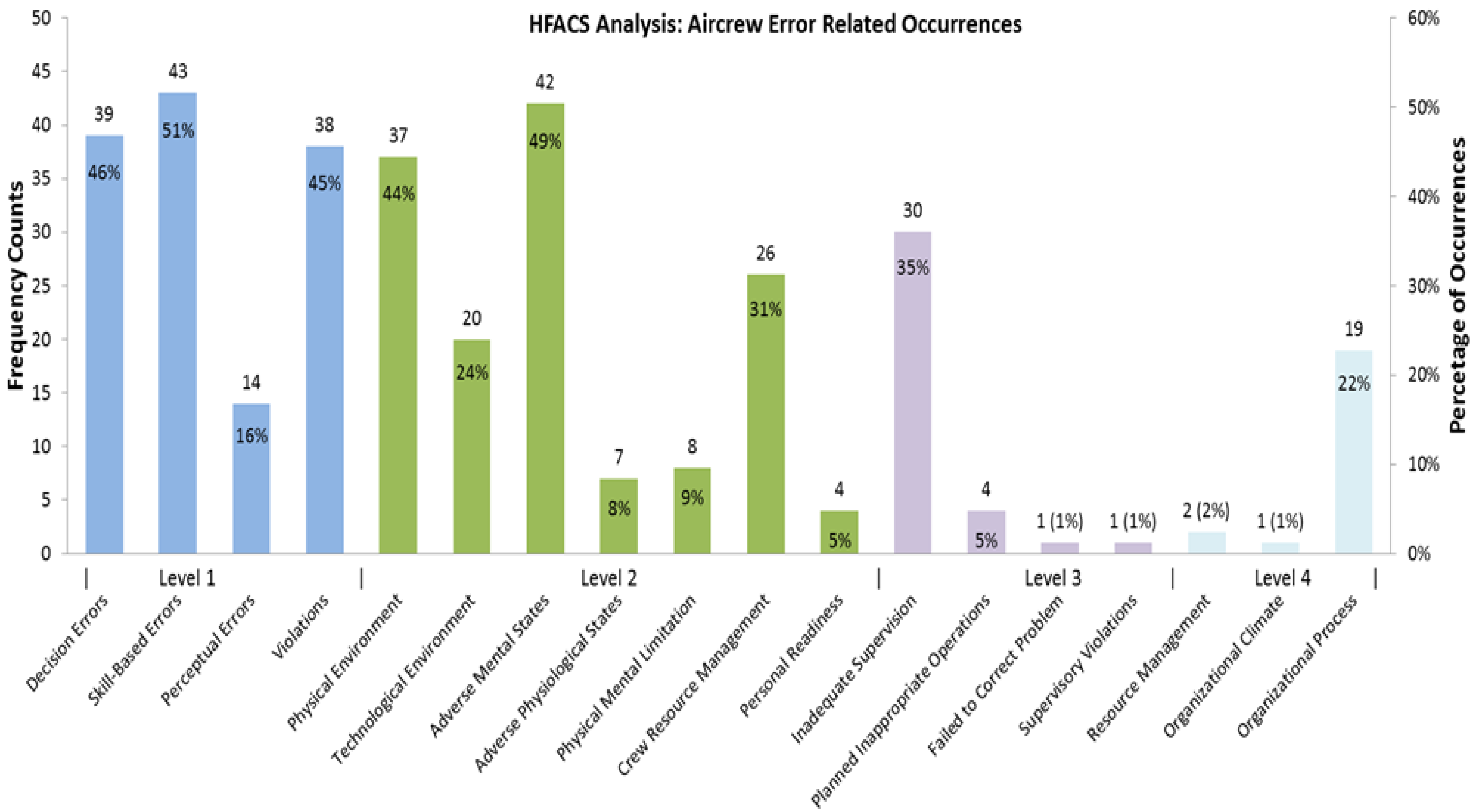


Figure 3.2 HFACS Analysis of Aircrew Error Related Occurrences

Note that the percentages in the figure will not add to 100%, because in most cases more than one HFACS categories were associated with the accident or incident.

To understand how the relative frequency of the most prominent categories was changing over time, the relative percentage of all occurrences of each subcategory was determined for each year in the data set. Results are presented below year-by-year for the top ten most prominent HFACS subcategories (HFACS subcategories which were contributing factors to more than 10% of aircrew related occurrences). These ten most frequent HFACS causal categories are: Level 1—Decision Errors, Skill-based Errors, Perceptual Errors and Violation; Level 2—Physical Environment, Technological Environment, Adverse Mental States, and Crew Resource Management. Inadequate Supervision under Level 3 and Organizational Process under Level 4 are also identified as prominent factors. Figure 3.3, Figure 3.4, and Figure 3.5 show the percentage of each year's occurrences of the high frequent HFACS categories for each HFACS level.

For Level 1 Unsafe Acts (Figure 3.3), the percentage of each type of error varies every year; no obvious increasing or decreasing trend is observed. When comparing this result to the previous research result from examining commercial aviation accidents from 1990 to 2002, the proportion of violations grows from around 10% to 30% (Shappell et al., 2007) to around 30% to 50%. More violations mean more proportion of occurrences are caused or contributed by pilots' failure to follow regulations and SOPs in recent years. Since incident data is also used in this study, one possible explanation may be that more violations are committed in incidents, because the crew believed that slight deviation from the rules would not be a big problem (i.e., cause an accident); however, these actions have the potential of creating more severe outcomes under certain conditions. For example, the crew decides to land the plane when the speed exceeds the SOPs' requirement because they think it is fine or they don't want to go around. This may lead to a long landing incident; however, if under certain conditions, such as wet runway, strong tailwind or suddenly failed brake, more severe consequences like runway excursion will occur. Therefore, the slight deviations identified from the incidents can be early warnings in accident prevention.

Figure 3.4 shows that Crew Resource Management (CRM) still presents at around 30% of aircrew error related occurrences, which is a relatively high proportion considering the emphasis placed on this issue over the years (Salas, Burke, Bowers, & Wilson, 2001). However, this finding is not surprising, because the CRM concept is multifaceted, from communication between operators to leadership and decision making, which make it a complex domain in safety management. Moreover, some of the CRM contents, such as communications and leaderships, are hard to measure, which increase the difficulty of CRM training and improvement.

The percentage of occurrences contributed by Inadequate Supervision increased from 2006 to 2010 (Figure 3.5). The key word identified as a primary issue within this category is "training". According to the categorization result, training issues such as that the organization failed to provide adequate training to pilots present more than 90% of the inadequate supervision issues cited as contributing factors in the accident reports. An airline that fails to provide adequate training may leads to pilots having inadequate experience with the systems and incorrect reactions when controlling the aircraft. The increasing percentage of this category suggests that training requirements are growing. Part of this is due to the increasing air traffic and rapidly evolving technology. The needs for more new pilots and for current pilots transferring to different types of aircraft and adapting to new technology are increasing.

The organizational process varied between 20% and 30%; the numbers are mainly contributed by unclear or unavailable organizational instructions identified in the investigations. This is highly relevant to the development of SMS documentation requirements. Since SMS had just started to be implemented in commercial airlines in North America during 2005 to 2010 (FAA, 2014a; Transport Canada, 2012), it actually provides a research opportunity to see how the relative frequency of organizational instructions change as contributing factors in occurrences with the improvement of SMS in airlines in the next few years. It is possible that the frequency of organizational instructions being cited as contributing factors decreases in the next few years due to the successful implementation of SMS. It is also possible that more instruction issues will be identified because of the lack of unified standards of SMS, which may cause confusion and discrepancy in the industry and the assessments.

Under each subcategory, there are various specific detailed factors and behaviours that are considered as risks, for example, incorrect use of control system is a specific type of risk which belongs to the subcategory of “skill-based error”. In order to gain insight of the specific type of risks that contributed to these occurrences, the top 15 specific risks under HFACS subcategories are presented in Figure 3.6. The SOPs noncompliance is the top one issue identified from the 85 aircrew related occurrences, followed by inadequate situation awareness, attention failure, weather, and training issues. Incorrect operations include incorrect use of controls and automation. Communication issues, distraction, fatigue, high workload, and ATC services, which all belong to Preconditions of Unsafe Acts, are also showed up most frequently in the investigation reports. Examples of major human factors risks from general levels to specific types of risks were identified from the HFACS analysis of previous occurrence reports. The results of semi-structured interviews, which collect information from the operational perspective, are presented in the next section.

In addition, the analysis was not able to separate whether any trends/changes noticed in the year-by-year analysis and comparison to previous research are due to underlying fundamental changes in how systems are operating, or changes in the awareness of investigators. For example, many years ago, the emphasis of air investigation was mechanical problems. Today, with the development of technology and safety theories, the investigators have realized the important role human factors plays in accidents (Dekker, 2000), so more emphasis may be put on identifying these issues.

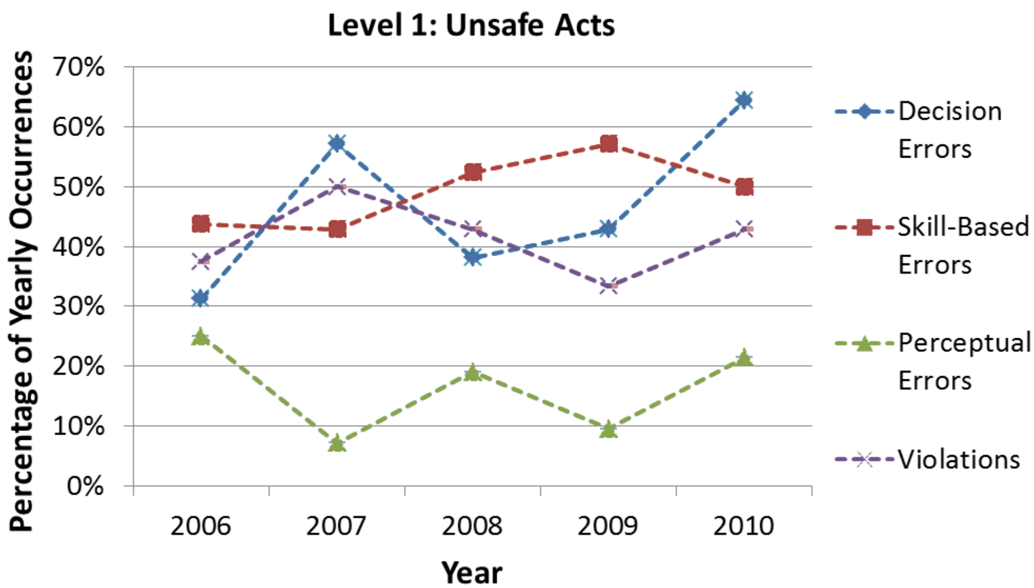


Figure 3.3 Percentage of Aircrew Error Related Occurrences Cited as Being Contributed by Four Types of Unsafe Acts by Year

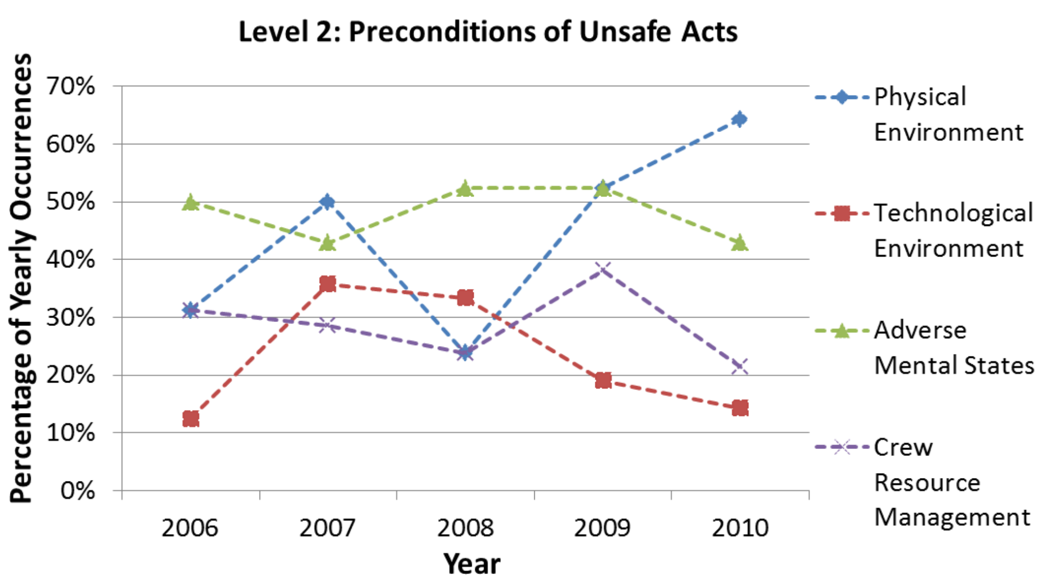


Figure 3.4 Percentage of Aircrew Error Related Occurrences Cited as Being Contributed by Four Major Preconditions of Unsafe Acts by Year

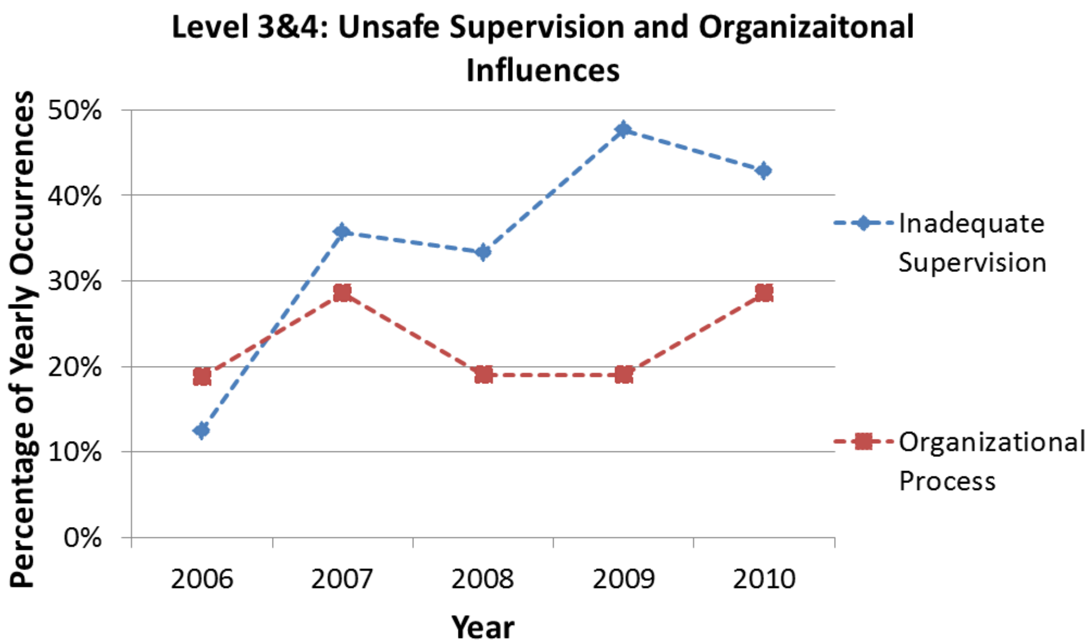


Figure 3.5 Percentage of Aircrew Error Related Occurrences Cited as Being Contributed by Major Unsafe Supervision and Organizational Influences by Year

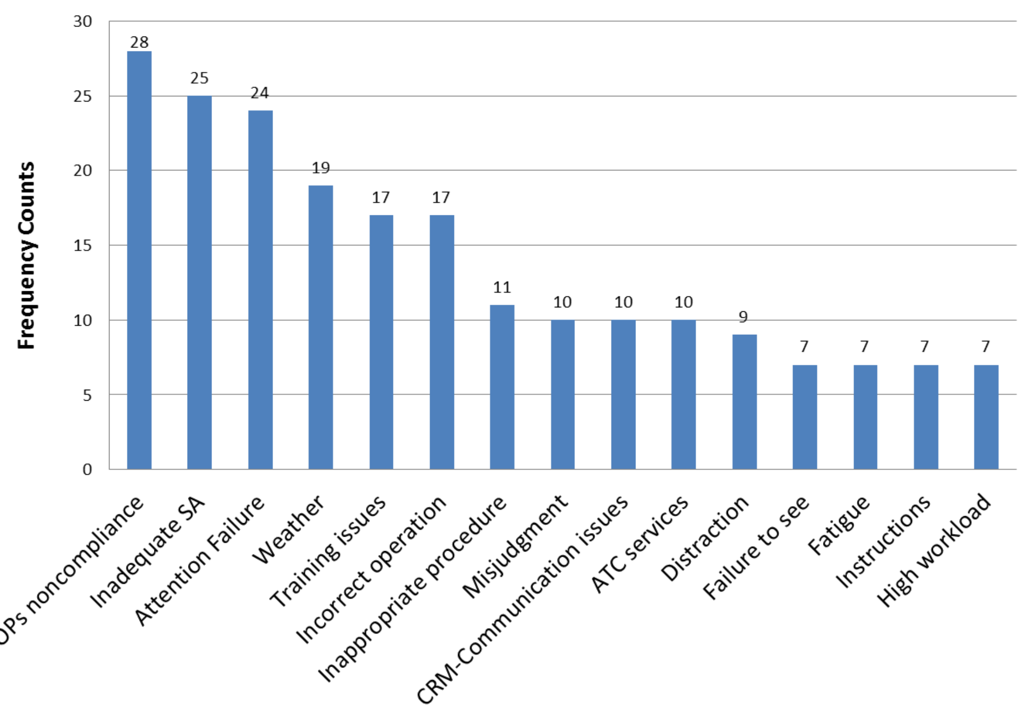


Figure 3.6 Frequency Counts for Specific Type of Human Factors Risks

3.3 Semi-structured Interviews

3.3.1 Interview Question Regarding Major Human Factors Risks

As discussed in Section 3.1, part of the semi-structured interview questions were designed to learn example major human factors risks of current and future concern from the air operators' perspective. The interview questions that used to identify airlines' perception of top human factors issues are presented in Table 3-4:

Table 3-4 Interview Questions Regarding Human Factors Risks

#	Question
1	What are the top five human factors risks that you think the airlines or even the entire North American industry is facing based on your experience in aviation safety risk identification?
2	Based on your experience and involvement with safety management activities, what are the upcoming changes in the airline's operational environment that might introduce new human factors issues or increase the current human factors risks?

Question #1 asked for the top five major risks, but the number of top risks listed by each participant was not rigid and the participants were not required to rank the risks. Question #2 aims to identify the influences of future changes in the industry operational environment on human factors risks to get insight of the upcoming issues of future concern and provide reference for airline's future risk assessment.

3.3.2 Participants and Interview Procedure

The semi-structured interviews were conducted with ten very experienced expert participants, including five senior safety managers and investigators, four flight data analysts and senior data managers from a major North American airline and a senior safety manager from an aviation council in North America. All the participants' daily working responsibilities are highly involved with aviation safety management, safety investigation and risk identification.

The interviews were conducted privately with only one participant at a time either in-person or over the telephone. Among the ten interviews, eight were recorded (with permission) for researcher review and analysis purposes. Handwritten notes of participant answers were taken during the interviews and all audio records were transcribed after the interviews. Notes were compared with the transcripts to verify the precision of the transcripts. For the two interviews, whose audio records are not available, detailed handwritten notes were taken during the interviews and the participants were asked to speak more slowly and pause if necessary. The study participates were recruited through the airline and were voluntary. They were informed before the interview that they could decline to answer any question if they wish and withdraw from the participation at any time. All participants were coded with numbers and all identifiers were removed from the transcripts and notes.

The answers provided by each participant to each question were analyzed by searching for main themes that over-lapped between participants. Key words were extracted to identify the themes and main categories in the responses. Data collected from FDM related questions were built into the models presented in the following sections in the next chapter.

3.3.3 Results

3.3.3.1 Question #1Top Human Factors Risks

After analyzing the interview responses for Question #1, fourteen key words that covered the viewpoints of the participants were identified. The top risks mentioned in the interviews are SOPs noncompliance, pressure, distraction, communication issues, fatigue, skill-based errors, training issues, decision errors, inadequate situation awareness (SA), complacency, ground service, ATC service, technology, and weather. The frequency of each risk mentioned in the interviews is shown in Figure 3.7. Based on the nature of these risks, they can be classified into three higher level HFACS categories: Unsafe Acts, Preconditions of Unsafe Acts and Unsafe Supervision (Shappell et al., 2007) as shown in Table 3-5. The organizational influences were not mentioned as major issues in interviews in response to this question. The number of participants who have mentioned at least one risk under each category was also counted to reflect their awareness of the level of these risks (Figure 3.8).

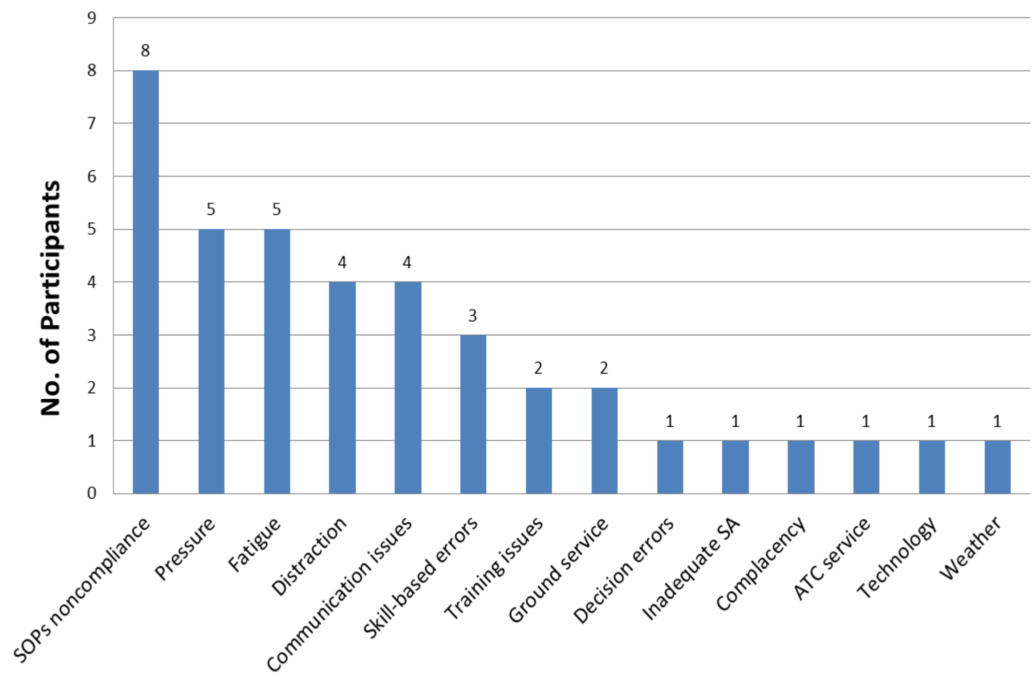


Figure 3.7 Frequency Counts of Major Risks Identified in Interviews

Table 3-5 Classification for Major Human Factors Risks Identified in Interviews

Categories	Risks Identified
Unsafe Acts	• SOPs noncompliance • Skill-based errors • Decision errors
Preconditions of Unsafe Acts	• Pressure • Fatigue • Distraction • Communication issues • Inadequate situation awareness (SA) • Complacency • ATC service • Technology • Weather
Unsafe Supervision	• Training issues

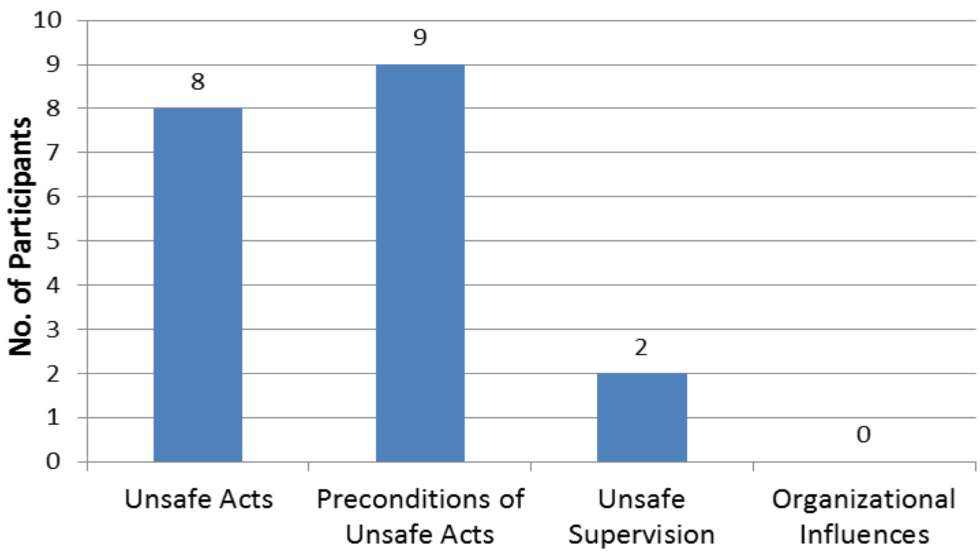


Figure 3.8 Number of Participants Who Mentioned the Risks under Each Category

As shown in Figure 3.7, SOPs noncompliance is mentioned by the experts most frequently in the interviews. 80% of the participants put SOPs noncompliance as one of the top risks. SOPs noncompliance means the pilots decide not to follow the SOPs while flying the aircraft, which can be a warning sign of routine violation (Shappell & Wiegmann, 2001). This result accords with the HFACS analysis result.

Pressure and fatigue are the next two risks frequently mentioned by the participants. Based on the participants' explanations, the pressure mainly comes from working environment, for instance, a company's on time policy. Fatigue is always a human factors issue in aviation operations. It is hard to detect and manage, partly due to the nature of flying task itself and the measurement techniques (Gartner & Murphy, 1976).

Almost half of the participants thought distraction and communication are among the current major human factors risks. During the flight, distractions may come from everywhere, including the passengers and the flight attendants. Communications here include communication between crew members, crew and Air Traffic Controllers (ATC), and crew and flight attendants. It is part of CRM, and the cooperation between crew members has been strengthened for years. However, it seems that continuous efforts still need to be made on CRM training to mitigate this risk. A few participants mentioned skill-based errors, which refers to pilots' incorrect behaviours with no conscious thoughts, such as incorrect use of the equipment and a break down in a visual scan pattern (Shappell et al., 2007).

Figure 3.8 indicates that 90% of the participants mentioned at least one human factors risk that belongs to preconditions of unsafe acts, and 80% thought that at least one of the unsafe acts is a current major risk. The participants' awareness of preconditions of unsafe acts indicates that they are not regarding identifying the human errors as the ultimate goal of safety management, they are aware that there are root causes behind the errors. Training issue was addressed as one of the supervision issues, whereas no organizational influence issues were mentioned specifically. Why no organizational risks were mentioned in the interviews is a question that needs to be considered. Is it because there are no big changes in the industry currently, is it because organizational issues are handled well enough, or is it because it is more easier to blame the operators and environmental influences like weather and technology? In fact, the prominence of SOPs noncompliance in the top risk list may indicate the existence of some organizational issues, because training and organizational culture influence are sometimes underlying causes of this kind of problem. It is reasonable to assume that although training and organizational issues might be the fundamental reasons behind SOPs noncompliance. It is also possible that under the interview circumstances and the way questions were asked, participants may find it easier to address the more obvious errors in daily operation.

3.3.3.2 Question #2 Upcoming Issues

Question #2 asks about upcoming changes in the organizational environment that might introduce human factors related issues. Answers cover a wide range of topics from front line operation to organizational management. The answers may indicate the upcoming trends of some human factors risks in the industry and serve as early warnings to future risk prevention. Eleven key words capturing the viewpoints of the participants were identified from the answers, including new policies, new pilots, and new types of aircrafts. The frequency counts of these factors mentioned in the interviews are shown in Figure 3.9. These changes were then categorized into five groups based on their features (Table 3-6). Example human factors issues introduced by these upcoming changes are also summarized from the answers and presented in Table 3-6. Figure 3.10 describes the number of participants who listed the upcoming changes under these categories.

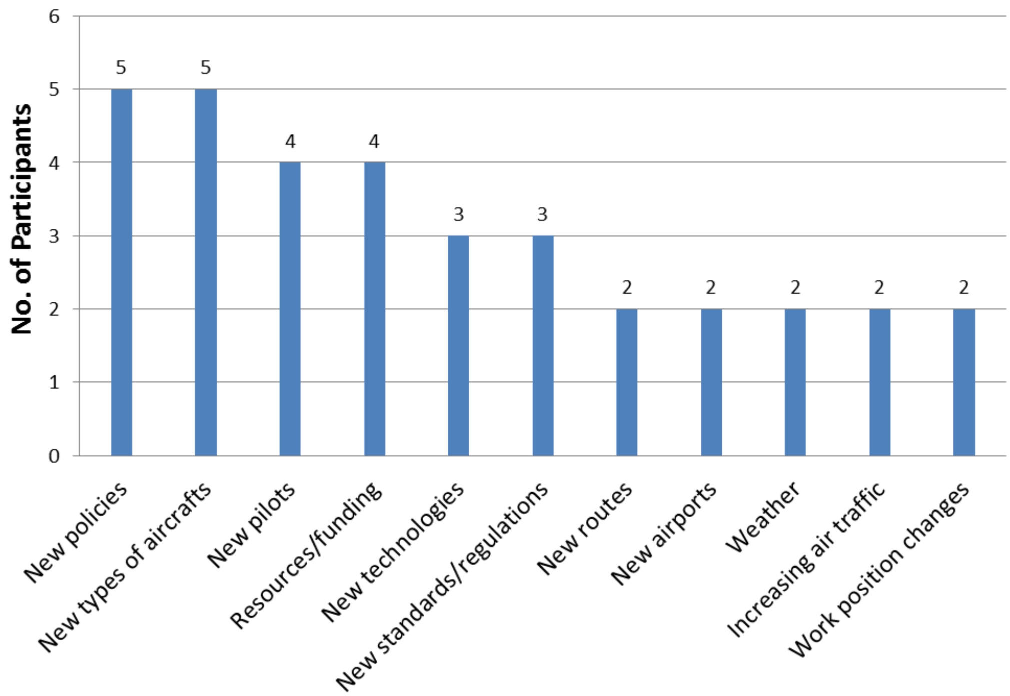


Figure 3.9 Frequency Counts of Major Upcoming Changes Identified in the Interviews

Table 3-6 Classification for Major Upcoming Changes and Resulting Human Factors Risks

Categories	Upcoming Changes	Resulting Human Factors Risks
Organizational decision changes	• New policies • New standards/regulations • New routes • New airports • New pilots • Work position changes	• Training issues • SOPs noncompliance • Automation • Increased workload • Pressure
Technology changes	• New types of aircrafts • New technologies	• Automation • Training issues
Money issues	• Resources/funding	• Training issues • Safety supervision issues
Increasing air traffic	• Increasing air traffic density	• ATC
Weather changes	• More severe weather	• Weather

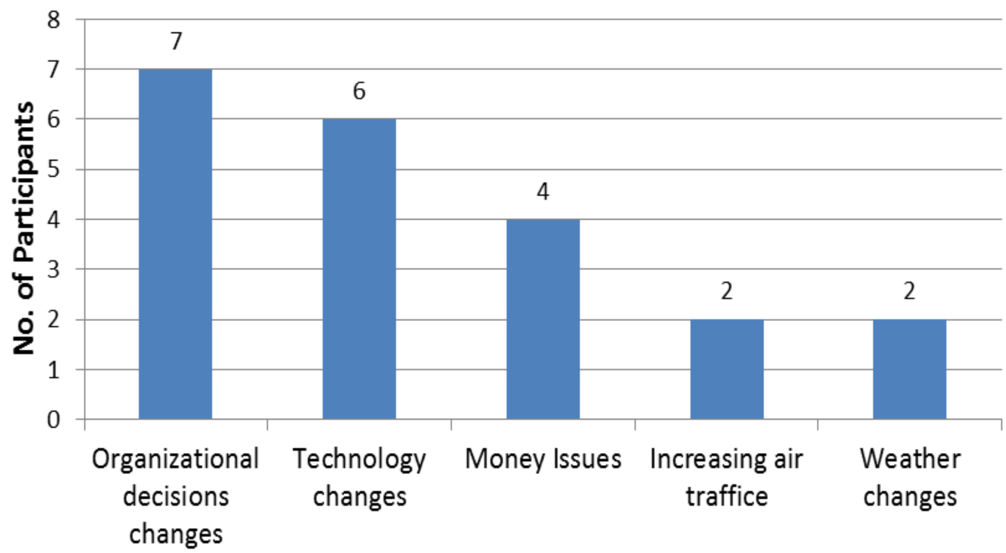


Figure 3.10 Number of Participants Who Mentioned the Upcoming Issues under Each Category

Most of the participants considered the changes in the organizational level and outside influences when asked about upcoming changes that might introduce human factors related issues. This indicates that that most of them believe that decisions made in the upper level management, including policies, standards, and recruitment of new employees are likely to introduce new risks to the operation in the future. The results also indicate that with the development of technology and continued growth of the aviation industry, human factors risks can also arise from the interaction with new automation systems, training for new types of aircraft and interaction with ATC.

According to the answers, potential human factors issues that might be brought by these upcoming changes include training issues, automation issues, workload, pressure and etc. Therefore, proactive risk identification and continuous monitoring of the issues mentioned above are necessary, especially to the changes that involve human operators, to ensure that the risks are proper managed in the evolving environment.

3.4 Discussion

In order to obtain a more comprehensive understanding of current major human factors risks in North American airline operations, the results of both investigation report analysis and interviews have been presented above. When combining the findings from interviews and HFACS analysis, common streams of frequent mentioned risks were identified, as well as some discrepancies.

First, Unsafe Acts and Preconditions of Unsafe Acts are the two most prominent human factors risk categories found in both interviews and investigations. Supervisory and organizational level issues were identified less than the first two categories. However, this pattern doesn't mean that supervisory and organizational issues must be less in the reality, because the Unsafe Acts and the Preconditions sometimes indicate the potential issues in the upper level management. In the interviews, no organizational issues were mentioned as current top concerns, whereas when talking about future changes which might cause new risks, organizational changes are the most prevalent ones on the list. It reveals that though upper level management issues are not cited as frequently as other risks like operational errors and violations, most of the participates believe that changes in the upper level management are the sources of other issues and will eventually influence the daily operations.

Second, the examples of major human factors risks of concern identified from both HFACS analysis and interviews can be put into three categories: identified in both interviews and investigation reports, identified only in interviews, and identified only in investigations (Table 3-7). SOPs noncompliance, fatigue, destruction, communication issues, inadequate situation awareness, training issues and etc. are listed as major human factors risks in both interviews and HFACS analysis. Pressure, complacency, and technology (primarily refers to automation), were mentioned as top human factors concerns in interviews, but didn't show up frequently in HFACS analysis. Similarly, attention failure, workload, failure to see, misjudgement (misjudge of distance, clearance, speed or altitude) and organizational instruction issues were identified as prominent risks in the reports, whereas they were not mentioned in the interviews.

Table 3-7 Major Human Factors Risks Finding Comparison

Both	Interview Only	Investigation Reports Only
• SOPs noncompliance • Fatigue • Training issues • Inadequate SA • Distraction • CRM (e.g., communication issues) • Decision errors (e.g., inappropriate procedures) • Skill-based errors (e.g., incorrect use of equipment/automation) • Weather • ATC services	• Pressure • Complacency • Technology (Automation)	• Attention failure • High workload • Failure to see • Misjudgement • Instruction issues (Inadequate/incorrect/not available)

The synthesized results show that SOPs noncompliance is the top one issue, followed by fatigue, distraction, and communication issues and inadequate situation awareness. Other major risks include training issues, CRM, pressure, and high workload. These are the risks of interest that the researcher wants to constantly track through FDM later in the final phase of the research, which are discussed in Chapter 5 of this thesis.

3.5 Chapter Summary

The analyses and findings presented in this section aim to identify examples of major human factors risks in current airline operations. The research is based on empirical evidence from ten semi-structured interviews with safety experts and the HFACS analysis of 267 North American occurrence final investigation reports. Current major issues in recent years, as well as possible upcoming issues were identified and analyzed.

By combining the perceptions of top human factors concerns identified through the trends identified from previous occurrences and semi-structured interviews, a more comprehensive list of example major human factors risks was determined. Both HFACS analysis and interview results show Unsafe Acts and Preconditions of Unsafe Acts are still the prominent risks. Among these two levels of failure, attention should be paid to violations of the SOPs, which have been identified as the top challenge. When adding incident data into the HFACS analysis, the increase of violations can be a warning to airlines. Fatigue, distraction, communication issues, and inadequate situation awareness are also identified as major risks from the synthesized results. Moreover, year-by-year analysis found that training issues and poor CRM have increased and become more prominent in recent years. These are the risks that airlines need to pay attention to and constantly track in their daily operations. Though there are not many supervisory and organizational risks identified from the research, the identified major risks above may be cues to help investigate the organizational and systematic factors.

Objective 1 stated in Chapter 1 was successfully achieved in this chapter. In the next chapter, the study of current FDM activities and flight data parameters are presented.

Chapter 4
FDM Process and Flight Parameter Analysis

To explore whether there are opportunities of addressing human factors risks through Flight Data Monitoring (FDM), current daily FDM activities need to be carefully studied. Although government aviation agencies have provided advisory circulars as guidelines for developing FDM programs in airlines, according to the literature review presented in Chapter 2, there are few studies on the real practices of this program in airline daily operations. This chapter presents the research methods and models developed in the effort of understanding the current FDM techniques and practices, including the general FDM process, event setting logic, daily data review activities, and flight parameters used in programing the events. In order to achieve the goal, field observations and semi-structured interviews were conducted; relevant documents regarding FDM processes and flight parameters were also reviewed.

4.1 Methodology

4.1.1 Field Observations

Unobtrusive field observations were conducted through multiple visits to the FDM department at a major North American airline. The researcher spent seven days (56 hours) in total with the FDM analysts, the senior data managers, and the gatekeepers to study the general process of flight data analysis, event setting, and other related activities. Notes were taken during the observations, questions were asked at the end of the observation day or during the spare time of the analysts in order to minimize the intervention to their daily work.

This method is crucial for understanding the practices of current flight data analysis and exploring future opportunities. The observations also helped to get exposure to the aviation environment and address confusions on site directly. The observation was conducted in a daily working environment and the researcher was able to carefully study the major tasks and the associated tools, including FDM's software, daily data review procedure, event programming process, and safety reports collecting systems. In addition, a demo flying in a high fidelity simulation was observed in order to better understand the flying tasks.

4.1.2 Semi-structured Interviews Regarding FDM Process

Semi-structured interviews introduced in Section 3.1 have also been used to collect data on the current FDM processes and activities. The questions with regards to the FDM processes were asked together with other questions on the topic of major human factors risks (Chapter 3) during the interviews. The procedure and analysis methods are the same as presented in Section 3.3.2. Themes and main categories of viewpoints were identified and summarized from the transcripts and handwritten notes to determine the frequency of participants who provided similar answers. In this chapter, results obtained from the FDM process related interview question are used in developing the models of current FDM practices.

In the interviews, part of the questions were designed to collect FDM practices information with respect to FDM process, current event setting and daily activities (Table 4-1).

Table 4-1 Interview Questions Regarding FDM Process

#	Question
1	What is the general process of the current FDM in major airlines? What are the inputs (e.g. flight data, requirements) and outputs (e.g., report, study) of the process?
2	What was the process of determining the original set of events when the program started?
3	Over the years, how did you determine that events needed to be changed? How were new events determined and added? Were some removed? Why?
4	What FDA tools are you using in daily monitoring?
5	Does safety department communicate with FDM department once you get a safety report? How often?
6	Is current FDM able to identify HF risks? How?

4.1.3 Literature Review

A literature review was done to develop insight into aviation human factors risks, FDM applications, backgrounds of flight data and flight data analysis. Sources reviewed include government agency documents, reports, meeting proceedings and research papers in the field of FDM implementation and application. Reviewed materials include ICAO regulations, descriptions of FDM programs implemented in the United States, Canada and other countries, reports of Flight Operational Quality Assurance (FOQA) program in the US, and research papers from academics on FDM application, for example, Transport Canada and FAA’s advisory circulars regarding FDM (or FOQA) programs

(FAA, 2004; Transport Canada, 2001). Other documents reviewed include FDM monthly report, traditional FDM event set recommended by advisory circulars, the general Standard Operational Procedures (SOPs), and some FDM safety studies' report. The literature review was used to supplement and generalize the insight gained from the field observations and interviews.

4.2 General FDM Process Model

Based on the findings through the methodologies discussed above, key procedures and components of FDM current practices were extracted based on their relationship to the observed tasks done by, and software used by, the analysts. A general FDM process model which presents the basic data information flow and functions of FDM program in major airlines was developed (Figure 4.1).

First, raw flight data is recorded by data recording unit on the aircraft and transferred to the ground station. Then, the flight data is de-identified and transferred to the analysis software. The event setting programs identify the safety events for the analysts. The analysts validate and analyze the flight data for the flights flagged by the software in order to detect safety risks (Yan & Histon, 2013).

Generally, there are five principle application areas of current FDM in most airlines shown as "FDM Activities" in the model: Routine Monitoring, Incident Investigation, Continuous Airworthiness Monitoring, Integrated Safety Studies, and Commercial Studies.

Routine Monitoring focuses on monitoring routine performance of an increasing number of line operation flights to identify risks and subtle trends that might be potential risks of accidents. This application mainly relies on exceedance detection of deviations from the SOPs such as heavy landings and the triggering of Ground Proximity Warning System (GPWS) warnings. It also requires sufficient techniques and resources to conduct daily review and analysis of a wide range of operational parameters, such as take-off weight, flap setting, and indicated air speed (Civil Aviation Authority, 2013).

Incident Investigation and Continuing Airworthiness Monitoring are another two essential FDM activities. Incidents usually provide equal value of information of risks as accidents. FDM data has been very useful as a quantitative complement and analysis resource for occurrence reports (e.g. mandatory and voluntary safety reports) (Civil Aviation Authority, 2013). Besides, both normal and event data retained by FDM can be used to monitor efficiency and predict future performance of engines and other aircraft systems. This could assist timing routine maintenance and ensuring continued airworthiness (Civil Aviation Authority, 2013). Mitchell, Sholy & Stolzer (2007) suggested that real-time monitoring can benefit aircraft maintenance, for example, identifying engine conditions. Additionally, monitoring landing performance coupled with damage detecting during maintenance inspection can help aircraft manufacturers to design systems more tolerant of stresses. Other tools that assist continuing airworthiness management have been developed by Airbus, Teledyne Controls, and other companies (GAIN, 2003).

Integrated safety analysis is a potential area where FDM can provide benefits by linking the FDM central database with other safety databases (e.g. safety reports) to gain a more comprehensive understanding of safety issues in the system. The integration of all available sources of safety data can provide the company's safety department with viable information on the overall safety of the operation (ICAO, 2005). However, at many airlines, the links between FDM and other safety data sources are not well developed. As learned in the interviews, because of concerns around data confidentiality, the interaction between safety department and flight data department can be limited in practice, and most times they only communicate after occurrences.

Based on the field observation, it was also found that FDM data can be used in commercial studies. For example, fuel consumption analysis for commercial purpose in order to reduce costs or prove the efficiency of new policies such as single engine taxi.

All these FDM activities discussed above, sometimes combined with information from other databases (e.g., safety reports and safety audits), are able to identify all kinds of safety risks and provide feedback and improvement suggestions to almost every link of the operations, including internal departments of flight crews, flight operations, maintenance, training, safety department, and external parties such as ATC, regulatory agencies, and industry groups. The commercial studies, such as fuel usage studies are also able to provide information to business departments to reduce costs. The entire process is a dynamic loop; the risk mitigation actions taken in the departments based on FDM feedback will feedback to continuously improve the airline's operational safety.

This general FDM process model is able to provide guidance to the further study of exploring human factors elements and opportunities in FDM. The most important components that have the potential to detect human factors risks are also the core components of the entire process: event setting programs, analysts' tasks and FDM daily activities. Therefore, based on the observations and information from the interviews, a current event setting process model and a daily flight data review workflow have been developed to explore the potential opportunities. Descriptions and discussions of the two models are presented in sections 4.3 and 4.4 of this chapter.

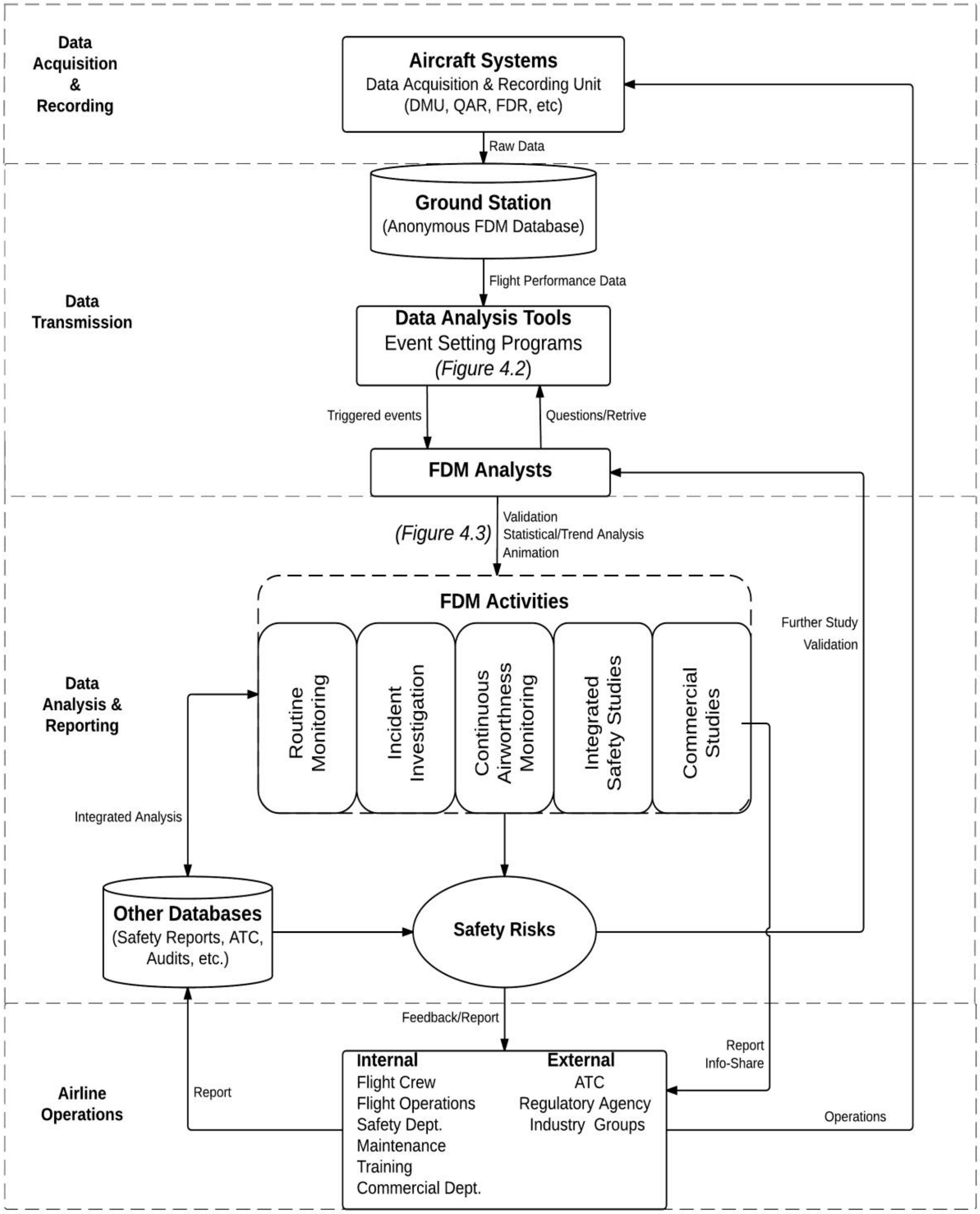


Figure 4.1 General FDM Process Model

4.3 Event Setting Process Model

As presented in the general FDM process model, flight data needs to go to data analysis tools for event detection before it is reviewed by the analysts. The event setting programs are regarded as a key component of the entire process, because daily routine data review mainly relies on the event settings. The FDM events discussed in this thesis refer to a certain type of flight performance which exceeds the set boundaries during the flight. For example, approach speed high at 1000ft above ground level and decent rate high between 1000ft to 500ft above ground level (FAA, 2004). The thresholds are determined by analysts based on their experience and the industry standards. The analysts need to decide how fast should be regarded as over speed, what range of decent rate is acceptable and if rate that exceeds the acceptable range should be regarded as high decent rate. Based on the advisory circulars provided by FAA and Civil Aviation Authority, UK, the current suggested events are able to capture flight performance from the moment engines start till landing (FAA, 2004; Civil Aviation Authority, 2013). Therefore, the basic events are fairly comprehensive at capturing abnormal flight performance. A list of example basic FDM flight performance events provided by FAA is presented in Appendix C.

Event setting is the first step in the FDM process where digital flight data has been defined to reflect flight performance. Understanding how the events were selected and set in the system is a precondition to understanding the other FDM activities and to identifying potential opportunities for human factors risk identification. This model (Figure 4.2) presents the current event setting process in FDM, including different constraints (left side of the model) which need to be considered while creating the events and event refining process. The right side of the model shows a simplified information flow of the analysts' daily data review task, which is extracted from the entire FDM general process model (Figure 4.1). Flight data is downloaded to FDM software, and then events are detected by the event setting programs for analysts to review. This task is performed on a daily basis. A detailed workflow is presented in Figure 4.3 in Section 4.4.

Four major constraints in developing FDM events have been summarized based on the field observation and interview results. These constraints can be regarded as the basic rules of FDM event settings. Constraint 1 refers to the company regulations, such as the SOPs, training standards and policies for economics purposes. These regulations define the flight performances FDM wants to track and the expected performances. Safety operation boundaries are the second constraint; it defines the thresholds for the events. By adding safety thresholds to a corresponding flight performance, a basic description of an event can be created. When programming the defined events into FDM software, another two factors need to be considered. First, the features of flight data recording equipment installed on the aircraft will influence the type and quantity of parameters recorded. The programmers have to consider the availability of the parameters and also select the required parameters that reflect the described events. Depending on the programming function of the FDM software, the events will be programed into the software based on the selected flight parameters. Finally, these programs will be applied in event detection function in the FDM analysis tools.

An ideal and advanced FDM program reviews data every day. Flight data downloaded in the last 24 hours from monitored flight all over the world comes into the analysis tools. If the values of certain parameters exceed the thresholds, events will be triggered for analysts to validate and analyze. This event setting process is also a closed loop system. The events can be refined if the results of the event review are unusual. For instance, if an abnormal trend of a certain event appears, the analysts will check the event setting, including the thresholds and the programs to examine the reasonability of the current setting in order to modify or reset it.

The study found that there are opportunities to add new types of events to track human performance through flight data to detect potential human factors risks. Details of this process are presented in Chapter 5.

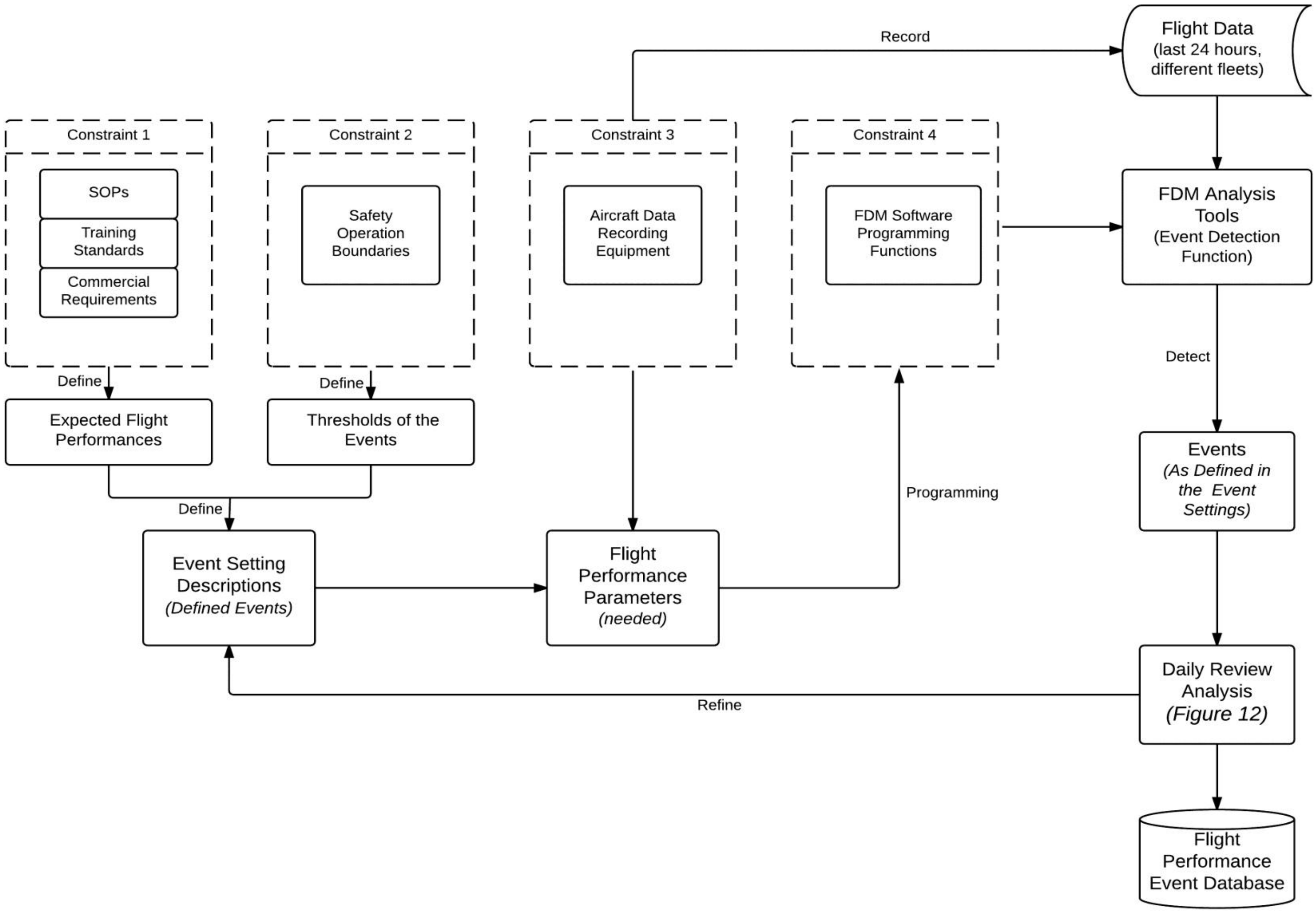


Figure 4.2 FDM Event Setting Process Model

4.4 Daily FDM Review Model

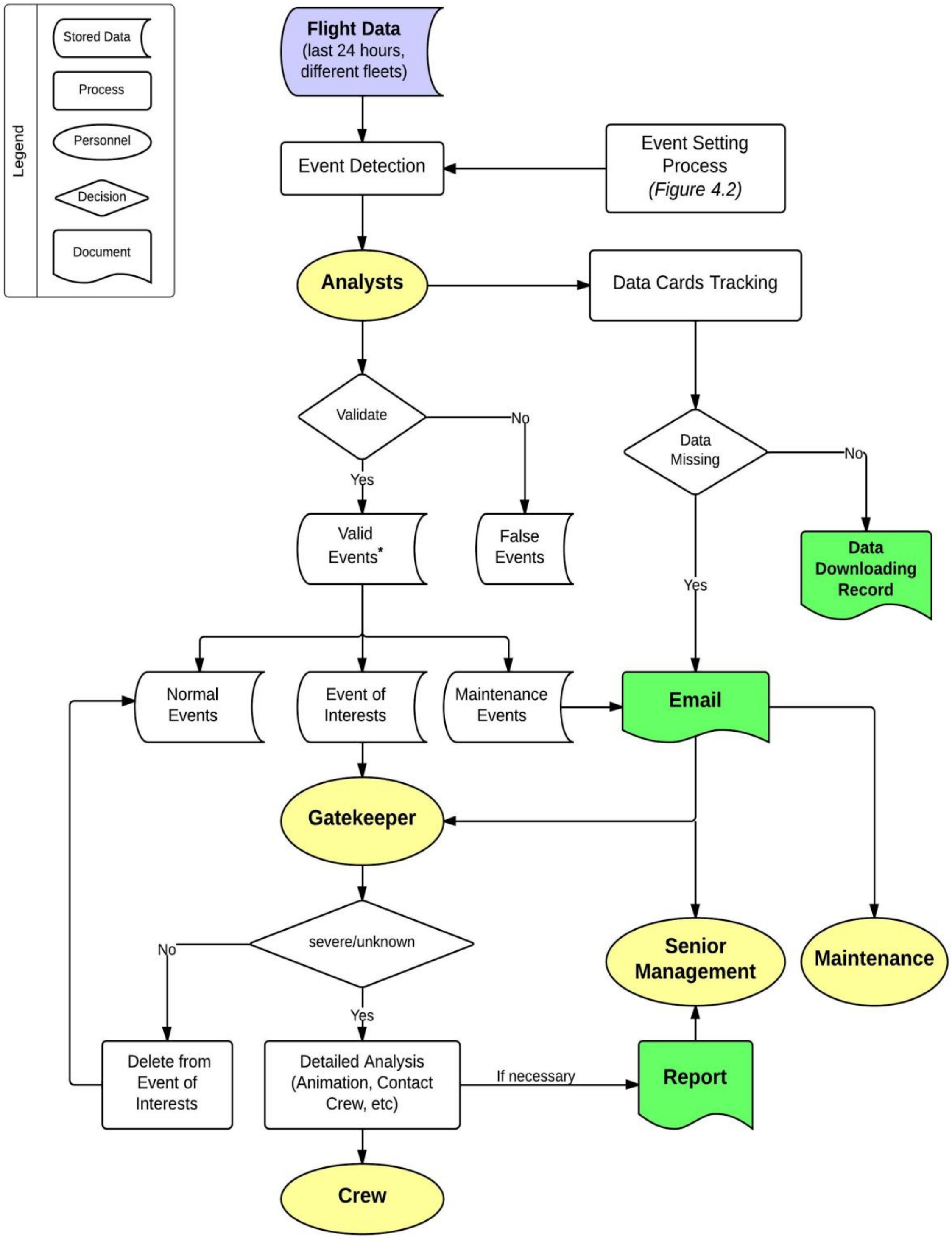
After the events are set up, the FDM analysts are able to validate and analyze the detected event occurrences using the specific software. Understanding how detected events are reviewed and diagnosed is also necessary to discover the potential of FDM in proactive human factors risk identification. A daily FDM morning review workflow (Figure 4.3) was developed to describe the daily tasks for FDM analysts and the detailed process of flight event review. This flowchart presents the detailed information of "FDM Analysts" and "FDM Activities" components in the general FDM process model (Figure 4.1).

One of the major daily tasks for the FDM analysts is the review of the newest flight data uploaded to the system in the past 24 hours. The daily review process is consisted of multiple subtasks, such as tracking data recording cards, validating events detected by the software, filtering events of interest, and reporting maintenance related events. The events detected by the programs in the software need manual validations because the computer is only able to identify abnormal data streams regardless of the actual causes. Therefore, sometimes no actual unsafe flight performance happened but the software identifies unsafe events, which are false alarms. The false alarms may be caused by various issues, for example, a missing data point for one second. Confirmed false events are marked to exclude the noises, and the events that need future reviewing are selected and reported to the gatekeepers.

Gatekeepers in the FDM department are the only people who have the access to the crew information. They are responsible for protecting the confidentiality of the flight data. If the gatekeeper finds the events severe or indicating unknown or potential issues, further detailed analysis will be conducted. Animations of aircraft performance might be created if required or useful for training purposes, and crew might be contacted if needed. Occasionally, an event will be reported to the upper level management for in-depth investigation if necessary.

In some airlines, the accumulated data in a certain time period will be pulled out for trend analysis. The detailed analysis and statistical results of valid events will be shared within the organization in monthly reports. Besides the morning review task and monthly review, the analysts also conduct safety studies (e.g., unstable approach analysis) and commercial studies (e.g., fuel usage study) based on certain types of events and flight parameters. As a specific example, the unstable approach analysis is based on the events related with approach operation (e.g., approach speed control) that happened in a certain time period (e.g., past three months). The fuel usage study is based on flight data related with fuel consumption information and the engine performance.

By observing these tasks, it is found that current FDM practices are relatively comprehensive at analyzing detected events and the analysts have made many efforts in exploring the usage of flight data. However, current tasks focus more on the flight performance issues. There is the potential for more human factors related information to be extracted and interpreted from the digital flight data. The opportunity of detecting human factors risks may also exists in conducting specific human factors related studies using stored flight data. A new perspective of retrieving data from the database is needed to reveal human factors information through safety studies.



Valid Events* detected through the month are analyzed by statistical method every month, results are compared and reported in FDM monthly report, along with FDA staff comments.

Figure 4.3 Daily FDM Review Workflow

4.5 Flight Parameter Grouping

Flight data used in FDM consists of a large amount of flight parameters that cover almost every aspect of aircraft system performance. In the FDM process models discussed above, flight parameters are one of the main resources used in FDM event setting and analysis. The ability of the flight parameters to reflect human factors issues needs to be examined in order to explore the opportunity of identifying human factors issues. To examine whether the flight parameters are able to reflect human factors related issues and to what extend the reflection can be, a flight parameter analysis was conducted. Relevant documents including aviation administration regulations were reviewed and flight data analysis experts were consulted during the field observations. Finally, a flight parameter grouping was performed to classify the recorded flight parameters based on their relevance to human performance.

The FAA Code of Federal Regulations (CFR) Part 121, Subpart 121.344 lists 91 groups of parameters which are required to be collected on the aircraft (FAA, 2014b). Based on the design of an airplane, more than one parameter may need to be recorded by the flight data recorder at the same time to meet each of these requirements. As a result, 91 defined operational parameters in the FAA rule will result in many more than 91 parameters actually recorded. To avoid confusion, the required parameters regulated can be called as parameter groups (Boeing, 2002). Transport Canada also specifies 46 parameter groups which are required to be recorded by flight data recorder (Transport Canada, 2009). Since the FAA’s list is more comprehensive and covers all the Transport Canada’s regulated parameters, the analysis and categorization of the recorded flight parameters uses FAA regulations as a reference. The 91 parameter groups regulated by CFR subpart 121.344 are listed in Appendix D.

Today, the data acquisition and recording unit (e.g., QAR) installed on most of the commercial aircrafts for routine monitoring purpose is able to record an expanded data frame, sometimes supporting over 2,000 parameters, which cover almost every aspect of aircraft system performance (FAA, 2004). This large amount of flight parameters contain all of the required parameter groups as the FAA’s CFR regulated, as well as a great number of other flight system data which are not required. Since the type and number of parameters recorded by different data acquisition equipment on different aircrafts vary, to better organize and analyze them from the general perspective, they can be represented by the 91 FAA regulated parameter groups plus a category of other system data that is not required in the regulation.

Based on the nature of these parameters and their relevance with human performance, the flight parameters can be categorized into seven classes, including pilot settings, cockpit control force, displays, warning systems, time, external environment, and other system data that is not available to pilots during flying. Some of the classes can be divided further into several subcategories. The relevance with pilot performance of the seven classes is reflected in three aspects as follows:

- **Input (reflect aircrew's actions):** parameters belong to this category include Class 1—Pilot Settings (e.g., pitch and flap control input) and Class 2—Cockpit Flight Control Force (e.g., Control wheel input forces) are able to directly reflect pilots' actions, because these are the pilots' inputs to the flight systems.
- **Output (reflect aircrew's awareness):** Class 3—Cockpit Displays (e.g., aircraft physical status data such as speed and altitude) and Class 4—Warning Systems data (e.g., GPWS warning) indicate the outputs of the aircraft systems. This kind of data shows the outcomes of pilots' inputs and is able to reflect aircrew's performance of monitoring these displays and their reactions to emergencies. Therefore, these parameters are related to pilots' awareness.
- **External Influences Factors (influence aircrew's actions and awareness):** refer to parameters like time of the day belongs to Class 5, external environment data such as weather and wind in Class 6. These factors have the potential to influence the pilot actions. This kind of data reflects the influence factors to aircrew performance.

Figure 4.4 shows the process of parameter grouping methods. Table 4-2 presents the seven flight parameter classes and their subcategories, as well as their relevance to aircrew performance.

Figure 4.4 Parameter Grouping Process

Table 4-2 Flight Parameter Grouping

Class	Name		Example Parameters	Relevance to Human Factors
1	**Pilot Settings**	Control input & selections	• Pitch control input • Flap control selections • Spoiler position/speed brake selections	**Input** **(Reflect aircrew's actions)**
		Automation mode selection	• Autopilot engagement status • Automatic flight system modes	
2	**Cockpit Flight Control Force**		• Control wheel input forces • Rudder pedal control input forces	
3	**Cockpit Displays**	Aircraft physical status data	• Speed • Altitude • Heading	**Output** **(Reflect aircrew's awareness)**
		Automation mode displays	• Autopilot engagement status • Automatic flight system modes	
		Other flight system displays	• Which are displayable to pilots	
4	**Warning Systems**		• GPWS warning • TCAS warning	
5	**Time**		• Hour/Day/Year	**External Influence Factors** **(Influence aircrew's actions and awareness)**
6	**External Environment**		• Weather • Wind direction	
7	**Other Flight System Data Not Available to Pilots**		• Air conditioning system • Electrical systems	

The findings presented above indicate that flight data has the ability to reflect human performance and has the potential to detect human factors related issues. If the human factors related parameters are incorporated into event settings in FDM, there are opportunities to analyze pilots' actions and awareness through digital flight data.

4.6 Discussion

By developing the FDM process models and analyzing flight parameters' relevance to human performance, general techniques, resources, and methods used in current daily flight data analysis were studied and understood.

It can be seen from the three models presented above that event setting is crucial in the entire FDM process. The daily routine monitoring and integrated safety studies mainly rely on the event detection function of the software. Reviewing the detected events is one of the major tasks in current FDM. The analysis of event setting process shows that there are some human factors elements in current FDM program. For instance, because current events are built based on the SOPs, the current program is relatively comprehensive at identifying violation of the procedures, which is one of the current major human factors risks (Chapter 3). These events are directly related to pilots' actions. In addition, based on the analysis of recorded flight parameters, flight data that is related with actions and awareness was identified. For example, the automation data in Class 1—Pilot Setting and Classis—Cockpit Displays can help the analysts understand the pilots' status at that moment—whether they were flying the plane manually or monitoring the flight status and their interactions with the automation system.

However, current FDM event sets mainly focuses on unsafe flight performance like high/low speed instead of human performance. Also, the analysis of human factors issues is limited to flights which are detected to have unsafe performance. For example, the human factors related information such as autopilot engagement, is only reviewed when a flight performance event is triggered. The concern is that some underlying human factors issues, which exist in operations that might not trigger the flight undesired states every time, particularly the risks that will not cause immediate aircraft performance consequences are neglected if analysts simply review the triggered flight performance events. For instance, high workload during a certain flight phase might not trigger the unsafe flight performance events programed in the current system, because the pilot performs the procedure correctly and within the safety boundaries even though the workload is high. However, high workload is a risk which needs to be tracked because it has the potential to cause incidents or accident under certain conditions, such as bad weather, suddenly broken equipment or other emergency situations. Another example is fatigue. Similar to high workload, fatigue is another underlying human factors risk which is hard to be detected simply from monitoring whether the flight performance exceeds the safety boundaries. Therefore, new methods of interpreting flight data in terms of human factors elements are needed.

In addition, the integrated safety studies and commercial studies based on collected events in a certain time period allow the analysts to capture trends and patterns in the flight operation from a comparatively large amount of data. This kind of analysis focuses on trends in the operation instead of on individual flights. The common patterns sometime indicate the existence of issues more in the operational environment rather than the individual. The issues may be from external environment (e.g., ATC), supervision (e.g., training) or organization policies. However, there are no current studies concentrating on those example major human factors risks as identified in Chapter 3. The status of some major human factors concerns are possible to be identified and better understood, if accumulated information collected by FDM can be used specifically in analyzing human factors issues.

The FDM models and parameter analysis also indicate that current use of flight parameters in the event setting and integrated safety studies focus mostly on their direct reflection of the flight performance rather than human operator's performance. The analysis and classification of 91 required flight parameter groups will assist the analysts in interpreting human performance from the digital flight data.

4.7 Chapter Summary

In summary, the overall findings of current FDM practices, including general FDM process (Section 4.2), event setting process (Section 4.3), daily FDM review tasks (Section 4.4), and flight parameter analysis indicate that there are potential opportunities of adding human factors elements into the programs. Objective 2 stated in Chapter 1 was successfully achieved.

The FDM general process model captures the basic information flow and core procedures of current program. It also provides guidance to further analyze this program and study its individual components. The event setting process model and daily review task workflow identify the strengths and problems regarding human factors risk detection in the current FDM. The analysis of the models shows that the current FDM practices are fairly comprehensive at flight performance event setting and detected events analysis. However, the focus of the events and daily activities is more on flight performance rather than human performance.

An analysis has been conducted to the recorded flight parameters in order to get insights into the relationships between digital data and human performance. The 91 required flight parameters can be classified into seven classes and three categories based on their relevance to aircrew performance. The flight parameters in these seven classes are able to reflect pilots' actions, awareness, and influence factors to pilots' performance. This finding shows that flight data has the potential of reflecting pilots' performance and detecting human factors risks.

Based on the findings in Chapter 3 and Chapter 4, the opportunities of using FDM to track some current major human factors issues are identified. Detailed examples of detecting some of the major human factors risks are presented in the Chapter 5.

Chapter 5

Potential Approaches of Tracking Human Factors Risks through FDM

Examples of major human factors risks in current airline operations in North America, including SOPs noncompliance, automation issues, fatigue, on time pressure, and high workload, were identified and summarized in Chapter 3. These risks are representative examples of the potential human factors related threats that airlines may hope to track as part of their risk management work. FDM, an accurate and objective information source of real time flight performance as introduced in Chapter 2 and Chapter 4, provides an opportunity for airlines to track these major human factors risks in airline routine operations. In the context of this chapter and thesis, tracking human factor risks means identifying, assessing, and analyzing the exposure and severity of the risks in current operations, as well as understanding why certain risks exist.

This chapter presents detailed explanations of two potential approaches to track the exposure of some major human factors risks through FDM: 1) developing human factors events (HF events), and 2) conducting specific human factors studies (HF studies). Examples of applying these two potential approaches to track some of the major risks are also presented. In addition to tracking the some current major human factors risks, these two preliminary approaches can also be applied to proactively identify the emerging human factors risks which are new or potential threats to airlines.

5.1 Identifying Approaches to Tracking Human Factors Risks through FDM

5.1.1 Airlines' Expectations and Constraints

In order to be practical and acceptable, any potential approaches to using FDM to track Human Factors issues need to be consistent with the airlines' expectations of the benefits they can obtain and costs they would incur. These expectations were derived from comments made by participants in the interviews described in Chapters 3 and 4, as well as informal discussions with representatives of other airlines met during industry conferences. The activities in Chapter 3 and Chapter 4 provided the current practices that any proposed approach would need to be compatible with.

Based on the understanding of the current FDM processes and the airlines' constraints of using flight data developed through field observations and interviews, three primary expectations of the human factors risk tracking approaches were summarized.

- Use de-identified flight data.

As discussed in Chapter 4, current flight data analysis is based on de-identified digital flight data to secure the privacy of the aircrew and maintain their trust. To comply with this current FDM rule, the interpretation of human factors issues should also be restricted to using de-identified flight data (FAA, 2004; Transport Canada, 2001). Using de-identified data is also consistent with the intended focus of developing better ways of understanding the existence and root causes of the human factors issues, rather than catching individuals making mistakes.

- Capable of being embedded in current daily routine FDM processes.

The potential approaches should be compatible with and complementary to current daily FDM processes. For airlines which already have a relative mature FDM program, the implementation of the human factors risk tracking approaches should have minimal impact on their current FDM activities. This expectation aims to make sure that the expanded use of FDM will improve the current risk identification and FDM processes without significantly affecting the original routine activities.

- Control costs.

The costs of implementing new risk tracking approaches in FDM include the required investment of human resources (e.g. subject matter experts and/or potentially additional personnel involved in activities such as daily flight reviews), as well as material resources and development costs. From a practical perspective, any new approaches should avoid requiring significant additional effort from existing personnel and should only require human involvement where it adds significant value to the process.

5.1.2 Method for Identifying Approaches to Track Human Factors Risks through FDM

To identify approaches meeting the expectations listed above, the current FDM data review process discussed in Chapter 4 was reviewed to determine where it might be expanded to track human factors risks, while staying consistent with the expectations just discussed. The review identified two opportunities for new approaches within current routine data monitoring activities.

The first approach was identified by recognizing the importance of the current event setting logic. The approach consists of adding new types of events specifically focusing on observable indicators of human factors issues. The new type of events can be referred to as “HF events”. If human factors elements can be embedded in event sets and reviewed by the analysts routinely, it will provide an opportunity to keep track of the human factors risks automatically through software. It also provides an opportunity to identify underlying human factors issues that might not always trigger flight performance events (e.g., high workload and fatigue), allowing them to be included in current daily monitoring processes. Since the analysis of flight parameters indicate that digital flight data are able to reflect human performance to some extent, there are opportunities to program HF events for specific human factors risks.

The second approach identified in the review was inspired by the integrated safety and commercial studies currently conducted based on the data collected from a number of flights (Figure 4.1, Figure 4.3). These studies can be expanded to include conducting specific HF studies to track some major human factors risks through FDM. Current FDM studies generally concentrate on one particular issue and have clear goals. Similarly, studies could be conducted concentrating on a particular human factors risk. The flight data and detected events usually contain more information than they appear to, especially when trend and statistical analysis are done to the accumulated information provided by certain types of events and specific flight parameters during a certain time period. Human factors knowledge and theories need to be applied to the studies, together with human performance related events.

A summary of the two potential approaches is shown in Figure 5.1.

- **Approach 1—HF Events.** Adding new HF events to current event settings in flight data analysis software to track some major human factors issues in routine operations.
    - A “micro”-approach, because it focuses on analyzing information collected from individual flights.
    - The programed HF events help detect human factors risks directly by flagging flights for follow up as part of the FDM daily review.
    - In addition, the HF events information collected through Approach 1 can provide support to Approach 2 in further studies.
- **Approach 2—HF Studies.** Tracking specific human factors risks through trend and comparative analyses with a new perspective of retrieving and analyzing data from FDM database.
    - A “macro”-approach, because it is based on aggregated flight data and events detected from a number of flights and it concentrates on the trends of a group of flights.
    - Approach 2 can be applied to identify underlying human factors risks that cannot be addressed through a single HF event or events detected from individual flight.

- This approach can also be used as the follow-up step of Approach 1 to identify if a risk detected from individual flight is a common risk in operation and how it changes over time.

Detailed explanations and examples of applying these two potential approaches are described in the following sections in this chapter.

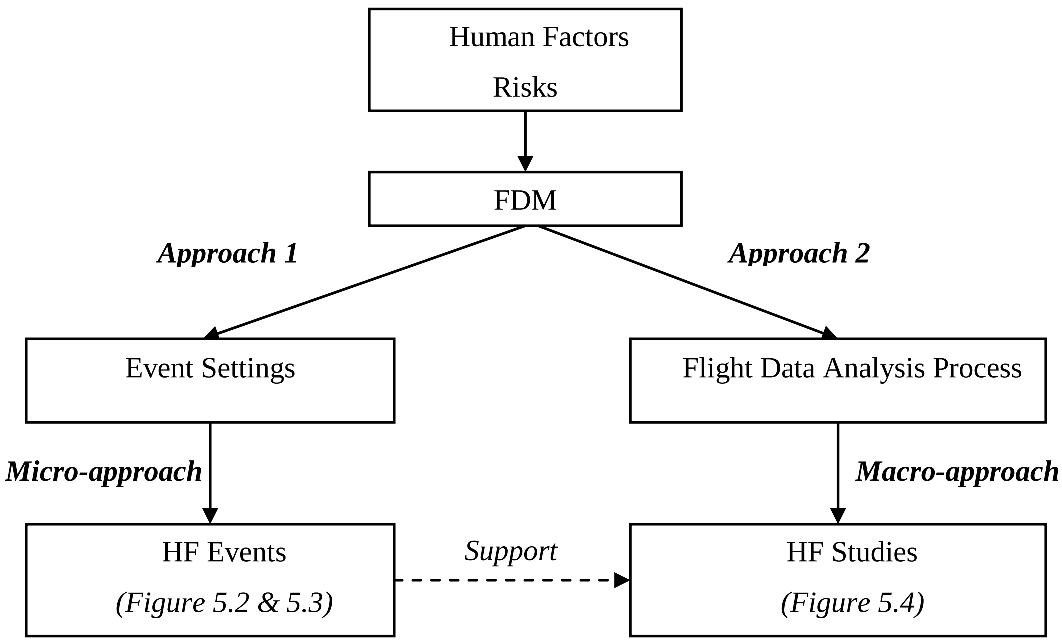


Figure 5.1 Potential Approaches

5.2 Approach 1—HF Events

Inspired by the current FDM event setting process model (Figure 4.2) and the findings from the flight parameter grouping analysis (Section 4.5), the first potential approach of using FDM to track human factors risks is setting up new HF event in the data analysis software.

Approach 1 allows the software to scan every flight and detect human factors events automatically in routine data monitoring. However, since this approach requires defining a rigorous relationship between human factors risks and flight parameters, not all major human factors risks can be addressed through Approach 1. The underlying logic is shown in Figure 5.2. If a human factors risk exists in an airline's operations, there should be causal factors which lead to the risk and impacts on human performance (consequences) caused by the risk. Causal factors are aircraft states, human operator actions, or other potential indicators that the presence of the human factor risk is likely. Consequences are expected outcomes, either in aircraft states or human operator actions that would indicate the presence of the risk. Therefore, the appearances of these signs (causal factors and consequences) may be indicators of the existence of the selected risk. If such indicators can be captured by certain flight parameters, so that recorded flight data can reflect the appearances of either the causal factors or the consequences of the selected risk, there is a possibility to track this risk by detecting such appearances through programing new HF events.

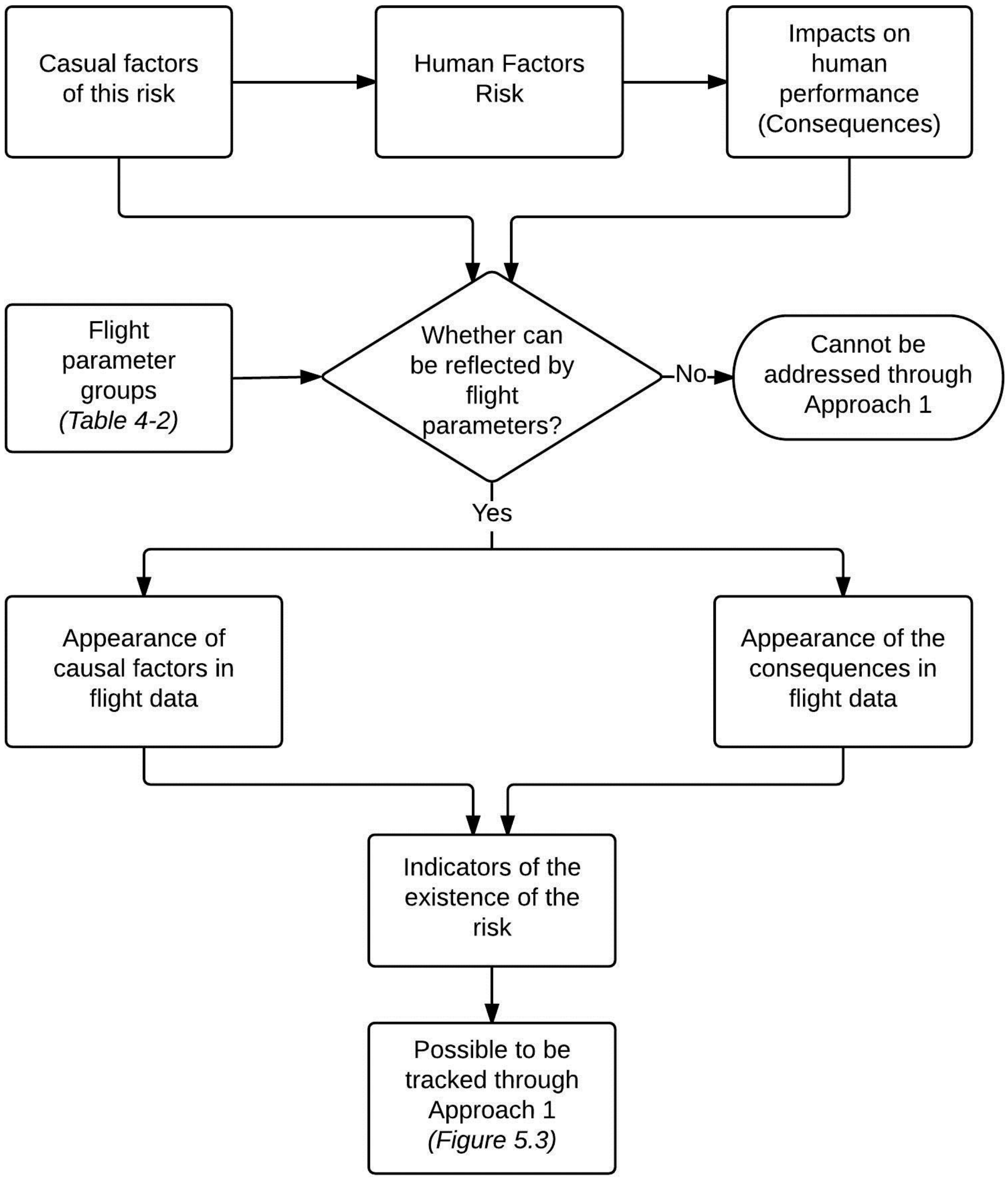


Figure 5.2 Logic of Approach 1

As shown in Figure 5.2, the core challenge is to determine whether the causal factors and consequences of the selected risk can be reflected by flight parameters. The seven parameters classes (Table 4-2) can be applied here. For example, workload risk is found related with the number of tasks and working environments (Gawron, Schiflett, & Miller, 1989). High workload may be caused by excessive number of tasks performed in a certain time period or inappropriate working environment. In this example, the number of tasks along with the state of the working environment (e.g. presence of weather) is identified as a causal factor that can be used as an indicator of the risk of excessive workload. The question then becomes one of determining if there appear to be parameters that are sufficient to reflect the pilot tasks and working environment. Parameters classes in the categories of input (Table 4-2) which reflect pilot actions have the potential to reflect performed tasks. Parameters in Class 6 External Environment can reflect the working environment. Explicit mapping between flight parameters and the selected risk will be done in the HF event setting process (Figure 5.3).

5.2.1 HF Event Setting Process

Figure 5.3 is a modified FDM event setting process model (Figure 4.2) for HF events. A new constraint regarding human factors risks is added. Other steps have been modified to fit the needs of human factors risk identification. For example, since the process is designed for HF events, the focus of the SOPs analysis and flight parameter selection is on human performance (i.e., what operators are required to do) rather than flight performance (i.e., what are the required flight states).

The HF event setting process can be described by the major steps labeled in Figure 5.3:

a. **Define the indicators of the selected risk.** As discussed in the context of Figure 5.2, the indicators can be causal factors of the selected risk or the consequence caused by the risk.

b. **Defined expected human performance.** The expected human performance (i.e., what the aircrew are expected to do) is able to be defined through the SOPs, training standards and other requirements. The indicators of the selected human factors issues represent the abnormal signals that might show in the data, they will need to be compared with expected data defined in this step in order to define an event for use in the FDM analysis.

c. **Define the thresholds for the selected human factors risk.** Different from the traditional flight performance event setting (Figure 4.2), the considerations of safety operation boundaries here not only include aircraft states, but also the thresholds of human performance/behaviours, as well as internal and external influences (e.g., workload and pressure) of human performance. The thresholds here are a set of limits which decide how much deviation from the standards should trigger the events. For example, if expected workload is to perform "x" (x is a number) tasks in a certain time period, performing "x+y" (y is a number) tasks during this time period will be regarded as high workload situation worthy of triggering an event. To actually define the event requires determining the number "y" as the threshold of the high workload issue.

Combining the elements defined from step a, b, and c, the initial event description for the selected human factors issue can be defined. The description of an HF event consists of a statement of the indicators of the issue, the expected human performance, and how much deviation from the standards is considered to be worthy of triggering an event for analysts to review.

d. **Translate the defined event description into related flight parameters.** This is a key step in the entire process. The analysts need to identify parameters that reflect the risk indicators, human performance, and thresholds defined in the events, and how to use the parameters to describe the event. To help mapping the human factors issue with available parameters in the flight data, the seven classes of human performance related parameters identified in Chapter 4 can be applied here. Examples of how to do this are presented in Section 5.2.2 below.

e. **Program the event into flight data analysis tools.** After the event was mapped to the related parameters, it needs to be programed into the flight data analysis tools. If the defined event cannot be programed into the software due to limitations of the software and the logic it supports, or parameters are unavailable at the required update rate, or any other reason associated with practically implementing the defined event, the basic event definition would need to be revised and refined. Experienced analysts who are familiar with the programing functions of the data analysis tools should consider its availability in terms of how to fit the functions best when designing the event. The HF event has to have a clear logic, and whether it is accurate and comprehensive to capture the tracked human factors issue will be determined through tests and practices. Therefore, not all the risks determined with the potential to be addressed through Approach 1 can be successfully programed.

f. **Review the detected events.** Once the event has been set into the software and detected by the analysis tools, it will go through the same daily review process as described in Chapter 4 (Figure 4.3). The threshold and the definition of the event can be refined if unreasonable patterns emerge or too many false alarms show up.

g. **Collect information for future study.** Finally, the information provided by this type of events will assist analysts in future HF studies (Approach 2, Figure 5.4).

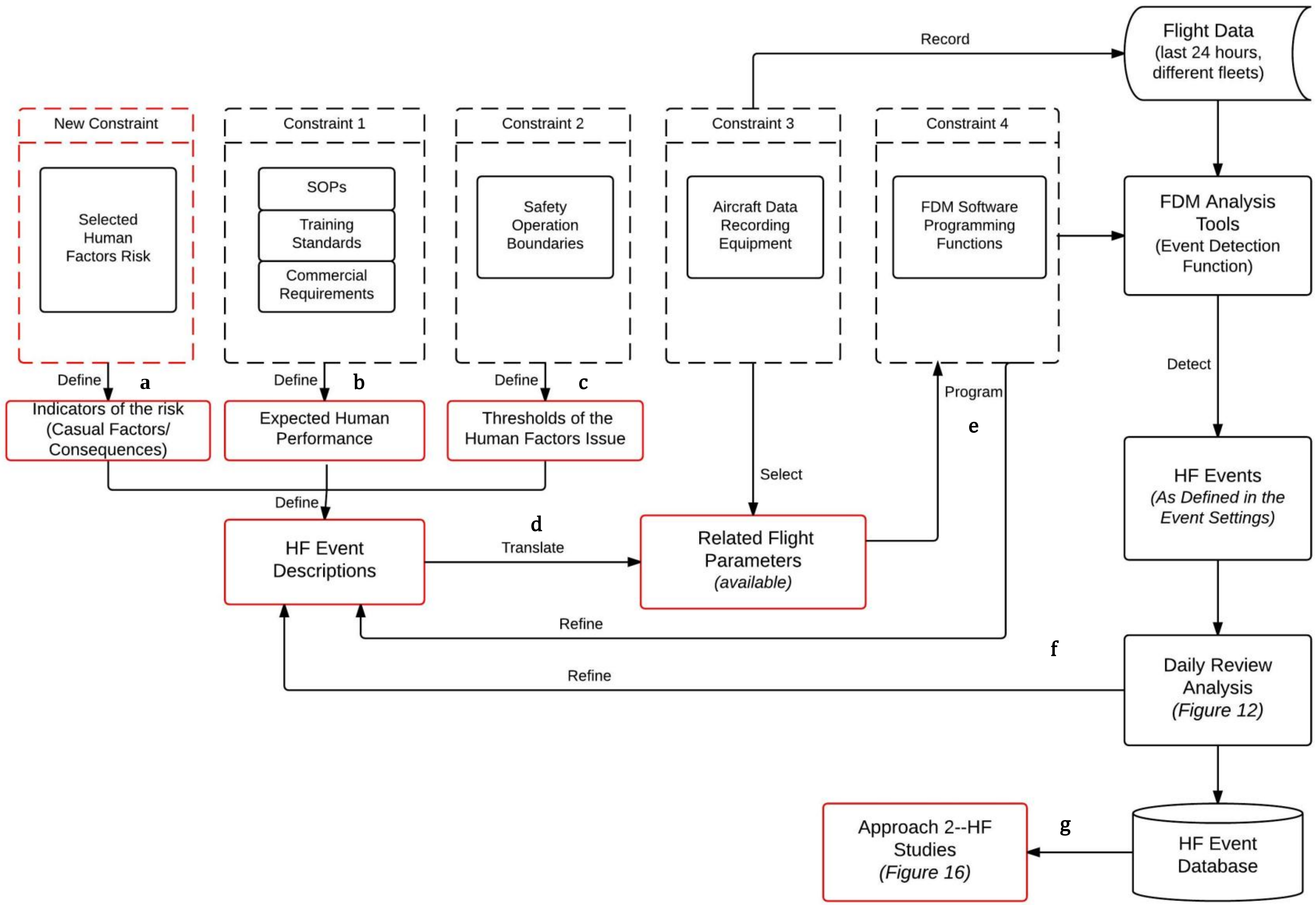


Figure 5.3 HF Event Setting Process

5.2.2 Approach 1 Implementation Examples

As discussed in the synthesized results in Chapter 3 from both the HFACS analysis and interviews, automation confusion and high workload issues are two major human factors in recent years. To demonstrate the application of the logic of Approach 1 (Figure 5.2) and the human factors event setting process (Figure 5.3), the following sections illustrate how these two major human factors risks could be tracked through Approach 1.

5.2.2.1 Example 1: Automation Mode Confusion

Automation has been introduced in the aviation industry for years to improve the performance and reduce mistakes. However, automation-introduced problems have long been one of the concerns in aviation safety management (Amalberti, 1998). Several commercial aviation accidents have been partly caused by pilot confusion about the operation of the aircraft automation systems. For example, a China Airlines Airbus 300 crashed during the approach to Nagoya Airport in Japan. The crew engaged a mode that commanded climb with full thrust, and meanwhile manually pushed the control wheel down in order to prevent the aircraft from climbing. The conflicting commands led to a very complex situation and the aircraft rolled to one side and crashed (Degani, Shafto, & Kirlik, 1996).

A previous study by NASA (Srivastava & Barton, 2012) and the investigation report analysis in Chapter 3 found that automation mode confusion is one of the current major risks. Automation mode confusion refers to the situations where the pilot is uncertain about the status or behavior of cockpit automation (Spencer, 2000). In the modern aircraft, there are multiple automation systems (e.g., autopilot, autothrottle, and navigation system). Different modes of the automation systems command aircraft to perform in certain ways to accomplish flying tasks in different flight phases. Based on the parameter analysis in Chapter 4, there is a group of flight parameters recording automation system configurations. Therefore, pilots' interactions with the automation systems can be observed. These automation system data provide an opportunity to track the automation confusion risk through Approach 1.

Among the multiple automation systems (e.g., autopilot, autothrottle, and navigation system), data analysts need to decide which automation systems to track and set up separate events for each system based on the type of aircrafts, because different systems require different operations. For example, if the airline just put a new model of aircraft into use which is equipped with a new designed navigation system, the FDM analysts may want to monitor the pilots' interactions with this new system to determine if automation confusion risk exists specifically with the new system.

The major steps in developing HF events for the automation confusion risk are discussed below (following steps in Figure 5.3):

a. **Define the indicators.** It can be seen from the accident example discussed above, the consequences caused by automation confusion issue include errors in the mode configuration procedures. These consequences can be the indicators of the existence of the automation confusion risk. Specifically, two example situations caused by the automation confusion could be: 1) the pilots cannot decide/remember which mode is correct, so they switch mode back and forward frequently (more than in normal situation). The undesired frequent change of automation mode may lead to undesired aircraft states and cause more confusion to the aircrew; 2) the pilots selected the inappropriate mode during a certain phase of flight without immediate correction.

b. **Defined expected human performance when operating the automation systems.** The expected mode selections of the automation systems and normal mode switch frequency during a certain flight phase can be determined from the SOPs and training standards. For instance, if events are set for tracking possible mode confusion issue on navigation system, then standard operations of this system need to be defined from rules and training regulations.

c. **Define the thresholds for automation confusion issue.** For the first mode confusion situation discussed in step a, the analysts should consider the normal frequency of automation mode changes during a certain flight phase and the safety boundaries of mode switch frequencies. Sometimes, in order to accomplish some task, the pilot might need to switch an automation mode several times. Therefore, to limit false alarms, a maximum acceptable mode switch frequency could be set. Only when the mode switch frequency is more than that limit, an event will be triggered to indicate potential mode confusion issue. The threshold may not exclude all the false alarms, but in order to make the false alarms under control, the value of the threshold need to be modified according to the test results. For the second situation, analysts should consider the correct setting of the modes regulated in standards. The threshold could be the deviation of actual mode selections of a certain automation system from the standards.

d. **Translate the defined automation confusion events into flight parameters.** In this case, the translation is comparatively straightforward, because the human operations on automation systems have direct correspondence in flight data. Available flight parameters related with automation systems should be selected to program the event. Among the seven flight parameter classes discussed in Section 4.5, Automation Mode Selection and Displays which belong to Class 1 Pilot Setting and Class 3 Cockpit Displays, includes automatic flight system mode input data and mode displays data such as pitch modes, thrust modes, and “On” or “Off” mode of the autopilot (Degani, Shafto, & Kirlik, 1996). Depending on which automation system analysts want to track, they need to choose relevant parameters (e.g., autothrottle, navigation or thrust modes). Other parameters such as time and altitude can also be used to reflect the phase of flight. Two general example automation mode confusion events can be described below.

- **Event HF01 Abnormal Automation Mode Change**: If the mode of automatic flight systems changes back and forward frequently (more than the acceptable maximum time of expected mode change) during a short time period an event will be triggered. The event set logic could be automation mode switch times > # during x min/for Height Above the Terrain (HAT)<x ft & HAT>x ft. HAT can be reflect by flight altitude data, and is used to determine the phase of the flight.

- **Event HF02 Incorrect Mode Selection**: If the selected mode is not accorded with the requirement in the SOPs and has not been corrected immediately, an Incorrect Model Selection event will be triggered. This event might need further investigation on whether the pilot made an error because of misunderstanding of automation systems or it is a violation of the standard requirements.

e. **Program these events into flight data analysis software.** The analysts need to consider the features of the programing function of the software when defining the events. The suggested basic automation events presented in this study need to be further explored and refined by the flight data analysts during actual implementation to fit the data analysis tools.

Step f and g are similar to the general process described in Section 5.2.1 and easy to understand, so details of these two steps will not be discussed in this example. Once these two automation confusion related events have been programed into the software, the automation mode selection related aircrew performance will be tracked by the programs. If the data exceeds the threshold, events will be detected and presented to the analysts. The triggered events will be validated and go through the daily review process as described in Figure 4.3, in order to constantly monitor this risk. The information collected by the detected automation confusion events can also provide an opportunity for the gatekeepers to further investigate why the mode confusion issue happen when contacting the aircrews. Determining the probable root causes of automation confusion, for example, whether it is because of inadequate training or consequence of a navigation procedure will help the safety department take corresponding mitigation actions to proactively control the risk. Moreover, the automation confusion events may also help identifying training needs for pilots operating new aircraft.

5.2.2.2 Example 2: High Workload

High workload is also determined as a major concern from the HFACS analysis of the investigation reports in Chapter 3. Workload of tasks represents the demand for an operator's mental resources used for attention, perception, reasonable decision making and action (Young & Stanton, 2001). Since human resources are limited, if the tasks during a certain time period are close to, or exceed, the available cognitive resources, errors may happen. Research shows that high level of flight workload, especially in noisy environment, lead to deficits in pilot's performance (Casto & Casali, 2013). Excessive workload has been cited as one of the contributing factors in several commercial aviation accidents, including the crash of American Airline Flight 965 into a mountain in Buga, Colombia in 1995 (Aeronautica Civil of the Republic of Colombia, 1995), and a recent accident of Ethiopian Airline B738 near Beirut in 2010 (Ministry of Public Works & Transport, 2012). The focus of developing high workload event is detecting excessive workload situations which are potential threats to flight safety.

Research shows that flight task workload commonly depends on two factors: tasks (number of procedures and their complexity) and environment conditions such as weather and time of the day (Gawron et al., 1989). The flying tasks can be reflected by the pilot input data (Class 1 Pilot Setting and Class 2 Cockpit Flight Control Force). The environment conditions can be reflected by weather data and time of the day. These flight parameters provide an opportunity to detect high workload situations through Approach 1.

To develop specific HF event to track high workload risk using Approach 1 (Figure 5.3), major steps are discussed as below:

a. **Define the indicators.** As discussed above, the indicators of high workload risk can be its causal factors including the number and complexity of the tasks during a certain time period and the environment condition where the tasks are performed. If more tasks need to be performed than expected or the difficulty of the tasks is more than expected, the workload will increase.

b. **Define the expected workload.** Based on the indicators of workload defined in step a, the expected workload can be represented by the number and complexity of the tasks required in the SOPs. One possible way of measuring the complexity would be to evaluate the task load of each task regulated in the standards based on required mental and physical resources to complete it. Then the sum of the task load of individual task performed during a certain time period can represent the one part of the total workload during this time period.

The other part of the total workload is contributed by environmental factors. Because bad weather conditions may increase the difficulty or complexity of conducting some tasks, thereby increase the workload. For example, the weather condition can be divided into several levels from good to severe with accorded values, assuming they can be determined from on-board parameters or the general 'day-of' weather information that is available. Warning signals may also influence the workload since it can act as environmental influence factors. The output of this step is the defined appropriate task load values for standard procedures and environmental factors.

One possible method of determining the task load values of procedures is using a task load index such as the NASA-Task Load Index (Hart & Staveland, 1988). Consider the feature of the flight tasks regulated in the SOPs, some changes of the measuring criteria need to be made if use NASA-Task Load Index as workload assessment tool. An example customized NASA-Task Load Index has been created and presented in Appendix E. Other workload assessment tools can also be used. Developing and interpreting the workload scale means the development of this workload event needs to be conducted in the collaboration with experienced pilots, human factors experts, and FDM analysts.

c. **Define the thresholds.** The human factors and flying experts need to set up a maximum acceptable workload threshold based on their experience and data analysis tests. For instance, if the expect workload value defined from the SOPs for a certain time period is "x", the workload value higher than "x+y%" are unacceptable, the analysts need to determine the proper value of "y". The thresholds (i.e., the maximum acceptable workload value), task loads of the tasks and calculated time period should be tested and refined by the analysts to make the event reasonable.

If task load values of tasks conducted in a certain time period exceeds the maximum acceptable value, a high workload situation might exist in the operation. Workload during normal flight operations should not be excessive, in order to ensure flight safety, but during flying, procedures will not be conducted at exactly the same pace as required in the SOPs. Weather conditions and other environmental factors (e.g., ATC and airports) may influence the pace of the procedures. For example, when a warning signal occurs, more procedures will need to be conducted by the pilots.

The suggested event for high workload situation identification is described as below:

- **Event HF03 High Workload**: If the sum up value of procedures conducted in a certain time period (e.g., 10 minutes or during landing phase) is higher than the threshold, than a high workload event will be triggered.

d. **Translate the Event HF03 into flight parameters.** This step is about mapping the defined workload event with flight parameters explicitly. Since the workload values are contributed by tasks and external environment conditions, if the performed tasks and external conditions can be captured by the change of flight data, the workload value can by calculated once the data indicate that the task is performed and certain environmental conditions. Therefore, parameters with the potential to reflect operational procedures and environment information need to be considered in programing this event. The flight parameters in Class 1 Pilot Setting, Class 4 Warning Systems, and Class 6 External Environment can be used in programing the event.

   The change of pilot settings can reflect the procedures the aircrew is conducting, so the change of pilot setting data can be used to determine which tasks and how many tasks have been performed during a time period. Then, the overall workload value can be calculated. If warning signals exist or the weather condition is bad during that calculated time, additional workload values will be added. Because noises like warnings and bad weathers may introduce more pressure and workload to the operators.

Step e, f, and g are similar to the general process described in Section 5.2.1 and easy to understand, so details of these steps will not be discussed in this example. Once the event has been programed into the software, it will be reviewed on a daily basis by the analysts. During the daily review, this event might be detected in two cases. First, if this event is detected together with other flight performance events in the same flight, further analysis of this flight should be conducted because high workload may be one of the probable contributing factors to other unsafe performance. Gatekeepers may contact the crew to enquiry whether the pilots felt workload high during flying and whether this factor influenced their operations.

Second, this event is able to identify the excessive workload situations for individual flight with no other flight performance events. High workload situations may not cause errors or other consequences every time, but this risk is a potential threat to operational safety. It will help prevent incidents and accidents if such situations can be monitored and mitigated proactively.

The information collected by workload event also helps to identify the possible inappropriate design of the airline's current SOPs or training issues if similar trends are identified from a group of flights in further studies in Approach 2.

5.2.3 Summary of Approach 1

HF events provide an opportunity to monitor some of the human factors risks independently from other flight performance events on a daily basis. In addition, currently, since there are no FDM events focusing on human factors risks except some SOPs noncompliance issues, data analysts and gatekeepers do not have regular triggers to discuss such issues with aircrews. The application of HF events in routine monitoring will help trigger the conversations between gatekeepers and aircrews on specific human factors issues, which will help to understand the root causes of the risks.

Figure 5.2, Figure 5.3 and the two implementation examples have provided detailed explanations of the potential application of this approach. The major steps of developing HF events include determining the indicators (causal factors and consequences) of the selected risk, defining the expected human performance from the SOPs, setting appropriate thresholds to detect the risk while minimizing false alarms, and mapping the indicators to flight parameters. The mapping is the key step in the entire process as it bridges the human factors elements with available FDM data, which makes it possible to interpret human factors risk related information from digital flight data.

The example HF events for automation confusion and high workload presented in this section can be customized to meet the requirement of different airlines. The HF01 and HF02 automation confusion events are especially recommended for new fleets (e.g., Boeing 787), where new pilots are interacting with new operational environments.

5.3 Approach 2—HF Studies

The second approach to track human factors risks through FDM is conducting aggregate data studies on individual human factors risks. This approach relies on the use of trend and comparative analyses based on accumulative information collected from a number of flights. The results can help analysts understand where in the airline's operations the selected risk exists and how it changes over time. Understanding these issues will help determine risk control mitigation plans. The ultimate goal is contributing to a comprehensive assessment of the risk; the proposed approach is only one piece of this complicated task that requires skilled and experienced analysts to consider a range of information sources and activities.

Approach 2 is well suited for those human factors risks that are hard to identify from individual flights (e.g., on time pressure) but which might be revealed by trends and patterns of certain performances across a number of flights. In addition, as discussed in Section 5.1, for the risks that are already captured by HF events in Approach 1, Approach 2 can be used as a follow-up step to further analyze whether these risks detected from individual flight exist commonly in the routine operation.

For both types of human factors risks (detected in Approach 1 and not detected in Approach 1), these analyses may also help examine different aspects of the selected risk, including, as examples commonly of interest, differences across aircraft types, airports, and phases of flight. This can be a useful input to the broader step of understanding the organization's exposure to the risk and how it is changing over time.

5.3.1 HF Study Process

The general HF study process using the FDM database is shown in Figure 5.4.

a. For a selected human factors issue, similar to Approach 1, its consequences and causal factors need to be determined. To understand the background knowledge of the selected risk, data analysts may need to review previous literature or consult with aviation human factors experts.

b. The next step is to select related events that can reflect the determined consequences and causal factors from the FDM event set, including both traditional flight performance event set and HF event set developed using Approach 1.

c. Once the related events are selected from the event set, analysts need to retrieve the occurrence data of these selected events from the FDM database, which stores all the detected valid events. While retrieving the occurrence data, analysts need to consider the scope of the analyses in terms of the amount of data.

d. Depending on the determined indicators of the risk and selected events, a wide range of analyses can be done. For example, straight forward trend analysis of the available indicators can be used to track the exposure of some risks. In addition, comparative analysis can be done to identify relationships between occurrence rate and certain comparative factors, such as different fleets and different flight routes. Patterns and trends which indicate the existence of the risk may be identified from these analyses.

e. Depending on the results, the study may need to be adjusted and refined. The analyses design may need to be adjusted and the selection of the related events may need to be refined. In addition, if the event set cannot satisfy the need of the study, adding new events to collect useful information for the HF study can be considered.

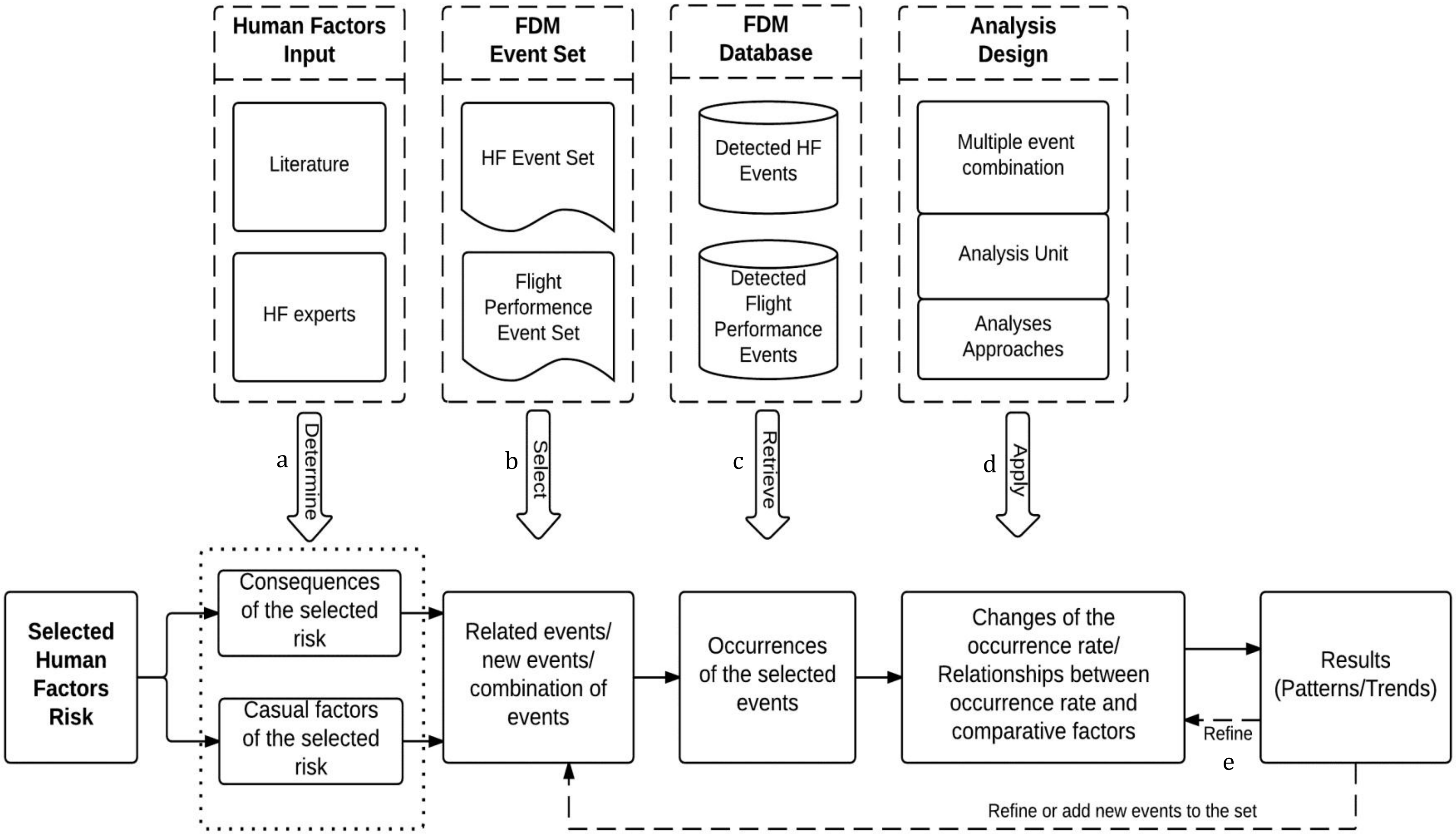


Figure 5.4 FDM HF Study Process

5.3.2 Key Decision Points in the HF Study Process

A review of the process proposed in Section 5.3.1 identified several key decisions that an analyst must make in implementing the process. These key decisions are discussed in detail in each section below.

5.3.2.1 Analysis of the Human Factor Risk (Step a)

Input from human factors research, including studies, best practices, domain guidelines etc.. should be used to decompose the HF issue into causal factors and consequences. This is similar to the step a described in Approach 1 (Section 5.2). As described there, causal factors are aircraft states, human operator actions, or other potential indicators that the presence of the human factor risk is likely. Consequences are expected outcomes, either in aircraft states or human operator actions that would indicate the presence of the risk. An initial breakdown of the risk is expectedly to identify a range of both factors and consequences; not all will be able to be captured through the FDM data available. In performing the breakdown, the goal should be identifying factors and consequences that are necessary and/or sufficient to capturing and tracking the existence of the risk. In order to perform the breakdown, and to understand the background knowledge of the selected risk, data analysts may need to review previous literature or consult with aviation human factors experts.

5.3.2.2 Mapping Causal Factors and Consequences to Events (Step b)

After determining the possible causal factors and consequences of the selected risk, the next step is to select related existing events that can reflect these causal factors and consequences from the programed FDM event set. Pre-existing HF events may already have this mapping established, but there may be additional pre-existing flight performance events that can also be used as indicators. This is different from Approach 1 where the focus was on mapping causal factors and consequences to the creation of new events. The selected events can be both traditional flight performance events and HF events developed using Approach 1. In some cases, analysts might find that the needs of the study motivate the definition of new events; in this case, the step becomes similar to that described in Approach 1 (Section 5.2).

For the set of causal factors identified in step a, the set of events available across the aircraft types of interest should be reviewed for events which either individually, or when occurring at the same time as another event(s), are indicators of the presence of the causal factor. For example, if a causal factor of the risk of distraction is the presence of warning signals, events capturing warning signals in the cockpit should be identified. This step will require careful judgement and consideration of the use of proxies and substitute events, and combination of events, as it is unlikely that every causal factor will be directly identifiable in the existing set of events. The same process would then be repeated for identified consequences, with the focus again being on identifying reasonable approximations, substitutions, and potential combinations of existing events.

There are several issues that will need to be resolved on a risk-by-risk basis. Not all risks will have matching events for both factors and consequences; the sufficiency of the identified events will require practical judgement and review with subject-matter-experts to confirm their appropriateness. Judgement and experience will also play a role in determining how many events are appropriate; too many events can dilute the ability to detect measurable trends, while too few events may lead to overconfidence in the value of the results of the study for assessing the presence of the risk. Clear documentation of the mapping between each causal factor, consequence, and the associated risks would help communicate the value of the subsequent analysis for assessing the overall risk.

5.3.2.3 Retrieving Occurrence Data for HF study (Step c)

Occurrence data of these selected events are the data sources used in the HF study. In this step, the first decision to make is the scope of the study. For airlines, especially big airlines which have several fleets, the FDM event data may cover most of the fleets and may keep data from years ago. It is not possible or efficient to retrieve all the available occurrences for the selected events in the databases for all the fleets. Therefore, the scope of the study, in terms of the amount of data the study hopes to review, needs to be defined. Too much data, for example, data in the past ten years, may include data from too long ago, which are no longer operationally relevant due to procedure and organizational changes. However, with too little data there may not be enough information to identify patterns and trends of the selected risk.

The occurrence data of the selected events retrieved from the database not only contain the information of the triggered events, but also include other information such as aircraft type, route of the flight, departure and destination airports, and weather conditions etc. Such information helps further narrow the range of data retrieving. Based on the analyses planned to do in the next step, occurrence data collected during the determined scope of study can be retrieved based on specific fleets, flight routes, and airports.

Setting a scope for the study and considering the later analyses before retrieving the data help make sure that the retrieved data include enough sample of information for comparative and trend analyses and match the goal of the analyses. The decisions made in this step also help improve the efficiency of the study by retrieving the most useful and relevant data.

5.3.2.4 Analysis Design (Step d)

All the information and data obtained from previous steps need to be applied in this analyses design step. Three key issues analysts need to carefully consider in designing the analyses for HF study are how to combine the events in the analyses if multiple events are selected, what type of analyses to conduct, and the choice of analysis unit (as shown in step d, Figure 5.4).

Combining events into objects of analysis

The selected human factors risks may have multiple causal factors and a variety of consequences as indicators. As discussed in the step b (Section 5.3.2.2), some of these indicators can be reflected by multiple events, while some indicators cannot be reflected by FDM events. For some risks there might be only two related events, and for some risks there might be more than 20. The challenge is how to handle the multiple events in order to gain insights into the underlying risk. Combining the occurrences of all events together into a single "object of analysis" may make it simpler to present and interpret the results but may also lose insights into effects seen only with the trends of individual events.

Therefore, the analysts need to decide how to combine these events into the objects of analysis. A simple approach is to combine the events together into a single combined "master" event, ignoring distinctions between the underlying events. Other alternatives could include applying metrics (such as maximum, or minimum functions) to occurrence rates of the individual events and treating the result of the metric as the object of analysis, or choosing to not combine the underlying events and instead to rely on analysts to synthesize themselves the results at the end of the analysis process.

Depending on different risks and objects of analysis, events can be combined variously. There are two factors thought to be most relevant to the choice of how to combine events.

One of the factors is the number of events selected in step b. Combining events into a single master event, or into a single metric, has the advantage of making interpretation of the results simpler and more direct and may give insights into the overall situation of the selected risk. On the other hand, examining each event individually can reveal different aspects of the selected risk. When there are a small number of events, it may be feasible and advantageous to examine both the results of a combined master event while at the same time also examining the results of each event individually. However, for the situation where a large number of events can be used in the analyses (e.g., more than 20 related events), it would likely not be feasible and efficient to examine each event individually.

The second factor is the features associated with events. For example, multiple events can be categorized based on some common features. Events in each category can be counted together as one type of event. As discussed in Chapter 4, the SOPs noncompliance events include multiple events which capture noncompliance performance through all the phases of flight. Errors made by pilots are common consequences caused by many human factors risks, so SOPs noncompliance events can be used to reflect consequences of some risks. Table 5-2 lists some example SOPs noncompliance events in the format of an event set and two possible ways to combine SOPs noncompliance events. One option is that they can be combined based on phase of flight (highlighted by the red box). During the analyses occurrences of events happened in each of the flight phase (takeoff, cruise, approach, and landing) can be calculated respectively. The SOPs noncompliance events can also be combined based on the type of operation, for example, operations related with speed, altitude, and flap setting etc…(heighted by different colors). Occurrences related with each types of operation can be calculated respectively in the analyses. These kinds of event combinations are able to help examine the risk from different aspects such as in which flight phase it is most likely to occur and which types of operation are influenced by the risk most.

Table 5-2 Event Combination Examples

Event #	Event Description	Flight Phase Event Detected in
001	Liftoff Speed High	Takeoff
002	Liftoff Speed Low	Takeoff
003	Early Flap Setting	Takeoff
004	Late Flap Setting	Takeoff
⋮	⋮	⋮
050	Approach Speed High	Approach
051	Approach Speed Low	Approach
052	Operation Above Glideslope	Approach
053	Operation Below Glideslope	Approach
052	Late Landing Flaps	Approach
⋮	⋮	⋮

In addition, relationships between the selected events can also be considered as a basis of event combination. For example, if the selected events include both events that reflect causal factors and events that reflect consequences, it is possible to match each causal factor events to its associated consequence events, and regard the presence of all events in the combination as a single event. By analyzing the occurrence rate of this type of combination may help identify which causal factors is more likely to create risk and lead to consequences in the operation.

Choosing the unit of analysis

Unit of analyses is another issue that need to be considered. Analysts need to determine the objective of the analysis which is expected to be dependent on the risk. For example, the objective might be to establish exposure to the risk on a likelihood of being present on a given flight, or it could be a risk that makes more sense to examine exposure to the risk per flight-hour. In addition, the analyst needs to consider how, or if, event occurrences should be combined; for example, analyses can be done to identify how many flights in the study scope had at least one occurrence of the selected events, or how many total occurrences of the selected events happened. The former approach can eliminate the problem of isolated ‘high occurrence rate’ flights swamping the analyses, while the later may be more intuitive as a way of describing overall exposure.

As an example, if the objective is as an example, if comparing the occurrence rate of high workload event (developed through Approach 1) of long haul flight and short haul flight, occurrence/flighthour would be not appropriate. If the workload event happened on 90% of the long haul flights, using flighthour as the unit of analysis will decrease this rate since long haul flight obviously has long flight hours. On the other hand, sometimes flighthour is better. For instance, flights operating on different routes require different operations; some long haul flights may need more operational procedures than the short haul flights. When comparing the occurrence of operational errors, flighthour may be a more appropriate unit because it takes this influence factors into consideration.

Approaches to Analysis

The two most common types of analyses that can be performed in HF studies are trend analysis and comparative analysis.

- ***Trend analysis***. Trend analysis focuses on the change of occurrence rate over time. Once the event combination and appropriate analysis unit have been determined, trend analysis can be done to track the occurrence of each event or event combination during the selected study scope. For example, in a given time period, the rate of flights experienced an occurrence can be plotted. This type of analysis helps identify the existence of risk and how it changes over time.
- ***Comparative analysis***. Comparative analysis aims to understand the relationships between occurrence rate and certain comparative factors, such as different fleets and

different flight routes. This kind of analysis helps examine the existence of selected risks from a different perspective and better understand where in the operation and under what conditions the risks are more likely to occur. Comparative analysis can be used to complement trend analysis.

Based on the mapping between causal factors and consequences of the risk and events established in step b (Section 5.3.2.2), there are two types of situations: (1) both causal factors and consequences of the selected risk can be mapped to certain events, or (2) only causal factors or consequences can be reflected by certain events. Based on the selected events in a given situation, a combination of both approaches can be used. Some possible ways of conducting analysis are discussed below.

(1) For the first situation, one possible way of conducting the analysis would be combining each causal factor event with associated consequence events into a single event indicating the presence of risk, as discussed in the event combination section above. Trend analysis can be done to track the occurrence of each combination. Comparative analysis can also be done to compare the occurrence rate of each combination to identify which combination has more occurrences. This kind of analysis may help understand which causal factors are more likely to create the selected risk.

(2) For the second situation, there is less confidence to detect the existence of risk based on the presence of either causal factors or consequences because the same causal factor may lead to different risks or a specific consequence may be caused by different risks. However, trend analysis of the available event occurrences is still valuable in providing relevant information about the risk. In this case, comparative analysis may help strengthen the saliency of selected events in order to identify the existence of the risk.

For example, if only consequence events are available, sometimes alternative indicators of the causal factors can be used in the analysis to motivate the design of comparative analysis. As a more specific example, the risk of fatigue may be caused by long working time and the consequences include increased tendency of making errors. This consequence can be reflected by the SOP noncompliance events, which captures the undesired flight status due to pilots' inappropriate operations. Since there are no events capturing long working time, alternative information that can reflect a pilot's working time could be a pilot's on duty time, which can be determined by flight length. If this is a long haul flight, how long the pilots are on duty during the flight, and if it is a short haul flight, how many continuous segments the pilots were required to fly. Comparative analyses can be done to examine the relationship between occurrence rates and the pilots working time.

For both situation (1) and (2) discussed above, comparative analysis may also be done to compare the occurrence rates of different fleets or on different routes in order to identify where in the operation (e.g., which fleets or which routes) the selected risk is most likely to occur.

In sum, the design of a study's analysis should be conducted on a risk-by-risk basis. Decisions regarding the design of the analysis should be made with consideration of the combination of events, the selection of analysis unit, and the different approaches to analysis. Careful consideration of these factors can help better define the study and identify expected patterns and trends in the analysis.

5.3.3 Approach 2 Implementation Examples

To illustrate how to apply the second approach, this section will walk through the process and a sampling of key decision points of Approach 2. Based on the general process of HF study, opportunities of using Approach 2 to track some of the major human factors risks discussed in Chapter 3 were identified. Risk of automation confusion and on time pressure will be used as implementation examples in this section.

5.3.3.1 Example 3: Automation Confusion

As presented in Approach 1, the issue of automation confusion has the potential to be addressed by setting up new HF events, including Event HF01 Abnormal Automation Mode Change and Event HF02 Incorrect Mode Selection. Example 3 will demonstrate how Approach 2 can be used as a follow-up step to further analyze the automation confusion risk using information collected by these two event settings.

Following the process presented in Figure 5.4, process and major key decisions of conducting automation confusion risk study are discussed below.

- **Analysis of the Risk and Mapping Causal Factors and Consequences to Events (Step a & b)**. In this case, the consequences and causal factors of automation confusion have already been determined in Approach 1 and there are specific events set for this issue, so step a and b are straightforward. The related events selected from the FDM event set are HF01 Abnormal Automation Mode Change and HF02 Incorrect Mode Selection.
- **Retrieving Occurrence Data for HF study (Step c)**. Analysts need to retrieve the occurrence data of event HF01 and HF02 from the database based on the scope of the study. As discussed in Section 5.3.2, the analysts need to decide a proper amount of data to review. Since these two HF events are new to the program, the analysts may choose to conduct this study two to three

months after implementation of the events to ensure enough data are available. This would also provide an opportunity to examine, refine, and adjust the event settings if necessary. In addition, if a new aircraft type (e.g., B787) has just come into service, analysts can also consider retrieving the data for the first few months the new fleet is in service. In order to provide an equitable basis of comparison, other fleet data during that time can also be retrieved as a comparison to the new fleet.

- **Analysis Design (Step d)**. After retrieving the data, analysts need to decide the combination of events, unit of analysis, and analysis approaches. In this study, two events are selected. HF01 reflects the pilots' confusion and hesitation of using automation systems and HF02 reflects misunderstanding of the automation system. These two events can be combined into one "Master" event which is interpreted as indicating the overall automation confusion risk situation in the operation. They can also be analyzed separately as each of them reveals different aspects of the risk.

  As discussed in the general discussion of step d, trend analysis can be conducted to track the changes of occurrence rates for this type of event (treat HF01 and HF02 as a single event) or for each of them in the past few months. Increasing or decreasing trends identified from this analysis would have the potential of giving insight into the change of automation confusion issue in the operation, which will help monitor this risk over time. If mitigation plans have been implemented at any point during this time period, this trend analysis will also help identify if automation confusion occurrence rate has been reduced to evaluate the effectiveness and efficiency of the mitigation plans.

  Both HF01 and HF02 reflect the consequences of the automation confusion issue. To help understand the existence of the risk, alternative indicators of the causal factors can be determined. As mentioned in Approach 1, one of the causal factors of automation confusion is recently introduced automation systems. This factor can be reflected by new fleet with new automation systems. This information helps motivate to compare whether new introduced automation system creates more automation confusion issues in the operation. Comparative analysis can be conducted to compare the occurrence rate of automation confusion events between a new type of aircraft (e.g., B787) and a type of aircraft that has been operated for years in the airline (e.g., B767). In such comparison, the occurrences happened on the same route or similar routes should be selected for analysis, in order to exclude the potential influences of other factors.

Using Approach 2 as a follow-up step of Approach 1, like this example of conducting specific study for automation confusion issue, especially for recently introduced aircraft types, provides airlines opportunities to not only track this risk in operations, but also identify some underlying issues such whether the training for pilots who are operating the new types of aircrafts is sufficient and effective.

5.3.3.2 Example 4: On Time Pressure

Different from Example 3, where there are specific HF events for the automation confusion risk and Approach 2 is used as a follow-up step, Example 4 demonstrates how Approach 2 can be used to track human factors risks with no specific HF events. The risk of on time pressure is used as an illustration in this section.

On time pressure caused by ever increasing competitive aviation market is another human factors risk of concern identified through the semi-structured interviews (Chapter 3). Due to various reasons, delayed departure or late arrival may occur and the on time policy may cause additional pressure on the pilots. Whether the on time pressure is an issue in the operations is a question to solve in the HF study, especially during the time period when on time policy is changed by the company. Major decision points in the HF study for on time pressure issue are discussed below. Since there are no direct HF events set for on time pressure issue, analysts need to look at step a and b carefully.

- **Analysis of the Risk (Step a)**. First, the causal factors and consequences of on time pressure need to be learned. In airline operations, on time pressure is often directly caused by flight delays and airlines' on time policy. Previous research shows that consequences of time pressure include anxiety, poor decisions, and it also increases the potential for errors (Salas, Diskell & Hughes, 2013). These example factors could be indicators of this risk.
- **Mapping Causal Factors and Consequences to Events (Step b)**. As discussed in the general process, not all indicators identified in step a can be mapped to related events. In this case, there are no direct and specific events capturing delay information, anxiety or poor decisions, but SOPs noncompliance events can be used to reflect one of the consequences of on time pressure—operational errors made by pilots. Since SOPs noncompliance events include multiple events that capture operational deviations from the standards and training requirements through all flight phases, it may be possible to use this type of events to reflect the influence of on time pressure in every phase of flight.

- **Retrieving Occurrence Data for HF study (Step c)**. Before retrieving the occurrence data of SOPs noncompliance events, analysts need to decide the scope of the study. For example, if on time policy has been enhanced in the past few months, the analysis may want to include the data collected both before and after the enhancement of on time policy to analyze the influence of the policy.

- **Analysis Design (Step d)**. SOPs noncompliance events include multiple events that capturing different types of errors in every phase of flight. Analysts need to decide how to combine these events into the objects of analyses. As discussed in Table 5-2, there are several ways these events can be combined in the analysis. They can be combined based on phase of flight to study the influence of on time pressure in different flight phases.

  Since only consequence events are available, alternative information representing causal factors can be determined. In this case, there are no specific HF events for this risk, and because SOPs noncompliance events may be caused by other risks other than on time pressure, it is better to use alternative information of causal factors in the analysis. Determining alternative indicators of causal factors of on time pressure will also help motivate the analyses of what kinds of analysis could be done.

  Comparative analysis can be done to compare the occurrence rate of selected events of on time flights and delayed flights. The assumption is that if on time pressure is an issue in the operation and influences the pilot behaviors, the occurrence rate of SOPs noncompliance events of delayed flights should be higher. To exclude other potential influence factors other than on time pressure, occurrences happened on the same type of aircraft operating on the same route should be used for comparison. This kind of comparison can be conducted for different routes to help identify which routes may be more effected by on time pressure.

  Delay as the causal factor can be determined by flight schedule and actual departure and landing time. Trend analysis can be done to identify the change of occurrence rate of SOPs noncompliance events on delayed flights during the study scope. For example, if the airline changed its on time policy three months ago, trend analysis of occurrence rate for the past six months on delayed flights can be done (three months after the policy and three months before the policy) to examine whether the enhancement of on time policy has increased the risk of on time pressure. Similar analysis can be done when mitigation plans are implemented. Similarly, other possible influences factors should be excluded in the analysis.

The analyses proposed in this example will help to identify the existence of on time pressure risk in operations; especially during the time when on time policy is pushed. They also help to identify which phase of flight on what route is more influenced by this risk and if mitigation actions are taken, whether they are effective and efficient.

5.3.4 Summary of Approach 2

The discussion on key decision points of the general HF study process (Figure 5.4) and the implementation examples of automation confusion study and on time pressure study have provided detailed demonstration of Approach 2.

Major decisions analysts need to make include determining the consequences and causal factors of the selected risk, mapping the determined indicators to FDM events, setting a scope for data retrieving, combining events, designing analysis approaches, and selecting analysis units. These decisions are the basis of conducting reasonable and practical HF studies. These HF studies synthesize human factors theories and the FDM information. In the process of developing HF studies, the contributions from human factors and flight data analysis experts are essential.

The systematic review of the events database using Approach 2 provides opportunities to further analyze human factors issues addressed in Approach 1 and track issues that are hard to be captured from individual flights. This kind of data review also helps understand where in the operations the risks are more like to exist and whether training and mitigation plans are effective and efficient to control the risks. It also complements the integrated safety studies in current FDM process (Figure 4.1).

5.4 Identifying Emerging Human Factors Risks through the Potential Approaches

The applications of these two approaches can be used beyond tracking current major risks to identifying potential risks that haven't shown up in the safety reports but might emerge in the operations. Generally, there are two possible ways of identifying emerging human factors risks through the two preliminary approaches proposed in this chapter.

First, intentionally keep track of some potential human factors issues, which are not current top concerns. These issues may not be current top concerns (e.g., decision making issues and supervision violations) and expected not to be seen often in the triggered events or trend analysis. If potential risks can be tracked through FDM processes before they appear in the safety reports after incidents or accidents, they can serve as early warning signs, and the airlines are able to proactively manage the safety risks. If airlines want to proactively identify these emerging issues, similar processes of Approach 1 and Approach 2 can be applied.

Second, identify unexpected emerging issues while tracking other risks. It is possible that during the daily review of HF events (Approach 1) and HF studies of specific certain issues (Approach 2), emerging human factors issues other than the target risks may be identified. These emerging issues could be new to the airlines, or potential issues which are neglected by the airlines. For example, while conducting trend analysis for fatigue issues, other "latent" failures in the supervisory and organizational level such as inadequate training, inadequate instruction, inappropriate SOPs, and unavailable policies are possible to be identified as well. Normally, this kind of "latent" risks is hard to be identified through safety reports and other data sources, and it is not identified as a major risk of concern in current operations in Chapter 3. However, if such risks exist, they might bring serious consequences. The two human factors risk tracking approaches presented in this chapter provide an opportunity to proactively identify these emerging risks before they become prominent and lead to occurrences.

5.5 Advantages of the Two Potential Approaches

Based on the discussions in previous sections, the advantages of these two approaches of tracking human factors risks proposed in this chapter are summarized.

- Able to satisfy the airlines' expectations (Section 5.1.1).

First, the two approaches satisfy the three airlines' expectations of the potential human factors risk tracking approaches. Both approaches use de-identified flight data collected in current FDM database to interpret human factors information. Approach 1 is developed based on current event setting process. Approach 2 uses similar techniques as current safety and commercial studies and can be conducted at the same frequency as other studies. Therefore, these two approaches should be able to be embedded to current daily routine FDM process and won't have a disruptive influence on the current daily tasks. As for the costs issue, no significant extra costs are needed for implementing these approaches, except for the training on human factors knowledge for data analysts and the contribution from human factors experts. Therefore, the costs of the implementation should be controllable and affordable for airlines.

- Able to complement the current FDM event database and current FDM safety studies.

Approach 1 adds HF events to the current database which provides an opportunity to monitor some of the human factors risks independently from other flight performance events. The added HF events can also complement the event databases. Similarly, Approach 2 adds new type of studies to current FDM safety studies, which complement the current FDM applications.

- Able to monitor the risks from both micro and macro perspectives.

Approach 1 provides most up-to-date information about human factors issues from individual flight, while Approach 2 tries to identify underlying human factors risks from trends show up in a number of flights. Approach 1 can also collect information for further trend and comparative analysis in Approach 2. These two approaches are comparatively comprehensive in identifying some human factors risks if combined together, because they collect and analyze data from both micro and macro perspectives.

- Help improve human factors risk identification and FDM applications.

Finally, these two approaches proposed in this thesis present a more accurate and proactive method of human factors risk identification. Using flight data to identify human factors issues helps the human factors risk identification shift from opinion driven to objective data driven. They also provide an opportunity to explore the potential usage of FDM database. Therefore, these two proposed approaches can help airlines improve human factors risk identification and the application of FDM program.

5.6 Limitations and Concerns

It should be noted that these two potential approaches are not able to address all human factors risks. For example, due to the nature of human factors risks, some of the problems such as complacency and communication issues (because cockpit voice recorder data is protected by Transport Canada and confidential to airlines) are difficult to be reflected by digital flight data. Therefore, the proposed approaches in this thesis are not applicable to identify such issues.

Second, this expanded usage of FDM in human factors risk identification is only applicable for airlines with a comparatively mature FDM program and experienced data analysts. For some small companies, the costs of purchasing and installing the basic equipment are beyond the budgets, not to mention the advanced application of the FDM program in human factors risk identification.

In addition, legal and labour concerns regarding to the liability of the human factors focused event and confidentiality of the flight data source might become even more prominent as flight data is used in analyzing the aircrew performance. Though the data is de-identified, sometimes cooperation of the pilot groups is needed in some studies in order to fully understand the situation and root causes. Therefore, trust from the pilot groups is necessary for a successful application of these approaches. And this trust, to some extent, depends on the development of organizational safety culture.

5.7 Chapter Summary

It can be seen from the discussions above, FDM data has great potential in human factors risk identification. The two potential approaches of tracking human factors risks provide airlines an opportunity to detect the risks proactively through routine monitoring before they lead to incidents and accidents. The approach processes and implementation examples presented in this chapter are not intended to be definitive and comprehensive. Rather, the aim of developing the potential approaches is to explore the opportunities of applying FDM in human factors risks identification. Adjustment and customization will be needed to fit airlines' own situations, including the parameters actually available.

In summary, Objective 3 stated in Chapter 1 of identifying potential approaches of using FDM to track human factors risks was successfully achieved. Airlines' expectations of such approaches were discussed. Based on the expectations and findings in previous chapters, two potential approaches, including setting up HF events and conducting HF studies were proposed in this chapter. Processes of the two approaches, major decision points and examples of how to apply the approaches in tracking some major human factors risks such as automation confusion, high workload, and on time pressure were discussed. The potential of using these two approaches in identifying emerging human factors risks was also discussed.

Finally, advantages, as well as limitations and concerns of the proposed approaches were addressed. The two approaches are able to satisfy the expectations of airlines and complement the current FDM application and risk management. In addition, though the methods developed in this chapter are based on de-identified data, the confidentiality of the data might become a concern because the topic of human factors issues is related with legal and labour liabilities. In this circumstance, trust from the pilots essential for successfully applying these methods.

Chapter 6
Conclusion

Human factors risks are one of the top concerns in today's aviation safety management. Although significant efforts have been made to mitigate these risks, they still exist in everyday operations where operators are interacting with complex systems. However, the traditional risk identification strategy of addressing problems after occurrences is limited. There is a need to constantly track major human factors risks of current concern in airline's routine operations to ensure safety in this rapidly growing industry. Since the Flight Data Monitoring (FDM) program provides comprehensive and reliable information of routine flight performance, it is beneficial for airlines if major human factors issues that they are facing today can be captured through FDM.

Motivated by this need, this thesis explored the opportunities and potential approaches of using FDM to track some major human factors risks of concern. This thesis first determined the examples of major human factors risks showed up frequently in recent years and then studied the current FDM practices in order to examine the opportunities of addressing these risks through FDM. Finally, two potential risk identification approaches were developed and proposed.

Standard human factors research methods, including Human Factors Analysis and Classification System (HFACS), semi-structured interviews, field observations, and literature review, were used in the research project. Work accomplished and findings obtained in this research project were presented and discussed. Contributions of this study, recommendations and future research opportunities are discussed in this chapter.

6.1 Research Objectives and Key Findings

The goal of this thesis is to explore the opportunities and potential approaches of addressing human factors risks through FDM to help airlines track and proactively manage some of the current major human factors risks. Three specific objectives presented in Chapter 1 were achieved respectively in this study:

Objective 1—Identify examples of major human factors risks in current airline operations in North America.

The first objective was achieved by conducting the HFACS analysis to accident and incident data from 2006 to 2010, for which relatively complete accident and incident investigations in North America are available. Semi-structured interviews with safety experts in the aviation industry provided insights into airline operators' perceptions of risk of concern and upcoming issues from the practical perspective. The comparison results show that the data collected from two methods complemented each other. Key human factors of concern were summarized from the results. The risk of SOPs noncompliance showed up most frequently in the analysis. Training issues were identified as an increasing concern and might still exist in the future because of the changing environment and technology. Other major risks include fatigue, pressure, attention failure, distraction, high workload, lack of situation awareness, communication issues, and complacency (Chapter 3). The result is able to provide a more comprehensive list of example major human factors challenges that the industry is facing now.

Objective 2— Understand current FDM practices and flight parameters available in current FDM analyses.

The second research objective was achieved by reviewing the literature (Chapter 2 and Chapter 4), conducting the field observations in a major North American airline, and interviewing FDM experts (Chapter 4). These research methodologies developed insight into the backgrounds of digital flight data, flight data analysis tools, and current FDM practices. A literature review identified that there are no systematic methods for using FDM for human factors risk identification on a routine basis. FDM process models and seven classes of flight parameters were established based on the analysis of recorded flight parameters, data analysis software, data analysis procedures, and the event programming process. Flight parameters were categorized into seven classes and three categories based their relevance to human performance. These findings can help better understand this program and identify potential opportunities of adding human factors elements into the programs. The FDM process and flight parameters were found to have the potential to reflect human performance and track human factors issues in routine operations.

Objective 3—Identify potential approaches of using FDM to track some major human factors risks.

Finally, the third objective was achieved by building on the findings from Objective 1 and Objective 2. Two approaches of using FDM to track some major human factors risks routinely were proposed in Chapter 5. Key steps and decision points, as well as implementation examples of these two approaches were discussed. The process of developing HF events was described in Figure 5.3. Example events collecting information on automation confusion and high workload situation were proposed to illustrate the application of Approach 1. The process of conducting specific HF studies was described in Figure 5.4. Example studies analyzing automation confusion and on time pressure issues were given to demonstrate the application of Approach 2. In addition to the major human factors risks already exist in current operation, these two preliminary approaches were also found possible to proactively identify the emerging and new human factors risks which are unknown or neglected by air operators. Two ways of using these approaches to identifying emerging issues were briefly discussed.

6.2 Contributions

There are several contributions of this thesis. First, the most significant contribution of this research is the proposed two approaches of using FDM to track human factors risks and the demonstrations of applying them to track some major risks, including automation confusion, high workload, and on time pressure issues. These approaches provide an opportunity to bridge the gap between human factors risk identification and flight data analysis.

Approach 1 provides an opportunity to monitor some human factors risks on a daily basis automatically through current FDM software. Detailed explanation of major steps of Approach 1, including determining the indicators of the selected human factors risk, defining proper thresholds of the HF event, and translating the defined HF event into the language of flight parameters, were provided in Section 5.2. Key decision points of Approach 2 such as decomposing risks into causal factors and consequences, mapping the indicators into related events, and combining multiple events in different analysis approaches were discussed in Section 5.3. These detailed discussions of the major issues that need to be carefully considered in real implementation are important contributions of this thesis. They help people understand how decisions made along the way of implementing these two potential approaches will affect the ability of using FDM to track and assess human factors risk.

Since the FDM database provides more updated and comprehensive information about daily flight performance than the occurrence safety reports, the two approaches proposed in this thesis will help airlines manage the human factors risks more proactively. These two approaches will also help the identification of human factors risks to shift from opinion driven to data driven and improve airlines' safety management.

Second, the FDM event setting model and daily FDM review model developed in Chapter 4 are able to provide guidance to airlines which do not have a well-developed FDM program or sophisticated data review process. Since the models synthesized regulations and recommendations from government documents and experiences from advanced FDM practices in the industry, they are relatively comprehensive at describing examples of current practices. Therefore, the models can also help airlines to improve their own FDM activities, from the overall FDM program development to specific process like event setting and daily data review.

A final contribution is the updating of the data on prominent aviation human factors risks in North America in recent years. Examples of major human factors risks of current concern and upcoming human factors issues that might be brought by changes in the industry were identified. This updated result is comparatively comprehensive since it is obtained from the perspectives of both investigation reports and airline operators. The results show that Unsafe Acts and Preconditions of Unsafe Acts are still prominent risk categories, within which violations of the SOPs is cited as a probable cause in an increasing number of occurrences. Training issues are also identified as increasing concern and may become more prominent since many future changes in the operational environment can initiate training challenges. Other major risks include fatigue, distraction, communication issues, and inadequate situation awareness. These findings provide a reference to commercial airlines for reviewing and improving their own operations to prevent accidents and incidents in the future.

6.3 Recommendations and Future Work

The research findings regarding the tracking of some current major human factors risks FDM are only initial work to understand the potential opportunities exist in this area. Based on the results of the research, there are several recommendations.

First, it is recommended that airlines explore the opportunities to conduct a testing of these two proposed approaches to validate and further refine the methods. If the test trial is successful and applicable in current operations, airlines could consider implementing these two approaches with necessary customization in their future safety program development. They should try adding new HF events into the system using human performance related parameters and conduct specific HF studies to address key issues, such as automation confusion, high workload, and on time pressure (Chapter 5). The discussion of key steps and decision points and examples of the approaches can be used as reference in the implementation.

Specifically, the automation mode confusion events, including abnormal automation mode change event and incorrect mode change event are recommended to be used to help understand pilots' interactions with the automation environment. This kind of events is highly recommended to be applied in monitoring the data from new types of aircraft, for example, the Boeing 787 aircraft, which has been introduced as a new model of commercial plane into the market recently. New cockpit designs have pilots interacting with new operational environments, and it takes time for operators to adapt to the new automation systems. The data collected from new operational environment would be valuable to help identify future training needs and offer feedback to the design of the new SOPs and the new aircraft.

For future work, the two preliminary approaches proposed in this thesis need to be further refined by conducting an exploratory trial using real data or a simulated experiment. Take the abnormal automation mode event development as an example. If a large number of flight data samples are available, the first step is to select out the flights under the similar operational conditions (same aircraft type, same airport, etc.). In the test trial, the analysts can select only one automation system parameter and a certain phase of flight (e.g., landing) for analysis. The standard operations during this phase of flight for the selected type of aircraft and an initial threshold for mode change frequency would need to be determined. A quick count of the mode change frequencies for the data samples and determination of the distribution may also help to identify an appropriate threshold. Then a test event can be programed into the software by following the process discussed in Section 5.2.2. The test can be conducted for one week and analysts may monitor the triggered events during this time and adjust the threshold and programming if needed. The triggered events need further validation and a summary after the test can be conducted to determine whether this event is applicable. A testing can also be done to further explore Approach 2 by selecting relevant flight data samples in a certain time period and identify the trends and patterns of the detected events. Such a test process could be similar to the type of road transportation accident analysis done by Hassan & Abdel-Aty (2011) based on real-time traffic flow data.

The two approaches can be investigated further to validate their accuracy in order to develop a practical and efficient human factors risks identification method. In addition, more opportunities regarding the usage of FDM in tracking human factors risks need to be explored. The risk identification is only the first step of the risk management. Detailed root cause investigation of what factors are the origins of all the problems is something that needs to be addressed in the future work as one of the next steps of the two proposed risk identification approaches.

Furthermore, if these two approaches can be successfully applied in real practice, the expected next step is integrating different databases in the Safety Management Systems (SMS) to better diagnose the risks and further enhance safety management. For example, the safety reports collected by safety investigation department can be a complementary data source for the human factors risk identification in the FDM department to obtain a comprehensive understanding of the issues. How to integrate and share the information constantly while protecting the crew information is a question that needs further study.

Finally, the findings presented in this thesis, including the examples of major human factors risks and the human factors identification approaches are not limited to be used only in commercial aviation operations. The results will also be interest to other complex systems such as helicopter companies, rail, and marine transportations. The major risks identified (Chapter 3) can help other organizations to better examine the risks in their own operations. And the approaches can be extended and customized to other complex systems to help them bridge the gap between human factors risk identification and operational data analysis.

References

Aeronautica Civil of the Republic of Colombia. (1995). Aircraft accident report: controlled flight into terrain American Airlines flight 965 Boeing 757-223, N651AA near Cali, Colombia December 20, 1995. Aeronautica Civil of the Republic of Colombia, Santafe de Bogota, D.C., Colombia. Retrieved from: http://sunnyday.mit.edu/accidents/calirep.html

Akerstedt, T. (2000), Consensus statement: fatigue and accidents in transport operations. *Journal of Sleep Research* 9(4), 395. doi: 10.1046/j.1365-2869.2000.00228.x

Amalberti, R. (1998), Automation in aviation: a human factors perspective, in D. Garland, J.Wise & D. Hopkin (Eds.), *Aviation Human Factors*, (173-192, Chapter 7), Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Ananda, C., & Kumar, R. (2008). Configurable flight safety system for trends and statistics analysis of avionics systems: an embedded perspective of an efficient flight safety tool, *International Conference on Avionics Systems*, 22-24, RCI Hyderabad.

ASIAS (2014, February 21), *ASIAS Overview*. Retrieved from http://www.asias.aero/overview.html

Billings, C. E., & Reynard, W. D. (1984). Human factors in aircraft incidents: results of a 7-year study. *Aviation, Space, and Environmental Medicine*, *55*(10), 960-965.

Boeing. (2002). Flight Data Recorder Rule Change. *AERO, QTR_02 1998*. Retrieved from http://www.boeing.com/commercial/aeromagazine/aero_02/textonly/s01txt.html

Bresee, J. S. (1996). Automating training management: a review of current us research and development in the use of flight data recording and analysis for training management. In *Proceedings of the Eastern European Civil Aviation Training Conference*, Prague. Retrieved from http://www.whidbey.com/frodo/jb7.htm

Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA). (2005). *Flight data recorder read-out technical and regulatory aspects,* Paris, France.

Caldwell, J. A. (2005). Fatigue in aviation. *Travel Medicine and Infectious Disease*, *3*(2), 85-96. doi: 10.1016/j.tmaid.2004.07.008

Caldwell, J. L., Chandler, J. F., & Hartzler, B. M. (2012). Battling fatigue in aviation: recent advancements in research and practice. *Journal of Medical Sciences (Taiwan)*, *32*(2), 047-056.

Callantine, T. J. (2001). Analysis of flight operational quality assurance data using model-based activity tracking (No. 2001-01-2640). SAE Technical Paper. doi: 10.4271/2001-01-2640

Callantine, T. J. (2001). The crew activity tracking system: leveraging flight data for aiding, training and analysis. In *Digital Avionics Systems, October, 2001. DASC. 20th Conference, Vol 1,* 5C3/1-5C3/12. IEEE. doi: 10.1109/DASC.2001.963408

Casto, K. L., & Casali, J. G. (2013). Effects of headset, flight workload, hearing ability, and communications message quality on pilot performance. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 55*(3), 486-498. doi: 10.1177/0018720812461013.

Celik, M., & Er, I. (2007). Identifying the potential roles of design-based failures on human errors in shipboard operations. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 1*(3), 339-343.

Chidester, T. R. (2003). Understanding normal and atypical operations through analysis of flight data. In *Proceedings of the 12th International Symposium on Aviation Psychology,* 239-242, Dayton, OH.

Chidester, T. R. (2004). *Example application of the aviation performance measuring systems (APMS),* Moffet Field, CA: NASA AMES Research Center and GAIN Working Group B.

Civil Aviation Authority. (2013). *Flight Data Monitoring (CAP739, 2nd ed),* West Sussex, UK: Safety Performance, Safety Regulation Group, Civil Aviation Authority.

Daramola, A. Y. (2014). An investigation of air accidents in Nigeria using the human factors analysis and classification system (HFACS) framework. *Journal of Air Transport Management, 35,* 39-50. doi: 10.1016/j.jairtraman.2013.11.004

Degani, A., Shafto, M., & Kirlik, A. (1996). Modes in automated cockpits: problems, data analysis and a modelling framework. In *Proceedings of the 36th Israel Annual Conference on Aerospace Science.*Haifa, Israel.

Dekker, S. W. (2000). Human factors in aviation-a natural history (technical report 2003-02). *Paper P resented at the FAI Conference, Linköping, Sweden.* Retrieved from http://www.lusa.lu.se/uploa d/Trafikflyghogskolan/TR2003-02_HumanFactorsinAviationaNaturalHistory.pdf

Diller, T., Helmrich, G., Dunning, S., Cox, S., Buchanan, A., & Shappell, S. (2013). The human factors analysis classification system (HFACS) applied to health care. *American Journal of Medical Quality: The Official Journal of the American College of Medical Quality, 29*(3), 181-190. doi:10.1177/1062860613491623

Dinges, & Powell, J. W. (1985). Microcomputer analyses of performance on a portable, simple visual rt task during sustained operations. *Behavior Research Methods, Instruments, & Computers, 17*(6), 652-655. doi: 10.3758/BF03200977

Dinges, D. F., Graeber, R. C., Connell, L. J., Rosekind, M. R., & Powell, J. W. (1990). Fatigue related reaction time performance in long haul flight crews. *Sleep Research*, *19*, 117.

Edwards, E. (1973). Man and machine-systems for safety (man machine systems for flight safety, studying accidents, human factors in system design and implementation of personnel). *Outlook on Safety*, 21-36.

Endsley, M. R. (1988). Situation awareness global assessment technique (SAGAT). In *Proceedings of Aerospace and Electronics Conference, 1988. NAECON 1988, Proceedings of the IEEE 1988 National, 3,* 789-795, Dayton, OH.

Endsley, M. R. (2013). Situation awareness. In J. D. Lee, A. Kirlik & M. J. Dainoff (Eds.), *The Oxford Handbook of Cognitive Engineering* (88-90, Chapter 5). New York: Oxford University Press.

FAA. (2004). *Flight operational quality assurance advisory circular* (Advisory Circular No. 120-82). Washington DC: FAA.

FAA. (2006). *Advanced qualification program advisory circular* (Advisory Circular No. 120-54A). Washington DC: FAA.

FAA. (2014a, August 13). *Safety management system: rulemaking activities.* Retrieved from https://www.faa.gov/about/initiatives/sms/rulemaking/

FAA. (2014b, October 2). *Electronic code of federal regulations.* Retrieved from http://www.ecfr.gov /cgi-bin/text-idx?SID=f00b2c0e6d02e0d9245b3718fb1ec593&node=14:3.0.1.1.7&rgn=div5#14: 3.0.1.1.7.11.2.32

FAA ASIAS. (2014, March 13). NTSB aviation accident and incident data system, *FAA Aviation Safety Information Analysis and Sharing*, Retrieved from http://www.asias.faa.gov/pls/apex/f?p=100: 24:0::NO:::

Flight Deck Automation Working Group. (2013). *Operational Use of Flight Path Management System* (Final Report), Washington, DC: FAA Performance-based operations Aviation Rulemaking Committee.

Gartner, W. B., & Murphy, M. R. (1976). *Pilot workload and fatigue: a critical survey of concepts and assessment technique* (NASA TN D-8365), Washington, DC: NASA Ames Research Center.

Gawron, V. J., Schiflett, S. G., & Miller, J. C. (1989). Measures of in-flight workload. In R. S., Jensen (Ed.), *Aviation Psychology* (240-287). Aldershot, Brookfield: Gower Technical.

Global Aviation Information Network (GAIN). (2003). 2.2 Types of Tools for Airline Flight Safety Analysis, *GAIN Guide to Methods & Tools for Airline Flight Safety Analysis* (2nd ed., pp. 8-10). Wisconsin, NW: Gain Working Group B.

Harboe-Sorensen, R., Poivey, C., Zadeh, A., Keating, A., Fleurinck, N., Puimege, K., Li, L. (2012). Proba-II technology demonstration module in-flight data analysis. *Nuclear Science, IEEE Transactions On, 59*(4), 1086-1091. doi: 10.1109/TNS.2012.2185062

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (task load index): results of empirical and theoretical research. *Advances in Psychology, 52*, 139-183. doi: 10.1016/S0166-4115(08)62386-9

Hassan, H., Abdel-Aty, M. (2011). Exploring visibility-related crashes on freeways based on real-time traffic flow data. In *Proceedings of the 90th Annual Meeting of the Transportation Research Board,* Washington, D.C.

Haverdings, H., & Chan, P. W. (2010). Quick access recorder data analysis software for windshear and turbulence studies. *Journal of Aircraft, 47*(4), 1443-1447.

Heinrich, H. W., Petersen, D., & Roos, N. (1950). *Industrial Accident Prevention.* New York: McGraw-Hill.

Hollnagel, E. (2004). *Barriers and accident prevention*. Aldershot: Ashgate.

ICAO. (1989). *Human Factors Digest* (Circular No. 216-AN/131). Montreal, Canada: ICAO.

ICAO. (2001). Chapter 1 Definition. *Annex 13 Aircraft Accident and Incident Investigation* (9th ed.). Montreal, Canada: ICAO International Standards and Recommended Practices.

ICAO. (2005). Chapter 7 Flight Data Analysis Programmes. *ICAO accident prevention programme (doc 9422)* (2nd ed.). Montreal, Canada: ICAO.

ICAO. (2010). Part 1 International Commercial Air Transport-aeroplanes, *Annex 6 operation of aircraft* (9th ed.). Montreal, QC, Canada: ICAO.

ICAO. (2012, July 5). *Robust traffic growth expected until 2014*. Retrieved from http://www.icao.int/Newsroom/Pages/robust-traffic-growth-expected-until-2014.aspx

Iden, R., & Shappell, S. A. (2006). A human error analysis of US fatal highway crashes 1990–2004. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 50*(17) 2000-2003. doi: 10.1177/154193120605001761. San Francisco, USA.

Johnson, W. B., & Maddox, M. E. (2007). A model to explain human factors in aviation maintenance. *Avionics News*, 38-41.

Koonce, J. M., & Debons, A. (2011). Chapter 1 A Historical Overview of Human Factors in Aviation. In J. A. Wise, V. D. Hopkin & D. J. Garland (Eds.), *Handbook of Aviation Human Factors* (2nd ed.). Florida: CRC Press.

Klinger, E., Gregoire, K. C., & Barta, S. G. (1973). Physiological correlates of mental activity: eye movements, alpha, and heart rate during imagining, suppression, concentration, search, and choice. *Psychophysiology, 10*(5), 471-477. doi: 10.1111/j.1469-8986.1973.tb00534.x

Lee, I., Bardwell, W. A., Ancoli-Israel, S., & Dimsdale, J. E. (2010). Number of lapses during the psychomotor vigilance task as an objective measure of fatigue. *Journal of Clinical Sleep Medicine: JCSM: Official Publication of the American Academy of Sleep Medicine, 6*(2), 163-168.

Lenné, M. G., Salmon, P. M., Liu, C. C., & Trotter, M. (2012). A systems approach to accident causation in mining: an application of the HFACS method. *Accident Analysis & Prevention, 48*, 111-117. doi: 10.1016/j.aap.2011.05.026

Leroux, J., Rizzo, J. A., & Sickles, R. (2012). The role of self-reporting bias in health, mental health and labor force participation: a descriptive analysis. *Empirical Economics*, *43*(2), 525-536. doi: 10.1007/s00181-010-0434-z

Li, L., Gariel, M., Hansman, R., & Palacios, R. (2011). Anomaly detection in onboard-recorded flight data using cluster analysis. In *Digital Avionics Systems Conference (DASC), 2011 IEEE/AIAA 30th,* 4A4-1-4A4-11. doi: 10.1109/DASC.2011.6096068

Li, W., & Harris, D. (2006). Pilot error and its relationship with higher organizational levels: HFACS analysis of 523 accidents. *Aviation, Space, and Environmental Medicine, 77*(10), 1056-1061.

Li, W., Harris, D., & Yu, C. (2008). Routes to failure: analysis of 41 civil aviation accidents from the republic of china using the human factors analysis and classification system. *Accident Analysis & Prevention, 40*(2), 426-434. doi: 10.1016/j.aap.2007.07.011

Maille, N. P., & Chaudron, L. (2013). Towards more integrated safety management tools for airlines. In *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, *228*(3), 342-354. doi: 10.1177/0954410012471489

Mason, J. (2004). In Lewis-Beck, M. S., Bryman, A. E., Liao, T. F. (Ed.), *The SAGE Encyclopedia of Social Science Research Methods* Sage Publications. doi:10.4135/9781412950589.

McDowd, J. M., & Craik, F. I. (1988). Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance*, *14*(2), 267-280. doi: 10.1037/0096-1523.14.2.267

Ministry of Public Works & Transport. (2012). Investigation Report on the Accident to Ethiopian 409, Boeing 737-800, Registration ET-ANB at Beirut, Lebanon on 25th January, 2010. Investigation Report-ET 409, Beirut, Lebanon. Retrieved from http://lebcaa.com/pdfs/Final%20Investigation%20Report%20ET%20409.pdf

Mitchell, K., Sholy, B., & Stolzer, A. J. (2007). General aviation aircraft flight operations quality assurance: overcoming the obstacles. *Aerospace and Electronic Systems Magazine*, *IEEE, 22*(6), 9-15. doi: 10.1109/MAES.2007.384075

Molloy, G. J., & O'Boyle, C. A. (2005). The SHEL model: a useful tool for analyzing and teaching the contribution of human factors to medical error. *Academic Medicine, 80*(2), 152-155.

Muraoka, K., & Tsuda, H. (2006). Flight crew task reconstruction for flight data analysis program. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *50*(11) 1194-1198. doi: 10.1177/154193120605001117. San Francisco, USA.

Nehl, R., & Schade, J. (2007). Update: concept and operation of the performance data analysis and reporting system (PDARS). *Aerospace Conference, 2007 IEEE,* 1-16. doi: 10.1109/AERO.2007.352953. Big Sky, MT.

NTSB. (2002). *Flight data recorder handbook for aviation accident investigation*. Washington, DC: Office of Aviation Safety, NTSB. Retrieved from https://www.ntsb.gov/doclib/manuals/FDR_Handbook.pdf

NTSB. (2010). *Loss of Control on Approach Colgan Air, Inc. Operating as Continental Connection Flight 3407 Bombardier DHC-8-400, N200WQ Clarence Center, New York February 12, 2009* (Accident Report No. NTSB/AAR-10/01). Washington, DC: NTSB.

Olsen, R. (2008). Self-selection bias. In Paul J. Lavrakas (Ed.), *Encyclopidia of Survey Research Methods* (pp. 809-811). Thousand Oaks, CA: Sage Publications, Inc. doi: 10.4135/9781412963947.n526

Reason, J. (1990). *Human error*. New York, USA: Cambridge University Press.

Salas, E., Burke, C. S., Bowers, C. A., & Wilson, K. A. (2001). Team training in the skies: Does crew resource management (CRM) training work? *Human Factors: The Journal of the Human Factors and Ergonomics Society, 43*(4), 641-674. doi:10.1518/001872001775870386

Salas, E., Driskell, J.E., & Hughes, S. (2013). Introduction: The study of stress and human performance. In Driskell, J. E., & Salas, E. (Eds.), *Stress and human performance* (pp. 1-46). Psychology Press.

Salmon, P. M. (2011). Accidents, accident causation models and accident analysis methods. In P. M. Salmon, N. A. Stanton, M. G. Lenné, D. P. Jenkins, L. Rafferty & G. Walker (Eds.), *Human factors methods and accident analysis: Practical guidance and case study applications* (pp. 1-6). Burlington, VT, USA: Ashgate Publishing, Ltd.

Sarter, N. B., Woods, D. D., & Billings, C. E. (1997). Automation surprises. *Handbook of Human Factors and Ergonomics*, (2nd ed., pp. 1-25). Wiley.

Seamster, T. L., Boehm-Davis, D. A., Holt, R. W., & Schultz, K. (1998). *Developing advanced crew resource management (acrm) training: A training manual* us department of transportation, FAA, Office of the Chief Scientific and Technical Advisor for Human Factors. Retrieved from http://www.hf.faa.gov/docs/GMUGRANT/AIRLINES/DACRMT.PDF

Shappell, S., & Wiegmann, D. (2004). HFACS analysis of military and civilian aviation accidents: A north american comparison. In *Proceedings of the Annual Meeting of the International Society o f Air Safety Investigators* (8) 135-140. Gold Coast, Queensland, Australia.

Shappell, S. (2000). *The Human Factors Analysis and Classification System–HFACS.* (Final Report No. DOT/FAA/AM-00/7). FAA Civil Aeromedical Institute, Oklahoma City: FAA.

Shappel, S. A., & Wiegmann, D. A. (2000). The human factors analysis and classification System–HFACS . (No. DOT/FAA/AM-00/7). Springfield, Virginia: Office of Aviation Medicine, FederalAviation Administration. Retrieved from https://www.hf.faa.gov/hfportalnew/admin/FAAAJP61/HFACS2000Tb.pdf

Shappell, S., & Wiegmann, D. (2001). Applying reason: The human factors analysis and classification system (HFACS). *Human Factors and Aerospace Safety, 1*(1), 59-86.

Shappell, S., Detwiler, C., Holcomb, K., Hackworth, C., Boquet, A., & Wiegmann, D. A. (2007). Human error and commercial aviation accidents: An analysis using the human factors analysis and classification system. *Human Factors, 49*(2), 227-242.

Spencer, C. F. (2000). *Cockpit automation and mode confusion: The use of auditory inputs for error mitigation* (Master, Air Command and Staff College, Air University). Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a394969.pdf

Srivastava, A. N., & Barton, P. (2012). *Nasa-Easyjet collaboration on the Human Factors Monitoring Program (HFMP) study* (NASA/TM-2012-216484), Second Interim Report. Moffett Field, CA: NASA Ames Research Center.

Stuss, D. T., Stethem, L. L., Hugenholtz, H., Picton, T., Pivik, J., & Richard, M. T. (1989). Reaction time after head injury: fatigue, divided and focused attention, and consistency of performance. *Journal of Neurology, Neurosurgery & Psychiatry*, *52*(6), 742-748.

Teledyne Technologies. (2013). *Quick access recorder: QAR features*. Retrieved from http://www.teledynecontrols.com/productsolution/qar/QAR.asp

Tran, T. Q., Boring, R. L., Dudenhoeffer, D. D., Hallbert, B. P., Keller, M. D., & Anderson, T. M. (2007, August). Advantages and disadvantages of physiological assessment for next generation control room design. In *Human Factors and Power Plants and HPRCT 13th Annual Meeting, 2007 IEEE 8th* (259-263). Monterey, CA, USA.

Transport Canada. (2001). *Flight Data Monitoring (FDM) Programs* (*Commercial and Business Aviation Advisory circular,* No. 0193). Canada: Transport Canada. Retrieved from https://www.tc.gc.ca/eng/civilaviation/standards/commerce-circulars-ac0193-1640.htm

Transport Canada. (2004). *Flight data monitoring within an integrated safety management system* [PowerPoint Slides]. Retrieved from http://www.tc.gc.ca/eng/civilaviation/standards/systemsafety-cass-2004-dunn-3219.htm.

Transport Canada. (2009). *Standard 625 Schedule 3 - Aeroplane Digital Flight Data Recorder (DFDR) Specifications.* Retrieved from http://www.tc.gc.ca/eng/civilaviation/regserv/cars/part6-standards-a625i3-2467.htm.

Transport Canada. (2012). *Safety Management System (SMS) implementing schedule*. Retrieved from http://www.tc.gc.ca/eng/civilaviation/standards/sms-implementation-617.htm.

Transport Canada & Software Kinetic Ltd. (1997). Canadian FDM Project. *Flight Data Monitoring Meeting. Section V Presentation Material*. Ottawa, ON, Canada.

TSB. (2013, August 9) *Aviation Investigation Report. Transportation Safety Board of Canada.* Retrieved from http://www.tsb.gc.ca/eng/rapports-reports/aviation/index.asp

Walker, G., & Strathie, A. (2012). Chapter 78 From flight data monitoring to rail data monitoring. In N. A. Stanton (Ed.), *Advances in Human Aspects of Road and Rail Transportation* (pp. 777-785). Boca Raton, FL: CRC Press.

Ward, R. (2012). Revisiting Heinrich's Law. In *Chemeca 2012: Quality of Life through Chemical Engineering: 23-26 September 2012*, Wellington, New Zealand.

Wenger, M. J., & Townsend, J. T. (2000). Basic response time tools for studying general processing capacity in attention, perception, and cognition. *The Journal of General Psychology*, 127(1), 67-99. doi: 10.1080/00221300009598571

Williams, K. W. (2011). *A Human Factors Analysis of Fatal And Serious Injury Accidents In Alaska, 2004-2009* (Technical Report No. DOT/FAA/AM-11/20). Oklahoma City,USA: FAA Civil Aerospace Medical Institute.

Yan, J., & Histon, J. M. (2013) Flight Data Monitoring and Human Factors Risks Identification: A Review of Best Practices. *Canadian Aeronautics and Space Institute 60th Aeronautics Conference and Annual General Meeting*, April 30-May 2, 2013, Toronto, Ontario.

Yan. J., & Histon, J. M. (2014) Identifying Major Human Factors Risks in North American Airline Operations: A HFACS Analysis of Accident and Incident Investigation Reports. In *Proceedings* of *Human Factors and Ergonomics 2014 International Annual Meeting* (Vol. 58, No. 1, pp. 120-124), October 27-31, 2014, Chicago, Illinois.

Young, M., & Stanton, N. (2001). Mental workload: Theory, measurement, and application. In W. Karwowski (Ed.) *International Encyclopedia of Ergonomics and Human Factors, 1*, 507-509. London: Taylor & Fran.

Zimmerman, J. (2013, June 12). FAA wants your data-will you give it to them? Retrieved from http://airfactsjournal.com/2013/06/faa-wants-your-data-will-you-give-it-to-them/

Appendix A

Brief Description of HFACS Causal Categories (Shappell et al., 2007)

Organizational Influences

Organizational climate: Prevailing atmosphere/vision within the organization, including such things as policies, command structure, and culture.

Operational process: Formal process by which the vision of an organization is carried out including operations, procedures, and oversight, among others.

Resource management: How human, monetary, and equipment resources necessary to carry out the vision are managed.

Unsafe Supervision

Inadequate supervision: Oversight and management of personnel and resources, including training, professional guidance, and operational leadership, among other aspects.

Planned inappropriate operations: Management and assignment of work, including aspects of risk management, crew pairing, operational tempo, etc.

Failed to correct known problems: Those instances in which deficiencies among individuals, equipment, training, or other related safety areas are "known" to the supervisor yet are allowed to continue uncorrected.

Supervisory violations: The willful disregard for existing rules, regulations, instructions, or standard operating procedures by managers during the course of their duties.

Preconditions for Unsafe Acts

Environmental factors

Technological environment: This category encompasses a variety of issues, including the design of equipment and controls, display/interface characteristics, checklist layouts, task factors, and automation.

Physical environment: Included are both the operational setting (e.g., weather, altitude, terrain) and the ambient environment (e.g., as heat, vibration, lighting, toxins).

Condition of the operator

Adverse mental states: Acute psychological and/or mental conditions that negatively affect performance, such as mental fatigue, pernicious attitudes, and misplaced motivation.

Adverse physiological states: Acute medical and/or physiological conditions that preclude safe operations, such as illness, intoxication, and the myriad pharmacological and medical abnormalities known to affect performance.

Physical/mental limitations: Permanent physical/mental disabilities that may adversely impact performance, such as poor vision, lack of physical strength, mental aptitude, general knowledge, and a variety of other chronic mental illnesses.

Personnel Factors

Crew resource management: Includes a variety of communication, coordination, and teamwork issues that impact performance.

Personal readiness: Off-duty activities required to perform optimally on the job, such as adhering to crew rest requirements, alcohol restrictions, and other off-duty mandates.

Unsafe Acts

Errors

Decision errors: These “thinking” errors represent conscious, goal-intended behavior that proceeds as designed, yet the plan proves inadequate or inappropriate for the situation. These errors typically manifest as poorly executed procedures, improper choices, or simply the misinterpretation and/or misuse of relevant information.

Skill-based errors: Highly practiced behavior that occurs with little or no conscious thought. These “doing” errors frequently appear as breakdown in visual scan patterns, inadvertent activation/ deactivation of switches, forgotten intentions, and omitted items in checklists. Even the manner or technique with which one performs a task is included.

Perceptual errors: These errors arise when sensory input is degraded, as is often the case when flying at night, in poor weather, or in otherwise visually impoverished environments. Faced with acting on imperfect or incomplete information, aircrew run the risk of misjudging distances, altitude, and descent rates, as well as of responding incorrectly to a variety of visual/vestibular illusions.

Violations

Routine violations: Often referred to as “bending the rules,” this type of violation tends to be habitual by nature and is often enabled by a system of supervision and management that tolerates such departures from the rules.

Exceptional violations: Isolated departures from authority, neither typical of the individual nor condoned by management.

Appendix B

Semi-structured Interview Questions

Note: the table below presents a basic semi-structured interview question list used in this research project. The actual questions asked are based on this sample question list, but the selection, the order and the narration of the questions may vary in the different interviews for experts in different domains.

Date:_______ Participant No.: _________ Interviewer: ______ Interview No.: _______

#	Theme	Questions
1		What is your position in this organization? What are your responsibilities? **No formal title. Can you describe your general position in company and what some of your responsibilities are?*
2	HF risks	What are the sources (e.g., safety reports, FDM, accident/incident investigation) is using in the current human factors risks identification? How do you integrate the different sources?
3	HF tools	What are concerns/challenges about current human factors risks identification?
4	HF risks	What are the top five human factors risks that you think the airlines or even the entire North American industry is facing based on your experience in aviation safety risk identification?
5	HF risks	Based on your experience and involvement with safety management activities, what are the upcoming changes in the airline's operational environment that might introduce new human factors related issues or increase the current human factors risks?
6	FDM Process	What is the general process of the current FDM in major airlines? What are the inputs (e.g. flight data, requirements) and outputs (e.g., report, study) of the process?
9	FDM Process	What was the process of determining the original set of events when the program started?
7	FDM Event Setting	Over the years, how did you determine that events needed to be changed? How were new events determined and added? Were some removed? Why?

8	FDM tools	What FDA tools are you using in daily monitoring?
9	HF & FDM	Does safety department communicate with FDM department once you get a safety report? How often? What information is shared between safety investigation and FDM?
10	HF & FDM	Is current FDM able to identify HF risks? How? What tools and process you are using?

Appendix C

Traditional Basic FDM Event Examples (FAA, 2004)

Event Name	Event Description	Parameters and Basic Event Definition	Notes
Pitch High at Takeoff	An event that measures pitch at takeoff in relation to the angle required to strike the tail of the aircraft.	Air/Ground Switch, Pitch Air/Ground = Ground, Pitch > x degrees	Limits are based on the angle required for the tail cone to contact the ground with struts compressed.
Takeoff Climb Speed High	An event to detect climb speed higher than desired during the Takeoff Phase of flight.	CAS, Gross Weight, HAT HAT > x feet, HAA < x feet, CAS > V_2 + x knots	Altitude ranges should be used to accommodate different desired climb speeds in those ranges. In certain ranges, the climb airspeed will be based on V_2.
Approach Speed High	An event to detect operation on approach that is in excess of its computed final approach speed.	Gross Weight, CAS, HAT, Flaps HAT > 1,000 feet, HAT < 3,000 feet, CAS > V_{FE} – x knots HAT < 1,000 feet, CAS > V_{RFE} + x knots	This event should be broken down into altitude bands. Suggested breakdown would be HAT > 1,000 feet, HAT 500 – 1,000 feet, HAT 50 – 500 feet, HAT < 50 feet. Speeds above 1,000 feet would reference a lookup table.
Operation Above Glideslope	An event to detect deviation above glideslope.	Glide Slope Deviation High, HAT Glide Slope > x dots, HAT < x feet	
Late Landing Flaps	An event to detect flap movement to the landing flap position below a pre-determined altitude.	HAT, Flap Handle Position, Air/Ground Switch Air/Ground = Air, HAT < x feet, Flap Handle Position at x feet HAT < Flap Handle Position at touchdown	This event is slightly different from Late Landing Configuration in that it detects flap movement below a set altitude rather than a flap setting.

Takeoff Warning	An event that would trigger on the same conditions that set off the takeoff warning horn.	Air/Ground Switch, Flap Position, Speed Brake Position, Throttle Position (or possibly N1) Air/Ground = Ground, Flaps < approved takeoff flaps, Flaps > approved takeoff flaps, Speed Brake > 0, Throttle Position > x	On some newer aircraft, Takeoff Warning is a discrete parameter. Trim Setting is normally a component that triggers Takeoff Warning, but it is sometimes not a recorded parameter.
GPWS Warning	An event to detect when a GPWS warning is triggered.	GPWS GPWS = On	This event should be subdivided for each of the different warning modes of the GPWS.
TCAS Advisory	An event to detect any TCAS advisory triggered.	TCAS Advisory (Up or Down) TCAS Advisory = On	This event should be separated for TCAS Traffic Advisories (TAs) and Resolution Advisories (RAs).

Appendix D

FAA Required Flight Parameters for Digital Flight Data Recorders (FAA, 2014b)

FAA CRF §121.344 — Digital flight data recorders for transport category airplanes

(1) Time;

(2) Pressure altitude;

(3) Indicated airspeed;

(4) Heading—primary flight crew reference (if selectable, record discrete, true or magnetic);

(5) Normal acceleration (Vertical);

(6) Pitch attitude;

(7) Roll attitude;

(8) Manual radio transmitter keying, or CVR/DFDR synchronization reference;

(9) Thrust/power of each engine—primary flight crew reference;

(10) Autopilot engagement status;

(11) Longitudinal acceleration;

(12) Pitch control input;

(13) Lateral control input;

(14) Rudder pedal input;

(15) Primary pitch control surface position;

(16) Primary lateral control surface position;

(17) Primary yaw control surface position;

(18) Lateral acceleration;

(19) Pitch trim surface position or parameters of paragraph (82) of this section if currently recorded;

(20) Trailing edge flap or cockpit flap control selection (except when parameters of paragraph (85) of this section apply);

(21) Leading edge flap or cockpit flap control selection (except when parameters of paragraph (86) of this section apply);

(22) Each Thrust reverser position (or equivalent for propeller airplane);

(23) Ground spoiler position or speed brake selection (except when parameters of paragraph (87) of this section apply);

(24) Outside or total air temperature;

(25) Automatic Flight Control System (AFCS) modes and engagement status, including autothrottle;

(26) Radio altitude (when an information source is installed);

(27) Localizer deviation, MLS Azimuth;

(28) Glideslope deviation, MLS Elevation;

(29) Marker beacon passage;

(30) Master warning;

(31) Air/ground sensor (primary airplane system reference nose or main gear);

(32) Angle of attack (when information source is installed);

(33) Hydraulic pressure low (each system);

(34) Ground speed (when an information source is installed);

(35) Ground proximity warning system;

(36) Landing gear position or landing gear cockpit control selection;

(37) Drift angle (when an information source is installed);

(38) Wind speed and direction (when an information source is installed);

(39) Latitude and longitude (when an information source is installed);

(40) Stick shaker/pusher (when an information source is installed);

(41) Windshear (when an information source is installed);

(42) Throttle/power lever position;

(43) Additional engine parameters;

(44) Traffic alert and collision avoidance system;

(45) DME 1 and 2 distances;

(46) Nav 1 and 2 selected frequency;

(47) Selected barometric setting (when an information source is installed);

(48) Selected altitude (when an information source is installed);

(49) Selected speed (when an information source is installed);

(50) Selected mach (when an information source is installed);

(51) Selected vertical speed (when an information source is installed);

(52) Selected heading (when an information source is installed);

(53) Selected flight path (when an information source is installed);

(54) Selected decision height (when an information source is installed);

(55) EFIS display format;

(56) Multi-function/engine/alerts display format;

(57) Thrust command (when an information source is installed);

(58) Thrust target (when an information source is installed);

(59) Fuel quantity in CG trim tank (when an information source is installed);

(60) Primary Navigation System Reference;

(61) Icing (when an information source is installed);

(62) Engine warning each engine vibration (when an information source is installed);

(63) Engine warning each engine over temp. (when an information source is installed);

(64) Engine warning each engine oil pressure low (when an information source is installed);

(65) Engine warning each engine over speed (when an information source is installed);

(66) Yaw trim surface position;

(67) Roll trim surface position;

(68) Brake pressure (selected system);

(69) Brake pedal application (left and right);

(70) Yaw or sideslip angle (when an information source is installed);

(71) Engine bleed valve position (when an information source is installed);

(72) De-icing or anti-icing system selection (when an information source is installed);

(73) Computed center of gravity (when an information source is installed);

(74) AC electrical bus status;

(75) DC electrical bus status;

(76) APU bleed valve position (when an information source is installed);

(77) Hydraulic pressure (each system);

(78) Loss of cabin pressure;

(79) Computer failure;

(80) Heads-up display (when an information source is installed);

(81) Para-visual display (when an information source is installed);

(82) Cockpit trim control input position—pitch;

(83) Cockpit trim control input position—roll;

(84) Cockpit trim control input position—yaw;

(85) Trailing edge flap and cockpit flap control position;

(86) Leading edge flap and cockpit flap control position;

(87) Ground spoiler position and speed brake selection;

(88) All cockpit flight control input forces (control wheel, control column, rudder pedal);

(89) Yaw damper status;

(90) Yaw damper command; and

(91) Standby rudder valve status.

The table below presents the detailed categorization of each parameter groups into the seven human factors relevance classes (Table 4-2). This table will assist future work on programing new HF events and conducting human factors focused FDM studies.

Categorization Based on FAA Parameter Groups

Class	Name		Parameters Groups
1	**Pilot Settings**	Control input & selections	(10), (12), (13), (14), (20), (21), (23), (25), (36), (57), (58), (72), (87), (90)
		Automation mode selection	
2	**Cockpit Flight Control Force**		(88)
3	**Cockpit Displays**	Aircraft physical status data	(2), (3), (4)—(9), (11), (15)—(18), (10), (22), (25), (26)—(29), (31)—(34), (37)—(39), (42)—(56), (59)—(61), (70)—(86), (89), (91), other system data available to pilots
		Automation mode displays	
		Other flight system displays	
4	**Warning Systems**		(30), (35), (40), (41), (44), (62)—(65)
5	**Time**		(1)
6	**External Environment**		(24)
7	**Other Flight System Data Not Available to Pilots**		Other flight systems data (e.g., Air conditioning system, Electrical systems)

Appendix E

Customized NASA-Task Load Index for High Workload Event

An example of customized NASA-Task Load Index is provided for reference. The ratings from more than two experts should be compared and calculated in order to determine the final task load of each procedure.

Hart and Staveland's (1988) NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales. This task requires more than one experience pilots to perform. First, the raters need to rate the procedures in the SOPs on the following 6 dimensions within a 100 points range. Then compare them pairwise based on their perceived importance. The frequent count of each dimension is chosen as more important is the weighted score. This is multiplied by the scale score for each dimension and then divided by 15 to get a workload score from 0 to 100, the overall task load index for individual subtask. The customized task load index is shown below. Based on the features of flying tasks, dimension four has been changed from "performance" to "collaboration", and dimension five has been changed from "effort" to "complexity".

Mental Demand How mentally demanding was the task?

Very Low Very High

Physical Demand How physically demanding was the task?

Very Low Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low Very High

Collaboration How much you need to collaborate with your partner to complete the work?

Very Low Very High

Complexity How complex you think this work is?

Very Low Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed will you be if you failed to perform the task?

Very Low Very High

Pairs	**More important**	**Pairs**	**More important**	**Pairs**	**More important**	**Weight**
MD/PD		PD/TD		TD/CR		MD=
MD/TD		PD/CL		TD/FR		PD=
MD/CL		PD/CP		CL/CP		TD=
MD/CP		PD/FR		CL/FR		CL=
MD/FR		TD/CL		CP/FR		CR=
Total=Sum (rate of each dimension *weight of each dimension)/15=						FR=