Flight Data Monitoring and Human Factors Risks Identification: A Review of Best Practices

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Abstract

Flight Data Monitoring (FDM) is a "systematic, pro-active and non-punitive program" (CAA, 2003), which aims to improve aviation safety by collecting and analyzing digital flight data. It has now become one of the major resources of operational performance measurement and a key component of Safety Management Systems (SMS). Analysis shows FDM has great potential as an anticipatory tool for investigating root causes and risk levels associated with human errors, allowing pro-active early identification of human factors risks. Literature on the evolution of the use of flight data and FDM practices are reviewed. Research projects on applying FDM data in human factors risks analysis and investigating common human factors concerns are summarized. Finally, potential research opportunities on proactively detecting human factors risks through FDM and better integrating FDM into broader SMS processes are identified.

1. Introduction

1.1 Problem Statement and Motivation

Flight data 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 resources of line operations performance management due to the establishment of Flight Data Monitoring (FDM) programs in many countries and major airlines during the past decade.

FDM is a "systematic, pro-active and non-punitive program" (Civil Aviation Authority [CAA], 2003), 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 line operations. It now serves as an important component of the Safety Management System (SMS) in commercial airlines. Similar flight data analysis programs include Flight Operational Quality Assurance (FOQA) program in the US and Flight Data Analysis Programs in several European and Asian airlines. These data monitoring programs benefit aviation industry in many areas, including training, reducing crew fatigue, and maintenance.

Research shows that around 70% to 80% aviation accidents today are related with human errors (Shappell & Wiegmann, 2004). Many efforts have been placed in preventing human errors; however, human factors risks still exist in everyday line operations, where operators are interacting with systems. Since the 1990s, modern safety theory has been used to view and manage aviation safety from a systematic and organizational perspective, which is the basis of SMS. Today, human factors is viewed as a significant element in SMS. How to identify, assess and mitigate human factor risks is of great importance in improving aviation safety. FDM, as one of the "reporting nodes" for safety oversight in SMS (Transport Canada, 2004), shows great potential in proactively anticipating emerging human factors challenges due to the fact that it provides objective information of actual trends and risks in daily operations. FDM information can also be compared and complemented by other data resources (e.g. voluntary safety reports) to offer feedbacks for training, maintenance and crew management (Transport Canada, 2004).

Numerous advances have been achieved in these areas, yet many of those applications mainly focus on information of "what happened" and "how it happened" (Walker & Strathie, 2012). The significant research opportunities remain in detecting root causes and better diagnosis (Walker & Strathie, 2012) of human factors problems. Therefore, it is very important to review the current practices of FDM to understand how FDM could be better applied to identify human factors challenges within an airline's SMS from the perspective of safety management department. Further research on potential applications of FDM for detecting proactively human factors issues will help airlines improve the daily operational quality and enhance the safety management.

1.2. Approach

In order to develop insights into FDM applications, backgrounds of flight data and flight data analysis were studied. Sources reviewed include prescriptive documents, reports, meeting proceedings and research papers in the field of FDM application, implementation of SMS and other similar programs. Examples of reviewed materials include International Civil Aviation Organization (ICAO) regulations, descriptions of FDM programs implemented in Canada and other countries, reports of FOQA and Aviation Performance Measuring (APMS) conducted by National Aeronautics and Space Administration (NASA) applications in the US, and research papers from academics on FDM application (e.g. Chidester, 2003) and human factors monitoring in aviation (Srivistava & Barton, 2012).

A general categorization of the papers and documents was performed based on the different focuses of the research projects. Documents and research papers were also classified based on the resources, to capture a global view of FDM in different countries. The process of SMS and its related reporting systems were studied, in order to identify potential research needs. Good practices associated with human factors issues, such as training and crew fatigue monitoring were identified from the previous work and analyzed. In addition, based on the general FDM process, an initial model of how FDM fits within SMS was built. There is a large amount of work; therefore, this review concentrates on the trends and major themes that are frequently discussed in the literature.

The literature review and analysis of current FDM practices focused on identifying:

- Current general applications of FDM and other related programs;
- Best current practices, previous achievements as well as limitations;
- The research and applications that addressed human factors challenges with FDM method;
- Future research opportunities in identifying and understanding human factors risks through FDM and potential improvements of SMS safety oversight.

In the remainder of the paper, literature on the evolution of the use of flight data and FDM practices is reviewed. Accomplishments on applying FDM data in human factors risks analysis and investigating common human factors concerns are summarized. Research and application challenges where additional efforts are needed are identified. Finally, potential research opportunities on detecting and understanding human factors risks through FDM and better integrating FDM into broader SMS processes are identified.

2. Review of Current FDM Practices

2.1. Background

Flight Data and Data Analysis Tools

Flight data consists of parameters that provide flight performance information throughout all phases of flight. The parameters are recorded by devices installed on an aircraft; the number of collected parameters varies with different types of aircraft (ICAO, 2010). Required parameters include Indicated Airspeed, Altitude and Acceleration. Recording intervals varies with different types of parameters from 0.125s to 1s (ICAO, 2010).

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 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 (BEA, 2005). 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 (Federal Aviation Administration [FAA], 2004). Direct Access Recorder is also a non-protect data recorder as QAR. It can acquire certain parameters with selected sampling frequency from data recording units. Traditionally, data needs to be downloaded to a removable disk regularly before the data is lost. But latest technologies allow wireless data transmission from recorders to the ground station, which is more accessible for research and monitoring purposes. Ground Data Replay and Analysis System (GDRAS) and other analysis tools can assist analysts to replay and animate the flight data (Campbell, 2007). Advanced data replay tools can provide different views of the flight. Relative high automation has been achieved by some of the analysis software, which greatly simplifies the data presentation method. Many other tools are involved in the flight data analysis processes (Global Aviation Safety Network [GAIN], 2003).and more advanced analysis tools have been developed over the past decade (e.g. Ananda & Kumar, 2008; Haverdings & Chan, 2010; Harboe-Sorensen et. al, 2012).

Flight Data Monitoring Program (FDM)

FDM is a "proactive and non-punitive programme for gathering and analysing 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 1970s, the UK CAA's Safety Regulation Group started to develop a similar program to apply FDM information in safety tasks (CAA, 2003). 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 (CAA, 2003), 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).

Figure 1 is a general FDM process model which presents the basic data information flow and functions of FDM. Typically, 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. There are five major application areas of FDM as shown in the figure; these practices provide feedbacks and improvement suggestions to the entire airline's operations system, including internal departments of flight crews, training, maintenance, operational control and external sections such as ATC, regulatory agencies and etc… The whole process is a dynamic loop; the risk mitigation actions taken in the departments based on FDM feedbacks will finally improve the operations of the aircraft systems continuously.

2.2. General Applications of FDM

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 (National Transportation Safety Board, 2002).

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. Daily routine FDM data today is being used in five major areas: exceedence detection, routine measurements, incident investigation, continuing airworthiness, and integrated safety analysis (ICAO, 2005).

Exceedence detection is using FDM data for detecting deviations from standard operating procedures such as heavy landing, GPWS warning and stall warning. Routine measurements focus on monitoring routine performance of an increase number of line operation flights rather than individual flight to identify subtle trends that might be potential risks of accidents. This application requires sufficient techniques and resources to conduct comparative analysis of a wide range of operational parameters, such as take-off weight, flap setting and speed (CAA, 2003). Research has previously been done in the areas of exceedence detection and routine measurements (e.g. Nehl & Schade, 2007). The statistical results of exceedence and trend analysis could provide important and reliable information for predicting potential risks and improving training techniques (e.g. Seamster, et al, 1998).

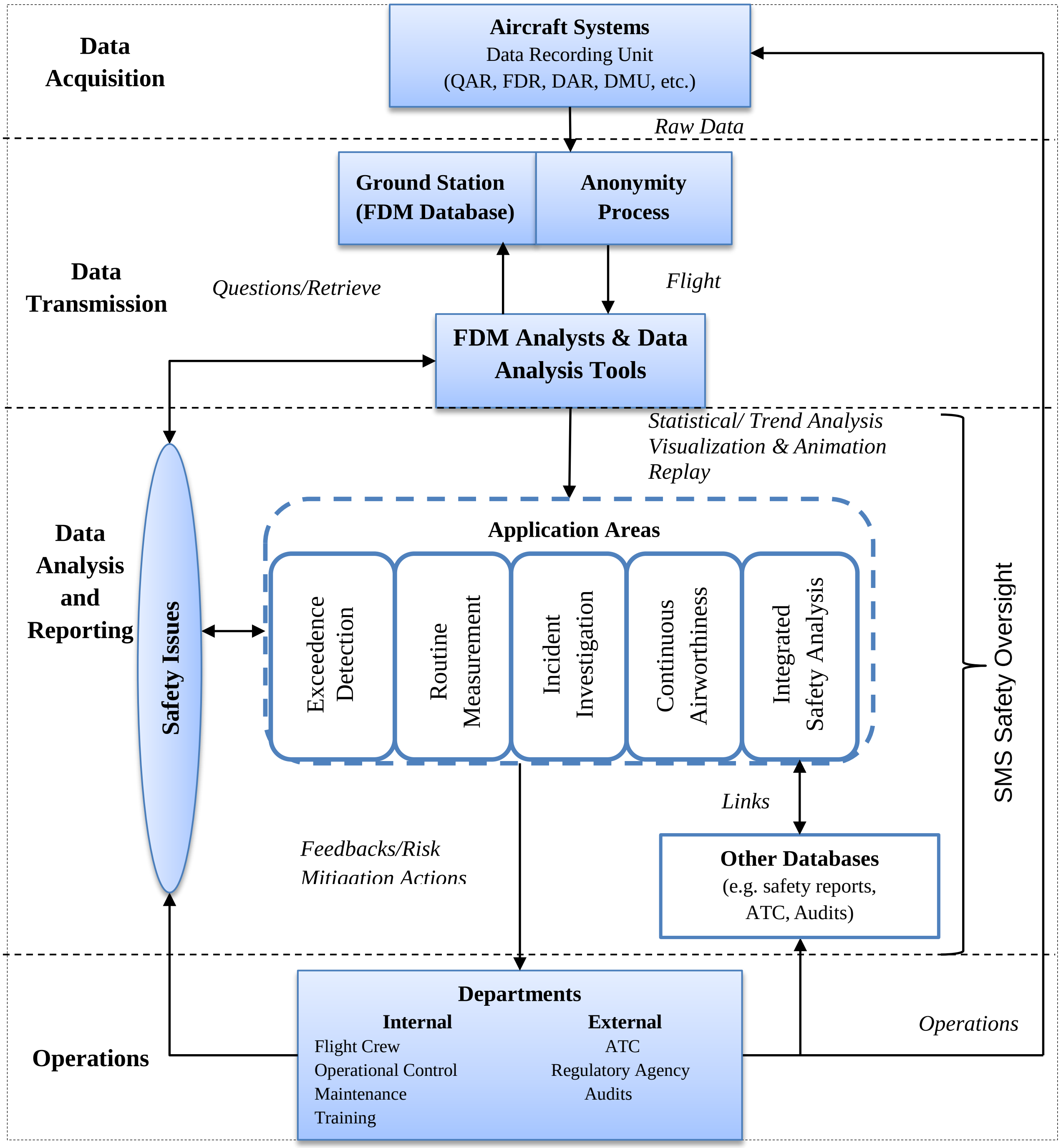

Figure 1 Generalized FDM Process Model

Incident investigation and continuing airworthiness are another two essential FDM applications. Besides accidents, incidents actually provide more information of risks and hazards. FDM data has been proved to be very useful as a quantitative complement and analysis resource for occurrences reports (e.g. mandatory and voluntary safety reports) (CAA, 2003). Besides, both routine and event data that are 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 (CAA, 2003). Mitchell et al (2007) suggested that real-time monitoring can benefit aircraft maintenance, such as identifying engine conditions. Additionally, monitoring of performance loading coupled with damage detected during inspection can be used by aircraft manufacturers to design systems more tolerant of stresses (FAA, 2000). 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 application benefits from linking the FDM central database with other safety databases (e.g. Aviation Safety Reporting System (ASRS)) to gain a more comprehensive understanding of safety issues in the system. The integration of all available sources of safety data provides the company's SMS with viable information on the overall safety of the operation (ICAO, 2005). However, the links between two or more data sources are not well developed, and research opportunities still remains in this area.

2.3. Other Related Programs and Systems

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 airlines and pilots to share de-identified aggregate information with the FAA so that the FAA can monitor national trends in aircraft operations and target its resources to address operational risks (FAA, 2004). The basic elements of the FOQA program include: Airborne Data Recording Systems, Air/Ground Data Transfers and GDRASs. The general process is similar to the FDM model shown in Figure 1. The analysis results can be used in the areas of: Operational Safety, Aircraft and Aircraft System Design and Performance, Crew Performance, Company Procedures, Training Programs and Effectiveness, Air Traffic Control System Operation, Airport Operations and Meteorological Issues (FAA, 2004).

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 is to analyze job tasks and required knowledge for the operators and qualify the standards and documents first, and then conduct training in small groups. Once initial performance data is collected and analyzed, the training program will be evaluated and revised to achieve continuous improvement (FAA, 2006). The FAA is working on integrating and using FOQA data in AQP, to provide an objective measurement of line performance. The methodology is to identify relationships between specific values or patterns of flight parameters and the crew's performance, which will assist training programs to describe the qualified standards (Bresee, 1996).

Aviation Performance Measuring System (APMS)

NASA is collaborating with airlines and FOQA venders in a project know as Aviation Performance Measuring System (APMS) ("APMS Research Overviews", 2012). The objectives of APMS are to develop advanced concepts and prototype software for flight data analysis to further Flight Operations Quality Assurance (FOQA) programs toward the proactive safety risk management (Chidester, 2003), and finally transferring these tools to industry. FOQA focuses mainly on exceedances detection and its processing is labor intensive and takes too much time. APMS thus aims at providing focused analysis of higher risk phases of flight, and mining for atypical, potential precursors of incidents and accidents (Chidester, 2004). It also supports AQP in setting training standards (Bresee, 1996). Advanced APMS tools now look beyond events within individual flights to identify routine systemic problems through statistical analysis. It is also working on combining weather and air traffic data with flight data analysis.

Fatigue Risks Management System (FRMS)

FRMS is a "data-driven, scientific" approach of identifying fatigue related safety risks in line operations to respond to the requirement of SMS. This process leads to continuous safety enhancements by identifying and addressing fatigue factors across time and changing physiological and operational circumstances. 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 programs (Srivistava & Barton 2012).

Other Related Systems

In addition, there are several other FDM related systems, such as Maintenance Operations Quality Assurance (MOQA), Helicopter Flight Data Monitoring Program (HFDM), Health and Usage Monitoring System (HUMS) and Aircraft Condition Monitoring System (ACMS). Although these systems differ from each other on specific areas of focus, they all aim to improve aviation safety.

3. FDM Practices and Human Factors

FDM events often contain a significant human factors element. In order to get an insight into human factors focused flight data application, previous work of FDM 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, and crew fatigue monitoring, as well as integrating FDM with other data sources. Many research projects have been done with the supports of FDM/FOQA, AQP and other related programs.

Mitchell et al (2007) have analyzed the benefits for FOQA programs in flight training application. 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 Crew Activity Tracking System (CATS) to identify training needs (Callantine, 2001). The CATS model compares state parameters from real flight data with constraint parameters and pilot actions to identify unsafe operations by the crew. In addition, the FAA is working on applying data obtained from FOQA programs into AQP to provide a solid base of training instructions (Bresee, 1996). Several projects as part of these efforts have successfully developed and included in software products, as well as procedure and analysis tools that aim to achieve reliable performance data and establish relationships between flight data parameters and operators performances (FAA, 2000). A FAA training manual also mentioned the method of using crew performance trend data for training purpose (Seamster, et al, 1998).

The second area of applying FDM data to address human factors issues is measuring crew performance. Chidester et al (2003) have applied APMS tools to understand the crew performance during approach and runway assignment changes. The Japan Aerospace Exploration Agency is developing a proactive flight crew operations safety analysis tool designed to be used within an air carrier's FDM. This tool is designed to reconstruct flight crew activities, including tasks that can be directly detected from changes of parameters and tasks that cannot be directly observed from dataset, by using an embedded rule-based human behavioural model (Muraoka & Tsuda, 2006). Research also has been conducted on applying FDM data for crew fatigue monitoring. For instance, EasyJet is collaborating with NASA in implementing Human Factors Monitoring Program, which provides a very practical example of integrating FDM data in fatigue risks identification (Srivistava & Barton 2012).

In addition, several research projects on have been done in the area of integrated safety analysis. Maille and Chaudron (2013) were recently working on developing a new methodology, which allows a combined exploration of different feedback databases. This new safety management analysis method highlights the links, which are unique flight identifications (e.g. flight number and departure time) between human-factor components in crew reports and operational deviations detected by digital flight data. 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 noted that current applications of flight data analysis lack a path to understand why the risks exist; they suggested a concept of applying human factors methods, such as Signal Detection Theory and Mental Models theory to analyze the information provided by digital data.

In addition, there are some examples of FDM applications associated with human factors risks in other domains. For instance, HFDM have already been applied in several major helicopter companies. Reports show that this program has great potential in addressing human factors challenges, such as pilot knowledge and skills, gaps in training and crew corporations (Norman, 2005; Evans et al, 2009). Also, since 1999, the FAA has been working on the Performance Data Analysis and Reporting System installed in a number of Air Route Traffic Control Centers and Service Area Offices. This system generates reports for performance measurement, route and airspace design and training purposes (Nehl & Schade, 2007).

As shown above, the applications of FDM in identifying human factors related risks are comparatively limited and lack a systematic approach. Current limitations in this application include difficulties in developing tools to analyze reliable qualitative data and identifying the relationship between human performance and certain flight parameters. Simply relying on FDM or occurrence reporting systems can only provide the information on "what" and "how" events happened. In order to identify root causes of human factors risks (i.e. "why" events happened), tight information links between real routine flight data and other "reporting nodes" (Transport Canada, 2004) in SMS are required.

4. Identifying Potential Human Factors Research Opportunities

4.1. Potential Research Opportunities

The review of the previous research work and current practices of FDM shows that significant progress and numerous achievements have been made during the past decades. However, most of the previous work focuses on FDM data analysis methods, techniques and processes. Previous practices of FDM reveal that routine monitoring data could provide valuable information on the risks associated with operators. Potential future research should take advantages of the objective information provided by flight data and information generated from other links in SMS to proactively detect human factors challenges within the operations system. Figure 2 highlights the places where potential research opportunities remain based on the FDM process model.

First, efficient information links between FDM database and other safety report databases are need to be established. In other words, the application area of integrated safety analysis needs to be explored and enhanced. Current human factors analysis tools and programs mainly rely on occurrence report databases, including Air Safety Report and Human Factor Confidential Report (GAIN, 2003). This kind of information is descriptive and qualitative. Sometimes, important information associated with human factors is missing in the reports because the reporters choose to ignore or are unaware of it. FDM data is able to identified hazards which are ignored by the reports. Meanwhile, unlike engine condition measurements, human factors issues cannot be thoroughly understood by merely analyzing digital data. Therefore, bridges between these two types of databases are necessary for human factors risks detection. These databases should complement each other at the same time, rather than regarding FDM as the follow-up of safety reports. The specific procedures of using the links between different databases also need to be developed. The purpose of the synthetic analysis of various databases is finally generating reliable and thorough human factors reports.

In order to integrate FDM data into report databases, valid methods are needed to analyze qualitative data and link these databases together. Data filter methods are needed to determine which data is related with operators' performances directly or indirectly among the huge volume of FDM data. Accurate relationships between real time monitoring data and human performances need to be well defined. Related research opportunities also include how to better enhance the confidential process while linking de-identified database (i.e. FDM data) with identified database (e.g. safety reports) (CAA, 2003).

Both the FDM data and reports are internal data from the airlines. Another future research opportunity is to find the links between internal data and external resource, such as ATC data and weather reports. If links between ATC data and internal data sources are built, human factors issues including communications and corporation between crew and ATC could be identified (e.g. Chidester, 2003).

In addition, areas of human factors concerns may not limited to just identify events that are already occur or detected through exceedences analysis. There is an opportunity to explore whether the performance data can be used to detect subtle underlying misunderstandings of the pilots of system operations, which do not lead to accidents or incidents under most conditions or even hard to detect from the exceedences detection. This kind of information if is able to generate from FDM data could serve as early warnings of latent problems in training, procedure design or understanding automation.

Finally, it is important to note that each box (e.g. "Departments" and "Analysts") in the FDM process model (figure 1 and figure 2) is an individual dynamic system. They have their internal operation systems, which together form the bigger system. Problems, such as communication and culture conflicts, may occur when integrating different systems together. Therefore, how FDM as a logical component and "reporting node" (Transport Canada, 2003) in SMS safety oversight can be integrated with the broader safety management processes (e.g. safety reports and safety audits), while taking individual internal systems into consideration, is a very significant and necessary research topic to look into. This improvement will allow flight safety departments in different scale of airlines take more advantages of SMS safety oversight to identify, manage, and resolve risks associated with human errors.

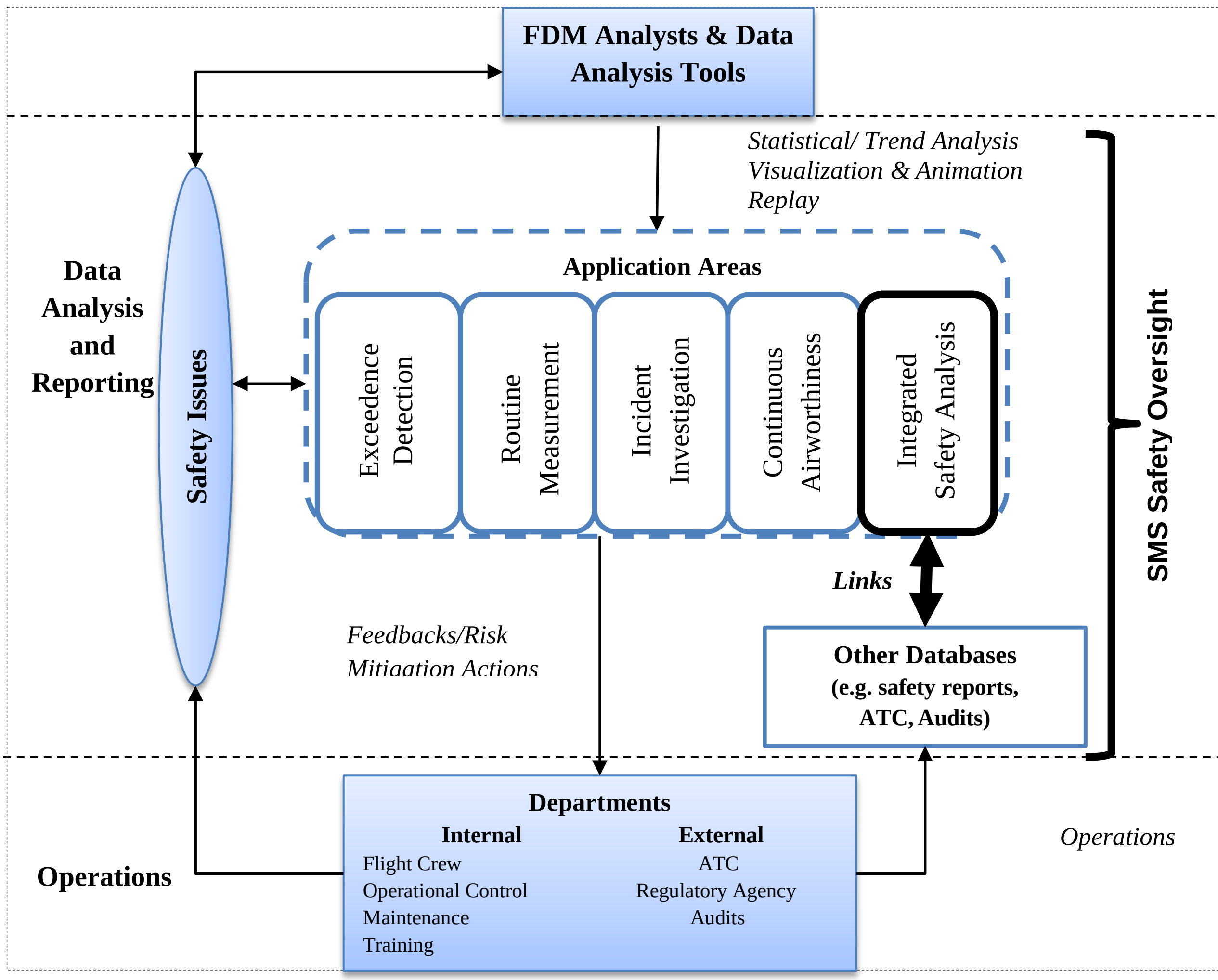

Figure 2 Future Research Opportunities within FDM Model

4.2. Challenges of Expanded Use of Flight Data

As we can see, FDM has a large spectrum of applications in the aviation industry. At the same time, with the expanded use of flight data, some of the common concerns which were addressed at the beginning of the FDM practices will still exist and some of them might become even more prominent than before.

The first concern is cost. FDM and other flight data analysis programs all require significant commitments of resources. FDM is labour intensive and takes too much time to finish the whole process of implementing (Mitchell et al, 2007). For some smaller companies, the costs of purchasing and installing the equipment are beyond the budgets.

Legal and labour concerns regarding to the liability of the safety event and confidentiality of the flight data source are also fairly important issues in FDM practices. Any effective FDM program requires the cooperation of the pilot group. This kind of concern will be more prominent as flight data is applied in more and more areas, especially when de-identified data is linked with identified data

5. Conclusion

FDM has provided a wide spectrum of applications of digital routine flight data. This paper has presented a review of FDM background and current FDM practices. Significant efforts have been made by the international aviation industry to explore the potential values of FDM. Major achievements of previous work include the establishments of the specific programs and data analysis tools and methods. Potential research opportunities of developing links between different databases to help address human factors risks by FDM and integrating FDM into broader process of SMS are identified. However, challenges and limitations still exist and may become more prominent with the expanded applications of FDM data..

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