Development of an Industry Standardized Auditing and Surveillance Tool: Minimizing Maintenance Errors

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Table of Contents

Proposal

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TABLE OF CONTENTS

1. PROJECT SUMMARY

Background

For the FAA to provide the public with continuing safe, reliable air transportation, it is important to have a sound aircraft inspection and maintenance system. This system is complex with many interrelated machine and human components. Recognizing the importance of the human in this process, the FAA has pursued human factors research, placing continuing emphasis on developing interventions to make the inspection/maintenance system more reliable and/or more error-tolerant. A key objective has been to reduce errors and to conduct research that provides the aircraft maintenance community with interventions/tools that will help in the identification of factors resulting in maintenance errors. Knowing which factors contribute to these errors can lead to strategies minimizing their effects. A potential area for the application of such an approach is in the arena of dispatching aircraft following service. In response to this need, this research focuses on developing a web–based surveillance tool to minimize maintenance errors prior to dispatch by airlines. It is anticipated that the use of this tool will facilitate the standardization of data collection on surveillance activity. To ensure that the tool addresses the needs of the aircraft maintenance community, this research will be pursued with an industry partner.

Objectives

The general objective of this research will be to develop and implement an application tool to perform surveillance activities to ensure that a consistent level of supervision is maintained over maintenance operations. The system will promote a standardized format for data collection, reduction and analysis to identify proactively contributing factors of improper maintenance. The research will be pursued over three years employing an integrated task analytic and user-centered software lifecycle development methodology with the following specific objectives: (1) identify an exhaustive list of impact variables that affect aviation safety and transcend across various aircraft maintenance organizations; (2) develop data collection/reduction and analysis protocol to analyze errors for the identified set of impact variables; and (3) using the results of the aforementioned activity develop and implement an application in performing surveillance/monitoring tool ensure so that a consistent level of oversight is maintained.

Intellectual Merit

This effort involves a team that will bring together a research university and an industry partner. The P.I. has extensive expertise in aircraft inspection and maintenance processes, human/machine systems design, training and the use of advanced technology to solve challenging human-machine systems design problems. The co-P.I.'s expertise is in human/computer systems and in the use and application of user-centered design methodologies, as well as demonstrable results from previous FAA, NASA, NSF and DOE grants. Moreover, both have the resources of the Advanced Technology Systems Laboratory at Clemson University at their disposal. The industry partner will contribute experienced practitioners and test beds for integrating and testing the web-based tool.

Impact

The development of a standardized web-based surveillance tool will benefit the FAA and the aviation maintenance industry in the following areas:

- Identification of potential factors causing maintenance errors. Eliminating the effects of these factors will help reduce maintenance errors, ultimately improving the safety and reliability of aircraft inspection and maintenance operations.
- Standardization of the data collection process supporting the analysis of maintenance errors prior to aircraft dispatch. This standardization will facilitate analysis across airlines.

- Alleviation of the problems inherent to OJT. This web-based tool can be combined with existing training programs to facilitate consistency in inspection training, to provide adaptive training and to support record keeping and performance monitoring.

In addition, this research will directly support AFS requirements and the AAR mandate for reducing maintenance accidents by conducting guidelines-based human factors research through identifying and implementing intervention strategies.

3. PROJECT DESCRIPTION

Introduction

Since the mission of the FAA is to provide the public with continuing safe, reliable air transportation, it is important to have a sound aircraft inspection and maintenance system (FAA, 1991). This system is a complex one (Gramopadhye et al., 1997; FAA, 1991) with many interrelated human and machine components. Its linchpin, however, is the human. Recognizing this fact, the FAA, under the auspices of the National Plan for Aviation Human Factors, has pursued human factors research (FAA 1991, 1993) to fulfill the mission of the FAA's Flight Standard Service of promoting "safety of flight of civil aircraft in air commerce by setting certification standards, for air carriers, commercial operators, air agencies and airmen; and by directing, managing and executing certification, inspection and surveillance activities to assure adequacy of flight procedures, operating methods, airman qualifications and proficiency, aircraft maintenance and maintenance aspects of continued airworthiness programs." Given this goal, surveillance of maintenance activity contributes an important function in maintaining and improving aviation safety. One arena where this surveillance activity can have tremendous impact is the implementation of a system that can be used by operators prior to delivery of aircraft to customers to reduce maintenance errors.

A study conducted by Boeing and US ATA (1995) found that maintenance error was a crucial factor in aircraft accidents from 1982 to 1991, contributing to 15% of the commercial hull loss accidents where five or more people were killed. Rankin et al. (2000) documented the most critical causes of those accidents:

23% involved incorrect removal or installation of components
28% involved a manufacturer or vendor maintenance/inspection error
49% involved error due to an airline's maintenance policy
49% involved poor design leading to maintenance errors

In addition, Rankin and Allen (1995) established the economic costs of these maintenance errors, estimating that 20 to 30% of in-flight shutdowns are due to maintenance error costing $ 500,000/shut down, 50% of the flight delays are due to engine problems caused by maintenance errors yielding $ 10,000/hour of delay and 50% of flight cancellations are due to engine problems caused by maintenance errors costing an average of $ 50,000/cancellation. The message is clear: we need a proactive system, which will help track maintenance errors, identifying both potential problem areas and the factors causing those errors. If such a system is developed, we will be in a position to manage maintenance errors, resulting in an aircraft maintenance system that is more safe and robust. To understand the need to develop such a system, the entire aircraft inspection and maintenance system needs to be understood.

The aircraft inspection/maintenance system

The complexity of the inspection/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 (refer to Figure 1). Inspection is regulated by the FAA as is maintenance. However, while the adherence to inspection procedures and protocols are closely monitored, evaluating the efficacy of these procedures is much more difficult.

When an airliner is brought into service, a process called MSG (Maintenance Service Group) is used to determine how each component failure is to be corrected to maintain a high level of safety. Aircraft for commercial use have their maintenance scheduled initially by a team that includes the FAA, aircraft manufacturers and start-up operators. These schedules are then taken by the carrier and modified so that they suit individual requirements and meet legal approval. Thus, within the carrier's schedule there will be checks at various intervals, often designated as flight line checks, overnight checks, and A, B, C and D, the heaviest, checks. The objective of these checks is to conduct both routine and non-routine maintenance of the aircraft, including scheduling the repair of known problems; replacing items after a certain air time, number of cycles or calendar time; repairing defects discovered previously, for example, from reports logged by pilot and crew, line inspection, or items deferred from previous maintenance; and performing scheduled repairs.

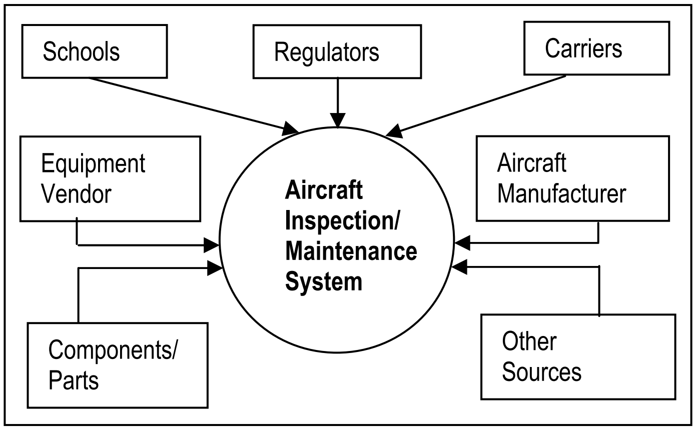

Figure 1. The Aircraft Inspection Maintenance System.

Once maintenance and inspection are scheduled for an aircraft, this timetable is translated into a set of job, or work, cards containing instructions for inspection and maintenance as the aircraft arrives at each maintenance site. Initially, the aircraft is cleaned and access hatches opened so that inspectors can view the different areas. This activity is followed by a heavy inspection check, primarily visual in nature. Since such a large part of the maintenance workload is dependent on the discovery of defects during inspection, it is imperative that the incoming inspection be completed as soon as possible after the aircraft arrives at the inspection maintenance site. In addition, there is pressure on the inspector to discover critical defects necessitating long follow-up maintenance times early in the inspection process. Thus, there is a heavy inspection workload at the commencement of each check. It is only after the discovery of defects that the planning group can estimate the expected maintenance workload, order replacement parts and schedule maintenance items. To meet this demand, maintenance facilities frequently resort to overtime, resulting in an increase in the total number of inspection hours, often leading to prolonged work hours. Further increasing the pressure, much of the inspection, including routine inspections on the flight line, is carried out during the night shift, between the last flight of one day and the first flight on the next. Once a defect is rectified, it may generate additional inspection, called "buyback" inspections, to ensure that the work meets necessary standards.

Thus, it is seen that initially the inspector's workload is very high at the arrival of an aircraft. As the service on the aircraft progresses, this workload decreases as the maintenance crew works on the repairs. The inspection load again increases towards the end of service. However, the rhythm of the work changes at this time because of frequent interruption as AMT's call in inspectors to conduct buybacks of completed work. All of these factors contribute to place stress on the inspectors and other personnel (Taylor, 1990), stress that is further compounded by the fact that the inspector has to search for multiple defects occurring at varying severity levels and locations (refer to Drury, Prabhu and Gramopadhye (1990) for further details).

The maintenance task is further complicated because of the wide variety of defects being reported in older aircraft. Scheduled repairs account for only 30% of all maintenance in these aircraft compared to 60-80% in the younger fleet, a fact which can be attributed to an increase in the number of age-related defects (FAA, 1991). Consequently, a more intensive inspection program is required for older aircraft, and inspection plays a more vital role. However, the introduction of newer aircraft will not substantially reduce the maintenance workload, as new airframe composites create an additional set of variables. The problem of maintenance is compounded since the more experienced inspectors and mechanics are retiring and are being replaced by a much younger and less experienced work force. Not only do the unseasoned AMT's lack the knowledge and skills of the far more experienced inspectors/AMT's they are replacing, they are also not trained to work on a wide variety of aircraft.

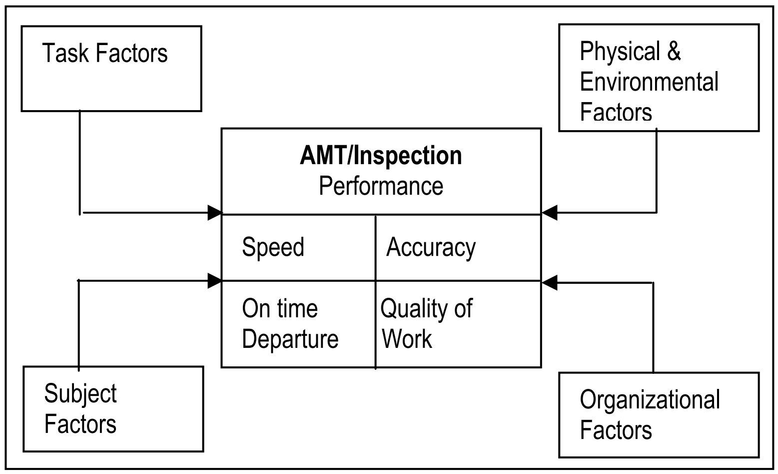

Figure 2. Factors Impacting Aircraft Inspection Performance.

Further, it is seen that the cost of inspection is rising. As a result, there is increasingly greater competitive pressure to reduce maintenance/inspection costs, for example, by maintaining minimum staffing levels and adhering to the mandated workload, without, of course, jeopardizing safety or disrupting flight schedules. From an airline management perspective, two goals need to be achieved by a maintenance/inspection program: safety and profitability. While safety is of paramount concern, profitability can be realized only when safety is achieved economically. For maintenance, this means that in addition to performing the task, technicians have to be sensitive to efficiency, the speed measure, and effectiveness, the accuracy measure, if they are to optimize their performance. The interrelationship between these performance measures and task factors, among others, is seen in Figure 2.

The stress produced by this complicated situation, requiring, at times, what appear to be contradictory goals, often results in maintenance errors, a fact that has been confirmed through task analysis of commercial maintenance and inspection activities (Drury, Prabhu and Gramopadhye, 1990) This analysis has revealed aircraft maintenance to be a complex activity requiring above average coordination, communication and cooperation between inspectors, maintenance personnel, supervisors and various other sub-systems (e.g., planning, stores, clean-up crew, shops, quality assurance) to be effective and efficient (FAA, 1991; FAA, 1993). Thus, it is clear that there exists potential for errors, and it is only through devising strategies that identify where they occur that we can eventually determine problem areas and develop interventions minimizing their impact.

Problem Statement

In response to this need to minimize maintenance errors, the aviation maintenance industry has invested a significant effort in developing methodologies investigating maintenance errors. Literature on human error is rich, having its foundations in early studies analyzing human error made by pilots (Fitts and Jones, 1947), human error work following the Three Mile Island incident, and recent work in human reliability (Swain, 1987) 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 and incidents, a recent example being the Maintenance Error Decision Aid

(MEDA) (Rankin et al; 2000). This tool, developed by Boeing along with representatives from British Airways, Continental Airlines, United Airlines, the International Association of Machinists and the US Federal Aviation Administration, helps analysts identify the contributing factors that lead to an accident.

In addition to this aid, various airlines have also developed their own internal procedures to track maintenance errors. One such methodology is the failure modes and effect analysis approach (Hobbs and Williamson, 2001) that classifies the potential errors by expanding each step of the task analysis into sub-steps and then listing all the failure modes for each. Lessons can also be learned from work done by the US Navy Safety Center in developing the Human Factors Analysis and Classification System – Maintenance Extension Taxonomy and the follow-up web–based maintenance error information management system developed by the Naval Safety Center to analyze naval aviation mishaps (Shappell and Wiegmann, 1997; Schmidt, et al.; 1998; Shappell and Wiegmann, 2001) and later used to analyze commercial aviation accidents (Wiegmann and Shappell, 2001). Although valuable in terms of their insights into identifying the performance-shaping factors leading to maintenance errors, these efforts tend to be reactive in nature; i.e., their focus is on analyzing maintenance accidents and errors following their occurrence, not developing preventative measures. Moreover, these efforts often tend to be ad hoc, varying across the industry with little standardization. The lack of standardization in data collection, reduction and analysis is the single biggest constraint in the analysis of maintenance errors within and across the maintenance industry. Without such standardization it is difficult to analyze data and identify potential problem areas at multiple and geographically dispersed maintenance sites.

As a result, a proactive approach is needed, one which will help analysts identify problem areas and devise strategies to minimize maintenance errors. Since the aircraft maintenance industry needs guidance in this area, this research proposes to develop and implement a web-based application tool to perform surveillance activities to ensure that a consistent level of supervision is maintained over maintenance operations. The system will promote a standardized format for data collection, reduction and analysis to identify proactively contributing factors of improper maintenance. The overall structure of the system is shown in Figure 3. The system will seek input from various sources, including In Process Surveillance, Verification Surveillance, Final Walk Around, Aircraft Walk Around, Inspection, Storage, among others. Data collected from these diverse sources will be reduced and analyzed, enabling researchers to identify future problem areas. The identification of these problem areas will let the industry prioritize factors that transcend across industry to systematically reduce or eliminate potential errors. The system will initially be developed with a specific aviation partner to ensure that it meets the needs of the aviation community and later will be made available as an application that can be downloaded for use by each maintenance facility. In summary, the objectives of this research are three fold: (1) identify an exhaustive list of impact variables that affect aviation safety and transcend across various aircraft maintenance organizations; (2) develop data collection/reduction and analysis protocol to analyze errors for the identified set of impact variables; and (3) using the results of the aforementioned activity develop and implement an application in performing surveillance/monitoring tool ensure so that a consistent level of oversight is maintained.

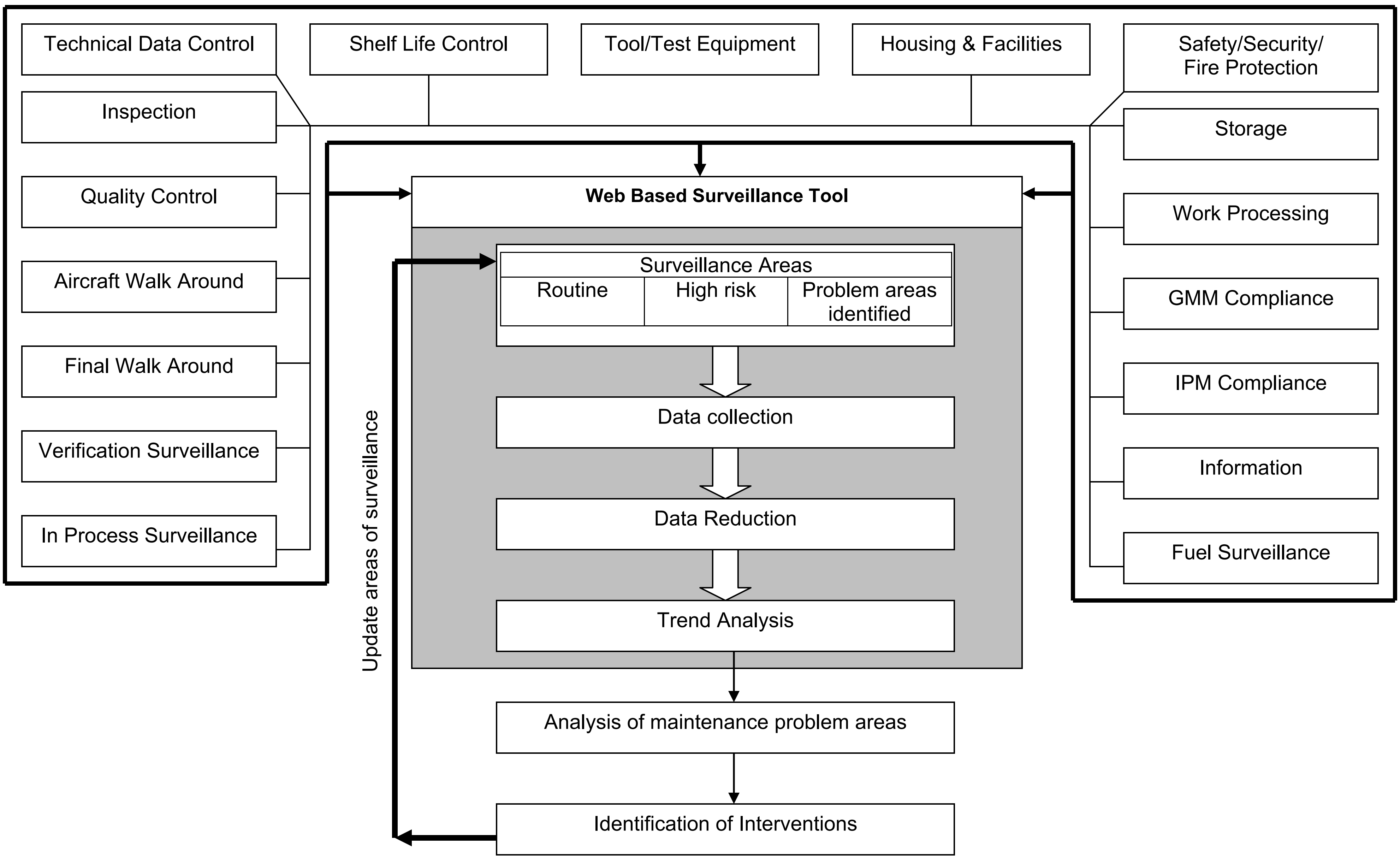

Figure 3: Web based Surveillance Tool with inputs from different sources

Methodology

The research will apply task analytic and a user-centered software lifecycle development methodology.

Year I: Identification of Impact Variables and Data Sources

The following specific activities will be conducted in Year 1:

1.1 Kick-off Meeting of Subject Mater Experts to outline the project's objectives, goals, and milestones. This step will develop a clearly articulated development process, which acts as a master plan that defines the role of each participant on the development team. The work will be done in collaboration with Fed Express team in Memphis. The FAA/AFS 300 will have this collaboration in place prior to commencement of the work.

1.2 The first step will identify and develop an exhaustive list of "impact variables" that could potentially impact airline safety. The initial work conducted by the industry partner (Fed Express) provides a good starting point.

1.3 Ensure that the variables identified are appropriate and representative of those used by other maintenance entities. This will be done by working with other representative maintenance entities (e.g., airlines, third party repair station).

1.4 Discuss with subject matter experts to develop a consensus on the list of impact variables.

1.5 Identify the limitations in using the specific variables and data sources that facilitate collection of error data related to the specific variables. [The focus is based on characterization of data (e.g., Redman, 1996) that looks at the following typical dimensions – for example quality of content (granularity, comprehensiveness, essentialness, flexibility, etc); quality of values (currency, timeliness, completeness of values, internal and external consistency, etc); quality of format (usability, comprehensibility, precision, etc); availability (accessibility, storage, protocol/collection procedures, etc.) and architecture]. Discussions will be conducted with subject matter experts on appropriateness on the use of specific data sources.

1.6 Finalize the list of impact variables and data sources identifying the limitations and protocol in the use of specific data sources for the surveillance and monitoring tool.

Year II: Develop Prototype Auditing and Surveillance Tool

The field of human-computer interface design has, over the past two decades, gravitated toward the application and refinement of this design process, which results in products that are both useful --helping users do what they want--and usable--reasonably easy to learn and use in the work environment. Usefulness and usability, in turn, foster acceptance. As a result, user-centered design methodology enables the development of tools that perform at a high level in the hands of the end user. The user-centered design process is guided by three principles, outlined by Gould and Lewis (1985) in their seminal work in the field:

1. Early and continual focus on users and their tasks. Direct contact with users, including discussion and observation of their tasks and work environment identifies their wants and needs.

2. Empirical testing with users. Users doing real work with mockups and prototypes of product concepts are observed to identify areas requiring revision.

3. Iterative design. The design, based on the results of user testing, is refined to bring the product into conformance with explicitly stated performance specifications.

These principles are practiced through the application of a variety of user-centered methodologies within a structured design process. Such methodologies include contextual design (Beyer and Holtzblatt, 1998), task analysis

(Gramopadhye and Thaker, 1998; Hackos and Redish, 1998), the development and use of personas (Cooper and Reimann, 2003) and scenarios (Rosson and Carroll, 2002), usability inspection methods (Nielsen, 1993), and usability testing (Dumas and Redish, 1993; Rubin, 1994). These practices have been integrated by Ulrich and Eppinger (2000) into a structured design process achieving a methodology that is both user-centered and compatible with current best practice in product design and development.

2.1 Product Phase

This phase includes the assessment of technological developments and project objectives. The output of the planning phase will be a project mission statement specifying the vision for the product, the target market, the project goals, the key assumptions, the constraints, and the stakeholders. The product vision statement briefly presents the key customer and user benefits of the product, but avoids implying a specific concept. To ensure that the appropriate range of development issues is addressed, all product stakeholders, i. e., the groups of people who will be affected by the product, will be identified and listed. This stakeholder list begins with the end user and customer but also includes those people tasked with installing, managing, and maintaining the product. The list of stakeholders helps to ensure that the needs of all who will be influenced by the product are identified and considered in its development.

2.2 Needs Analysis Phase

As a necessary condition for success, a product must offer perceived benefits to the customer and user. Products offer benefits when they satisfy needs. The needs analysis phase creates a high-quality information channel between the customer and intended users, and the developers of the product. It requires that the product developers interact directly with the customers and users, and that they observe and experience the environment and context in which the product will be used. This helps ensure that technical tradeoffs are made appropriately during the development process in addition to increasing the likelihood that innovative solutions to user needs will be discovered.

2.2.1 Gathering of Stakeholder Data

This process seeks to identify what the stakeholders need to support their performance and utilization of maintenance audits. The methods used to collect this data include interviews, focus groups, observations of the use of the existing system, and the analysis of documentation describing current procedures and regulations for maintenance auditing. While the primary user group to be studied during this phase will be the maintenance personnel who carry out the auditing task, those who use the data collected through the audits and those who must manage and maintain the auditing process will also be included.

2.2.2 Interpretation of the Raw Data in Terms of Customer Needs

The verbatim statements of the stakeholders and the information gleaned from observations of the existing audit process and documentation will be translated into a set of user need statements and a task description. The need statements express stakeholder needs in terms of what an improved human-machine system has to do, but not in terms of how it will be done. The needs will be organized into a hierarchical list of primary and secondary ones using affinity diagramming. The primary needs are the most general categories, while the secondary ones express specific needs in more detail.

The task description will be used to develop a set of representative task scenarios and to perform a detailed task analysis. A task scenario describes activities, or tasks, in a form that allows exploration and discussion of contexts, needs, and requirements with users. It avoids making assumptions about the details of a particular interface design. The task analysis assists in the identification of the specific cognitive and manual processes critical in the performance of the auditing task, as well as existing human-machine system mismatches leading to inefficiency and error.

2.2.3 Establishment of the Relative Importance of the Needs

A sense of the relative importance of the various needs is essential for making trade-offs and allocating resources in the design of a product. For this purpose, stakeholders will be surveyed to rate the relative importance of the needs that have been identified.

2.4 Product Specifications Phase

A preliminary set of target specifications, spelling out in precise, measurable detail what the product has to do, will be determined from the list of stakeholder needs. User-centered design involves specifications that address not only the functionality of the product--what the product has to do--but also the constraints under which the product must operate. These constraints include environmental and context-of-use specifications, user specifications based on the characteristics of the intended user group, and usability specifications. The latter typically include metrics and target levels of performance with respect to effectiveness, efficiency, safety, utility, learnability, and memorability.

2.5 Conceptual Design Phase

The conceptual design phase uses the needs and specifications developed in the previous phases to generate design concepts. The task description, analysis, and scenarios provide clarification of the problems that must be solved. External search, including the benchmarking of related existing products, and internal search, in consultation with the stakeholder groups, are used to generate promising design concepts. These concepts are then explored systematically, through the development of low-fidelity prototypes. These prototypes enable comparative evaluation through interviews and simulation tests with representative users, as well as expert reviews, such as heuristic evaluation and cognitive walkthroughs. The product concepts are then refined and combined to determine the most promising design, the one that is subsequently designed in detail. The target specifications are refined, based on the concept selected.

2.6 Initial Design Phase

The refined product specifications and the selected product concept form the basis for the construction of the details that, together, fulfill the selected design concept. In carrying out this activity, the concepts, principles, and methodologies of human-computer interface design will be applied to satisfy stakeholder needs. An initial working prototype of the product will be coded and debugged. The typical prototype will include: an application, incorporating a recommended categorization and data collection scheme for maintenance auditing/surveillance/monitoring application; a data reduction module that allows the analysts to conduct central tendency analysis and data analysis module that facilitates trend analysis.

2.7 Iterative Test and Refinement Phase

The initial prototype will be tested with representative users and other relevant stakeholders to determine how well the design satisfies stakeholder needs. Based on the results, a series of iterative cycles of prototype refinement and evaluation will be carried out to ensure the development of a product that meets stakeholders' requirements in terms of functionality, efficiency, utility, usability, and acceptability. The evaluation methodologies used will include expert reviews, such as heuristic evaluation and cognitive walkthroughs, and usability testing.

2.8 Implementation Phase

In this phase, the product will be delivered to FedEx for trial use. Documentation and training materials will be developed and supplied. The use of the tool will be demonstrated and documented through the collection of data in a real-world environment.

2.9 Reporting

i. Quarterly progress reports: Informal e-mail reports from Aviation Maintenance Human Factors Program Manager to the Aviation Maintenance TCRG representative will be submitted in December, March, June, September.

ii. Annual Report: The grantee will submit an annual report on AAR-100's Productivity Report website http://www.hf.faa.gov/report/.

Year III: Data Analysis and Validation Module

The following activities will be pursued in Year 3.

3.1 Develop Advanced Data Analysis Module into Prototype Application

Researchers will evaluate the potential for enhancing the data analysis module developed in Year 2 to include more advanced analysis (e.g., multi-variate analysis, risk assessments). This module will enable the analyst to conduct advanced analysis of select data sets to identify problem areas and will form the first step to conducting risk assessments.

3.2 Validation Phase

In this phase, field data will be collected to verify that the web-based tool enhances maintenance supervision. Operational problems identified through use in the field will be resolved. Measurements of system effectiveness will be obtained through such tools as problem reports, questionnaires, interviews, field observations, and on-line data logging.

3.3 Reporting

i. Quarterly progress reports: Informal e-mail reports from the Aviation Maintenance Human Factors Program Manager to the Aviation Maintenance TCRG representative will be submitted in December, March, June, and September.

ii. Annual Report: The grantee will submit an annual report on AAR-100's Productivity Report website http://www.hf.faa.gov/report/.

Deliverables

Year I

i. Report identifying the list of impact variables to be used.
ii. Report on identifying the limitations and use of specific data sources for use in the auditing and surveillance tool.

Year II

i. Report on the final design specifications.
ii. Report on the development process that was used in developing the web based tool. Results of data collection using the web based tool.
    - → Deliver the tool that included the data collection and reduction modules by December 2005.
    - → The Federal Aviation Administration will own the auditing/surveillance tool source code.

Year III

i. Deliver the prototype tool that incorporates the trend analysis module.
ii. Report providing guidance and recommended practices in using the auditing/surveillance tool for oversight of maintenance.

iii. Deliver final auditing/surveillance tool source code and documentation

Schedule

Year I Tasks: FY03/FY04
Year II Tasks: FY04/FY05
- Deliver Web Based Tool (May 2005)

Year III Tasks: FY06
- Final Report and source code delivered (September 2006)

Significance and impact of proposed research

The development of a web-based surveillance tool has the potential to reduce maintenance errors impacting aviation safety. Specifically, the advantages of developing such a tool are the following:

- This proactive approach will reduce maintenance error by identifying problem areas and error contributing (causal) factors

- The adoption of this tool by the aircraft maintenance industry will promote standardization in data collection, reduction and analysis of maintenance error data from varied sources;

- This standardization will result in superior trend analysis of problem areas (causal factors that lead to maintenance errors) within and across organizations;

- The findings can be shared by manufacturers, airlines, repair stations and air cargos to help identify and prioritize factors that transcend across industry; and

- This research will directly support AFS/NTSB needs and AAR's mandate of reducing maintenance accidents and errors by conducting guidelines-based human factors research identifying and implementing intervention strategies.

Technology Transfer

The results of this research will be disseminated to the aviation community via a number of avenues. These include, but are not restricted to, scholastic publications, presentations at professional conferences (e.g., Human Factors and Ergonomics Society Annual Meeting, Aviation Psychology Conference, and FAA sponsored conferences) and training software available for download from FAA's web site. In particular, the results of the research will be regularly conveyed to the industry partners. This research will lead to graduate theses. In addition, the software will be used as a resource in the following graduate and courses Human Factors in Quality Control (IE 811), and Human computer Systems (IE 461)).

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Process Measures Definitions

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www.ces.clemson.edu/ie/research/hcsl/websat

Creation Date: 08/03/04

WebSAT Process Measures Validation Survey for Surveillance

www.ces.clemson.edu/websat/index_surveillance.html

WebSAT Goal: The purpose of Web-based Surveillance and Auditing Tool (WebSAT) is to capture and analyze data for different processes involved in the surveillance, auditing, and airworthiness directives departments of the aviation maintenance industry. To achieve standardization in data collection, data needs to be collected on certain variables which measure maintenance processes and eliminate existing inconsistencies. These variables are defined by the research team 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.

Purpose of the Survey: This survey validates the process measures that have been identified by the WebSAT research team by taking input from partnering airlines.

Surveillance: It is the day-to-day oversight of the vendor's maintenance activities performed by the customer's representatives. It involves the continuous monitoring and evaluation of contracted work to determine the level of compliance with FAA regulations, the vendor's procedures manual and with the customer's maintenance manual. This oversight is to guarantee that each aircraft dispatched from an airframe substantial maintenance vendor is safe, airworthy, reliable, and regulatory compliant.

Process measures for Surveillance: Surveillance is conducted on the work cards of a scheduled maintenance event accomplished by a vendor at his facility. The data obtained from surveillance process will be grouped into categories to facilitate further data analysis and comment on the effectiveness of the surveillance process. These categories are defined as process measures. The identified process measures for surveillance are defined in the "Process Measures Definitions for Surveillance" section of this document.

Some of the terms used consistently throughout this document have been defined carefully for the reader to better understand the process measures explained in the subsequent sections.

Customer and Vendor: A customer refers to an airline organization itself. A vendor refers to a company providing its services to the airline (customer).

Technical Process Measures (T): 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. Example would be a panel removed and routed to a composites back shop for repair, then reinstalled on the aircraft.

Non-Technical Process Measures (NT): The surveillance activities involving verification of standardized procedures, referenced manuals, equipment, and facility maintenance requirements are referred to as Non-Technical Process measures.

Document Structure: This document includes the following sections:

I Process Measures Definitions for Surveillance

1 **In-process Surveillance (T):** It is the act of observing a maintenance task that is currently in work. The on-site surveillance representatives will select certain work cards, AD driven work cards, EOs, EAs, non-routines and observe the task being accomplished by the vendor mechanic or inspector to ensure competency, correctness and adequacy of the customer's paper work to complete the task. This surveillance should be performed progressively throughout the maintenance event. Preparation before a job, torquing of an item, the use of tooling and such items, are typical examples of in-process surveillance activities.

2 **Verification Surveillance (T):** It is the re-inspection/re-accomplishing of completed work cards, AD driven work cards, EOs, EAs and non-routines that are signed off by the vendor personnel as "Complete." No additional reopening of access panels that have been closed or disassembly of the aircraft or assistance from vendor personnel will be required unless poor workmanship or other conditions are evident during the surveillance. This surveillance activity is to ensure that the intent of the task has been complied with, the workmanship meets acceptable standards and that the customer's paper work is adequate to complete the task. This surveillance should be performed progressively throughout the maintenance event as the tasks are completed.

3 **Final Walk Around (T):** It is a surveillance of the aircraft at the end of the scheduled maintenance event that checks the general condition of the aircraft usually after the vendor has completed the work scope assigned. For example: obvious safety, legal fitness, airworthiness items, general condition, cleanliness and completeness of the aircraft's cockpit, lavatory, courier area and cargo

compartments, landing gear wheel wells, all access panels properly installed and no indication of fuel, oil or hydraulic leaks. Proper completion of the aircraft logbook should also be included in this activity.

4 **Documentation Surveillance (NT):** This surveillance is performed on the vendor's documented system to validate the quality control, technical data control, inspection, and work-processing programs, as presented in C.A.S.E. standard 1-A (Revision 45- 1/7/2004). The vendor should be able to provide the required documents and certificates upon request.

i) **Certifications:** This surveillance ensures that the certification program includes certificates, operations specifications, licenses, repairman certificates, antidrug and alcohol misuse program certificates, registrations and capabilities listing required by the Code of Federal Regulations for any individual, equipment or facility. These documents are required to be kept current and made readily available for inspection and verification. For detailed instructions and description refer to C.A.S.E. standard 1-A section 2.

ii) **Quality Control:** This surveillance ensures that the quality control program includes procedures and operation which must be described in a quality control manual or other appropriate document. These documents are required to be kept current and made readily available to the surveillance representatives. For detailed instructions and description refer to C.A.S.E. standard 1-A section 3.

iii) **Inspection:** This surveillance ensures that the inspection program includes procedures to maintain an up-to-date roster of supervisory and inspection personnel who are appropriately certified and are familiar with the inspection methods, techniques and equipment that they use. For detailed instructions and description refer to C.A.S.E. standard 1-A section 4.

iv) **Technical Data Program:** This surveillance ensures that the technical data program requires all the maintenance operations to be accomplished in accordance with customer's manuals. It also ascertains that the vendor has a documented system to maintain current technical data and a master copy of each manual. For detailed instructions and description refer to C.A.S.E. standard 1-A section 6.

v) **Work Processing:** This surveillance ensures that there exists a documented system for all the programs and procedures that the vendor adopts for training, identification of parts, and use of appropriate tools and equipment in good condition to perform a maintenance task. For detailed instructions and description refer to C.A.S.E. standard 1-A section 13.

vi) **Tool/Test Equipment (NT):** This surveillance ensures that the tools and the test equipment used by the vendor for maintenance are frequently calibrated to the required standards. It also ensures that the tools and the test equipment program includes identification of tools and test equipment, identification of individuals responsible for the calibration, accomplishment of periodic calibrations, and applicable tolerance or specification. For detailed instructions and description refer to C.A.S.E. standard 1-A section 8.

5 **Facility Surveillance (NT):** This surveillance is performed on the vendor's facility to validate the shelf life control, housing and facilities, storage and safety/security/fire protection programs, as presented in C.A.S.E. standard 1-A (Revision 45- 1/7/2004). The vendor should implement programs to maintain the facility and prevent damage, material deterioration, and hazards.

i) **Shelf Life Control:** This surveillance ensures that the vendor describes in their manual a shelf life program, procedure, and a detailed listing of parts and materials which are subjected to shelf life. It also identifies the expiration date of each shelf life item. For detailed instructions and description refer to C.A.S.E. standard 1-A section 7.
ii) **Storage:** This surveillance ensures that the vendor identifies, maintains and protects parts and raw material during a maintenance event. For detailed instructions and description refer to C.A.S.E. standard 1-A section 12.
iii) **Housing and Facilities:** This surveillance ensures that the vendor houses adequate equipment and material, properly stores supplies, protects parts and sub-assemblies, and ensures that the facility has adequate space for work. For detailed instructions and description refer to C.A.S.E. standard 1-A section 10.
iv) **Safety/Security/Fire Protection:** This surveillance ensures that the vendor provides adequate safety, security and fire protection at the maintenance facility. It also ensures that the fire protection devices and systems are inspected periodically, and maintained in serviceable conditions. For detailed instructions and description refer to C.A.S.E. standard 1-A section 11.

6 **Procedures Manual Violation (NT):** This surveillance ensures that the vendor is complying with the requirements set forth in the customer maintenance manual, and compliance requirements presented in the vendor Inspection Procedures Manual (IPM) or Repair Station Manual (RSM).
i) **Customer Maintenance Manual Compliance:** This surveillance requires the vendor to comply with programs, documented procedures, and standards described in the customer maintenance manual.
ii) **Vendor Inspection Procedures Manual Compliance:** This surveillance ensures that the vendor complies with programs, documented procedures, and standards described in the vendor IPM or RSM. It also ensures if the vendor IPM is adequate to meet with the customer maintenance manual requirements.

II **Fuel Surveillance Module:** The fuel vendor surveillance module evaluates the fuel vendor's operational system, fueling equipment, records and the quality of the fuel. **Note:** This module is a standalone and is not a process measure to evaluate the surveillance process. However, this surveillance module conducts data analysis based on the data captured from fuel operations.

III Additional Findings Module for Surveillance

This module documents additional information pertaining to surveillance work domain. However, the categories in this module listed below do not hold the vendor responsible for the findings obtained. This module helps the surveillance representatives to document any information both technical and non-technical, beyond the work scope of the scheduled maintenance event. The customer maintenance program could be updated with this information to help in the future.

Note: Although these categories are not process measures, the findings obtained from this module are documented and reported through WebSAT.

1 **Information:** It includes the surveillance activities and data that the on-site surveillance representative needs to document for informational purposes. This surveillance activity is always non-technical and should not penalize the vendor for findings beyond the scope of a particular maintenance event.

2 **Aircraft Walk Around:** This surveillance category is to be used only for those technical findings that cannot be traced to a scheduled maintenance task and are beyond the current work scope of the scheduled maintenance event. Every attempt should be made to ensure that the finding is not part of the scheduled event prior to using this category.

IV Glossary

Abbreviation	**Full Form**
C.A.S.E.	Coordinating Agency for Supplier Evaluation
DPM	Desktop Procedures Manual
EO	Engineering Order
EA	Engineering Authorization
FAA	Federal Aviation Administration
FR	Federal Register
FAR	Federal Aviation Regulation
NPRM	Notice of Proposed Rule Making
QA	Quality Assurance
WIC	Work Instruction Card

Acknowledgements: We would like to thank FedEx for their cooperation in this project. FedEx's Desktop Procedures Manual was used to derive the terms used in this document.

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Department of Industrial Engineering
Clemson University
www.ces.clemson.edu/ie/research/hcsl/websat

Creation Date: 08/03/04

WebSAT Process Measures Validation Survey for Technical Audits

http://www.ces.clemson.edu/websat/index_technicalaudit.html

WebSAT Goal: The purpose of Web-based Surveillance and Auditing Tool (WebSAT) is to capture and analyze data for different processes involved in the surveillance, auditing, and airworthiness directives departments of the aviation maintenance industry. To achieve standardization in data collection, data needs to be collected on certain variables which measure maintenance processes and eliminate existing inconsistencies. These variables are defined by the research team 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.

Purpose of the Survey: This survey validates the process measures that have been identified by the WebSAT research team by taking input from partnering airlines.

Technical Audits: 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 FARs, and established company policies and procedures.

Process measures for Technical Audits: The data collected from the technical audit checklists will be grouped into categories to facilitate further data analysis and comment on the effectiveness of the technical audit process. These categories are defined as process measures. The identified process measures for technical audits are defined in the "Process Measures Definitions for Technical Audits" section of this document.

Customer and Vendor: A customer refers to an airline organization itself. A vendor refers to a company providing its services to the airline (customer).

Document Structure: This document includes the following sections:

I Process Measures Definitions for Technical Audits:

1 **Compliance/Documentation:** This process measure verifies documentation systems, authorization of personnel and administration requirements of vendors and sub-contractors. The process measure includes items such as quality programs, manuals and forms control, list of authorized persons, certification, certificate forms, etc. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

(a) Quality programs
(b) Certification
(c) Certificate forms
(d) Internal audit and surveillance
(e) Manuals and forms control
(f) Paper work control
(g) Administration requirements

2 **Inspection:** This process measure verifies the certification of the inspector, the existence of acceptable sampling procedures of parts, compliance of parts to specifications, and the validity of the inspection stamps at the vendor location. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

(a) Fuel inspection (Fuel truck inspection, Fuel farm inspection, Hydrant inspection)
(b) Inspection programs

3 **Facility Control:** This process measure verifies the vendor facility for shelf life control, housing and facilities, storage, and damage protection programs. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

(a) Housing and facilities
(b) Material control and storage
(c) Segregation of parts
(d) Packaging
(e) List of shelf items
(f) Practices to prevent damage and cannibalization
(g) Shelf life control and material storage

4 **Training and Personnel:** This process measure verifies that the vendor employees are properly trained, and have the required certification to perform operations. It also verifies the supervisory personnel, inspection personnel, return-to-service personnel, and personnel responsible for various programs in the facility like shelf life, technical data, calibration etc. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

(a) Employee training
(b) Verification of personnel
(c) List of authorized personnel

5 **Procedures:** This process measure verifies that the vendor adheres to regulatory guidelines while executing various operations within each program such as shipping procedures, NDT evaluations, and Aircraft deicing programs at the vendor facility. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

(a) Shipping procedures
(b) Tool and test equipment (calibration & measurement) and procurement
(c) Scrapped parts
(d) Work processing
(e) Processing
(f) Process control
(g) NDT evaluation
(h) Precision tool control
(i) Aircraft anti-tipping and tether maintenance
(j) Aircraft deicing program
(k) Weight and balance
(l) Weighing scales
(m) Ramp operation *

* **Note:** The findings of ramp activities related to administration requirements, employee training, and dangerous goods are not included in this process measure - 'Procedures.'

6 **Data Control:** This process measure verifies the availability of up-to-date technical data for parts at the vendor's facility. It also verifies the identification of parts to their testing records and validates the fuel audit records. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

(a) Technical data control
(b) Record keeping
(c) Fuel records (Fuel facility records, Fuel vehicle records, Pipeline fuel receipt records, Transport truck fuel receipt records)

7 **Safety:** This process measure overlooks the safety of the vendor facility. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

(a) Safety
(b) Fire protection
(c) Fire protection and flammable material protection
(d) Aircraft maintenance procedures
(e) Dangerous goods

Note: Please refer to FAR 121 and C.A.S.E. 1A and 3A standards for detailed descriptions of these process measures.

II Glossary

Abbreviation	**Full Form**
C.A.S.E.	Coordinating Agency for Supplier Evaluation
DPM	Desktop Procedures Manual
EO	Engineering Order
EA	Engineering Authorization
FAA	Federal Aviation Administration
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FAR	Federal Aviation Regulation
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Acknowledgements: We would like to thank FedEx for their cooperation in this project. FedEx's Desktop Procedures Manual was used to derive the terms used in this document.

Human Computer Systems Laboratory
Department of Industrial Engineering
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www.ces.clemson.edu/ie/research/hcsl/websat

Creation Date: 08/03/04

WebSAT Process Measures Validation Survey for Internal Audits

www.ces.clemson.edu/websat/index_internalaudit.html

WebSAT Goal: The purpose of Web-based Surveillance and Auditing Tool (WebSAT) is to capture and analyze data for different processes involved in the surveillance, auditing, and airworthiness directives departments of the aviation maintenance industry. To achieve standardization in data collection, data needs to be collected on certain variables which measure maintenance processes and eliminate existing inconsistencies. These variables are defined by the research team 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.

Purpose of the Survey: This survey validates the process measures that have been identified by the WebSAT research team by taking input from partnering airlines.

Internal Audits: The evaluation of internal processes in the departments of an organization is referred to as Internal Audit. The work function of the internal audit department is to sample the process being used by departments in an organization and to verify their compliance with regulatory, company and departmental policies and procedures.

Process measures for Internal Audits: The data collected from the internal audit checklists will be grouped into categories to facilitate further data analysis and comment on the effectiveness of the internal audit process. These categories are defined as process measures. The identified process measures for internal audits are defined in the "Process Measures Definitions for Internal Audits" section of this document. The process measures defined by the research team verify information on flight operations, and engineering, material, and maintenance.

Note: Information and findings obtained from Air Transportation Oversight System (ATOS) evaluations are not included by these process measures.

Document Structure: This document includes the following sections:

I Process Measures Definitions for Internal Audits
II Glossary

I Process Measures Definitions for Internal Audits

1 **Administration:** This process measure ensures the departments' ability to manage up-to-date documented systems and ensure the adequacy of various programs followed in-house.

2 **Training:** This process measure ensures that the employees of the departments within the organization are trained properly, and have the required certification to perform operations.

3 **Records:** This process measure ensures that the required records are made available for review by the departments within an organization.

4 **Safety:** This process measure ensures the overall safety aspect of the departments within an organization.

5 **Manuals:** This process measure verifies the technical data, manuals, and forms provided by the departments within an organization.

6 **Procedures:** This process measure ensures that the maintenance and flight operations departments adhere to federal aviation regulatory guidelines and company departmental policies while executing various operations within each program.

II Glossary

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Creation Date: 08/03/04

WebSAT Process Measures Validation Survey for Airworthiness Directives

www.ces.clemson.edu/websat/index_AD.html

WebSAT Goal: The purpose of Web-based Surveillance and Auditing Tool (WebSAT) is to capture and analyze data for different processes involved in the surveillance, auditing, and airworthiness directives departments of the aviation maintenance industry. To achieve standardization in data collection, data needs to be collected on certain variables which measure maintenance processes and eliminate existing inconsistencies. These variables are defined by the research team 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.

Purpose of the Survey: This survey validates the process measures that have been identified by the WebSAT research team by taking input from partnering airlines.

Airworthiness Directives Control: 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 control department is to review AD-related EO/WIC, acquisition process, and the customer's maintenance manual.

Process Measures for Airworthiness Directives Control: The data collected from the AD-related EO/WIC review, acquisition process, and the revision of the customer's maintenance manual will be grouped into categories to facilitate further data analysis and comment on the effectiveness of the airworthiness directives control department. These categories are defined as process measures. The identified process measures for airworthiness directives control are defined in the "Process Measures Definitions for Airworthiness Directives Control" section of this document.

Document Structure: This document includes the following sections:

I Process Measures Definitions for Airworthiness Directives Control
II Glossary

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I Process Measures Definitions for Airworthiness Directives Control

1 **Information Verification:** This process measure validates the information presented on AD-related EO/WIC, manuals and other documents involved with the compliance of airworthiness directives. It also verifies information related to the AD status reports.

2 **Loading and Tracking Verification:** This process measure verifies the adequacy of the activities involved in the loading and tracking of airworthiness directives, including inspection intervals.

II Glossary

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Proceedings of Safety Across High-Consequence Industries

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WEB-BASED SURVEILLANCE AND AUDITING TOOL (WEBSAT): A PROACTIVE SYSTEM TO CAPTURE MAINTENANCE ERRORS

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Surveillance and auditing of maintenance activities is an important function to improve aviation safety. Significant efforts have been invested to investigate and track inspection and maintenance errors. Although valuable in terms of their insights into identifying the performance-shaping factors leading to maintenance errors, these efforts tend to be reactive in nature. They are not preventive measures, but rather investigations of maintenance accidents and errors subsequent to their occurrence. A system that documents the processes and outcomes of maintenance activities and makes this documentation more accessible offers the promise of reduction of future maintenance error rates. Such a system would then support more robust and safer aircraft maintenance operations. This paper addresses the development of a web-based surveillance and auditing tool (WebSAT) which promotes a standardized format for data collection, data reduction and data analysis across airlines to proactively identify the factors contributing to improper maintenance.

Introduction

The mission of the Federal Aviation Administration (FAA) is to provide the public with continuing safe and reliable air transportation and to ensure airworthiness of aircraft. This mission can be fulfilled by minimizing aircraft accidents. Maintenance error has been found to be a crucial factor in aircraft accidents (Boeing and US ATA, 1995). The increasing number of maintenance and inspection errors in the aviation industry motivated the need for human factors research in this area (FAA 1991, 1993). Human factors research in maintenance deemed the human as the central part of the aviation system (Gramopadhye and Drury, 2000). This human factors research considers the psychophysiological aspects of the human and explains the need for developing different human factors interventions which ensure that task, job and environment are defined judiciously to match human capabilities and limitations. This enduring emphasis on humans and their role in aviation system results in the development of error-tolerant systems.

Federal agencies and other regulatory bodies ensure that safety and regulatory compliance procedures are met by the airline industries. In order to minimize maintenance errors, the aviation maintenance industry has 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 and Jones, 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 and incidents, a recent example being the Maintenance Error Decision Aid (MEDA) (Rankin et al., 2000). This tool, developed by Boeing, with British Airways, Continental Airlines, United Airlines, the International Association of Machinists and the U.S. Federal Aviation Administration, helps analysts identify the contributing factors that lead to an aviation accident. Various airlines have also developed their own internal procedures to track maintenance errors. One such methodology employs the failure modes and effects analysis approach (Hobbs and Williamson, 2001) and classifies the potential errors by expanding each step of a task analysis into sub-steps and then listing all the failure modes for each substep. The US Navy Safety Center developed the Human Factors Analysis and Classification System – Maintenance Extension Taxonomy and the follow-up web–based maintenance error information management system to analyze naval aviation mishaps (Shappell and Wiegmann, 1997; Schmidt, et al., 1998; Shappell and Wiegmann, 2001). Later, this system was used to analyze commercial aviation accidents (Wiegmann and Shappell, 2001). Although valuable in terms of their insights into identifying the performance-shaping factors that lead to maintenance errors, these efforts tend to be reactive in nature; i.e., their focus is on analyzing maintenance accidents and errors following their occurrence, rather than developing preventive measures. Moreover, these efforts often tend to be ad hoc, varying across the industry, with little standardization. Analyzing the efficacy of maintenance and inspection procedures is of primary importance in order to proactively identify the potential factors contributing to improper maintenance. This can be achieved by closely monitoring and evaluating aircraft maintenance and inspection activities. As a part of this evaluation, surveillance of maintenance and inspection activities is conducted in a rigorous fashion by the quality assurance department of an airline. The surveillance and auditing activities constantly monitor and evaluate the flight procedures to determine their level of compliance. The objective of these activities is achieved through effective functioning of the quality assurance representatives and auditors who perform these activities. Their findings help in the evaluation and assessment of the internal and external organizations associated with the airline which influence the safety and airworthiness of aircraft. The surveillance and auditing activities are of foremost importance in ensuring adherence to the quality assurance requirements and also maintaining a consistent level of supervision over maintenance operations. Given this scenario, the goal of surveillance and auditing activities can be achieved through implementation of a system that documents the processes and outcomes of maintenance activities and makes this documentation more accessible. Thus, there is a need to develop a system that ensures superior performance of these activities. This system should perform the following functions:

1. Seek input from diversified sources
2. Proactively identify contributing factors
3. Promote a standardized format for data collection, data reduction and data analysis within and across the aircraft maintenance industry
4. Generate trend analysis for problem areas (causal factors within and across organizations)

In response to this need, this paper reports on a project to develop a proactive surveillance and auditing tool and devise strategies that enable identifying future problem areas. The identification of these problem areas will allow the industry to prioritize factors that apply across the industry to systematically reduce or eliminate potential errors. The work will be done in collaboration with FedEx in Memphis, Tennessee. The system will be a web-based application which will initially be developed with FedEx as the aviation partner and later will be made available as an application that can be used by other maintenance facilities. The objective of WebSAT is to proactively capture maintenance errors. The system will capture and record errors that occur during maintenance and inspection and supports analysis of this data. The specific objectives of this research are to

(1) Identify an exhaustive list of performance variables that potentially impact the aviation safety and transcend various aircraft maintenance organizations;
(2) Develop data collection/reduction and analysis protocols to analyze errors for the identified set of impact variables; and
(3) Using the results of the aforementioned activity, develop and implement a surveillance/monitoring tool which assures that a consistent level of oversight is maintained.

Background

The Quality Assurance (QA) department of FedEx will be the primary user of this tool. However, the needs of the Surveillance, Auditing and Airworthiness Directives groups will also be addressed.

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 FedEx's Continuous Airworthiness Maintenance Program (CAMP) and General Maintenance Manual (GMM). The primary objective of surveillance is to provide FedEx, through the accomplishment of a variety of specific surveillance activities on a planned and random sampling basis, an accurate, real-time, and comprehensive evaluation of how well each substantial maintenance vendor is complying with FedEx and FAA approved CAMP, GMM, and regulatory requirements. A QA representative, stationed at the vendor location, 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 the surveillance schedule. The results are documented and used to analyze the risk factors associated with that particular vendor and that particular aircraft.

Auditing. Audits are a more formal activity that addresses specific issues. A request sent to the QA technical audit manager from any department triggers an audit. The manager will assign an auditor and schedule the audit. The auditor will select the audit standards, perform pre-audit analysis and finally complete the audit. The auditor then reports the findings to the manager. This results in a 'Corrective Actions' document. These audits are recurrent. Oversight of functions relating to aircraft line maintenance, ramp operations and aircraft fueling, whether FedEx owned or contracted, is accomplished by a formal system of technical audits performed by qualified FedEx Senior Technical Auditors.

Airworthiness Directives Control. The Airworthiness Directives Control Group (ADCG) is responsible for the implementation of new, revised or corrected Airworthiness Directives (AD) appearing in the Federal Register. If the "applicability statement" of an AD refers to an aircraft model and series or engine model and series operated by FedEx, or if the AD addresses an appliance or component that could be installed on an aircraft operated by FedEx, the ADCG considers the AD to be initially applicable. A Work Instruction Card (WIC) generated by the ADCG is used by the appropriate mechanics to check for compliance with the AD. There are checklists to review the compliance of a WIC. These checklists can be used as a process measurement tool to review each WIC and identify any discrepancies. The findings obtained from these reviews can be used to identify risk factors. Follow up of these discrepancies results in corrective actions.

Methodology

A task analytic and user-centered software lifecycle development methodology will be applied to this research. A comprehensive view of the different surveillance and auditing processes, their functions and the different tasks involved in accomplishing these processes will be developed. Research will be conducted to identify the process measurement variables and performance metrics that potentially impact aviation safety. These performance metrics are termed *impact variables,* since they potentially impact the safety of the aircraft. It will be ensured that the variables identified are appropriate and are representative of those used by other maintenance entities. This will be done by working with other airline maintenance facilities (e.g., those of other airlines and third party repair stations). Subsequently, the list of impact variables and the limitations and protocols for the use of specific data sources with the surveillance and auditing tool will be finalized.

The product design and development phase will be guided by a user-centered design methodology that enables the development of tools that perform at a high level in the hands of the end user. The structured approach of contextual design will be used to gather and represent information acquired (Beyer and Holtzblatt, 1998). The following principles (Gould and Lewis, 1985) guide our application of structured design methodology:

1. Early and continual focus on users and their tasks. This requires direct contact with users, including discussion and observation of their tasks and work environment, and identification of their wants and needs.
2. Empirical testing with users. This involves users doing real work with mockups and prototypes of product concepts.
3. Iterative design. This involves refinement of the design, based on the results of user testing, to bring the product into conformance with explicitly stated performance specifications.

The process of product design and development progresses through several phases.

Planning Phase. This phase includes the assessment of technological developments and project objectives. The output of the planning phase is a project mission statement which specifies a vision for the product, the target market, project goals, key assumptions, constraints, and stakeholders. The mission statement for WebSAT is given in Figure 1. The product vision statement briefly presents the key customer and user benefits of the product, but avoids implying a specific concept. To ensure that the appropriate range of development issues is addressed, all WebSAT stakeholders, i.e., the groups of people who will be affected by WebSAT, are identified and listed in the mission statement. This stakeholder list begins with the end user and customer but also includes those people tasked with installing, managing, and maintaining WebSAT. The list of stakeholders helps to ensure that the needs of all who will be influenced by WebSAT are identified and considered in its development. This mission statement essentially summarizes the direction to be followed by the product development team (Ulrich and Eppinger, 2004).

Needs Analysis Phase. The needs analysis phase creates a high-quality information channel between the customer and intended users, and the developers of the product. It requires that the product developers interact directly with the customers and users, and that they observe and experience the environment and context in which the product will be used. This helps ensure that technical tradeoffs are made appropriately during the development process and increases the likelihood that innovative solutions to user needs will be discovered. The WebSAT team is currently conducting interviews to identify FedEx's needs with respect to documentation and access to surveillance and auditing activities.

Gathering of Stakeholder Data. This process seeks to identify what the stakeholders need to support their performance and utilization of maintenance audits. The methods used to collect this data include interviews, focus groups, observations of the use of the existing system, and the analysis of documentation describing current procedures and regulations for maintenance auditing. While the primary user group to be studied during this phase will be the quality assurance personnel who carry out the auditing task, those who use the data collected through the audits and those who must manage and maintain the auditing process will also be included.

Mission Statement: Web-based Surveillance and Auditing Tool Prototype	
Product Description	• A distributed application, incorporating a recommended categorization and data collection scheme for maintenance surveillance and auditing application • A data reduction module that allows analysts to conduct data analysis module that facilitates trend analysis
Key Business Goals	• Achieve standardized data collection, reduction and analysis of maintenance errors across geographically dispersed entities of the airline industry • Develop a proactive system that captures maintenance errors • Accomplish trend analysis in future versions of WebSAT
Primary Market	• Federal Aviation Administration (FAA)
Assumptions & Constraints	• Develop WebSAT such that it adheres to FAA standard research software design specifications (For e.g., SQL server, ASP.NET, PHP)
Stakeholders	• FAA • FedEx QA Department • QA representatives/auditors • Information Technology department • Other airlines

Figure 1: Mission Statement for WebSAT

Interpretation of the Raw Data in Terms of Customer Needs. The verbatim statements of the stakeholders and the information gleaned from observations of the existing audit process and documentation will be translated into a set of user need statements and a task description. The need statements express stakeholder needs in terms of what an improved human-machine system has to do, but not in terms of how it will be done. The needs will be organized into a hierarchical list of primary and secondary needs using affinity diagramming. The primary needs are the most general categories, while the secondary needs express specific needs in more detail. The task description will be used to develop a set of representative task scenarios and to perform a detailed task analysis. A task scenario describes activities, or tasks, in a form that allows exploration and discussion of contexts, needs, and requirements with users. It avoids making assumptions about the details of a particular interface design. The task analysis assists in the identification of the specific cognitive and manual processes critical in the performance of the auditing task, as well as existing human-machine system mismatches leading to inefficiency and error (Gramopadhye and Thaker, 1998; Hackos and Redish, 1998).

Establishment of the Relative Importance of the Needs. A sense of the relative importance of the various needs is essential for making trade-offs and allocating resources in the design of a product. For this purpose, stakeholders will be surveyed to rate the relative importance of the needs that have been identified.

Product Specifications Phase. A preliminary set of target specifications, spelling out in precise, measurable detail what the product has to do, will be determined from the list of stakeholder needs. User-centered design involves specifications that address not only the functionality of WebSAT--what WebSAT has to do--but also the constraints under which WebSAT must operate. These constraints include environmental and context-of-use specifications, user specifications based on the characteristics of the intended user group, and usability specifications. The latter typically include metrics and target levels of performance with respect to effectiveness, efficiency, safety, utility, learnability, and memorability.

Conceptual Design Phase. The conceptual design phase transforms the needs and specifications developed in the previous phases into conceptual models which result in the generation of deign concepts. The task description, analysis, and scenarios provide clarification of the problems that must be solved. External search, including the benchmarking of related existing products, and internal search, in consultation with the stakeholder groups, are used to generate promising design concepts. These concepts are then explored systematically, through the development of low-fidelity prototypes. These prototypes enable comparative evaluation through interviews and simulation tests with representative users, as well as expert reviews, such as heuristic evaluation and cognitive walkthroughs. The product concepts are then refined and combined to determine the most promising design, the one that is subsequently designed in detail. The target specifications are then refined, based on the concept selected.

Initial Design Phase. The refined product specifications and the selected product concept form the basis for the construction of the details that, together, fulfill the selected design concept. In carrying out this activity, the concepts, principles, and methodologies of human-computer interface design will be applied to satisfy stakeholder needs. An initial working prototype of the product will be coded and debugged. This prototype will include: an event recording component that incorporates a recommended categorization and data collection scheme for maintenance auditing/surveillance application; a data reduction component that allows analysts to conduct central tendency analysis; and a data analysis module that facilitates trend analysis.

Iterative Test and Refinement Phase. The initial prototype will be tested with representative users and other relevant stakeholders to determine how well the design satisfies stakeholder needs. Based on the results, a series of iterative cycles of prototype refinement and evaluation will be carried out to ensure the development of a product that meets stakeholders' requirements in terms of functionality, efficiency, utility, usability, and acceptability. The evaluation methodologies used will include expert reviews, such as heuristic evaluation and cognitive walkthroughs, and usability testing.

Implementation Phase. In this phase, the product will be delivered to FedEx for trial use. Documentation and training materials will be developed and supplied. The use of the tool will be demonstrated and documented through the collection of data in a real-world environment.

Discussion

WebSAT is intended to enhance the utility of surveillance, auditing and airworthiness directive activities associated with commercial aircraft maintenance. This tool will be helpful in identifying risk factors and thereby generating a safety index for maintenance operations. Standardization of data facilitates the identification of potential problems areas at multiple and geographically dispersed maintenance sites. The tool can incorporate checklists and other verification standards used in auditing to achieve standardization of data collection, data reduction and data analysis. The maintenance personnel and quality assurance representatives who provide input to the tool from diversified sources should be able to access trends in the data proactively. This gives ownership to the personnel of the data that is being collected. The tool should also support the activities of the airworthiness directives group of FedEx, helping them to assure compliance with ADs. Essentially, WebSAT should ensure that a consistent level of oversight is maintained in performing surveillance and auditing activity, thereby achieving an aircraft maintenance system that is more robust and safer.

Conclusions

As we proceed in accomplishing the goal of WebSAT, we envision a tool which can perform superior trend analysis of the risk factors that lead to maintenance errors within and across commercial air carriers. This research will directly support the FAA's mandate to reduce maintenance-related accidents and errors by conducting guidelines-based human factors research and identifying and implementing intervention strategies.

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Standardized Auditing and Surveillance of Aircraft Maintenance Operations

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Abstract

The safety and reliability of air transportation depends on minimizing inspection and maintenance errors that occur in the complex aircraft maintenance system. Significant efforts have been invested to investigate and track maintenance errors. However, these efforts are typically not preventative measures; rather they are reactive in nature: they focus on analyzing maintenance accidents and errors after their occurrence. There exists a lack of standardization in the assessment of maintenance errors across the maintenance industry. This paper addresses the need for development of a proactive system, which promotes standardization in data collection and identifies the contributing, factors that impact aircraft safety.

Keywords
Aviation maintenance, Impact variables, Web-based tool, Proactive system, Surveillance

1. Introduction
Since the mission of the FAA is to provide the public with continuing safe and reliable air transportation, it is important to have a sound aircraft inspection and maintenance system [3]. The system is complicated [3, 6] with interrelated human and machine components. The important aspect is the human. Realizing this, the FAA has pursued human factors research for some time now under the National Plan for Aviation Human Factors [3, 4] to fulfill the mission of the FAA's Flight Standards Service of promoting safety of flight of civil aircraft in air commerce by setting certification standards for air carriers, commercial operators, air agencies, and airmen. By directing, managing and executing certification, inspection and surveillance activities are assured adequacy of flight procedures, operating methods, airman qualifications and proficiency, aircraft maintenance and maintenance aspects of continued airworthiness programs. Given this objective, surveillance of maintenance activity contributes an important function in maintaining and improving aviation safety. Surveillance activity can have a tremendous impact in the implementation of a system that can be used by operators prior to the delivery of an aircraft to the customer to reduce maintenance errors. 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 the airline's Continuous Airworthiness Maintenance Program (CAMP) and General Maintenance Manual (GMM). The primary objective of surveillance is to provide the airline, through the accomplishment of a variety of specific surveillance activities on a planned and random sampling basis, an accurate, real-time, and comprehensive evaluation of how well each substantial maintenance vendor is complying with the airline and FAA approved policies and regulatory requirements.

A study conducted by Boeing and US ATA [1] found that maintenance error was a crucial factor in aircraft accidents from 1982 to 1991, contributing to 15 % of the commercial hull loss accidents where five or more people were killed. Rankin and Allen [9] established the economic costs of these maintenance errors, estimating that 20 to 30 % of in-flight shutdowns are due to maintenance error, 50 % of flight delays are due to engine problems caused by maintenance errors, and 50 % of flight cancellations are due to engine problems caused by maintenance errors. The indication is apparent for a proactive system which will help track maintenance errors, identifying both potential problem areas and the factors causing errors. If such a system is developed it will be possible to manage maintenance errors, resulting in aircraft maintenance which is more safe and robust. To understand the need to develop such a system it is essential to understand the entire aircraft inspection and maintenance system.

2. Background

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. Inspection is regulated by the FAA as is maintenance. However, while adherence to inspection procedures and protocols are closely monitored, evaluating the efficacy of these procedures is much more difficult.

When an aircraft is brought into service, a process called MSG (Maintenance Service Group) is used to determine how each component failure is to be corrected to maintain a high level of safety. Aircraft for commercial use have their maintenance scheduled initially by a team that includes the FAA, aircraft manufacturers and start-up operators. These schedules are then modified by the air carrier so that they suit individual requirements and meet legal approval. Thus, within the carrier's schedule there will be checks at various intervals, often designated as flight line checks, overnight checks, and A, B, C, and D, the heaviest, checks. The objectives of these checks is to conduct both routine and non-routine maintenance of the aircraft, including scheduling the repair of known problems; replacing items after a certain air-time, number of cycles, or calendar time; repairing defects discovered previously, for example, from reports logged by the pilot and crew, line inspection, or items deferred from previous maintenance, and performing scheduled repairs.

Once maintenance and inspection are scheduled for an aircraft, this schedule is translated into a set of job, or work cards containing instructions for inspection and maintenance as the aircraft arrives at each maintenance site. The aircraft is cleaned and the access hatches opened so that inspectors can view the different areas. This activity is followed by a heavy inspection check, primarily visual in nature. Since a significant amount of the maintenance workload depends on the defects found during inspection, it is important that the incoming inspection be completed as soon as possible after the aircraft arrives at the inspection maintenance site. There is always pressure on the inspector to discover critical defects necessitating long follow-up maintenance early in the inspection process. There is a heavy inspection workload at the commencement of each check. It is only after the discovery of defects that the planning group can estimate the expected maintenance workload, order replacement parts and schedule maintenance items. To meet this demand, maintenance facilities frequently resort to overtime, resulting in an increase in the total number of inspection hours, leading to prolonged working hours. Further, inspection such as routine inspections on the flight line is carried out during night shift, between the last flight of one day and the first flight on the next day. Once a defect is rectified, it may generate additional inspection, called 'buyback' inspections, to ensure the work meets the necessary standards.

As evident, the inspector's workload is very high at the arrival of an aircraft. As the service on the aircraft progresses, this workload decreases as the maintenance crew works on the repairs. The inspection load increases at the end of service. Various factors contribute towards the stress of the inspectors and the other personnel [18], stress that is further compounded by the fact that the inspector has to search for multiple defects occurring at varying severity levels and locations [2].

The maintenance task is further complicated because of the wide variety of aircraft defects being reported in older aircrafts. Documented facts indicate that scheduled repairs account for only 30 % of all maintenance in these aircrafts compared to 60-80 % in the younger fleet, a fact attributed to an increase in the number of age-related defects [3]. Thus, a more intensive inspection program is required for older aircraft, and inspection plays a more vital role. It should be realized that the introduction of newer aircraft will not substantially reduce the maintenance workload, as new airframe composites create an additional set of critical variables, affecting maintenance and inspection. The problem of maintenance is further demanding when more experienced inspectors and mechanics are retiring and being replaced by a much younger and less experienced work force. Not only do the new inspectors lack knowledge and skills of the far more experienced inspectors, they are also not trained to work on a wide variety of aircraft.

The cost of inspection is going up. This has resulted in a greater competitive pressure to reduce maintenance and inspection costs. The reasons for increased costs include maintaining minimum staffing levels and adhering to the mandated workload, without of course, risking safety of aircrafts or disrupting flight schedules. From an airline management perspective, two goals need to be achieved by a maintenance and inspection program: safety and profitability. Even though safety is of critical importance, profitability can be realized only when safety is achieved economically. For maintenance it means that in addition to performing the task, technicians have to be sensitive to efficiency, the speed measure, and effectiveness, the accuracy measure, if they are to optimize their performance. The relationship between performance measures and task factors are of critical importance in the maintenance/inspection environment.

The stress produced by this complicated situation, requiring, at times, what appear to be contradictory goals, often results in maintenance errors, a fact that has been confirmed and documented through task analysis of commercial maintenance and inspection activities [2]. This analysis has revealed that aircraft maintenance is a complex activity requiring above average coordination, communication and co-operation between inspectors, maintenance personnel, supervisors and various other sub-systems to be effective and efficient [3, 4]. Thus, it is clear that there exists potential for errors, and it is only through devising strategies that identify where they occur that we can eventually determine problem areas and develop interventions minimizing their impact.

3. Problem Statement

To minimize maintenance errors, the aviation maintenance industry has invested a significant effort in developing methodologies investigating maintenance errors. Literature of human error is rich, having its foundations in early studies analyzing human error made by pilots [5], human error work following the Three Mile Island accident, and recent research in human reliability and the development of error taxonomies [8, 11, 12, 13, 17]. This research has centered on analyzing maintenance accidents and incidents, a recent example being the Maintenance Error Decision Aid (MEDA) [10]. This tool, developed by Boeing along with representatives from British Airways, Continental Airlines, United Airlines, the International Association of Machinists and the US Federal Aviation Administration, helps analysts identify the contributing factors that lead to an accident.

In addition to this, various airlines have also developed their own internal procedures to track maintenance errors. Once such methodology is the failure modes and effect analysis approach [7] that classifies the potential errors by expanding each step of the task analysis into sub-steps and then listing all the failure modes for each. The US Navy Safety Center has done a commendable job in developing the Human Factors Analysis and Classification System-Maintenance Extension Taxonomy and the follow-up web-based maintenance error information management system developed by the Naval Safety Center to analyze naval aviation mishaps [14, 15, 16] and later used to analyze commercial aviation accidents [19]. Although valuable in terms of their insights into performance-shaping factors leading to maintenance errors following their occurrence, these efforts are reactive in nature; i.e., their focus is on analyzing maintenance accidents and errors following their occurrence, and not developing preventative measures. Moreover these efforts are usually ad hoc, varying across industry with little standardization. The lack of standardization in data collection, reduction and analysis is the single biggest constraint in the analysis of maintenance errors within and across the maintenance industry. Without such standardization it is difficult to analyze data and identify potential problem areas at multiple and geographically dispersed maintenance sites.

4. Strategy for Future Research

A proactive approach is required, one which will help identify problem areas and devise strategies to minimize maintenance errors. Since the aircraft maintenance industry needs direction in this area, our future research proposes to develop and implement a web-based application tool (http://www.ces.clemson.edu/~jsg/hcsl/) to perform surveillance activities to ensure that a consistent level of supervision is maintained over the maintenance and inspection operations. The system advocates the need to promote a standardized format for data collection, reduction and analysis to proactively identify contributing factors of improper maintenance. The overall structure of the system is shown in Figure 1. The system will seek input from various sources, including In-Process Surveillance, Verification Surveillance, Final Walk Around, Aircraft Walk Around, Inspection, Storage, among others. These are the sources which provide the maximum input about maintenance and inspection errors and hence are termed as the potential impact variables that affect the performance of the surveillance activity. Data collected from these diverse sources will be reduced and analyzed, enabling researchers to identify future problem areas. The identification of these problem areas will let the industry prioritize factors that transcend across industry to systematically reduce or eliminate potential errors. The system will be developed with a specific aviation partner (FedEx in Memphis, TN) to ensure that it meets the needs of the aviation community and later will be made available as an application that can be downloaded for use by each maintenance facility.

5. Significance and Impact of Proposed Research

The development of a web-based surveillance tool has the potential to reduce maintenance errors impacting aviation safety. The specific advantages of developing such a tool are the following: (1) this proactive approach will reduce maintenance errors by identifying problem areas and error contributing factors; (2) the adoption of this tool by the aircraft maintenance industry will promote standardization in data collection, reduction and analysis of maintenance error data from varied sources; (3) this standardization will result in superior trend analysis of problem areas within and across organizations; (4) the findings can be shared by manufacturers, airlines, repair stations and air cargos to help identify and prioritize factors that transcend across industry; and (5) this research will support the reduction of maintenance accidents and errors by conducting guidelines-based human factors research identifying and implementing intervention strategies.

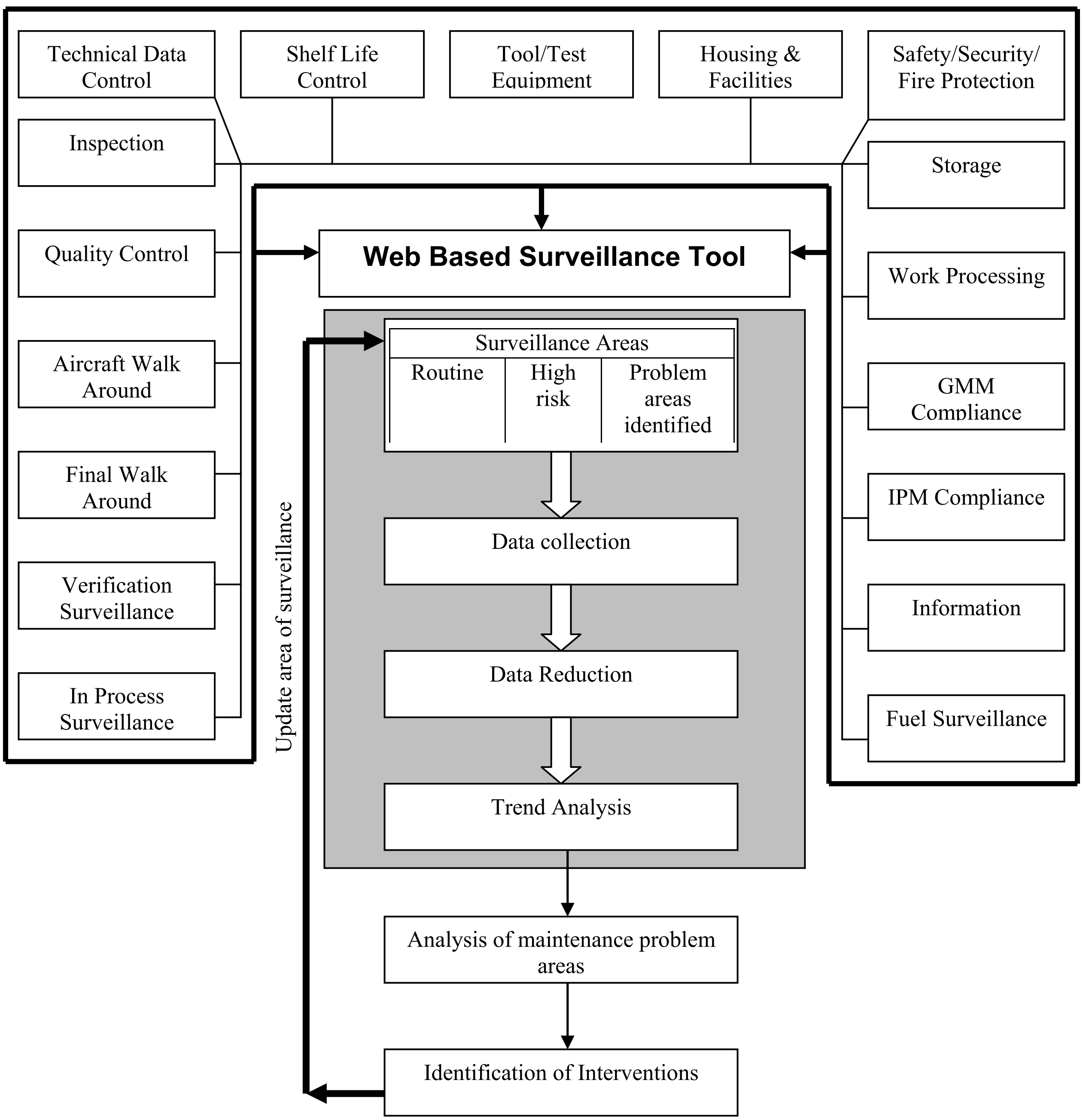

Figure 1. Web based Surveillance Tool with inputs from different sources

6. Conclusion

In summary, the objectives of this research are three fold: (1) identify an exhaustive list of impact variables that affect aviation safety and transcend across various aircraft maintenance organizations; (2) develop data collection/reduction and analysis protocol to analyze errors for the identified set of impact variables; and (3) using the results of the aforementioned activity develop and implement an application in performing surveillance/monitoring to ensure a consistent level of oversight in maintenance.

The results of this research will be disseminated to the aviation community via a number of avenues. These include, but are not restricted to, scholastic publications and training software available for download from FAA's web site. Most importantly, the results of this research will be regularly conveyed to the industry partners.

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Data Gathering Methodologies to Identify Impact Variables in Aviation Maintenance

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Abstract

Impact variables are factors which must be taken into account to assure quality maintenance inspection. There are methodologies to collect and interpret information on impact variables. The choice of a particular methodology is based on factors such as the type of data to be gathered, the manner in which the data is applied, and the time available for data collection. The methodology employed has a direct effect on the quality and value of the information collected. This research analyzes data collection methodologies such as observation sessions, interviews, and surveys for the identification of impact variables in aviation maintenance.

Keywords
Data collection methodologies, Aviation maintenance, Selection matrix, WebSAT, Impact variables

1. Introduction

The mission of the FAA is to provide safe and reliable air transportation and to ensure airworthiness of the aircraft. The increasing number of maintenance and inspection errors in the aviation industry has motivated the need for human factors research. Maintenance error is a crucial factor in aircraft accidents. Human factors research in maintenance has deemed the human as the central part of the aviation system [4]. 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. As a part of this evaluation, surveillance of maintenance and inspection activities must be conducted in a rigorous fashion. The objective of these activities is achieved through effective functioning of the auditors who perform these activities. The findings of these auditors help in the evaluation and assessment of the internal and external agencies of each airline that influence the safety and airworthiness of their aircraft. Thus, surveillance and auditing activities are of foremost importance in ensuring adherence to quality assurance requirements and maintaining a consistent level of supervision over maintenance operations. Given this, there is a need to develop a system that ensures superior performance of surveillance and auditing activities. This system is required to perform the following functions: (a) Seek input from diversified sources; (b) Proactively identify factors contributing to maintenance errors; (c) Promote a standardized format for data collection, data reduction and data analysis within and across the aircraft maintenance industry and lastly, (d) Generate trend analysis for problem areas (causal factors within and across organizations).

We propose to develop a web-based surveillance and auditing tool (WebSAT: http://www.ces.clemson.edu /~jsg/hcsl/) to proactively capture maintenance errors. The system will capture and record errors that occur during maintenance and inspection and analyze these findings. The specific objectives of this research are to:

(1) Identify an exhaustive list of impact variables that affect aviation safety and transcend various aircraft maintenance organizations.
(2) Develop a data collection/reduction and analysis protocol to analyze errors for the identified set of impact variables.
(3) Use the results of the aforementioned activity to develop and implement a surveillance/monitoring tool that assists in the maintenance of a consistent level of oversight.

The first step of this research is to identify impact variables. In order to do so it is important to understand current maintenance, surveillance and auditing processes. This necessitates the use of data collection methodologies to understand and subsequently identify the different variables. Impact variables are performance measures or requirements which would indicate the effectiveness and efficiency of the process. Taylor's [18] investigation of the causes of Information Technology (IT) project failure, revealed that "there is no single cause of IT project failure," but requirements issues figured highly in the findings. A set of stable requirements can be defined by collecting sufficient, relevant, and appropriate data using proper data gathering methodologies.

Whether or not "human needs" are ontological facts of life [9], the extensive use of the word, and the concept it entails in various disciplines, presupposes that there exists a mutual understanding of its meaning, or of some phenomenon it represents. The most prevalent use of the term "needs" in the ergonomics, business and design engineering literature is to consider it as being used to establish some connection between a user and an artifact [5, 6, 7, 10, 19]. Data gathering is an important part of the requirements and evaluation activity as it helps us in understanding what these needs really are. The appropriate method depends on the time at which it is conducted and the manner in which information will be collected. These methods are aimed at providing information that drives improvements to the existing design [20]. The purpose of data gathering is to collect sufficient, and relevant, data so that a set of stable requirements can be produced [13]. This activity is typically applicable before the design process begins. The information gathered using these data collection methods allows us to understand what the system should look like. Trials, surveys, focus groups and, observations are some of the methods of acquiring this information [11]. One of the most powerful ways of obtaining user information that can be incorporated very early in the development process is through observation of users in their work context. Using a variety of ethnographic methods, developers who already thought they had a good idea of the users' work and needs are usually amazed at how much they learn through observation [15]. Observation is the cornerstone of usability testing and an important strategy in evaluating websites [16]. Alan et al., [1] identify various factors which distinguish different evaluation techniques to allow one to make an appropriate choice. Rudman and Engelbeck [17] describe how they used different techniques to establish the requirements for a complex graphical user interface for a telephone company, and how different methods resulted in understanding different requirements. The techniques for data gathering can be combined and extended in many ways, which makes the possibilities for data gathering flexible.

2. Current Methods

The various data gathering methods that are currently used are questionnaires, interviews, focus groups and workshops, observation sessions and studying documentation. Some of them, such as focus groups, require active participation from stakeholders, while others, such as studying documentation, require no involvement at all. In addition, various props can be used in data-gathering sessions, such as descriptions of common tasks and prototypes of possible new functionality.

2.1. Questionnaires

Questionnaires are a series of questions designed to elicit specific information from their readers (participants). Some questionnaires require yes/no answers; others ask for a choice from a set of pre-supplied answers and others ask for a longer response or comment. Sometimes questionnaires are sent in electronic form, and sometimes they are given to the participants on paper. In some cases, the questionnaire is administered at a distance. Well-designed questionnaires are effective at getting answers to specific questions from a large group of people, especially if that group of people is spread across a wide geographical area, making it infeasible to visit them all. Questionnaires are often used in conjunction with other techniques. For example, information obtained through interviews might be corroborated by sending a questionnaire to a wide group of stakeholders to confirm conclusions.

2.2. Interviews

Interviews involve asking the participants a set of questions verbally. Often interviews are face-to-face, but they do not have to be. If interviewed in their own work or home setting, people may find it easier to talk about their activities and respond by showing the interviewer what they do and what systems and other artifacts they use. Interacting with people encourages them to respond effectively. In the context of establishing requirements, it is equally important for development team members to meet stakeholders and for users to feel involved. This aspect alone may be sufficient motivation to arrange interviews. However, interviews are time consuming and it may not be feasible to visit all stakeholders or pertinent users.

2.3. Focus Groups and Workshops

Meghan Ede [2] has an interesting perspective on focus groups: they are a way to get users to talk about long term issues that would take too long to study directly. Interviews tend to be one-on-one, and elicit only one person's perspective. As an alternative or as corroboration to another data collection method, placing a group of stakeholders together to discuss issues and requirements can be very revealing. Focus groups and workshops are useful to gather a consensus and/or to highlight areas of conflict. They also allow stakeholders to meet the project team, and to express their views openly. It is not uncommon for one set of stakeholders to be unaware that their views are different from another set, even though they are in the same organization. These sessions need to be structured carefully and the participants should be selected carefully. One or a few people can dominate discussions, especially if they have control, higher status, or influence over the other participants.

2.4. Observation Sessions

People find it difficult to describe what they do or how they achieve a particular task. As a result, analysts rarely get an accurate story from stakeholders using any of the methods listed above. The techniques used in interviews can help prompt people to be more accurate in their descriptions, but observation provides a richer view. Observation involves spending some time with the stakeholders at their day-to-day tasks, observing work as it happens in its natural setting. Observation is an invaluable way to gain insights into the task(s) of the stakeholders and can complement other investigations. The level of involvement of the observer in the work being observed is variable along a spectrum with no involvement (outside observation) at one end and full involvement (participant observation) at the other. Observation help fill in details and nuances that do not come out of other investigations.

2.5. Studying Documentation

Procedures and rules are often written down in manuals and these are a good source of data. Such documentation should not be used as the only source, as practices may have been devised by those concerned to make the procedures work in a practical setting. Thus, an idealized account is given in the manuals, as compared to everyday practices.

3. Choosing a Data Method

There are no targeted rules to decide which methods are the most appropriate for identifying specific research needs. Each method has its particular strengths and weaknesses and each is useful if applied appropriately. However, there are various factors which should be considered when selecting methods. This paper considers this issue carefully to arrive at certain guidelines that can be used to select one or several data gathering methodologies to allow collection of useful data. Choosing the appropriate set of techniques for a project is crucial as it affects the requirements identified for the design process. Olson and Moran [12] suggest that the choice of data-gathering techniques rest on two issues: the nature of the data gathering technique itself, and the nature of the task to be studied. Data gathering methods differ in two main respects: the amount of time they take, and the information they provide. The following factors affect the choice of a data gathering method.

3.1. Project Phase

The first factor to affect the choice of data gathering method is the stage in the project at which the data is gathered. It would be useful to include data gathering of some sort throughout the project phases. Identifying user needs and performance measures early-on in the project provides information to drive the development of the system to be developed. This system may be anything from a paper mockup to a full implementation, but it is something concrete which can be tested.

3.2. Data Gathering Environment

The environments in which the studies are conducted vary from the laboratory to a user's place of work or field location. Laboratory studies allow controlled experimentation and observation but lose some of the naturalness of the user's environment [1]. Field studies retain the latter but do not allow full control over user activity.

3.3. Subjective vs. Objective Data Gathering Methods

Some methods rely heavily on the interpretation of the investigator, while others would provide similar information regardless of who is performing the data gathering. Thus, data gathering methods also vary according to their objectivity. The more subjective techniques, such as interviews, rely to a large extent on the knowledge and expertise of the investigator, who must recognize problems and understand what the user is doing. They can be useful if used correctly and provide information that may not be available from more objective method. However, investigator bias should be recognized and avoided. One way to decrease the possibility of bias is to use more than one investigator. Objective data methods, on the other hand, should produce repeatable results that do not depend on the persuasion of the particular evaluator. Controlled experiments are an example of an objective data gathering method. These experiments avoid bias and provide comparable results, but they may not reveal unexpected problems or give detailed feedback on user experience. Ideally, both objective and subjective measures should be used to mitigate the weaknesses of each data gathering method.

3.4. Qualitative and Quantitative Measures

The type of measurement provided by the data gathering method is an important consideration. There are two basic types: quantitative measurement and qualitative measurement. Quantitative measurements are usually numeric and can be easily analyzed using statistical techniques. Qualitative measurements are non-numeric and are therefore more difficult to analyze, but can provide important details which cannot be determined from numbers. The type of measure is related to the subjectivity or objectivity of the technique. Subjective techniques tend to provide qualitative measures, and objective techniques tend to provide quantitative measures.

3.5. Information Detail

The information detail required by the investigator at any stage of the project may vary. Some data gathering methods, such as controlled experiments, are excellent at providing information with less detail; an experiment can be designed to measure a particular aspect of an interface. Another example would be a well designed survey which allows the audience to respond to certain specific variables without being provided the information needed to understand the system in all its detail. Higher level information can be gathered using questionnaire and interview techniques to provide a more general impression of the user's view of a system.

3.6. Response Time

Another factor distinguishing the data gathering methods is the immediacy of the response they provide. Methods such as observation sessions record the user's behavior at the time of the interaction itself. Other methods, such as interviews, rely on the user's recollection of events. Such recollection is liable to suffer from bias in recall and reconstruction, with users interpreting events according to their preconceptions. Recall may also be incomplete. However, immediate techniques can also be problematic since the process of measurement can actually alter the way the user works.

3.7. Resources

Availability of resources is paramount when selecting a data method. Resources to consider include equipment, time, money, participants, context, and the expertise of investigator. Some decisions are forced by resource limitations, other decisions are not so clear cut. For example, time and money may be limited, forcing a choice between two possible methods. In these circumstances, the investigator must decide which evaluation tactic will produce the most effective and useful information for the system under consideration. It may be possible to use results from other investigators' experiments to avoid having to conduct new experiments.

4. Selection Matrix

Table1. Selection Matrix of various data gathering methods
Q= Questionnaires; I = Interviews; W=Workshop; O= Observations; and D= Document Studies.

Criteria	**Data Methods**				
	Q	**I**	**W**	**O**	**D**
Phase (T= Throughout)	T	T	T	Data Gathering Phase	T
Environment: (L=Lab & F=Field)	L/F	L/F	L/F	F	L/F
Objective?	Yes/No	Yes/No	No	No	No
Qualitative or Quantitative Measure	Both	Both	Both	Both	Both
Level of Detail: H=High, M=Medium & L=Low	H	H	M	H	M to H
Response Time: S=Short, M=Medium & L=Long	M to L	L	L	S to M	S
Time Requirements: H=High, M=Medium & L=Low	L	L	H	H	H
Equipment Requirements: H=High, M=Medium & L=Low	L	L	L	L	L
Expertise Requirements	L	L	L	H	M

Table 1. represents a matrix to accommodate the factors discussed above. This matrix provides a tool which can be used to select one or several methods based on project criteria. The general approach adopted in the creation of this matrix was to consider the various factors that influence the choice of a data gathering method and addresses them with simple responses - Yes/No, High/Medium/Low, or Short/Medium/Long.

4.1 Application of Selection Matrix to WebSAT

The following factors were considered in the selection of data gathering methods to help identify impact variables in aviation maintenance;

- The general objective of this research is to identify an exhaustive list of impact variables that affect aviation safety and transcend various aircraft maintenance organizations.
- The research team hopes to identify the variables by the end of the year 2004.
- The partnering airline is located in the state of Tennessee. The geographical distance between the airline headquarters and the research laboratory in South Carolina adds its own complications to information gathering.
- The participants are senior managers in the surveillance and audit departments, maintenance personnel, and FAA representatives. The maintenance personnel are located at the substantial maintenance department in Alabama. The FAA representatives (stakeholders) are located in Washington, DC.
- It is expected that the impact variables will be qualitative in nature. The WebSAT tool may provide an approach to quantify these variables.
- The date gathering session has to be detailed, as the research team is new to the airline industry and needs to understand the basic workflow of the industry before beginning to look for impact variables.
- Three students, with a background in the field of human computer interaction, are working on this project.
- The costs of traveling to the airline headquarters and the aircraft maintenance site are high.

5. Discussion

The Selection Matrix is an effective reference to guide the selection of data gathering methods based on the applicable factors. This matrix can be further improved by introducing additional factors such as cost and stakeholder privacy. A next step might be to make this matrix more quantitative to allow for a scoring system that would assist the user in the selection of methods. Our research team used this matrix to decide which data methods to adopt for the WebSAT project. After careful review of the factors and keeping the selection matrix in mind, it was determined that the following data methods (in the order of preference) would be appropriate for this project:

(1) Interviews: This method is suitable for meeting the airline managers. This will also allow us to take a first-hand look at their work environment and will allow us to collect useful documents. The stakeholders will get an opportunity to put a face to the names they believe are involved in the project.

(2) Observation Sessions: To understand how aircraft maintenance is done, it is important to see how the maintenance personnel carry out their day-to-day work. Observation sessions would be the best method to collect this information. The medium to long response time will not be a hindrance for this project as sufficient time is available.

(3) Document Study: Since the airline industry is a highly regulated industry, it will be easier for us to learn more about it by reading relevant procedural manuals.

(4) Questionnaires: We believe that questionnaires should be used in a later phase of the project. They will be particularly useful if implemented as a web survey. This will allow us to evaluate (remotely) the appropriateness of impact variables with additional airlines.

6. Conclusion

Data gathering methods are an integral part of the design process. Data gathering should take place throughout the design life cycle to identify requirements early on and to later test the functionality and quality of the product. Data gathering can take place in the laboratory or in the user's workplace, and may involve active participation on the part of the user and the investigator. Interpreting user needs before any implementation work has started is an efficient way to minimize the commission of early design errors. The identification of the impact variables in aviation maintenance will enable the aviation industry to prioritize factors that transcend individual airlines. This information will be used to develop a tool that can systematically reduce or eliminate potential maintenance errors.

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A STRATEGY FOR THE DEVELOPMENT OF A WEB-BASED TOOL TO REDUCE AVIATION MAINTENANCE ERRORS

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The safety and reliability of air transportation depends on minimizing inspection and maintenance errors that occur in the aircraft maintenance system. Efforts have been invested to track maintenance errors. These efforts are reactive in nature: they analyze maintenance errors after their occurrence. There is a lack of standardization in the assessment of maintenance errors across the maintenance industry. Surveillance and auditing of maintenance activities are two important functions which help ensure airworthiness of an aircraft. A system that will document the processes and outcomes of these maintenance activities and will make this documentation more accessible will accomplish the goal of this research to reduce maintenance error. Such a system would then support robust and safer aircraft maintenance operations. Our research is developing a web-based surveillance and auditing tool (WebSAT) that promotes a standardized format for maintenance data collection, reduction and analysis to proactively identify the factors contributing to improper maintenance.

INTRODUCTION

The aircraft maintenance system is complicated (Gramopadhye, Drury and Prabhu, 1997), with interrelated human and machine components. Realizing this, the FAA has pursued human factors research for some time now under the National Plan for Aviation Human Factors (FAA, 1991; FAA, 1993) to fulfill the mission of the FAA's Flight Standards Service of promoting safety by setting certification standards for air carriers, commercial operators, air agencies, and airmen.

A study conducted by Boeing and the US Air Transport Association (1995) found that maintenance error was a crucial factor in aircraft accidents from 1982 to 1991, contributing to 15% of the commercial hull loss accidents where five or more people were killed. Rankin and Allen (1995) established the economic costs of these maintenance errors, estimating that 20 to 30% of in-flight shutdowns are due to maintenance error, 50% of flight delays are due to engine problems caused by maintenance errors, and 50% of flight cancellations are due to engine problems caused by maintenance errors. The need is apparent for a proactive system which will help track maintenance errors, identifying both potential problem areas and the factors causing errors. If such a system is developed it will be possible to better manage maintenance errors, resulting in aircraft maintenance which is safer and more robust.

Problem Statement

To minimize maintenance errors, the aviation maintenance industry has developed methodologies to investigate maintenance errors. The literature of human error is rich, having its foundations in early studies analyzing human error made by pilots (Fitts and Jones, 1947), human error work following the Three Mile Island accident, and recent research in human reliability and the development of error taxonomies (Norman, 1981; Rasmussen, 1982; Reason, 1990; Rouse and Rouse, 1983; Swain and Guttman, 1983). This research has centered on analyzing maintenance accidents and incidents, a recent example being the Maintenance Error Decision Aid (MEDA) (Rankin, Hibit, Allen and Sargent, 2000). This tool, developed by Boeing along with representatives from British Airways, Continental Airlines, United Airlines, the International Association of Machinists and the US Federal Aviation Administration, helps analysts identify the contributing factors leading to an accident. Various airlines have developed internal procedures to track maintenance errors. One such methodology is the failure modes and effects analysis approach (Hobbs and Willamson, 2001) that classifies potential errors by expanding each step of a task analysis into sub-steps and then listing the potential failure modes. The US Naval Safety Center developed the Human Factors Analysis and Classification System- Maintenance Extension Taxonomy and the follow-up web-based maintenance error information management system to analyze naval aviation mishaps (Schmidt, Schmorrow and Hardee, 1998; Shappell and Wiegman, 1997, 2001) and later used to analyze commercial aviation accidents (Wiegman and Shappell, 2001). Although valuable in terms of their insights into performance-shaping factors leading to maintenance errors following their occurrence, these efforts are reactive in nature. Maintenance error tracking efforts are also ad hoc in nature, varying across the industry with little standardization. The lack of standardization in data collection, reduction and analysis is the single biggest drawback in the analysis of maintenance errors within and across the maintenance industry. This research is developing a web-based surveillance and auditing tool (WebSAT) that promotes standardized data collection and analysis. Surveillance, auditing, and airworthiness directives are the activities which will be the primary data sources for WebSAT, as shown in Figure 1.

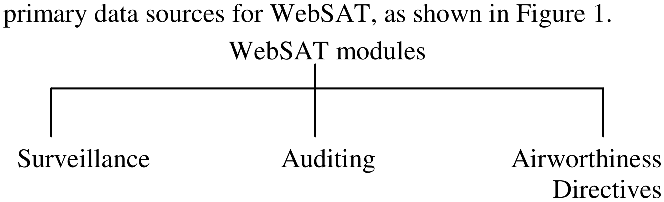


Figure 1. Data sources for WebSAT

Substantial maintenance vendor and fuel vendor surveillance activities will form the basis for our inputs on surveillance activities. Technical audits, internal audits, self audits, and fuel, maintenance and ramp audits will form the basis for inputs on auditing activities. Airworthiness directives data will be derived from work instruction cards and engineering orders. For the purpose of illustration, we use surveillance activity as an example to describe our initial development efforts in this paper.

Surveillance: Surveillance is the day-to-day oversight and evaluation of the work contracted to an airframe substantial maintenance vendor or fuel vendor to determine the level of compliance with the airline's Continuous Airworthiness Maintenance Program (CAMP) and General Maintenance Manual (GMM). The objective of surveillance is to provide the airline, through the accomplishment of a variety of specific surveillance activities on a planned and random sampling basis, an accurate, real-time, and comprehensive evaluation of how well each maintenance vendor is complying with airline and FAA approved policies and regulatory requirements. WebSAT will perform surveillance activities to ensure that a consistent level of supervision is maintained over maintenance and inspection operations. The system will seek input from various sources, including In-Process Surveillance, Verification Surveillance, Final Walk Around, Aircraft Walk Around, Inspection, Storage, among others, as shown in Figure 2.

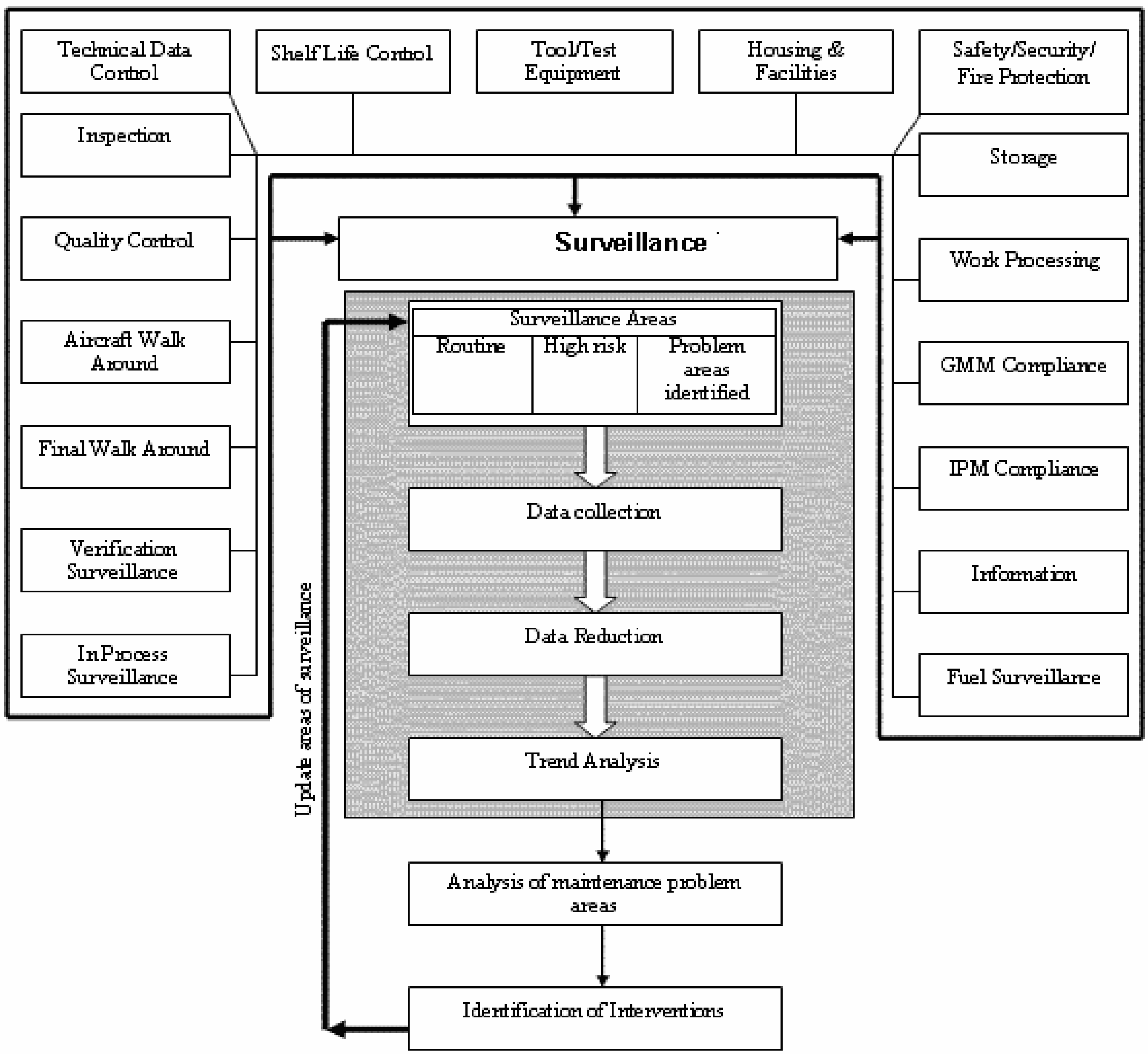


Figure 2. Data sources involved in a surveillance activity

These are the sources which provide the most information about maintenance and inspection errors and hence are termed the potential process measures that affect the performance of the surveillance activity. Similar variables are being identified for the other activities mentioned in Figure 1, namely auditing and airworthiness directives.

Data collected from these diverse sources will be analyzed to identify potential problem areas. The identification of these problem areas will let the industry prioritize factors that transcend the individual airlines to systematically reduce or eliminate potential errors. The WebSAT system is being developed with a specific aviation partner (FedEx in Memphis, TN) to ensure the needs of the aviation community are addressed. It will be made available as an application that can be downloaded for use by each maintenance facility.

METHODOLOGY

The research is being conducted in three phases.

Phase 1: Identification of Process measures and Data Sources.

- Identify the process measures which would help to identify the potential problematic areas
- Ensure that the identified process measures are representative of those used by most maintenance entities by conducting an online survey with the partnering airlines.
- identify the limitations in using the specific process measures identified.

The first phase of the research will finalize the list of process measures.

Phase 2: Develop Prototype of Auditing and Surveillance Tool

- Product phase: The research team will achieve consensus on the project mission statement.
- Needs analysis phase: In this phase the researchers will gather data, identify customer needs, and establish the relative importance of the needs.
- Product specifications phase: The researchers will develop a preliminary set of target specifications.
- Conceptual design phase.
- Concept generation and selection phase.
- Detail design of selected concept to create an initial working prototype.
- Testing and refinement of the initial working prototype with representative users.
- The delivery of a refined prototype to FedEx for trial use.

Phase 3: Develop Data Analysis and Validation Module

- Develop advanced data analysis tools that include multivariate analysis and risk assessment.
- Validate using field data.

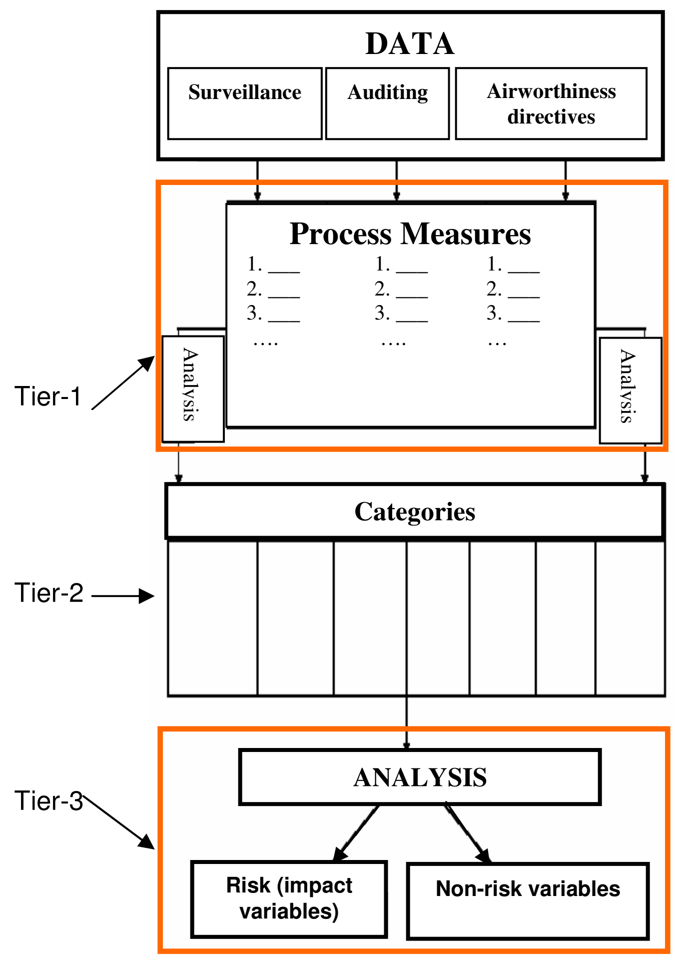
WEBSAT RESEARCH FRAMEWORK

The WebSAT research framework shown in Figure 3 has 3 tiers associated with it. In tier 1, relevant data collected from the three modules (surveillance, auditing and airworthiness directives) will be analyzed using the identified process measures which allow us to evaluate the effectiveness of each module.

Further analysis of data will lead us to the categories in tier-2 which evaluates the performance of the airline across the three modules. These categories are factors such as cost, economy, etc. which have a direct bearing on the impact on the safety of an airline.

Our research team will then conduct analysis of tier-2 and estimate safety index of the airline by identifying the risk-causing factors represented in tier-3. In tier 3 it is demonstrated that the variables are of 2 kinds: risk and non-risk. The upper management is interested in the risk or impact variables, which will be indicated by the tool. The research team finds it appropriate to report results of analysis for non-risk variables, contemplating that useful input will be generated.

Figure 3. WebSAT Framework Prototype



SIGNIFICANCE AND IMPACT OF WEBSAT

The development of a web-based surveillance and auditing tool has the potential to reduce maintenance errors impacting aviation safety. The specific advantages of this tool are the following: (1) a proactive approach reduces maintenance errors by identifying problem areas and error contributing factors; (2) the adoption of this tool by the aircraft maintenance industry promotes standardization in collection, reduction and analysis of maintenance error data; (3) this standardization will result in superior trend analysis of problem areas; and (4) the findings can be shared by manufacturers, airlines, repair stations and air cargo handlers to identify and prioritize factors which lead to maintenance errors.

CONCLUSION

In summary, the objective of this research is to: (1) identify an exhaustive list of process measures that affect aviation safety and transcend various aircraft maintenance organizations; (2) design and develop web-based surveillance and auditing tool which uses the identified set of process measures for data analysis. The results of this research will be disseminated to the aviation community via a number of avenues. These include scholastic publications and training software available for download from the FAA's web site and the regular communication of the results of this research to industry partners.

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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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Selection Strategy for Identification of Process Measures for Surveillance in Aviation

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Abstract

Inspection and maintenance errors that occur in aircraft maintenance systems have a formidable impact on the safety and reliability of air transportation. Evaluation of the aircraft maintenance system requires an analysis of the maintenance processes in use. The systematic evaluation of data collected on the aviation maintenance process can provide management with feedback on the performance of the airline and consequently provide proactive support of the decision-making process prior to the dispatch of the aircraft. Recognizing that surveillance, auditing and airworthiness directives form a significant portion of the quality assurance function of an airline, it is critical that data be collected on these processes. Significant efforts have been made to investigate and track inspection and maintenance errors. Although valuable in terms of their contributions to the identification of the performance-shaping factors that lead to maintenance errors, these efforts have tended to be reactive in nature. Surveillance has a more practical bearing on the maintenance of aircraft. Process measures for surveillance was identified by the research team based on human-factor principles, utility of data being captured, and working around mental models of quality assurance personnel. This research establishes the identification strategy the research team adopted to finalize the process measures for surveillance.

Keywords

Surveillance, Aviation maintenance, Selection strategy, WebSAT, Process measures

1. Introduction

The mission of the FAA is to provide safe and reliable air transportation and to ensure airworthiness of the aircraft. The increasing number of maintenance and inspection errors in the aviation industry has motivated the need for human factors research. Maintenance error has been found to be a crucial factor in aircraft accidents [2]. Human factors research in maintenance has deemed the human as the central part of the aviation system [7]. 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 continually complex. The significance of the maintenance function was captured by Weick et al. [22] 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" [22]. Given the ever increasing complexity of an 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 these 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 [5], work following the Three Mile Island incident, recent work in human reliability and the development of error taxonomies [20, 14, 19, 17, 18]. 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 [3]. 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 [8]. 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 [12].

Attempts have been made to define a core set of constructs for safety climate [6]. 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 [21] 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. Questions relating to these areas also appear in the questionnaire to be used in the current research. Patankar [16] 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 the 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, the devised empirical models and tools are required to employ standardized data collection procedures, provide a basis for predicting unsafe conditions and design interventions that will lead to reduction in maintenance errors.

This research hopes to indicate the error causes and occurrences using a web based surveillance and auditing tool (WebSAT) tool. The WebSAT team's aviation industry partner is FedEx. This tool will capture and analyze data for surveillance and auditing. Consequently, the first step of this research is to identify process measures. The focus of this paper is to explain the approach used by the team to establish process measures for surveillance. In order to do so, it is important to understand current surveillance process.

2. Method

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 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 is currently using categories to collect the data obtained from a surveillance visit at the maintenance facility. The team used these categories as a starting point in their process to identify the process measures. Some of the categories currently being used by FedEx are in-process surveillance, final walk around, and verification surveillance. These categories were created based on various surveillance tasks and the C.A.S.E. (Coordinating Agency for Supplier Evaluation) guidelines that have to be adhered to by the substantial maintenance vendor and the airline.

The team was tasked with identifying process measures which cover all the data to be gathered during surveillance. The team was also aware of the existence of inconsistency in the definition of the existing categories amongst the surveillance representatives. The selection strategy adopted by the team included noting the fact that the surveillance representatives use just a notepad and pen to document what is abnormal or improper in the maintenance facility. The team was also aware that the representative's own experience could be a road block, preventing him from correctly assigning an error to a category. The details of this strategy have been presented below.

2.1. Human Factor Principles

Humans have three distinct memory storage capabilities (not including permanent deletion). The first is sensory memory, referring to the information we receive through the senses. This memory lasts for a few seconds. Short Term Memory (STM) takes over when the information in our sensory memory is transferred to our consciousness or our awareness [4, 11]. This is the information that is currently active such as reading this page, talking to a friend, or writing a paper. STM can definitely last longer than sensory memory (up to 30 seconds or so), but it still has a very limited capacity. According to research, we can remember approximately 5 to 9 (7 +/- 2) bits of information in our short term memory at any given time [13]. Working Memory is the process that takes place when we continually focus on material for longer than STM alone will allow [1]. The Long Term Memory (LTM), unlike the other two types, is relatively permanent and practically unlimited in terms of its storage capacity. The team was aware of the fact that the surveillance representatives relied on their memory to categorize what they saw in the maintenance facility. This meant that there must be lesser categories and they should be easy to remember.

2.2. Utility of Captured Data

The utility and value of the data being gathered is of paramount importance. The process measures being used for data analysis in surveillance were high in number, had a redundant nature, and there was no common consensus between the various surveillance personnel within the department at FedEx. 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. 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 importance to the aircraft airworthiness. For example, non-technical measure such as shelf life is very important and any mistakes on these measures should be noted and documented as much as hands documentation is done on surveillance of the aircraft itself.

2.3. Mental Working Model of the Surveillance Personnel

In the research team's conversation with the QA surveillance group at FedEx, the team gained insights into the mental working model of the surveillance representatives, the personnel who do the daily surveillance activities on the aircraft, and their managers. One of the managers has been a surveillance representative in the past and hence could empathize with the surveillance representatives. The team recognized that it was pertinent to recognize these models and use them to identify process measures.

3. Choosing a Process Measure

There are no targeted rules to decide which methods are the most appropriate for identifying specific research needs. Each method has its particular strengths and weaknesses and each is useful if applied appropriately. The team applied the three mentioned methods in selecting the final list of process measures. There are various factors which should be considered when selecting process measures.

3.1. Overlap and Redundancy

The first factor to affect the choice of the research team is overlap and redundancy. The team wanted to make sure that the data that fall under one process measure does not fall under other process measures. This can be avoided by identifying measures which do not overlap and through training. There was a situation where the quality assurance representatives felt that General Maintenance Manual (GMM), and Inspection Procedures Manual (IPM) was restricting them. They felt that since GMM is more airline specific and more exhaustive, IPM should be avoided. They mentioned occasions where they go on for an entire stretch of surveillance of an aircraft without documenting anything under IPM. The representatives mentioned that since IPM is vendor specific it becomes extremely overwhelming to cater to various vendor needs and restrictions. However, the management thought differently, and said that the inclusion of IPM would keep the vendor on a strict check.

3.2. Data Gathering Environment

The environment in which the activity happens dictates a lot of final results. The surveillance department is very work intensive, and the aviation industry is extremely regulated. The surveillance representatives are looking for defects. Since they are in the maintenance facility, they have to stay focused with the work card on hand and inspect the operations performed. This also means that the representatives must avoid being distracted by other minor errors without missing the major one. The managers also expressed a need to document the positive notes on the surveillance site. It was felt that this would be important historical data to help keep a greater control and monitoring on the future maintenance events.

3.3. Process Measure Usage

The kind of work being scrutinized is also an additional factor to consider while deciding on the final set of process measures. The research team spent hours walking around with vendor maintenance personnel, vendor inspectors and, surveillance representatives at these maintenance sites. The team actually took a lot of subtle input from watching people work in their own work domain. This gave the team a better understanding in the limitations of certain process measures when it comes down to finalizing a particular category. The team recognized the fact that it is important to not loose focus with the initial purpose of the surveillance event while identifying a process measure. For instance, if a surveillance representative was doing in-process surveillance on the new paint coat given to a panel on the wing of an aircraft, and he realizes that the paint spray bottle has an expired date on it, the finding would be documented under in-process surveillance, and not under shelf-life, the way many quality assurance representatives do. This sounds right, because the traceability of a problem, and the cause of it, is both accounted for immediately.

3.4. Validation of Process Measures

Once the research team finalized the process measures definition document, and finalized a list of the process measures to be used for surveillance, it was important for the research team to validate their research efforts. The team conducted a two-phase on-line survey to validate results. An on-line survey was initially sent to the surveillance personnel at FedEx. There were two managers, and four quality assurance representatives who took part in the first survey. Prior to the surveillance personnel taking the survey, the research team sent out an e-mail to the participants. This e-mail had detailed instructions about how to take the survey, and the team also expressed its motive for the survey. The team also sent the participants the definitions document to read before taking the survey. The survey was designed to last a maximum of 60 minutes (including the time taken to read the surveillance definition document) and included 21 questions. The questions were of two kinds. There were Yes or No response questions, and open-ended questions. Irrespective of the nature of the 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 subjects taking the survey because of the regulated nature of the aviation industry. The team felt that if there were aspects which the participants were not in agreement with the research team, the team wanted a detailed explanation from the participants. All the participants of the survey were given the same set of questions. The participants taking the survey were not identified. With no identifiers, the WebSAT team would not know if the responses were from a manager or some other personnel lower on the hierarchy. 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, who also happened to be the primary customer of the product. A conference call was conducted with the managers at FedEx to finalize the first iteration.
In the next stage, the research team sent out the same survey to other supporting and partnering airline organizations. These airlines were Alaska Airlines, Delta Airlines, IATA, and America West. The results of this survey are still awaited.

4. Result

The first phase of the survey, gave positive results. The six proposed process measures were accepted by the surveillance representatives. The participants ranked the technical category process measures as the most important. Based on the preliminary results from the second survey, the research team proposes six process measures. In-Process, Verification, and Walkthrough surveillance suggest the technical aspect to surveillance. There are three non-technical surveillance categories. The first amongst these is Documentation surveillance which documents findings coming from surveillance performed on the vendor's documented system to validate issues such as quality control, technical data control, inspection, and work-processing programs. The next non-technical category is Facility surveillance, which documents findings from surveillance which is performed to validate shelf life control, housing and facilities, storage and safety/security/fire protection programs. The final category is Procedures Manual Violation. This surveillance ensures that the vendor is complying with the requirements set forth in the customer maintenance manual, and compliance requirements presented in the vendor Inspection Procedures Manual (IPM) or

Repair Station Manual (RSM). The team also designed a separate Fuel Surveillance Module which evaluates the fuel vendor's operational system, fueling equipment, records and the quality of the fuel. The survey data shows that there is a similarity in the application of surveillance in the other airlines. It appears, unlike FedEx, other airlines tend to perform more detailed audits as compared to hands-on surveillance. In other words, surveillance itself is *not* further categorized into other process measures. Further, it appears that non technical surveillance is not performed in as detailed a manner as conducted by FedEx. Considering technical process measures individually, the survey participants ranked the In process Surveillance process measure as the most important -as expected by the team.

5. Discussion

Overall, the methods adopted and the survey results show that more validation must be conducted on the process measures. The WebSAT research team plans to approach this by visiting other airlines onsite to understand the differences in the surveillance process. The survey is a first step taken by the team to evaluate the identified process measures. The team survey data indicates that the surveillance personnel would find lesser process measures easier to handle and categorize maintenance events. There are often anomalies in deciding what process measure a particular work card would fall into. Though the definitions of the existing process measures were not ambiguous to the managers they were often confusing to the representatives. Previously, there were five process measures which were of either a controversial nature or were inadequately defined and redundant on certain occasions. These categories were Inspection, Quality Control, Work Processing, General Maintenance Manual (GMM), and Inspection Procedures Manual (IPM). The valuable input here was the fact that these were all included in the Non-Technical process measures category. Further, the research team tried to eliminate the ambiguity by reducing the number of process measures and incorporating sub categories in some of these process measures. This allows the representative to choose from the given options, and not to memorize them.

Considering human limitations on processing information, the team adopted a total of 6 process measures for surveillance which fall in the range of 7 plus or minus 2 (13). Further, there are two other modules which capture data from surveillance work function. However, these are not process measures that are required to be memorized by the QA representative The research team identified a new process measure called "Facility Surveillance" and incorporated the currently used measures like "Housing & Facilities" , "Shelf Life Control" and others that have been borrowed from C.A.S.E. standards as sub-categories in this primary measure. It was also identified that there were lot of ambiguities in choosing a process measure for a given discrepancy arising from procedures manuals violation used by the vendors and the company and that of C.A.S.E. standards. Further, the surveillance personnel of the company have to be aware of the details in the procedures manuals of vendors at different locations and the company's manual. In order to assist the personnel in this regard, the research team has combined these two measures in to one measure called "procedures manual violation" so that the data can be consistently captured into one process measure. There are advantages of having both these process measures because it provides the managers with an insight into the vendors' regulated procedures and the discrepancies that exist between vendors' and company's procedures. Hence, 'Vendors Inspection Procedures Manual' and 'Company General Maintenance Manual' are provided as sub categories in the Vendor Inspection Procedures Manual. The survey results showed that the participants perceived no ambiguities in the identified process measures.

"Additional Findings" module further has two sections in it namely 'Information' and 'Aircraft Walk Around.' Information includes the surveillance activities and data that the on-site surveillance representative needs to document for informational purposes and does not necessarily hold the vendor against these occurrences. For example, this data could provide details on a discrepancy identified in the company's own manuals which would eventually help the company to refine it for future use. The other section, 'Aircraft Walk Around' captures data on any technical anomalies found on an aircraft which are beyond the scope of the scheduled maintenance event. Every attempt has to be made by the surveillance representatives to make sure that the finding is not part of the scheduled maintenance event and hence cannot be measured by the process measure -verification surveillance.

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USE OF PRODUCT DESIGN METHODOLOGY TO DEVELOP THE TECHNICAL AUDIT PROTOTYPE FOR WEBSAT

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Data analysis tools are effective in evaluating various processes and identifying problematic areas. Safety being the primary concern of the aviation industry, it is imperative that effective data analysis be conducted on data obtained from various aviation processes. WebSAT is a web-based surveillance and auditing tool which is intended to capture errors from aviation maintenance processes and analyze the data to further evaluate on the effectiveness of each of the maintenance processes. WebSAT will collect data for the quality assurance work functions of aircraft maintenance, which are surveillance, internal audits, technical audits, and airworthiness directives. This paper presents the product design methodology used to prototype the technical audit module for WebSAT. As a part of the design methodology, customer statements were analyzed and corresponding need statements were generated. These were then used to generate metrics in terms of which product specifications will be established. Concepts were generated for the design of the module and were tested with potential users to identify the most promising one. Later, the selected concept was refined by incorporating features of other concepts that were preferred by the user.

Introduction

The Federal Aviation Administration has continually supported human factors research to explore various strategies that improve aviation safety. Aviation maintenance is identified as a crucial factor that contributes to accidents (Boeing and US ATA, 1995) and hence considerable amount of research in past has focused on identifying intervention strategies that enhance the functioning of the aviation maintenance system. Previous research on aviation maintenance investigated issues pertaining to the performance of the inspector or the aviation maintenance technician (AMT). These studies have devised several training strategies, such as on-the-job training (OJT), computer-based training (CBT) and training in a virtual reality environment to improve the efficiency and the effectiveness of the AMT (Nickles et al, 2001). There have also been studies which looked at the psychophysical aspects of the inspector, such as age, fatigue, and cognitive abilities to assess the performance of an inspector on the highly demanding inspection task, where errors have a severe impact on aircraft safety (FAA, 1991).

Various methodologies have been adopted to analyze errors so as to recommend human factors interventions that enhance the safety of an aircraft. Error classification schemes (Patankar, 2002) are very useful for identifying weak points in a system, provided they are backed by comprehensive investigation procedures. In addition to these schemes, empirical models are needed to determine how the parts of the system interact to influence outcomes. A recent example is the Maintenance Error Decision Aid (MEDA) (Rankin et al., 2000). MEDA helps analysts identify the contributing factors that lead to an aviation accident. However, the MEDA process is dependent on the erring technician's willingness to be interviewed about an error. Anything that would decrease this willingness, such as a fear of being punished for the error, would have a detrimental effect on MEDA implementation.

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: 1) professionalism, which is defined in terms of reactions to work stressors and personal assertiveness and 2) trust, defined in terms of relations with co-workers and supervisors.

All these efforts tend to be reactive in nature, analyzing accidents subsequent to their occurrence. Hence, there is a need for empirically validated models/tools that capture data on maintenance work and provide a means of assessing this data prior to dispatch of the aircraft. The inspection carried out on an airplane by the AMTs is often overseen and audited by the airlines which own the airplane. The data that comes out of these surveillance and auditing processes is an indicator of the efficiency and effectiveness of the maintenance and inspection tasks that are being carried out by the AMT. An appropriate data collection strategy could identify the significant sources of improper maintenance, which would in turn reflect on the efficacy of the aviation maintenance process. Furthermore, the data thus collected can be utilized to conduct analysis and assess risk related factors which would eventually impact the safety of the aircraft. Also, the data analysis could provide valuable information such as error trends specific to a fleet type or a particular vendor which would help the airline management to proactively mitigate risk. However, existing models and schemes often tend to be ad hoc, varying across the industry, with little standardization. In order to address this issue, the devised empirical models and tools must employ standardized data collection procedures, provide a basis for predicting unsafe conditions, and produce interventions that will lead to a reduction in maintenance errors.

To collect the relevant data from disparate sources that supervise aviation maintenance, the research team has proposed to design a system (WebSAT – Web-based Surveillance and Auditing Tool) that performs standardized data analysis while allowing standardized data collection. This research also proposes that standardization in data collection can be obtained by collecting data on variables which effectively measure maintenance processes and eliminate existing inconsistencies. These variables are defined by the research team as *process measures*. Process measures incorporate the response and observation-based data collected from various aviation maintenance processes and facilitate the process of data analysis. This research seeks to collect and present the error causes and occurrences using WebSAT. The industry partner the team is working with is FedEx, in Memphis, TN. The work functions for which data will be captured through WebSAT are surveillance, internal audits, technical audits and airworthiness directives. Dharwada et al. (2004) defined and described the aforementioned work functions in detail. To tailor the WebSAT system to the needs and job roles of the users at FedEx, the team started the development process by following the product development methodology developed by Ulrich and Eppinger (2003).

The research team gathered user requirements with respect to WebSAT in the first phase of the research. During data gathering sessions for the surveillance process, the team observed that the primary responsibility of the quality assurance representatives is to carry out surveillance on work cards performed by the AMT who directly impacts the safety of the aircraft. Collecting data from the surveillance activities performed by these representatives in a standardized way is imperative to identify error trends and mitigate risk proactively. Hence, apart from conducting surveillance, the quality assurance representatives are responsible for categorizing the data obtained into appropriate process measures.

In a similar fashion, the auditors from the technical audits process are responsible for verifying the adequacy of the procedures followed at the vendor's facility with regard to aircraft maintenance. The auditors perform their tasks using different checklists for different vendors, based on the type of vendor. Therefore, WebSAT needs to ensure aggregation of data into the appropriate process measures. For effective functioning of the system, it is very important that the system satisfies the users' needs and supports the accomplishment of their goals.

Within each of the 4 aforementioned work functions, there are two types of users – one at the operator level (e.g., the auditor) and the other at the management level of the work function in the quality assurance department of airline. There is also a third level of user in the hierarchy: the senior manager responsible for the overall adequacy of all the quality assurance functions.

Given the different scenarios that are to be presented to each user, based on their requirements, the design of the system plays a vital role in the accomplishment of the users' goals. Every design decision plays a role in the overall utility of the system in achieving the primary goal of ensuring aircraft safety. There are four modules to design. The current paper focuses on the application of Ulrich and Eppinger's design methodology to design the Technical Audit (TA) Module of the WebSAT prototype.

Methodology

User-centered design methodology enables the development of tools that perform at a high level in the hands of the end user. The user-centered design process is guided by three principles, outlined by Gould and Lewis (1985) in their seminal work in the field.

1. Early and continual focus on users and their tasks. Direct contact with users, including discussion and observation of their tasks and work environment identifies their wants and needs.

2. Empirical testing with users. Users doing real work with mockups and prototypes of product concepts are observed to identify areas requiring revision.

3. Iterative design. The design, based on the results of user testing, is refined to bring the product into

conformance with explicitly stated performance specifications.

These principles are practiced through the application of a variety of user-centered methodologies within a structured design process. Such methodologies include contextual design (Beyer and Holtzblatt, 1998), task analysis (Gramopadhye and Thaker, 1998; Hackos and Redish, 1998), the development and use of personas (Cooper and Reimann, 2003) and scenarios (Rosson and Carroll, 2002), usability inspection methods (Nielsen, 1993), and usability testing (Dumas and Redish, 1993; Rubin, 1994). These practices can be integrated into Ulrich and Eppinger's (2003) structured design process to achieve a methodology that is both user-centered and compatible with current best practice in product design and development.

The design and development methodology proposed by Ulrich and Eppinger can be structured in four phases:

1. Identifying Needs
2. Developing Product Specifications
3. Generating and Selecting Concepts
4. Iterative Prototype Testing

The following sections will explain how the above mentioned phases were carried out to develop the Technical Audit (TA) module of the WebSAT prototype.

Phase I - *Identifying Needs*: The research team used interviews, focus groups, observation sessions and surveys to collect data on the aviation maintenance processes at FedEx. Three members of the team prepared interview questions before hand. These questions were to guide them through the interview process, and were helpful in raising the issues that needed to be studied at FedEx. The techniques of contextual inquiry proposed by Beyer and Holtzblatt (1998) were used as the interview progressed. If the interviewee shared information which was not directly related to the question asked but was relevant to the product, the research team added inquiry into those topics. Process documentation was sought by the team to enhance their understanding of procedures better. Observation sessions helped the team to understand a typical day of the technical auditor. Focus groups conducted with the manager of technical audits and another technical auditor helped the team identify the intricacies of the technical audit process. While one person in the team focused on questioning the users, a second person focused on taking down notes. The third person concentrated more on capturing behavioral gestures, concerns and emotions of the user describing the current system. The team members also switched their roles and, if one of them felt it appropriate to interrupt the process to clarify certain issue, he / she did not hesitate to do so.

Information Gathered on the Technical Audit Process:
There are two types of technical audits: 1) Supplier Audits and 2) Fuel, Maintenance and Ramp (FMR) Audits. Further, in supplier audits alone there are several types of vendors involved. For each type of vendor, the auditors might use just one checklist or more than one. These checklists have questions that evaluate the procedures, regulatory policies, and compliance of the vendors in terms of the requirements of FedEx and the FAA. The data collected from the checklists are responses in the form of Yes, No, Not Applicable, Not-Observed or some open ended comments. The findings obtained are shared with the vendor and the vendor is expected to implement corrective action within a stipulated period of time. The data collected from the technical audit checklists for a particular vendor is reported to the TA manager by the auditors. This report also includes concerns of the auditor and comments with respect to the vendor personnel, the facility or fleet type. The users involved in this work domain are the technical auditor and the TA manager.

Having gathered data on the TA work domain, the team moved towards identifying process measures for the work function. Process measures classify the data collected from the checklists. In order to identify the process measures, the team studied the various checklists that existed for TA. The team also studied the Coordinated Agency for Supplier Evaluation (C.A.S.E) standards which contain a detailed description of the various categories related to vendor evaluation. Using this documentation, the team formulated process measures based on the sections in the checklists (Iyengar et al., 2004).

Phase II – *Developing Product Specifications*: With the material gathered on the work flows, the team discussed the transcribed material and encapsulated the information in the form of work flow diagrams. The team converted each customer statement into need statement. These need statements were grouped based on relatedness and were then arranged in a hierarchy. Each group was given a name, which was considered to be the primary need and all the need statements within that group were termed secondary needs. This hierarchy of primary and secondary needs was sent to the stakeholders to elicit an importance rating for each need. The team members also gave a rating to the needs, based on their understanding of the process. The average of the rating obtained from the team members was compared with the rating obtained from the client and in most cases the ratings were similar to each other. Based on the project scope and team consensus, two needs were eliminated. Every need statement was then converted into a 'metric' which appropriately measured the performance of the product with respect to the need. An example of a customer statement, need statement and its metric is shown in Table 1 below.

Table 1: Conversion of Customer Statement to Need Statement and to Metric

Customer Statement	I would like the tool to provide documentation of corrective actions for Non-Systematic audits.
Need Statement	The tool stores documentation on non-systematic audits.
Metric	Time taken to download the documentation on corrective actions for audits
Unit	Seconds

Having generated metrics, the team started generating design concepts, while working on competitive benchmarking in tandem. Each member in the team generated one concept. Subsequent to the generation of the concept, the team followed the gallery method, using a whiteboard to refine the concept with various ideas of the team members. Depictions of the three concepts are shown in the figures below. Different scenarios were developed with respect to the two types of users. Then the team had brainstorming sessions on the pros and cons of each concept and consequently, attempted to refine each concept further.

<u>Phase III</u> - *Testing*: In this phase the concepts were pilot tested with two faculty members at Clemson University. These were representative users only to the extent that their age matched with that of the users. The testing took place with low-fidelity prototypes, in that the prototypes depicted the features of the concepts, but they were not functional. Prior to testing, the participants were informed about the auditor's job role and responsibilities.

Subsequently, the participants were presented with three scenarios and were asked to point out how they would go about performing the task with each concept. They were asked to think aloud while performing these tasks. The feedback obtained from this testing was documented but was not acted upon before the second phase of testing, which involved testing with real users.

Figure 1: Concept 1- Based on the Google Search Engine but with multiple search criteria.

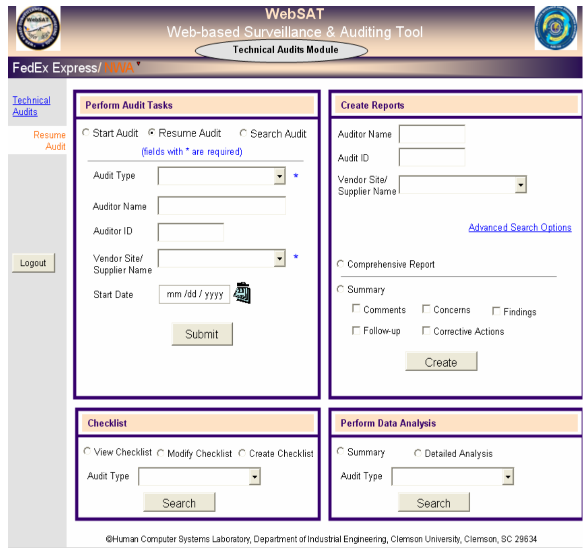
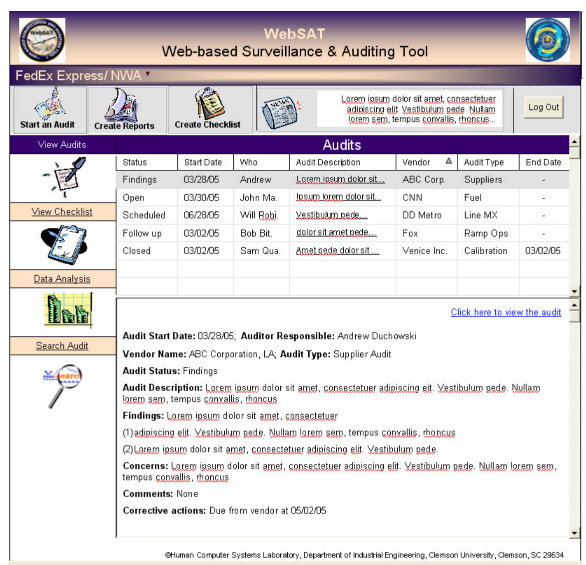


Figure 2: Concept 2 - Based on Microsoft Outlook



Two audit managers were recruited for testing. They signed a consent form before participating in the study. The users were physically located in Memphis, while the experimenters were in Clemson. To enable remote testing, the participants were sent PowerPoint files consisting of storyboards of all the screen shots, with instructions. A scenario was presented to them on one slide and the screens were presented on the next slide. The testing was done during a conference call so that the team could ensure that the users were "on the same page" as the experimenters.

Figure 3: Concept 3 - Based on Tab Metaphor

Figure 4: Final Concept - Tab metaphor of concept 3 combined with data grid of concept 2.

Results and Discussion

The results of the initial testing phase with the faculty showed that the organizational structure of concept three was preferred to that of the other two concepts. These users also mentioned that the grid feature of concept two was easy to understand and intuitive. The results from final testing also showed that concept three was preferred overall. The grid feature of concept two was also preferred by all of the users who participated in the two phases of testing.

One user mentioned that the vendor dropdown for vendor list needed to be constrained based on criteria such as vendor type, as there could be as many as in some cases, 600 vendors. With the feedback obtained from testing, the concepts were further refined and combined. A screen shot of the final concept is shown in Figure 4. Having selected this concept, the team proceeded to develop this concept using Microsoft ASP.NET 2002 and SQL server.

Conclusions

The team still is in the process of competitive benchmarking and setting the target specifications for the product. Subsequent to the development of the product, user testing will take place with representative users to compare the performance of the prototype with the product specifications and drive iterative refinement of the design. After the completion of the TA module, the research team will proceed to the development of the other modules using the same structured methodology. The research team is finding this methodology extremely helpful in developing a product that can positively influence aviation safety.

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WEBSAT: DEVELOPMENT OF PROCESS MEASURES FOR AIRCRAFT SAFETY

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ABSTRACT

Inspection and maintenance errors that occur in aircraft maintenance systems have a formidable impact on the safety and reliability of air transportation. Evaluation of the aircraft maintenance system requires an analysis of the maintenance processes in use. Significant efforts have been made to investigate and track inspection and maintenance errors. Although valuable in terms of their contributions to the identification of the performance-shaping factors that lead to maintenance errors, these efforts have tended to be reactive in nature. The systematic evaluation of data collected on the aviation maintenance process can provide management with feedback on the performance of the airline and consequently provide proactive support of the decision-making process prior to the dispatch of the aircraft. Recognizing that surveillance, auditing and airworthiness directives form a significant portion of the quality assurance function of an airline, it is critical that data be collected on these processes. Process measures for these work functions were identified by the research team based on human-factor principles, utility of data being captured, and working around mental models of the quality personnel. This research presents the identification strategy adopted by the research team to finalize the process measures for the three work functions mentioned above. Following this identification phase, the team carried out two surveys to validate the process measures. The first survey was taken by FedEx to finalize and prioritize process measures, the results of which have been presented in this paper. In the second survey, the team will validate with other industry partners to prioritize process measures, the results of which are awaited.

1.0 INTRODUCTION

Air transportation is becoming continually complex. To ensure safe and reliable air transportation, the Federal Aviation Administration (FAA) issues and enforces regulations and minimum standards covering manufacturing, operations, and aircraft maintenance to minimize the aircraft accidents. Maintenance error has been found to be a crucial factor in aircraft accidents (Boeing and US ATA, 1995). 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" (Weick, Sutcliffe, & Obstfeld, 1999, p. 93). Given the ever increasing complexity of an 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 these errors and the possible solutions to counter this situation. Human factors research in maintenance deemed the human as the central part of the aviation system (Gramopadhye and Drury, 2000). This human factors research considers the psycho-physiological aspects of the human and explains the need for developing different human factors interventions which ensure that the task, job and environment are defined judiciously to match human capabilities and limitations. This enduring emphasis on humans and their role in aviation system results in the development of error-tolerant systems.

There has been research involving the analysis of a maintenance incident database and the associated incident investigation reports. Although the database and incident reports highlighted the relevance of factors such as inadequate training, poor supervision, and individual factors such as stress and fatigue as causes of maintenance-related incidents, this approach is still very reactive in nature. This approach involved a series of focus group and interviews with maintenance personnel and their supervisors to ascertain their perceptions of factors that impact on maintenance work. 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 and Jones, 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 and incidents. 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 (cited in 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 (cited in McKenna, 2002).

Various airlines have also developed their own internal procedures to track maintenance errors. One such methodology employs the failure modes and effects analysis approach (Hobbs and Williamson, 2001) and classifies the potential errors by expanding each step of a task analysis into sub-steps and then listing all the failure modes for each sub-step. The US Navy Safety Center developed the Human Factors Analysis and Classification System – Maintenance Extension Taxonomy and the follow-up web–based maintenance error information management system to analyze naval aviation mishaps (Shappell and Wiegmann, 1997; Schmidt, et al., 1998; Shappell and Wiegmann, 2001). Later, this system was used to analyze commercial aviation accidents (Wiegmann and Shappell, 2001). The development of descriptive models of human error and accident causation (Reason, 1990; Senders & Moray, 1991) and the recent adaptation of Reason's model to aviation maintenance (Reason & Hobbs, 2003) are major steps in the right direction. Research on error classification schemes (e.g., Patankar, 2002; Shappell & Wiegmann, 1997) and, more recently, safety culture (Taylor & Thomas, 2003; Patankar, 2003) are some other valuable literature in this area of research. The increasingly sophisticated error classification schemes now in use in the aviation industry recognize the multiple causes of error by providing categories that capture the role of organizational, social, and individual variables. These categories embrace the roles of maintainers, operators, supervisors, as well as various levels of management (e.g., Shappell & Wiegman, 1997). The problem with classification schemes, however, is that there is no causal model embedded in the schemes to show how the linkages within the system operate. Classification schemes, provided they are backed by comprehensive investigation procedures, are very useful for identifying weak points in a system. However, in addition to these schemes, empirical models are needed to illustrate how the parts of the system work to influence outcomes. Another recent example would be the Maintenance Error Decision Aid (MEDA) (Rankin et al., 2000). This tool, developed by Boeing, with British Airways, Continental Airlines, United Airlines, the International Association of Machinists and the U.S. Federal Aviation Administration, helps analysts identify the contributing factors that lead to an aviation accident. MEDA was easy to use once it had been implemented – the main problem was MEDA process implementation. MEDA needed a management champion for its implementation at each airline. Consequently, airlines that typically punished maintenance technicians for errors found it harder to implement MEDA than airlines that had not carried out discipline for error. Since the MEDA process is dependent on the erring technician's willingness to be interviewed about the error, anything that would decrease this willingness, such as a fear of being punished for the error, would have a detrimental effect on MEDA implementation.

Attempts have been made to define a core set of constructs for safety climate (Flin, Mearns, O'Connor, & Bryden, 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: 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 the descriptive accident causation models, classification schemes, and self report questionnaires, 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, the devised empirical models and tools are required to employ standardized data collection procedures, provide a basis for predicting unsafe conditions and design interventions that will lead to reduction in maintenance errors.

Analyzing the effectiveness of maintenance and inspection procedures is of primary importance to accomplish the objective of standardized data collection and to proactively identify the potential factors contributing to improper maintenance. This can be achieved by closely monitoring and evaluating aircraft maintenance and inspection activities. As a part of this evaluation, surveillance of maintenance and inspection activities is conducted in a rigorous fashion by the quality assurance and or control department of airlines. The surveillance, auditing and airworthiness directives groups constantly monitor and evaluate the flight procedures to determine their level of compliance. The objectives of these groups are achieved through effective functioning of the representatives who perform surveillance and auditing activities. Their findings help in the evaluation and assessment of the internal and external organizations associated with the airline which influences the safety and airworthiness of aircraft. The surveillance and auditing activities are of foremost importance in ensuring adherence to the quality requirements and also maintaining a consistent level of supervision over maintenance operations.

1.1 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. The primary objective of surveillance is to provide the airline, through the accomplishment of a variety of specific surveillance activities on a planned and random sampling basis, an accurate, real-time, and comprehensive evaluation of how well each substantial maintenance vendor is complying with the airline's and FAA requirements. For example, FedEx has a Quality Assurance (QA) 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 the surveillance schedule. The results are documented and used to analyze the risk factors associated with the concerned vendor and aircraft. The FedEx surveillance department is already using categories to collect the data obtained from a surveillance visit at the maintenance facility. The team used these categories as a starting point in their process to identify the process measures. Some of the categories currently being used by FedEx are in-process surveillance, final walk around, verification surveillance etc. These categories were created based on the various surveillance tasks and the C.A.S.E. (Coordinating Agency for Supplier Evaluation) guidelines that have to be adhered to by the substantial maintenance vendor and the airline.

1.2 Audit

Audit is a more formal activity that addresses specific issues. Auditing may be performed at two levels- Internal and Technical audits. Internal audits are those that are performed within and/or across the airline departments. Oversight of functions relating to aircraft line maintenance, ramp operations and aircraft fueling, whether owned by the airline or contracted, is accomplished by a formal system of technical audits performed by qualified technical auditors. The audit manager will assign an auditor and schedule the audit. The auditor will select the audit standards, perform pre-audit analysis and finally complete the audit. The auditor then reports the findings to the manager. This results in a corrective actions report. These audits are recurrent. Currently, FedEx's team of internal auditors uses categories to group the data that is collected during an internal audit. The categories are built into the checklist used by the auditors. Although not much analysis is done on the data collected, this method presents a good approach to viewing the information collected during an internal audit. A similar approach is used by the FedEx technical audit team for some of their audits.

1.3 Airworthiness Directives Control

The Airworthiness Directives Control Group (ADCG) is responsible for the implementation of new, revised or corrected Airworthiness Directives (AD) appearing in the Federal Register. If the "applicability statement" of an AD refers to an aircraft model and series or engine model and series operated by the airline, or if the AD addresses an appliance or component that could be installed on an aircraft operated by the airline company, the ADCG considers the AD to be initially applicable. A Work Instruction Card (WIC) generated by the ADCG is used by the maintenance personnel to check for compliance with the AD. There are checklists to review the compliance of a WIC. These checklists can be used as a process measurement tool to review each WIC and identify any discrepancies. The findings obtained from these reviews can be used to identify risk factors. Follow up of these discrepancies results in corrective actions.

Given the four above mentioned work functions, the goal of surveillance and auditing activities can be achieved through implementation of a system that documents the processes and outcomes of maintenance activities and makes this documentation more accessible. Thus, there is a need to develop a system that ensures superior performance of these activities. This system should perform the following functions:

1. Seek input from diversified sources
2. Proactively identify contributing factors
3. Promote a standardized format for data collection, data reduction and data analysis within and across the aircraft maintenance industry
4. Generate trend analysis for problem areas (causal factors within and across organizations)

In response to this need, the research team is developing a proactive surveillance and auditing tool to devise strategies that enable identifying future problem areas. The identification of these problem areas will allow the industry to prioritize factors that apply across the industry to systematically reduce or eliminate potential errors. The work is done in collaboration with FedEx in Memphis, TN. The system will be a web-based application (WebSAT – **W**eb-based **S**urveillance and **A**uditing **T**ool) which will initially be developed with FedEx as the aviation partner and later will be made available as an application that can be used by other airlines.

To achieve standardization in data collection, data needs to be collected on certain variables which measure maintenance processes and eliminate existing inconsistencies. These variables are defined by the research team as process measures. The process measures incorporate the response and observation-based data collected during surveillance, audits, and the airworthiness directives control processes. The specific objectives of this research are to:

(1) Identify an exhaustive list of process measures that potentially impact the aviation safety and transcend various aircraft maintenance organizations;

(2) Develop data collection/reduction and analysis protocols to analyze errors for the identified set of impact variables; and

(3) Using the results of the aforementioned activity, develop and implement a surveillance/monitoring tool which assures that a consistent level of oversight is maintained.

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.

The current paper focuses on the first phase of the project which concentrates on the identification of process measures. The various steps taken to identify these process measures are explained in detail in the methodology section. The results section provides details on the various process measures that have been developed and currently being validated by other airlines through a survey. The discussion section presents the various decisions and problems encountered in the development of the process measures.

2.0 METHODOLOGY

A task analytic and user-centered software lifecycle development methodology is being applied to this research. The team started of by gaining a comprehensive view of the different surveillance and auditing processes, their functions and the different tasks involved in accomplishing these processes. Research was conducted to identify the process measurement variables and performance metrics that potentially impact aviation safety. These performance metrics are termed as process measures. It was ensured that the variables identified are appropriate and are representative of those used by other maintenance entities. This was done by working with other airline maintenance facilities (e.g., substantial maintenance vendors and third party repair stations). The product design and development phase was guided by a user-centered design methodology that enables the development of tools that perform at a high level in the hands of the end user. The structured approach of contextual design was used to gather and represent information acquired (Beyer and Holtzblatt, 1998).

2.1 WebSAT Phases: The WebSAT research is being conducted in three phases:

2.1.1 Phase 1: Identification of Process Measures and Data Sources

- Product planning phase
- Gathering stakeholder data
- Interpreting raw data in terms of customer needs and process measures
- Identify the process measures
- Ensure that the identified process measures are representative of those used by most maintenance entities
- Identify the limitations in using the specific process measures identified

The first phase of the research will finalize the list of process measures.

2.1.2 Phase 2: Develop Prototype of Auditing and Surveillance Tool

- Needs analysis phase
- Product specifications phase
- Concept generation and selection phase
- Detailed design of selected concept to create an initial working prototype
- Testing and refinement
- Delivery of a refined prototype to FedEx for trial use

2.1.3 Phase 3: Develop Data Analysis and Validation Module

- Develop advanced data analysis tools that include multivariate analysis and risk assessment.
- Validate using field data.

The details on the current phase (Phase 1) are presented below:

Product planning phase: This phase includes the assessment of technological developments and project objectives. The output of the planning phase was a project mission statement which specifies a vision for the product, the target market, project goals, key assumptions, constraints, and stakeholders. The mission statement for WebSAT is given in **Figure 1**.

Mission Statement: Web-based Surveillance and Auditing Tool Prototype	
Product Description	• An application, incorporating a recommended categorization and data collection scheme for maintenance auditing and surveillance application; a data reduction module that allows the analysts to conduct central tendency analysis and data analysis module that facilitates trend analysis.
Key Business Goals	• Achieve standardized data collection/reduction and analysis of maintenance errors across the geographically dispersed entities of the airline industry • Develop a proactive system that captures maintenance errors • Generate trend analysis
Primary Market	• FedEx
Secondary Market	• Other airlines in the Airline Industry
Assumptions & Constraints	• SQL server, ASP.NET
Stakeholders	• FedEx QA Department • Airworthiness Directives Control Group • FedEx Technology Group • Other airlines

Figure 1: WebSAT Mission Statement

A product mission statement briefly presents the key customer and user benefits of the product, but avoids implying a specific concept. It summarizes the direction to be followed by the product development team (Ulrich and Eppinger, 2004).To ensure that the appropriate range of development issues is addressed, all WebSAT stakeholders, i.e., the groups of people who will be affected by WebSAT, are identified and listed in the mission statement. This stakeholder list begins with the end user and customer but also includes those people tasked with installing, managing, and maintaining WebSAT. The list of stakeholders helps to ensure that the needs of all who will be influenced by WebSAT are identified and considered in its development.

Gathering of stakeholder data: This phase has identified the stakeholders' needs to support the performance of maintenance activities. The methods used to collect this data include interviews, focus groups, observations of the use of the existing system, and the analysis of documentation describing current procedures and regulations for maintenance auditing.

Interpretation of the raw data in terms of customer needs and process measures: The verbatim statements of the stakeholders and the information gleaned from observations of the existing process and documentation was used to understand the process as a whole. This allowed the WebSAT team to brainstorm on the process measures that would evaluate the various work functions of surveillance, auditing and airworthiness directives group. The identified process measures were validated through a survey. The details on this phase are presented in the "Data Collection" section in this paper.

The information from the data gathering sessions will be translated into a set of user need statements and a task description. The need statements express stakeholder needs in terms of what an improved human-machine system has to do, but not in terms of how it will be done. The needs will be organized into a hierarchical list of primary and secondary needs using affinity diagramming. The primary needs are the most general categories, while the secondary needs express specific needs in more detail. The task description will be used to develop a set of representative task scenarios and to perform a detailed task analysis. A task scenario describes activities, or tasks, in a form that allows exploration and discussion of contexts, needs, and requirements with users. It avoids making assumptions about the details of a particular interface design. The task analysis assists in the identification of the specific cognitive and manual processes critical in the performance of the auditing task, as well as existing human-machine system mismatches leading to inefficiency and error (Gramopadhye and Thaker, 1998; Hackos and Redish, 1998).

2.2 Data collection

There are methodologies to collect and interpret information on process measures. The choice of a particular methodology is based on factors such as the type of data to be gathered, the manner in which the data is applied, and the time available for data collection. The methodology employed has a direct effect on the quality and value of the information collected. The team adopted interviews as they are a suitable strategy to meet the airline managers. It also allowed the WebSAT team to take a first-hand look at the stakeholders' work environment and collect useful documents. It provided the stakeholders with an opportunity to put a face to the names involved in the research project. Observation sessions are important to understand how aircraft maintenance is done and to see how the maintenance personnel carry out their day-to-day work. Since the airline industry is a highly regulated industry, it was easier for the team to learn more about the industry by reading relevant procedural manuals. The team used questionnaires in a web survey subsequent to the interviews, focus groups and observation sessions. This allowed the team to evaluate (remotely) the appropriateness of the identified process measures with FedEx and other airlines.

2.3 Procedure for initial data gathering

The team sought Institutional Review Board approval (IRB Protocol #40159) before beginning the trips to conduct interviews. The research team would establish the agenda for each visit, and would get in touch with the concerned personnel via e-mail and telephone at least two weeks before the meetings. The team would then e-mail the personnel concerned with each visit with an agenda for the meeting, valid questions which the research team would plan to ask on the day of meeting, and the team would also give a time estimate to the personnel about the estimated time for each meeting. A time would be finalized two days before the departure of the research team. The managers, quality assurance representatives, and the personnel associated with the daily repair and maintenance of the aircraft would allow the research team to have access to documents if the team found a certain document necessary for in-depth study, at their own research laboratory. The FedEx personnel were more than helpful in this regard.

2.4 Subjects for initial data gathering

The interview sessions, observation sessions, and the documents were the initial methodologies used to gather data for the first phase of the project. This data was used to finalize an initial WebSAT framework as shown in **Figure 2**.

The WebSAT framework strategy for the research revolved around three tiers. As seen in Figure 2, 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 the final tier, tier 3, another analysis would finally categorize the variables into risk (impact variables), and non-risk variables.

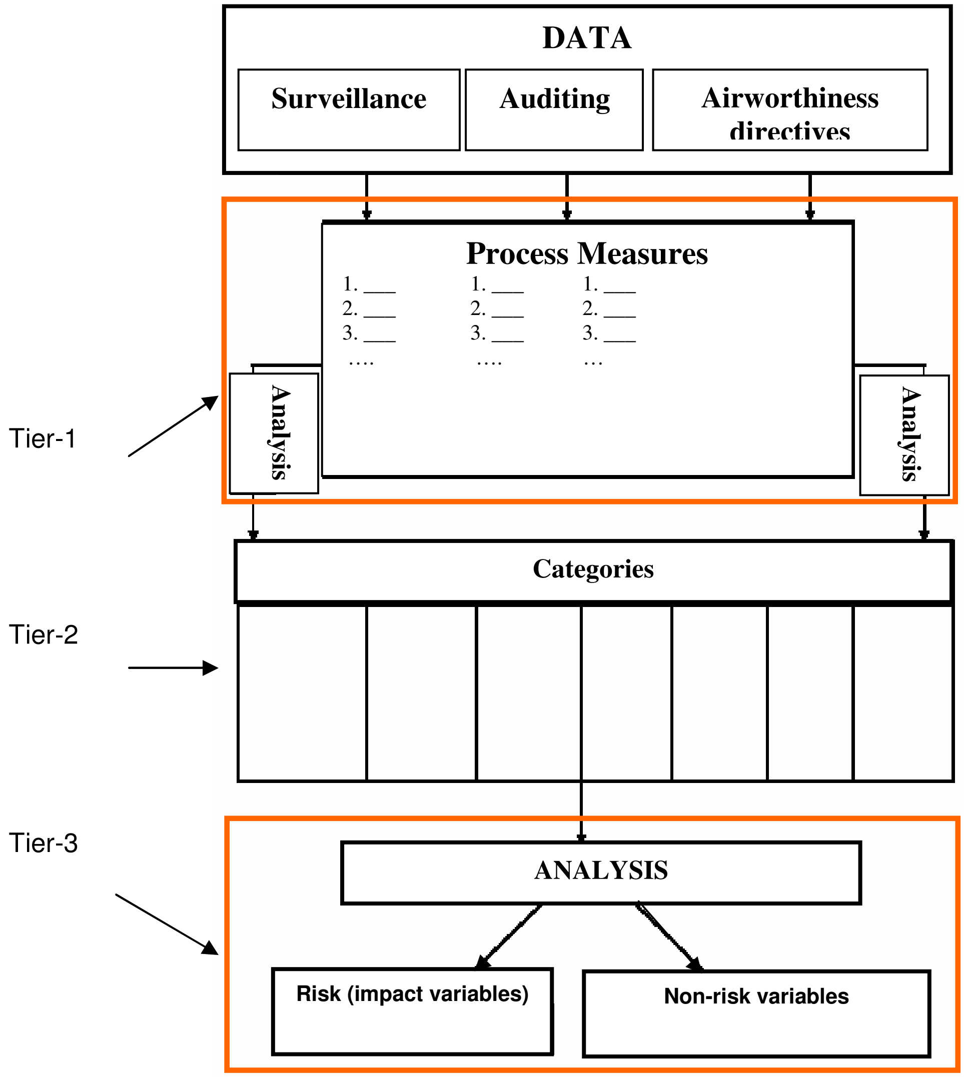

Figure 2: WebSAT framework

The initial data also conveyed to the team the expectations of the personnel who were finally going to use the product. This data gave the team an insight into the utility of the process measures. For this initial phase, the subjects who were interviewed and observed in their work domain setting were quality assurance representatives from the surveillance, internal audit, technical audit, and the airworthiness departments at FedEx. The team conducted at least five sessions at the vendor facility at Mobile, AL, and the FedEx headquarters at Memphis, TN. The team also conducted phone interviews with FedEx personnel.

2.5 Procedure for the survey

Following the initial data gathering, surveys were conducted in two phases to validate the data gathered. In the first phase, there were four different surveys: one each for surveillance, internal audits, technical audits, and the airworthiness directives. The team sent out a detailed e-mail to all the participants regarding the survey which had instructions on how to take a survey. All the four surveys provided a link to a definitions document which explained what the process measures are and how they have been defined by the team. The e-mail also provided the participants with the contact information of the research team. The first survey was completed by all the participants at FedEx in 14 days. The feedback was utilized to refine the process measures definitions, and the scope of data being gathered by each process measure. The next seven days were utilized to refine the identified process measures based on the input obtained from this survey. In case the team needed some clarification in their decision making process, they made a conference call with the work function manager for clarification. The refined process measures were used to send out the next survey to other partnering airlines. The second phase of the survey with the partnering airlines is being conducted at present, and the research team is awaiting the results.

2.6 Customer selection matrix for the survey

There were three kinds of users. The first kind was subjects in the managerial positions, who would be involved in intricate data analysis. They would use findings, information, and data from their respective work domains and departments to keep a vigil on the proceedings in the organization and their own departments. The second kind of users was subjects who work under these managers. Their involvement is on a daily basis, and involves subjects from the surveillance departments. The third kind of user is auditors and personnel from airworthiness directives departments, who do not use the product on a daily basis, but as and when the need arises for some sort of data evaluation. The customer selection matrix is presented below in Figure 3.

Market/Users	Managers	QA Representatives	Auditors / AD personnel
Surveillance	2	4	--
Internal Audit	1	--	5
Technical Audit	1	--	5
Airworthiness Directives	1	--	5

Figure 3: Customer Selection Matrix for the WebSAT survey.

2.7 Subjects for the survey

There were six subjects including the manager for each work function and hence a total of 24 subjects from the Quality Assurance department of FedEx who were randomly selected for the first iteration to finalize the appropriateness of the process measures. Definitions were refined based on their inputs to the survey. Twenty subjects from other partnering airlines were asked to take a survey to further validate the research team's findings on the process measures.

2.8 Survey design

The survey was designed to last a maximum of 60 minutes for each of the three work functions: surveillance, auditing, and airworthiness directives. The questions were of two kinds. There were Yes or No response questions, and open-ended questions. Irrespective of the nature of the 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 subjects taking the survey because of the regulated nature of the aviation industry. The team felt that if there were aspects which the subjects were not in agreement with the research team, the team wanted a detailed explanation from the subjects. See **Figure 4 a & b** for survey screenshots.

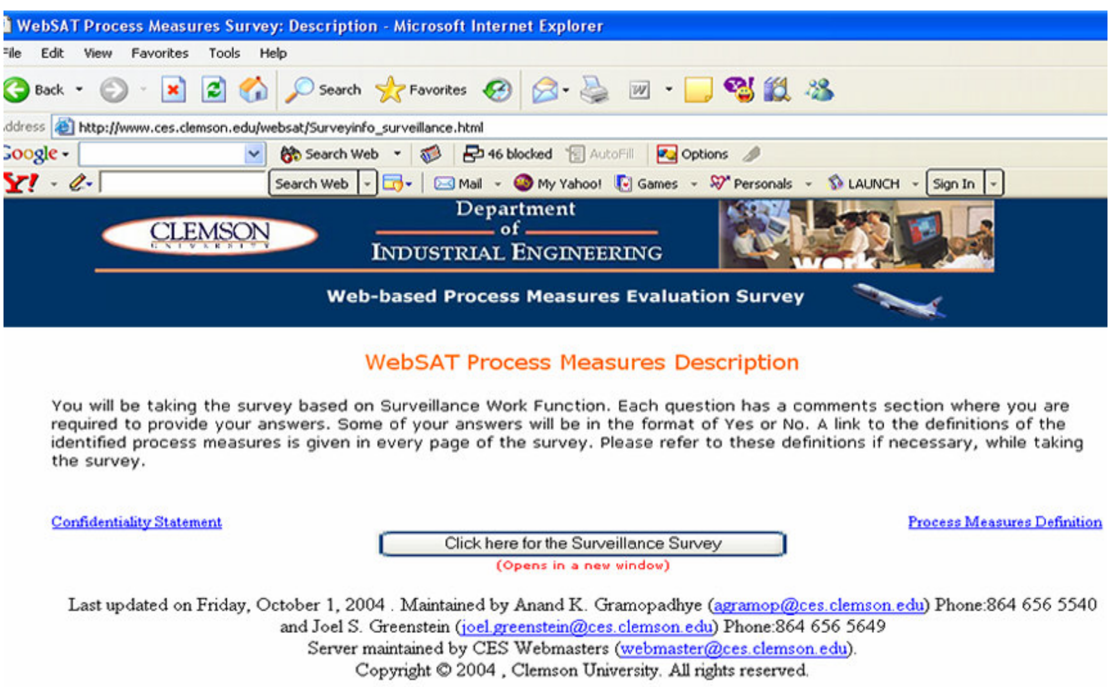

Figure 4 a: Survey Screenshot – First screen the participant sees before taking the survey

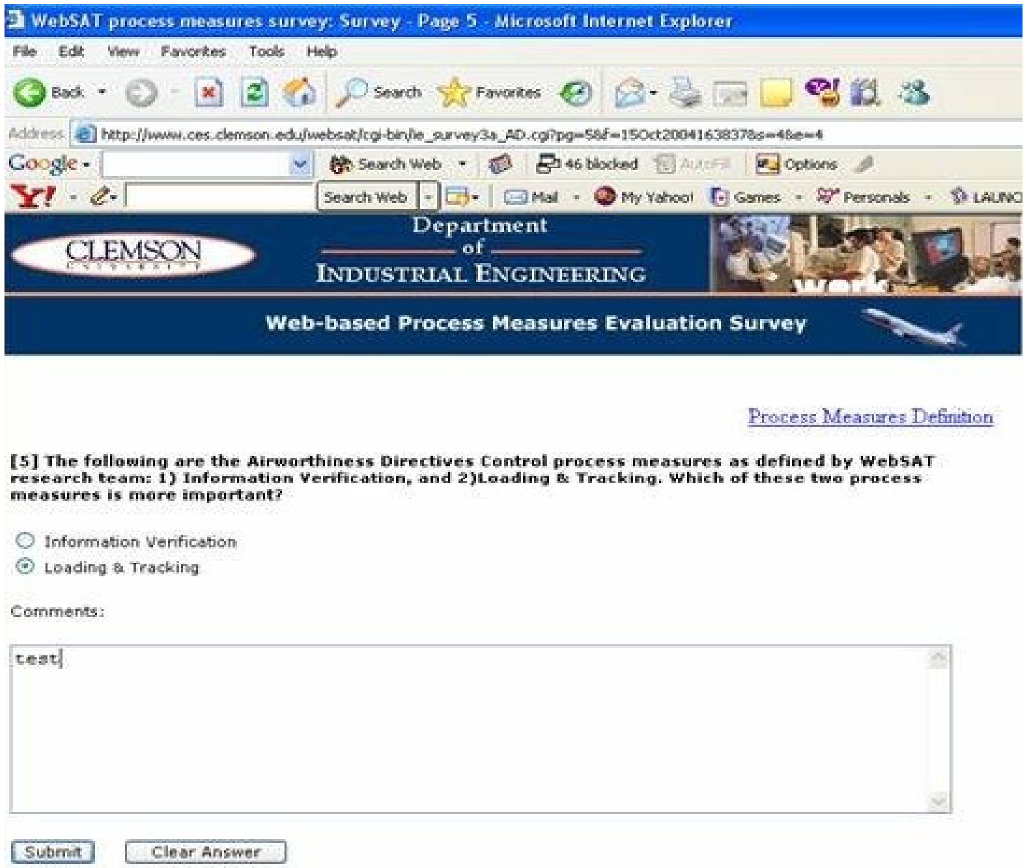

Figure 4 b: Survey Screenshot – Questions' screen

All the participants of the survey were given the same set of questions. The participants taking the survey were not identified. With no identifiers, the WebSAT team would not know if the responses were from a manager or some other personnel lower on the hierarchy. Each survey had a link to individual definitions document for each work function which detailed on the definitions and scope of each process measure. The initial part of the survey asked the participants on how they performed their day-to-day work routine. It also asked if the participants categorized their current work processes. Further into the survey, the questions became more specific to the process measures and their utility to the participants. The participants were also asked to rate the importance of each process measures. The survey also included questions on the redundancy, functionality and purpose of the process measures as presented in the definitions document. The survey included 21, 14, 7 and 5 questions for the surveillance, technical audits, internal audits and airworthiness directives survey respectively.

The programming effort required HTML, PERL scripting, and the usage of the cgi-bin on the Clemson engineering systems network. The data in terms of responses were stored in text files (.txt) with the date stamp in the cgi-bin.

3.0 RESULTS

The identified process measures for different processes are given below:

Process measures for Surveillance

1. In process Surveillance: It is the act of observing a maintenance task that is currently in work. The on-site surveillance representatives will select certain work cards, AD driven work cards, EOs, EAs, non-routines and observe the task being accomplished by the vendor mechanic or inspector to ensure competency, correctness and adequacy of the customer's paper work to complete the task.
2. Verification Surveillance: It is the re-inspection/re-accomplishing of completed work cards, AD driven work cards, EOs, EAs and non-routines that are signed off by the vendor personnel as "Complete." No additional reopening of access panels that have been closed or disassembly of the aircraft or assistance from vendor personnel will be required unless poor workmanship or other conditions are evident during the surveillance.
3. Final Walk Around: It is a surveillance of the aircraft at the end of the scheduled maintenance event that checks the general condition of the aircraft usually after the vendor has completed the work scope assigned. For example: obvious safety, legal fitness, airworthiness items, general condition, cleanliness and completeness of the aircraft's cockpit, lavatory, landing gear wheel wells, all access panels properly installed and no indication of fuel, oil or hydraulic leaks.
4. Documentation Surveillance: This surveillance is performed on the vendor's documented system to validate the quality control, technical data control, inspection, and work-processing programs, as presented in C.A.S.E. standard 1-A (Revision 45- 1/7/2004). The vendor should be able to provide the required documents and certificates upon request.
    a. Certifications: This surveillance ensures that the certification program includes certificates, operations specifications, licenses, repairman certificates, anti-drug and

alcohol misuse program certificates, registrations and capabilities listing required by the Code of Federal Regulations for any individual, equipment or facility. For detailed instructions and description refer to C.A.S.E. standard 1-A section 2.

b. Quality Control: This surveillance ensures that the quality control program includes procedures and operation which must be described in a quality control manual or other appropriate document. For detailed instructions and description refer to C.A.S.E. standard 1-A section 3.

c. Inspection: This surveillance ensures that the inspection program includes procedures to maintain an up-to-date roster of supervisory and inspection personnel who are appropriately certified and are familiar with the inspection methods, techniques and equipment that they use. For detailed instructions and description refer to C.A.S.E. standard 1-A section 4.

d. Technical Data Program: This surveillance ensures that the technical data program requires all the maintenance operations to be accomplished in accordance with customer's manuals. It also ascertains that the vendor has a documented system to maintain current technical data and a master copy of each manual. For detailed instructions and description refer to C.A.S.E. standard 1-A section 6.

e. Work Processing: This surveillance ensures that there exists a documented system for all the programs and procedures that the vendor adopts for training, identification of parts, and use of appropriate tools and equipment in good condition to perform a maintenance task. For detailed instructions and description refer to C.A.S.E. standard 1-A section 13.

f. Tool/Test Equipment: This surveillance ensures that the tools and the test equipment used by the vendor for maintenance are frequently calibrated to the required standards. It also ensures that the tools and the test equipment program includes identification of tools and test equipment, identification of individuals responsible for the calibration, accomplishment of periodic calibrations, and applicable tolerance or specification. For detailed instructions and description refer to C.A.S.E. standard 1-A section 8.

5. Facility Surveillance: This surveillance is performed on the vendor's facility to validate the shelf life control, housing and facilities, storage and safety/security/fire protection programs, as presented in C.A.S.E. standard 1-A (Revision 45- 1/7/2004). The vendor should implement programs to maintain the facility and prevent damage, material deterioration, and hazards.
    a. Shelf Life Control: This surveillance ensures that the vendor describes in their manual a shelf life program, procedure, and a detailed listing of parts and materials which are subjected to shelf life. For detailed instructions and description refer to C.A.S.E. standard 1-A section 7.
    b. Storage: This surveillance ensures that the vendor identifies, maintains and protects parts and raw material during a maintenance event. For detailed instructions and description refer to C.A.S.E. standard 1-A section 12.
    c. Housing and Facilities: This surveillance ensures that the vendor houses adequate equipment and material, properly stores supplies, protects parts and sub-assemblies, and ensures that the facility has adequate space for work. For detailed instructions and description refer to C.A.S.E. standard 1-A section 10.
    d. Safety/Security/Fire Protection: This surveillance ensures that the vendor provides adequate safety, security and fire protection at the maintenance facility. For detailed instructions and description refer to C.A.S.E. standard 1-A section 11.
6. Procedures Manual Surveillance: This surveillance ensures that the vendor is complying with the requirements set forth in the customer maintenance manual, and compliance requirements presented in the vendor Inspection Procedures Manual (IPM) or Repair Station Manual (RSM).
    a. Customer Maintenance Manual Compliance: This surveillance requires the vendor to comply with programs, documented procedures, and standards described in the customer maintenance manual.
    b. Vendor Inspection Procedures Manual Compliance: This surveillance ensures that the vendor complies with programs, documented procedures, and standards described in the vendor IPM or RSM.

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: This module documents additional information pertaining to surveillance work domain. However, the categories in this module listed below do not hold the vendor responsible for the findings obtained. This module helps the surveillance representatives to document any information both technical and non-technical, beyond the work scope of the scheduled maintenance event. Note: Although these categories are not process measures, the findings obtained from this module are documented and reported through WebSAT.
    a. Information: It includes the surveillance activities and data that the on-site surveillance representative needs to document for informational purposes.
    b. Aircraft Walk Around: This surveillance category is to be used only for those technical findings that cannot be traced to a scheduled maintenance task and are beyond the current work scope of the scheduled maintenance event.
2. Fuel Surveillance Module: The fuel vendor surveillance module evaluates the fuel vendor's operational system, fueling equipment, records and the quality of the fuel.

Process Measures for Internal Audits

1. Administration: This process measure ensures the departments' ability to manage up-to-date documented systems and ensure the adequacy of various programs followed in-house.
2. Training: This process measure ensures that the employees of the departments within the organization are trained properly, and have the required certification to perform operations.
3. Records: This process measure ensures that the required records are made available for review by the departments within an organization.
4. Safety: This process measure ensures the overall safety aspect of the departments within an organization.
5. Manuals: This process measure verifies the technical data, manuals, and forms provided by the departments within an organization.

6. Procedures: This process measure ensures that the maintenance and flight operations departments adhere to federal aviation regulatory guidelines and company departmental policies while executing various operations within each program.

Process Measures for Technical Audits

1. Compliance/ Documentation: This process measure verifies documentation systems, authorization of personnel and administration requirements of vendors and sub-contractors. The process measure includes items such as quality programs, manuals and forms control, list of authorized persons, certification, certificate forms, etc. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.
   a. Quality programs
   b. Certification
   c. Certificate forms
   d. Internal audit and surveillance
   e. Manuals and forms control
   f. Paper work control
   g. Administration requirements
2. Inspection: This process measure verifies the certification of the inspector, the existence of acceptable sampling procedures of parts, compliance of parts to specifications, and the validity of the inspection stamps at the vendor location. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.
   a. Fuel inspection (Fuel truck inspection, Fuel farm inspection, Hydrant inspection)
   b. Inspection programs
3. Facility Control: This process measure verifies the vendor facility for shelf life control, housing and facilities, storage, and damage protection programs. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.
   a. Housing and facilities
   b. Material control and storage

c. Segregation of parts

d. Packaging

e. List of shelf items

f. Practices to prevent damage and cannibalization

g. Shelf life control and material storage

4. Training and Personnel: This process measure verifies that the vendor employees are properly trained, and have the required certification to perform operations. It also verifies the supervisory personnel, inspection personnel, return-to-service personnel, and personnel responsible for various programs in the facility like shelf life, technical data, calibration etc. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

    a. Employee training

    b. Verification of personnel

    c. List of authorized personnel

5. Procedures: This process measure verifies that the vendor adheres to regulatory guidelines while executing various operations within each program such as shipping procedures, NDT evaluations, and Aircraft deicing programs at the vendor facility. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

    a. Shipping procedures

    b. Tool and test equipment (calibration & measurement) and procurement

    c. Scrapped parts

    d. Work processing

    e. Processing

    f. Process control

    g. NDT evaluation

    h. Precision tool control

    i. Aircraft anti-tipping and tether maintenance

    j. Aircraft deicing program

k. Weight and balance

l. Weighing scales

m. Ramp operation Note: The findings of ramp activities related to administration requirements, employee training, and dangerous goods are not included in this process measure - ‘Procedures.’

6. Data Control: This process measure verifies the availability of up-to-date technical data for parts at the vendor’s facility. It also verifies the identification of parts to their testing records and validates the fuel audit records. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

   a. Technical data control

   b. Record keeping

   c. Fuel records (Fuel facility records, Fuel vehicle records, Pipeline fuel receipt records, Transport truck fuel receipt records)

7. Safety: This process measure overlooks the safety of the vendor facility. Listed below are some of the items that may occur in a technical audit checklist and will be evaluated by this process measure.

   a. Safety

   b. Fire protection

   c. Fire protection and flammable material protection

   d. Aircraft maintenance procedures

   e. Dangerous goods

Process Measures for Airworthiness Directives

1. Information Verification: This process measure validates the information presented on AD-related EO/WIC, manuals and other documents involved with the compliance of airworthiness directives. It also verifies information related to the AD status reports.

2. Loading and Tracking Verification: This process measure verifies the adequacy of the activities involved in the loading and tracking of airworthiness directives, including inspection intervals.

This survey is an attempt to understand if the identified process measures entirely capture all the relevant data from each department and also clearly communicate their purpose. Hence the data was mostly subjective generated from 'Comments' section. This paper does not report any quantitative analysis of data. However, there were questions in binary form which give the number of responses that indicate complete satisfaction with the identified process measures.

The results from the first survey which were utilized in refining the identified process measures have shown that these process measures evaluate the respective work functions precisely. In surveillance, four of the six responses (66.7%) indicated that these process measures were precise to evaluate surveillance process. However, two responses indicated that the metrics in the additional findings module – "information" and "aircraft walk around" need to be incorporated as process measures rather than other modules. For internal audits, two responses of the six (33.3%) have indicated that the process measures do not capture data from Air Transport Oversight System (ATOS) and hence do not capture the data relevant to internal audits department in its entirety. The results obtained from technical audits have indicated that these process measures capture all the relevant data from the technical audit department and also communicate the purpose of each measure appropriately. However, one response indicated in the comments section that the process measure compliance/documentation should also verify the regulatory compliance and documentation standards of sub–contractors of the airline. All of the responses for airworthiness directives have indicated that the given process measures capture all the data relevant to ADs.

4.0 DISCUSSION

There were 17 process measures initially in the surveillance work function. The interaction of the research team with the quality assurance personnel from this work function has provided the team with the insight that 17 is a very large number for humans to remember. In spite of training it could be a difficult task to accomplish on the shop floor. Moreover, the surveillance representatives are mostly focused on issues directly related to the aircraft than capturing data for later analysis. For example, if a discrepancy or defect is identified by a representative that has not been fixed by the vendor personnel, the representative's primary attention is focused on trying to fix the defect rather than collecting data on this issue. Although the surveillance representatives perform data collection on daily basis, it is a secondary task to them, where the primary task is to see the safety of the aircraft that is ready to leave the maintenance facility. On the other hand, the perception of the managers is different to that of the quality assurance representatives. They want the representatives to record data from different work cards on which they perform surveillance. They are concerned that an adequate sample of data acquired from the surveillance activities preformed by the representatives needs to be recorded to facilitate data analysis. Hence, the managers felt that 17 was an optimum number of process measures to capture data on all the aspects of surveillance. With this scenario, the team had to strike a balance between the perception of the managers and the representatives to come up with a reasonable number of process measures.

Considering human limitations on processing information, the team has adopted a total of 6 process measures for surveillance which fall in the range of 7 plus or minus 2 (Miller, 1956). Further, there are two other modules which capture data from surveillance work function. However, these are not process measures that are required to be memorized by the QA representative. There are often anomalies in deciding what process measure a particular work card would fall into. Though the definitions of the existing process measures were not ambiguous to the managers they were often confusing to the representatives. In view of these things, the research team tried to eliminate the ambiguity by reducing the number of process measures and incorporating sub categories in some of these process measures. This allows the representative to choose from the given options, and not to memorize them. For example, the research team identified a new process measure called "Facility Surveillance" and incorporated the currently used measures like 'Housing & Facilities', 'Shelf Life Control' and others that have been borrowed from C.A.S.E. standards as sub-categories in this primary measure. It was also identified that there were lot of ambiguities in choosing a process measure for a given discrepancy arising from procedures manuals violation used by the vendors and the company and that of C.A.S.E. standards. Further, the quality assurance personnel of the company have to be aware of the details in the procedures manuals of vendors at different locations and the company's manual. In order to assist the personnel in this regard, the research team has combined these two measures in to one measure called "procedures manual violation" so that the data can be consistently captured into one process measure. There are advantages of having both these process measures because it provides the managers with an insight into the vendors' regulated procedures and the discrepancies that exist between vendors' and company's procedures. Hence 'Vendors Inspection Procedures Manual' and 'Company General Maintenance Manual' are provided as sub categories in the Vendor Inspection Procedures Manual. The survey results showed that the participants perceived no ambiguities in the identified process measures.

"Additional Findings" module further has two sections in it namely 'Information' and 'Aircraft Walk Around.' Information includes the surveillance activities and data that the on-site surveillance representative needs to document for informational purposes and does not necessarily hold the vendor against these occurrences. For example, this data could provide details on a discrepancy identified in the company's own manuals which would eventually help the company to refine it for future use. The other section, 'Aircraft Walk Around' captures data on any technical anomalies found on an aircraft which are beyond the scope of the scheduled maintenance event. Every attempt has to be made by the surveillance representatives to make sure that the finding is not part of the scheduled maintenance event and hence cannot be measured by the process measure -verification surveillance. This metric also does not hold the vendor responsible for the finding because his scope.

As mentioned earlier in the results section, two responses indicated that 'Information' and 'Aircraft Walk Around' need to be considered as process measures rather than a different module. They have also indicated that these measures help the representatives to document any important information related to the maintenance event and bring it to the notice of the managers. However, after carefully understanding the rationale behind this alternative, the research team reached to a consensus to retain them in additional findings module for two reasons: 1) the vendor is not held responsible for these findings; 2) the data can still be collected and analyzed to report the findings. Hence these do not measure the process but are events that need to be recorded for later reference.

The fuel surveillance module has been identified by the team as a different module and not necessarily a process measure. Facilities in which fuel surveillance takes place, will record the data in this module. Also, from the knowledge gained by the research team it is understood that fuel surveillance is done only in few locations. Further, this fuel data is also collected during the routine annual audit.

For internal audits, the team carefully discerned the existing measures and reached a consensus that these adequately capture the relevant data to measure the process in internal audits department. Two responses of six in the survey have indicated that the process measures do not capture data from ATOS. The team did not take into consideration those measures which look into ATOS because of the project scoping issues. The team identified that ATOS was not mandatory to a company, however, was a very good business practice. This supported the team's decision on not implementing ATOS in WebSAT. Hence, the team went ahead to the next survey with other airlines incorporating the existing number of six process measures.

The technical audits group did not have any process measures in place but had several checklists for various types of vendors. The questions in this checklist were process specific and were grouped into categories based on the requirements they address. The research team tried to understand the nature of these checklists and grouped various categories into process measures. The basis for these process measures are C.A.S.E. standards. The team addressed all the checklists that are related to the technical audits group. There are fuel, maintenance and ramp audit checklists on one hand and there are other checklists for various types of suppliers. The identified process measures evaluate the standards and procedures of suppliers, fuel vendors, and ramp operations at a system level and ensure the compliance with FARs, and established company policies and procedures. All the six respondents in the survey have commented that these process measures effectively evaluate the technical audits process and also clearly communicate the purpose. They have also indicated that there are no ambiguities in these process measures.

The responses from the airworthiness directives department have indicated that the process measures capture all the relevant data in the AD department regarding the AD control process. The responses also indicated that there are many tasks assigned to AD group that are only remotely associated with AD control process and hence the process measures cover only the AD control process but not the other activities assigned to the group. This information indicated that the identified process measures adequately evaluate the AD control process.

The team sought an importance rating on the identified process measures for each of the work functions. Although, some of the respondents indicated the importance rating, from a safety perspective it was identified that all these process measures are equally important and hence cannot be ranked. All the process measures are required equally to evaluate the respective processes effectively and efficiently. For example, in AD group, if the process measure 'information verification' shows that the information is good but the loading and tracking is not done correctly in the computer, the process will fail as the work will not be done per the time constraint. On the other hand, if the information is bad and gives improper work instructions to the maintenance technician but it is loaded and tracking correctly in the computer the process will fail as the work will be done within the deadline but it will be done incorrectly.

6.0 CONCLUSIONS

The survey provided a qualitative approach of validating the identified process measures. The definitions of these process measures were refined based on the inputs provided by the participants in FedEx. The results obtained from the second survey would further validate these process measures which would eventually achieve standardized data collection through WebSAT across the aviation industry. After the completion of the first phase, the team would go ahead with Phase 2 which is the tool development.

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DEVELOPMENT OF A KNOWLEDGE MANAGEMENT SYSTEM TO REDUCE ERRORS IN AVIATION MAINTENANCE

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Abstract: One of the causes of aviation accidents is lack of overview and analysis of the data particularly obtained from its maintenance operation performance. The aircraft maintenance system of an airline is a complex structure with information flow involving various stakeholders ensuring aircraft airworthiness while adhering to several regulatory standards, policies and procedures of Federal Aviation Administration (FAA). Further, the prevalence of HCI design methodologies to perform data management in the aviation industry is very negligible. Little literature exists on information management of the data obtained from various aircraft maintenance processes which have a direct effect on the safety of the aircraft and hence the airline. The current research studies the intricacies of the aircraft maintenance system work flow processes, in order to develop a system that analyzes the aviation maintenance errors. This paper discusses the advantages of using a knowledge management system that shares information and knowledge across various operational hierarchies.

1. INTRODUCTION

Human factors research in aviation 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. The increasing number of maintenance and inspection errors in the aviation industry has motivated the need for human factors research. Maintenance error has been found to be a crucial factor in aircraft accidents (Boeing/ ATA, 1995). 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" (Weick et al., 1999). Given the ever increasing complexity of an 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 these individuals involved in aviation maintenance, understand the causal factors for these errors and the possible solutions to counter this situation.

On January 8, 2003 Air Midwest (doing business as US Airways Express) flight 5481, crashed shortly after takeoff at Charlotte, North Carolina. The two flight crewmembers and 19 passengers aboard the airplane were killed, one person on the ground received minor injuries, and the airplane was destroyed by impact forces and a post-crash fire. The night before an Air Midwest commuter plane crashed, a mechanic-in-training at an independent repair station improperly adjusted a set of cables that control the pitch of the plane. The National Transportation Safety Board (NTSB, 2003) determined the airplane's loss of pitch control during take-off as the probable cause of this accident. Contributing to the cause of the accident was Air Midwest's lack of oversight of the work being performed at the Huntington, West Virginia, maintenance station and Air Midwest's maintenance procedures and documentation. While any mechanic could make such an error, the fact that it was done by a contractor, instead of a certified, union airline employee, has revived concerns about the airline industry's outsourcing of repair work. It's a trend that started a decade ago, but has accelerated rapidly in the past two years as the major carriers have struggled to survive financially. This has prompted the need to establish better ways to monitor maintenance and identify errors.

The aviation maintenance industry has invested a significant effort in developing methodologies for investigating maintenance errors. 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 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 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. Questions relating to these areas also appear in the questionnaire to be used in the current research. 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 the 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, the devised empirical models and tools are required to employ standardized data collection procedures, provide a basis for predicting unsafe conditions and design interventions that will lead to reduction in maintenance errors.

A closer look at the aviation maintenance industry shows that it involves structural hierarchies which results in slow communication of knowledge and information on causes-and-effect of maintenance errors on the aircraft from one hierarchical level to the next. Further, these systems have inherent limitations by virtue of their environment. Consequently, the errors occurring in the systems are a result of human work environment, material fatigue and human error. One way to address this issue would be to continuously monitor the maintenance process and collect information on the efficiency and accuracy of the process. This research hopes to collect the error causes and occurrences using a web based surveillance, airworthiness directive and auditing tool (WebSAT). FedEx is the airline industry partner for this research. This tool will capture and analyze data for surveillance and auditing. However, in addition to adopting surveillance system, there is a need to share information and knowledge across individuals. Knowledge management (KM) has been found to be an important way of rethinking and redesigning organizations (Ernst & Young, 1997; KPMG Consulting, 1998; The Conference Board, 1998). KM initiatives are rare, if they exist, in the aviation industry. This industry although highly regulated, is unfortunately resistant to introduction of new initiatives.

Any industry's viability, like the aviation industry, relies on movement of information seamlessly across the various departments. This movement is hindered by barriers. Two major types of barriers - conceptual and cultural - are inherent in KM initiatives and make it difficult to realize the full value of KM efforts (McCann et al., 2004). Many prevailing values and beliefs within an organization's culture posing as cultural barriers, can be challenged by KM initiatives. There are growing ethical and legal concerns about how organizations capture, share, and transform knowledge into intellectual capital and property. KM initiatives break down barriers and alter the way individuals and groups - both inside and outside an organization interact and share what they know and how they use that knowledge (Davenport et al., 1998; De Long and Fahey, 2000). When intellectual capital is openly circulated, there is a potential threat to the organization. Rewards and incentives systems must, for example, reinforce knowledge creation, sharing, and retention norms (Soliman and Spooner, 2000), and information systems similarly must support open access and sharing (Davenport et al., 1998).

KM largely represents the intersection of four diverse schools of thinking and practice: industrial economic policy (Porter, 1990; Thurow, 1992; US Department of Commerce, 1977); total quality management (Deming, 1982; Juran, 1964; Watson, 1994); organizational learning (Coleman, 1988; Handy, 1989; Hedberg, 1981; Senge, 1990); and enterprise-wide information systems and technologies (Quinn, 1992). The diversity from each of these schools also leads to very different vocabularies, assumptions, models, and solutions that pose a fundamental difficulty in strategically integrating KM initiatives.

The Industrial policy school supports policy initiatives that would increase patent protection in a specific technology industry sector, or lead to government incentives to increase the number of graduates in a scientific field (Thurow, 1992; US Department of Commerce, 1977). Prevalence of Six Sigma and ISO certification (Watson, 1994) shows the integration of Total quality management (TQM) in some form within many organizations. The organizational learning school makes a major contribution by promoting open systems thinking and providing a basis for linking "hard" structural design and "soft" behavioral dimensions of an organization (Hansen et al., 1999; Hedberg, 1981; Nevis et al., 1995). It is important for the organization to make sense of its environment. This can primarily be achieved by interpreting the information and if necessary filtering it before translating it in terms of its impact - all critical dimensions of effective KM. Organization theory and design views the organization as a dynamic integration of people, processes, technologies, structures, and systems designed to achieve an objective (Galbraith, 1995; Miles et al., 1997; Nadler and Tushman, 1997).

It is known that effective KM is impossible without effective information systems and technologies (IS/IT). The IS/IT enable information acquisition, retention, and sharing. Company intranets and knowledge sharing portals are increasingly common. IS/IT produces a conceptual barrier, however, when information is fundamentally confused with knowledge, IS/IT captures or "codifies" information (Hansen et al., 1999). However, it is important to make the distinction that information is not knowledge. Further, timely information is primarily the factor that translates it to knowledge. Meaningful knowledge creation and application, requires information to be accessible and relevant to a moment and situation. Mountains of information captured by very expensive, often inflexible IS/IT initiatives too frequently make it difficult to identify and measure what really drives organization performance. Major investments in information systems will, however, never pay their way until IS/IT accepts a subordinate, enabling role in KM. IS/IT is a means, not an end in itself, and must be effectively integrated with people-based KM initiatives (Hansen et al., 1999). This paper explores WebSAT's ability to harness IS/IT for information sharing to reduce the errors and to implement KM initiatives.

2. METHOD

The airlines maintenance environment, involves several vendors. There is a need to monitor these vendors to provide continuous quality and air safety. Aircraft 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, the airline 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 data obtained from a surveillance visit at the maintenance facility is grouped into categories. These categories are called process measures. They measure maintenance processes and eliminate existing inconsistencies. The process measures were identified based on various surveillance tasks and the C.A.S.E. (Coordinating Agency for Supplier Evaluation) guidelines that have to be adhered to by the substantial maintenance vendor and the airline.

The figure 1 depicts the hierarchy of data flow across the different levels in a maintenance environment. The figure 1. below shows the following:

1. Senior manager refers to the higher manager who reviews all the maintenance activities;
2. Manager refers to the individual who reviews and reports on all the maintenance activities to the senior manager;
3. Airline representative refers to the individual who performs day-to-day surveillance at the vendor location;
4. Vendor refers to the independent maintenance operator who performs maintenance operations on the aircraft.

As shown in Figure 1, the information flow is bidirectional. However, there is a growing need to understand the value of such a system. The senior manager is interested in reviewing all the maintenance activities. The senior manager is always kept informed about the overall performance of the various vendors by the manager. The manager, in turn, communicates the quality goals that the airline representative has to achieve for continuous airworthiness of the airline itself. The airline representative is consciously aware of the aircraft safety and the federal aviation regulations (FAR) that are associated with a maintenance activity. By continuous oversight, the information from this representative is passed to the maintenance personnel working on an aircraft. The information passed by the representative to the vendor personnel is primarily errors such as inadequate lubrication, lack of training certification etc., noticed by him while observing the maintenance work. Thus, there is a transfer of information across the various levels for maintenance. However, what is not noted is the repetition in this information sharing. One direct consequence of this is that there is no direct measure on how effective the vendor is performing unless a methodology is implemented where the information transfer between the two individuals is documented and stored for future reference. The information at the appropriate time helps in translation into knowledge (Hansen et al., 1999). Further, repetitive delivery of information means there is little or no knowledge translation.

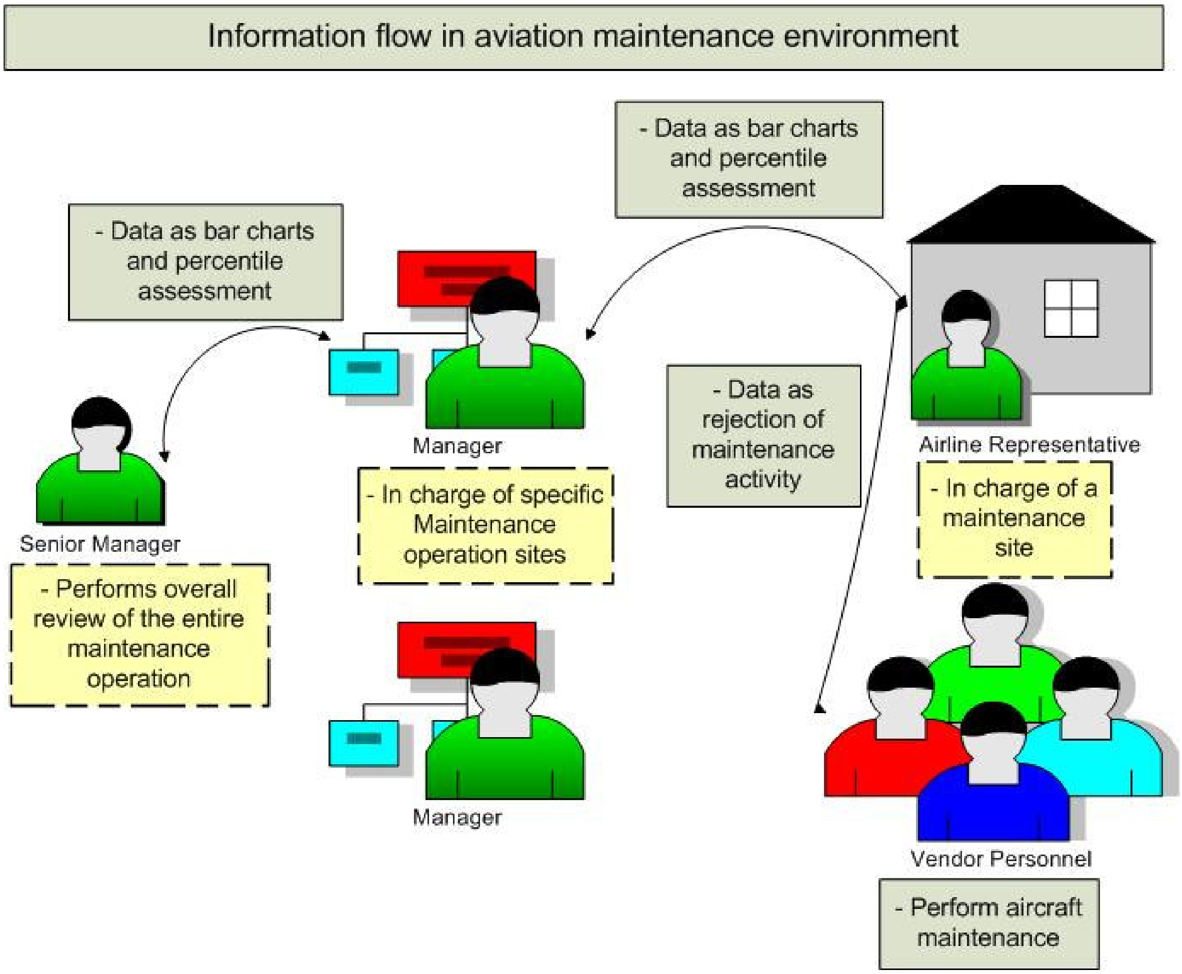

Figure 1. Information flow in aviation maintenance environment

3. DISCUSSION

The research team currently has the ability to measure the repetitive nature of information delivery. The team has developed process measures which allow the airline representative to categorize the surveillance they perform on the vendor's maintenance activities. This means that increase in process measure findings or rejection of a surveillance activity/work card by the surveillance representative, compared to a previous maintenance event, would mean repetition in information indicating lack of knowledge transfer. It must be noted that there is information transfer between the manager and the airline representative. The information here is the percentile completion of the aircraft maintenance and the accuracy of performance (aircraft errors performed by the maintenance/vendor personnel.) Further, the rejection of a work card is often qualitatively described by the representative. This data in an open ended form are invaluable as not only do they provide insight on the cause of the error but in doing so they also provide an opportunity to categorize them. These categories provide more information on the impact these errors have on the aircraft and have therefore been called as aircraft level impacts (ALI). The ALI allows the manager and the representative to communicate the cause of the error clearly between each other.

WebSAT has the ability to store this maintenance data in terms of process measures and ALI. These measures allow the airline to interpret and assess the transfer of knowledge. Despite the perception that knowledge is a competitive asset to be actively managed, some very basic steps need to be taken to introduce KM initiatives with WebSAT. Creating a learning organization and involving the managers and higher executives to manage its knowledge in this effort is paramount. Seeking corporate assistance during WebSAT implementation would allow KM strategies to collect and define very specific knowledge and anticipate future trends and errors. Further, this will also facilitate flow mapping information flow for investigation of knowledge transfer and decay. Finally, it is very important that the right information is getting to the right people when it is needed, and how well it helps integrate the organization's people with its other stakeholders through shared knowledge systems (Quinn *et al.*, 1997; Winslow and Bramer, 1994). To motivate the vendor maintenance fleet and improve vendor performance, the airline should also develop strategies such as referral, rewards and other incentive schemes. Concerns about vendor performance, airline industry safety, and competition in the budding knowledge age are valid. It is therefore, essential for us to appreciate what it means to strategically manage knowledge for sustained competitive advantage.

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