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.

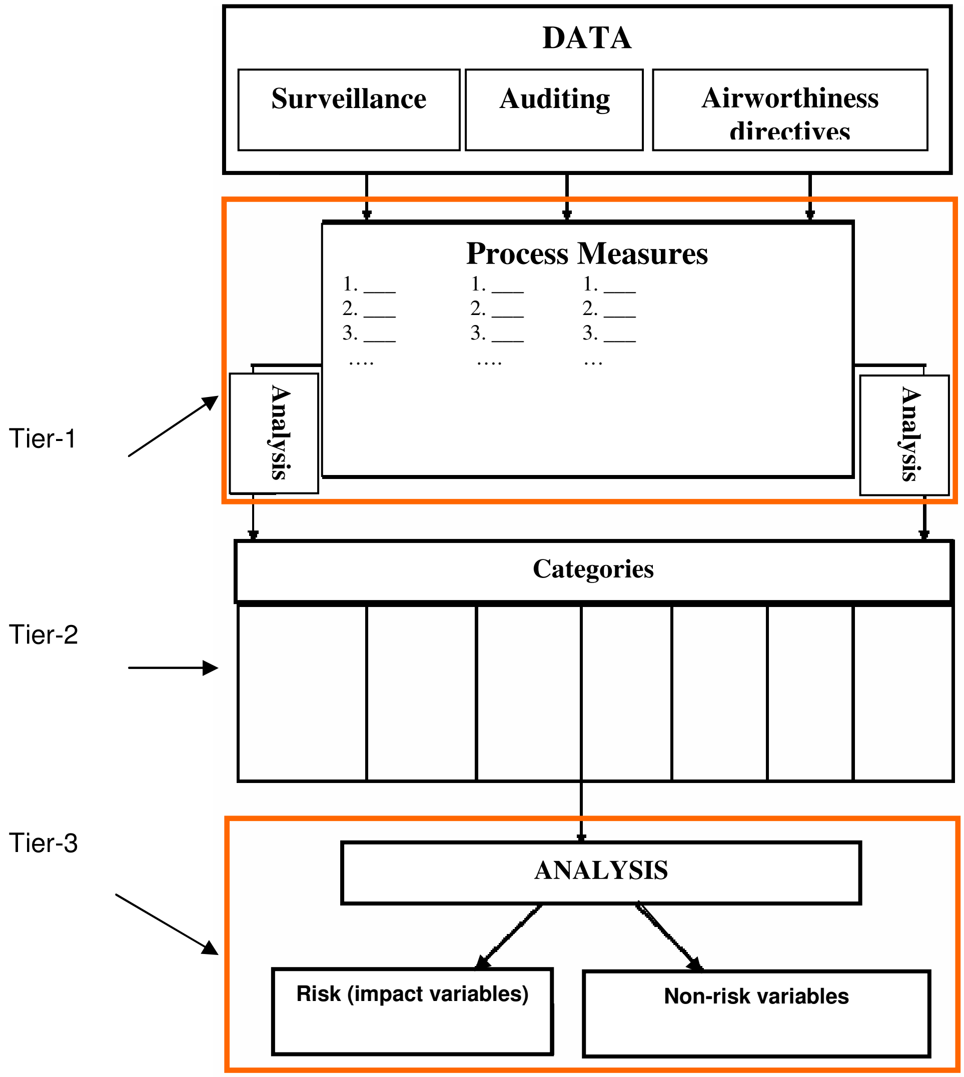

Figure 2: WebSAT framework

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.

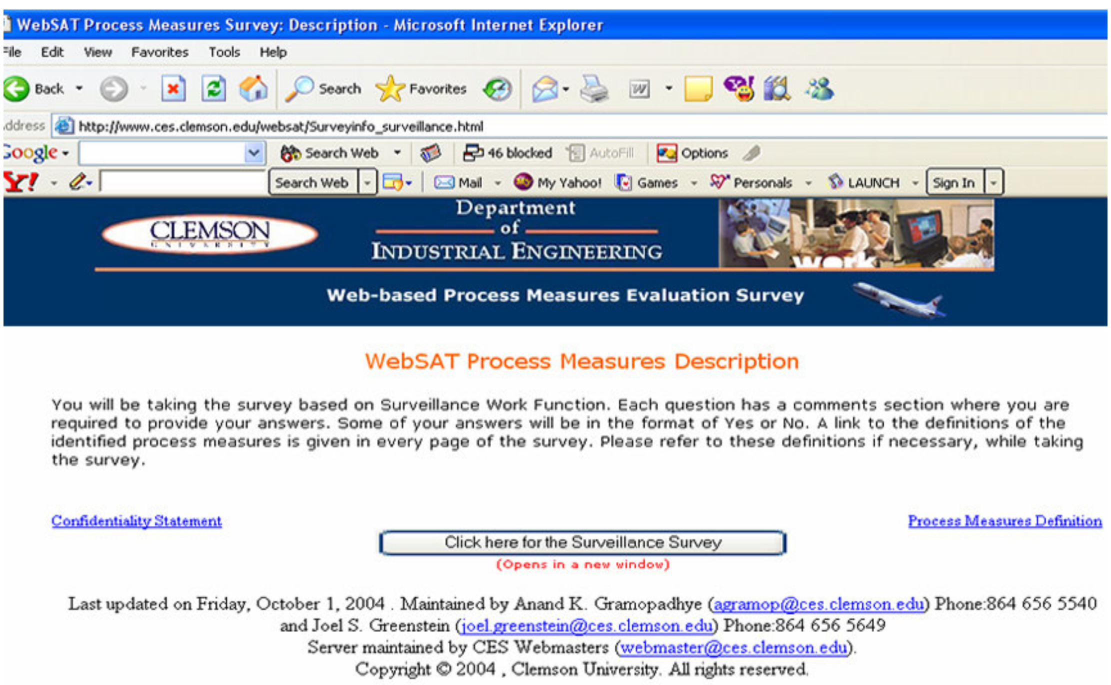

Figure 4 a: Survey Screenshot – First screen the participant sees before taking the survey

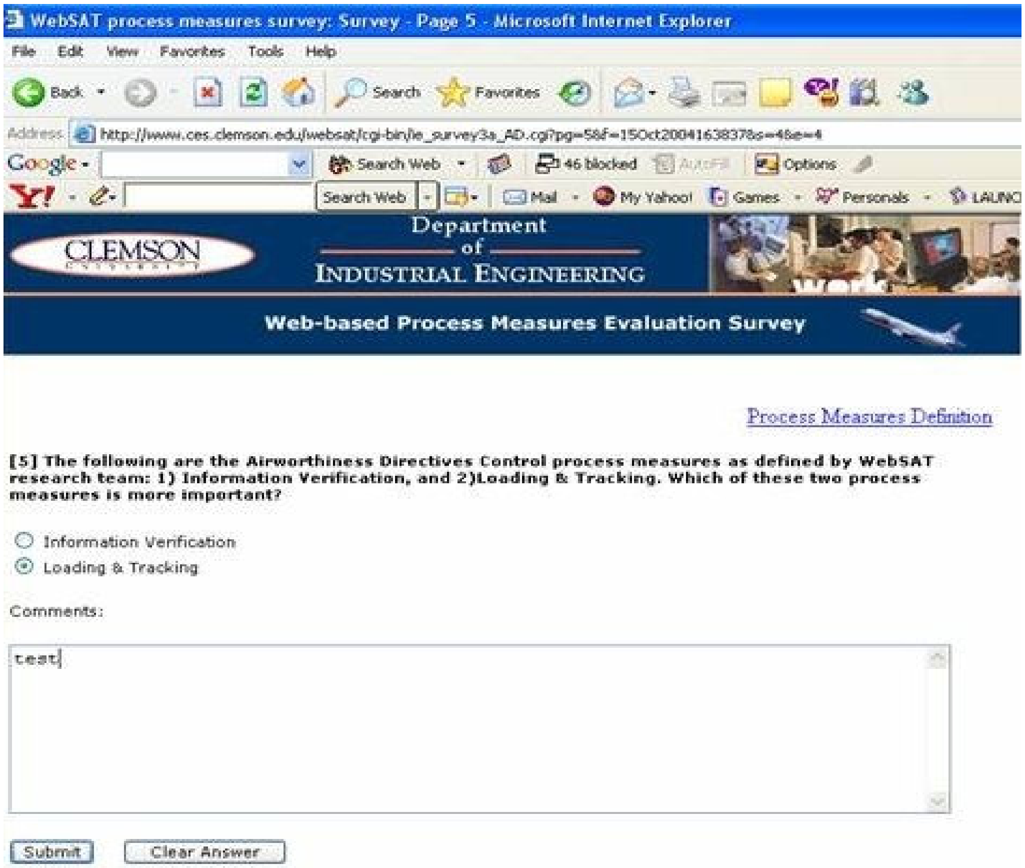

Figure 4 b: Survey Screenshot – Questions' screen

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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