EVALUATION OF AIRCRAFT MAINTENANCE OPERATIONS USING PROCESS MEASURES

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This research focuses on the development of a proactive system (a Web-based Surveillance and Auditing Tool - WebSAT), which promotes standardization in data collection and identifies the contributing factors that impact aircraft safety. This system will document the processes and the outcomes of maintenance activities, make the results more accessible, and reduce future maintenance error rates. WebSAT will capture and analyze data for the different operations involved in surveillance, auditing, and airworthiness directives. To achieve standardization in data collection, data needs to be collected on certain variables which measure maintenance processes. These variables are defined as process measures. The process measures incorporate the response and observation-based data collected during surveillance, audits, and the control of the airworthiness directives. This paper elaborates on the processes that exist in the aviation maintenance work group, the concerns that need to be addressed while identifying the process measures, and the utility of these process measures in conducting data analysis. Once data is captured in terms of these process measures, data analysis can be conducted to identify the potential problematic areas affecting the safety of an aircraft.

Introduction

The mission of the FAA is to provide safe and reliable air transportation and to ensure aircraft airworthiness. Maintenance error has been found to be a crucial factor in aircraft accidents (Boeing/ATA, 1995). The increasing number of maintenance and inspection errors in the aviation industry has motivated the need for human factors research. Human factors research in maintenance has deemed the human as the central part of the aviation system (Gramopadhye et al., 2000). The emphasis on the human and his role in aviation systems results in the development of error tolerant systems. Such systems will be efficient if they closely monitor and evaluate aircraft maintenance and inspection activities. Air transportation is becoming increasingly complex. The significance of the maintenance function was captured by Weick et al. (1999) when they observed that: “Maintenance people come into contact with the largest number of failures, at earlier stages of development, and have an ongoing sense of the vulnerabilities in the technology, sloppiness in the operations, gaps in the procedures, and sequences by which one error triggers another”. Given the ever increasing complexity of aircraft, a significant proportion of these errors come at the hands of the maintenance personnel themselves, due to greater demands on these individuals. Thus, it is very important to take a closer look at the humans involved in aviation maintenance, understand the causal factors for their errors and the possible solutions to counter this situation.

The aviation maintenance industry has also invested a significant effort in developing methodologies for investigating maintenance errors. The literature on human error has its foundations in early studies of errors made by pilots (Fitts, 1947), work following the Three Mile Island incident, recent work in human reliability and the development of error taxonomies (Swain and Guttman, 1983, Norman, 1981, Rouse and Rouse, 1983, Rasmussen, 1982, Reason, 1990). This research has centered on analyzing maintenance accidents. Figures emerging from the United Kingdom Civil Aviation Authority (CAA) show a steady rise in the number of maintenance error mandatory occurrence reports over the period 1990 to 2000 (Courteney, 2001). A recent Boeing study of worldwide commercial jet aircraft accidents over that same period shows a significant increase in the rate of accidents where maintenance and inspection were primary factors (ICAO, 2003). The FAA, in its strategic plan for human factors in aviation maintenance, through to 2003, cited statistics from the Air Transport Association of America (ATA) showing that the number of passenger miles flown by the largest US airlines increased 187% from 1983 through to 1995. Over that same period, the number of aircraft operated by those airlines increased 70%, but the number of aviation maintenance technicians increased only 27%. The FAA concluded that the only way the maintenance program could cope with the increased workload was by increased efficiency at the worker level (McKenna, 2002).

Attempts have been made to define a core set of constructs for a safety climate (Flin et al., 2000). Although not entirely successful in establishing core dimensions, this research is useful in suggesting constructs that should be considered for inclusion in research on maintenance errors. Taylor and Thomas (2003) used a self-report questionnaire called the Maintenance Resource Management/Technical Operations Questionnaire (MRM/TOQ) to measure what they regarded as two fundamental parameters in aviation maintenance: professionalism and trust. The dimension of professionalism is defined in their questionnaire in terms of reactions to work stressors and personal assertiveness. Trust is defined in terms of relations with co-workers and supervisors. Patankar (2003) constructed a questionnaire called the Organizational Safety Culture Questionnaire which included questions from the MRM/TOQ along with items from questionnaires developed outside the maintenance environment. Following the application of exploratory factor analytic routines to a dataset generated from respondents that included 124 maintenance engineers, Patankar identified four factors as having particular relevance to the safety goals of aviation organizations. They are emphasis on compliance with standard operating procedures, collective commitment to safety, individual sense of responsibility toward safety, and a high level of employee-management trust.

In addition to descriptive accident causation models, classification schemes, and culture surveys, there is a need for empirically validated models/tools that capture data on maintenance work and provide a means of assessing this data. However, such models and schemes often tend to be ad hoc, varying across the industry, with little standardization. In order to contend with this issue, new empirical models and tools are needed which employ standardized data collection procedures, provide a basis for predicting unsafe conditions, and design interventions that will lead to reductions in maintenance errors.

Process Measures

This research seeks to identify error causes and occurrences using a web based surveillance and auditing tool (WebSAT). The purpose of WebSAT is to capture and analyze data for different processes involved in the surveillance, auditing, and airworthiness directives functions of the aviation maintenance industry. To achieve standardization in data collection, data needs to be collected on certain variables which measure maintenance processes. These variables are defined as process measures.

The process measures incorporate the response and observation-based data collected during surveillance, audits, and the airworthiness directives control processes. Once data is captured in terms of these process measures, data analysis can be conducted to identify the potential problematic areas affecting the safety of an aircraft. In this stage of data analysis, the performance of processes and those conducting these processes will also be evaluated.

Quality Assurance Work Functions

The complexity of the inspection and maintenance system is complicated by a variety of geographically dispersed entities ranging from large international carriers, repair and maintenance facilities through regional and commuter airlines, to the fixed-based operators associated with general aviation (Kapoor et al., 2004, Dharwada et al., 2004). Inspection is regulated by the FAA, as is maintenance. However, while adherence to inspection procedures and protocols is closely monitored, evaluating the efficacy of these procedures is much more difficult. This section explains the quality assurance work functions which are responsible for aircraft maintenance.

Surveillance

Surveillance is the day-to-day oversight and evaluation of the work contracted to an airframe substantial maintenance vendor to determine the level of compliance with airline’s Maintenance Program and Maintenance Manual with respect to the airline’s and FAA requirements. For example, FedEx, our partner in this project has a surveillance representative, stationed at the vendor location who schedules surveillance of an incoming aircraft. The specific task to be performed on an aircraft at a vendor location is available on a work card. The representative performs surveillance on different work cards according to a surveillance schedule. The results are documented and used to analyze the risk factors associated with the concerned vendor and aircraft. The FedEx surveillance department classifies the data obtained from a surveillance visit at the maintenance facility into categories. These categories are based on various surveillance tasks and the C.A.S.E. (Coordinating Agency for Supplier Evaluation) guidelines that are adhered to by the substantial maintenance vendor and the airline. The team used these categories as a starting point to identify process measures. Some of the categories currently being used by FedEx are in-process surveillance, final walk around, and verification surveillance.

Technical Audit

The system level evaluation of standards and procedures of suppliers, fuel vendors, and ramp operations done on a periodic basis is referred to as Technical Audit. The work function of technical audits is to ensure compliance with Federal Aviation Regulations (FARs), and established company policies and procedures. The team worked towards identifying process measures for this work function. Data collected from the technical audit checklists will be utilized for analysis on the effectiveness of the technical audit process.

Internal Audit

The evaluation of internal processes in the departments of an airline is referred to as Internal Audit. The work function of the internal audit department is to sample the processes being used by departments in an organization and to verify their compliance with regulatory, company and departmental policies and procedures. Similar to the technical audits, the data collected from internal audit checklists will be grouped into process measures to facilitate further data analysis and assess the effectiveness of the internal audit process.

Airworthiness Directives Department

The evaluation of the applicability, loading, and tracking of airworthiness directives is referred to as airworthiness directives control. The work function of the Airworthiness Directives (AD) control department is to review AD-related Engineering Order/Work Instruction Cards (EO/WIC), the acquisition process, and the customer's maintenance manual. The data collected from these processes will be grouped into categories to facilitate further data analysis and assess the effectiveness of the airworthiness directives control department.

Observations during the Identification of the Process Measures

The team adopted the following data collection methods: Interviews, Observation Sessions, Document Study, and Questionnaires (Iyengar et al., 2004). The team determined that the process measures being identified must include all the data that is gathered during the maintenance operations. The team observed inconsistency in the definition of the existing categories among the surveillance representatives. The representative's own experience could be a road block, preventing him from correctly assigning an error to a category. The internal audit department employed a definitive structure of six categories, and after scrutiny of the internal audit documents, the team concluded that these categories covered the entire span of the data generated during audits in the internal audit department. The data analysis in the technical audit department lacked strategy. The personnel in the airworthiness directives department utilized canned statements for data analysis, which lacked strategy. There were two major work domains being considered in the AD department: information verification based on AD department-related engineering order/ work instruction cards (EO/WIC), manuals and other documents involved with the compliance of airworthiness directives. The AD department also verifies information related to AD status reports.

Observations for Surveillance

The surveillance representatives relied on their memory to categorize what they saw in the maintenance facility. This suggested that there must be a manageable number of categories and they should be easy to remember. There were process measures being used for data analysis in surveillance, some of which were redundant, and there was no consensus among the surveillance personnel within the department at FedEx in the classification of a work card into a specific process measure. There were two distinct categories of process measures: Technical and Non-Technical. Process measures which include surveillance involving scheduled maintenance activities performed on an aircraft during a maintenance event are referred to as technical process measures. These process measures include technical activities that are hands-on and performed directly on the aircraft. Technical activity also includes maintenance that is performed in a back shop setting on a removed aircraft part. An example would be a panel removed and routed to a composite back shop for repair, then reinstalled on the aircraft. The surveillance activities involving verification of standardized procedures, referenced manuals, equipment, and facility maintenance requirements are referred to as non-technical process measures. It was important for the team to understand the purpose of the data being gathered and its relevance to aircraft safety. Hence, collection of data on non-technical measures was given equal emphasis on technical measures. The team recognized the importance of incorporating the concerns of the quality assurance representatives while finalizing the list of process measures for surveillance.

Observations for Internal Audits

The internal audit department at FedEx was working with a robust set of process measures. These were administration, training, records, safety, manuals, and procedures. The team scrutinized the documents and check lists the personnel in the internal audit department work with. These process measures would effectively categorize all the data being generated in this department.

Observations for Technical Audits

The technical audits department conducts annual audits on all FedEx vendors. These vendors are substantial supplier vendors, fuel, ramp operations, and aircraft maintenance vendors using checklists which are query based. The team determined that each check list had a series of questions dedicated to one fundamental domain, such as inspection or facility control. These domains were consistent for the different checklists emphasizing the needs of diverse vendors such as the supplier vendor and the fuel vendor. A final consensus within the research team finalized the process measures as these categories within check lists itself.

Observations for Airworthiness Directives Department

The personnel in this department are involved in two primary activities. They validate the information presented on AD-related EO/WIC, manuals, status reports and other documents involved with the compliance of airworthiness directives. The personnel also verify the adequacy of the activities involved in the loading and tracking of airworthiness directives, including inspection intervals.

Process Measures Validation

Once the research team finalized the process measures definition document, and finalized a list of the process measures to be used for the different work functions, it was important for the research team to validate their research efforts. The team conducted a two-phase on-line survey to validate results. The online survey was initially sent to the surveillance, auditing, and airworthiness directives department personnel at FedEx. There were six participants from each department. Prior to the participants taking the survey, the research team sent out an e-mail to them. This e-mail had detailed instructions about how to take the survey, and the team also expressed the goal of the survey. A process measure definitions document to be read before taking the survey was sent to the participants. The survey had four modules. The survey was designed to last a maximum of 60 minutes. It included 7 to 21 questions depending on the survey module. The questions were of two kinds. There were forced-choice questions, and open-ended questions. Each question had a field for the comments of the personnel taking the survey. The reason for this was that the team wanted detailed feedback from the participants. The participants taking the survey were not identified. The team gave two weeks to get inputs from the participants of the survey. Once the data was generated and analyzed, the research team iterated its definition document to incorporate changes expressed by the participants.

In the next phase, the research team sent out the same survey to other supporting and partnering airline organizations: Alaska Airlines, Delta Airlines, IATA, and America West. The results of this survey are still awaited.

Use of Process Measures in WebSAT

The following is a list of identified process measures for the fours modules WebSAT is involved with.

Process Measures for Surveillance
1. In process Surveillance
2. Verification Surveillance
3. Final Walk Around
4. Documentation Surveillance
5. Facility Surveillance
6. Procedures Manual Surveillance

The other data capturing modules in surveillance which facilitate capturing of the data but are not process measures of the surveillance work function are given below:

1. Additional Findings Module
2. Fuel Surveillance Module

The above mentioned modules are not process measures since they do not evaluate the routine surveillance process. The information captured from the additional findings module is important for an airline for documentation purpose. This data is not used to rate vendor performance of maintenance tasks. Fuel surveillance is not performed in every maintenance facility. To avoid inconsistencies in data classification across the facilities, the team proposed to treat the process of fuel surveillance as a separate module. The data captured in this module will be analyzed separately to comment on the effectiveness of fuel surveillance.

Process Measures for Internal Audits
1. Administration
2. Training
3. Records

4. Safety
5. Manuals
6. Procedures

Process Measures for Technical Audits
1. Compliance/ Documentation
2. Inspection
3. Facility Control
4. Training and Personnel
5. Procedures
6. Data Control
7. Safety

Process Measures for Airworthiness Directives
1. Information Verification
2. Loading and Tracking Verification

The WebSAT framework strategy for the research revolved around three tiers (stages). The first tier involved the collection of data with respect to work functions of surveillance, auditing (internal & technical), and airworthiness directives. Once the data involving the maintenance of an aircraft was gathered from these sources, they would be scrutinized with respect to the process measures. In the next stage, tier 2, the analysis of the relevant data would be categorized. In tier 3, a final analysis would categorize the variables into risk (impact variables), and non-risk variables. To implement this framework, WebSAT will use a data model to interpret and analyze the data gathered. Traditional analytical techniques deal mainly with the identification of accident sequence and seek unsafe acts or conditions leading to the accident. Such techniques include the sequence of events (domino effect), known precedents etc. For example, Pate-Cornell (1993) has developed an analytical framework, to establish the causal relationship between the basic events, decision and actions, and organization factors. She demonstrated the use of this framework in the analysis of the Piper Alpha accident which occurred due to a massive explosion on the offshore oil and gas production platform (Pate-Cornell, 1993, Cojazzi and Cacciabue, 1994). However, the post-hoc nature of these frameworks renders them inadequate for a proactive WebSAT. The team hopes to develop a data model in which the process measures can be used to establish causal relationships in the QA processes.

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