Task Analysis of Shift Change Activity in Aviation Maintenance Environment: Methods and Findings

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Abstract

Task analysis of maintenance activities has revealed aircraft inspection to be a complex activity requiring above average coordination, communication and cooperation between inspectors, maintenance personnel, supervisors and various other sub-systems to be effective and efficient. A large portion of the work done by inspectors and maintenance technicians is accomplished through teamwork. One of the areas requiring the use of effective team skills is shift change. In response to this need, this research looked at the entire shift change process to identify human factors interventions that can be applied to develop a standardized shift change process that will help minimize shift change errors. The paper outlines the task analytic methodology used to analyze the shift change process at representative aircraft maintenance sites, the taxonomy of errors developed and the human factors interventions to prevent errors. Finally, the paper documents a standardized shift change process detailing the shift change protocol.

Introduction

For the Federal Aviation Administration (FAA) to provide the public with a safe, reliable air transportation system, it is important to have a sound aircraft inspection and maintenance system (FAA, 1991). The inspection/maintenance system is a complex one with many interrelated human and machine components. The linchpin of this system, however, is the human. Recognizing this, the FAA under the auspices of National Plan for Aviation Human Factors has pursued human factors research (FAA, 1991; FAA, 1993). In the maintenance arena this research has focused on the aircraft inspector and the aircraft maintenance technician (AMT) (Drury, Prabhu and Gramopadhye, 1990; Shepherd, 1992; Shepherd, Layton, and Gramopadhye, 1995). Since it is difficult to eliminate errors completely, continuing emphasis must be placed on developing interventions to make the inspection/maintenance procedures more reliable and/or more error-tolerant. 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 carrier requirements and meet legal approval. Thus, within the carriers' schedules, there will be checks at various intervals, often designated as flight line checks; overnight checks; A, B, C and, the heaviest, D checks. The objective of these checks is to conduct both routine and non-routine maintenance of the aircraft. This maintenance includes 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 or from line inspection, or items deferred from previous maintenance; and performing scheduled repairs.

Task analysis of maintenance activities has revealed aircraft inspection 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) to be effective and efficient (FAA, 1991; FAA, 1993). A large portion of the work done by inspectors and maintenance technicians is accomplished through teamwork. The challenge is to work autonomously but still be a part of the team. In a typical maintenance environment, first, the inspector looks for defects and reports them. The maintenance personnel then repair the reported defects and work with the original inspector or the buy-back inspector to ensure that the job meets predefined standards. During the entire process, the inspectors and maintenance technicians work with their colleagues from the same shift and the next shift as well as personnel from planning, stores, etc. as part of a larger team to ensure that the task gets completed (FAA, 1991). Thus, in a typical maintenance environment, the technician has to learn to be a team member, communicating, and coordinating the activities with other technicians, and inspectors.

One of the areas requiring the use of effective team skills is shift change, but this procedure has been widely reported as a cause of several errors/accidents in the aircraft maintenance industry (see FAA, 1991; FAA, 1993; Hobbs and Williamson, 1995 and the recent Continental Express crash). This can be attributed to a lack of well-defined shift change procedures for use by the aircraft maintenance industry. In response to this need, industry has developed ad-hoc measures and general guidelines to assist various personnel involved in the shift change process. This has resulted in various organizations developing their own internal procedures, which vary in their level of instruction/detail. Because of this situation, shift change procedures are not standardized across the industry. Moreover, they are often not based on sound principles of human factors design. Hence, there exists a need to look at the shift change process. In response to this need, this research looked at the entire shift change process to identify human factors interventions that can be applied to develop a standardized shift change process which will minimize shift change errors. The specific objectives of this research were to analyze the shift change process at representative aircraft maintenance sites, develop a taxonomy of errors and identify human factors interventions to prevent them and document a standardized shift change process.

Methodology

As a first step, the study analyzed the shift change process at representative aircraft maintenance sites, including the communication norms, information transfer procedures, shift change procedures, guidelines and FAA-mandated procedures. Next, a detailed error taxonomy was developed to help classify the typical shift change errors. The errors were analyzed and interventions identified to develop a standardized shift change process to minimize errors. Throughout this research, the researchers focused on the mechanic/inspectors, their respective supervisors, and the various entities that they interact with. As a final step, detailed guidelines and procedures were developed to outline a standardized shift change process that can serve as a benchmark for the industry.

Analysis of the Shift Change Operation

A detailed task analysis of the operations was conducted with data collected using shadowing, observation, and interviewing techniques. The team partners provided the research team with access to their facilities, personnel, and documentation and allowed the research team to analyze their existing shift change protocol. The team analyzed shift change at three different maintenance sites (located within the continental US) at different times of the shift. Site A had three shifts, sites B and C each had two. The research team worked with the manager, line supervisor/shift foreman, inspectors, and aircraft maintenance technicians. The study involved over 150 inspectors, 100 maintenance technicians and 25 supervisors. The research team visited sites that had both light and heavy inspection and maintenance work. During a typical site visit, the research team followed one or more inspectors and maintenance technicians, attended shift meetings, and asked probing questions, if necessary, during direct observations. Following this step, the researchers conducted follow-up interviews with the various personnel involved to ensure that all aspects of the shift change process were covered. These interviews covered issues concerning the tasks they were undertaking or had just performed and general issues concerning their work environment, both physical and organizational.

Shift Change – Scope of the Analysis

The scope of the analysis was restricted to shift changes on the hangar floor of an aircraft maintenance facility. Thus, this analysis focuses on activities related to those of inspectors, AMTs and foreman or shift supervisors during shift change. However, for the purpose of brevity, only those of an inspector are outlined in this paper. The study does not analyze specific work conducted by individuals on a shift; rather it is based on data collected by observing various personnel at different sites over several shift turnarounds. Different teams and different activities were observed between the day and night shifts, enabling the research team to observe shift change procedures between different outgoing and incoming shifts.

Task Analysis

The study was initiated with a meeting between the members of the research team and the airline personnel to outline the objectives and scope of the study. The objective was to identify human-machine system mismatches that could lead to errors through shadowing, observing, and interviewing techniques. The goal of the task analysis, which was to understand how the existing system works, was achieved using a formal task analytic approach (Gramopadhye and Thaker, 1998). The first step in this approach is to develop a description of the task that outlines in detail the steps necessary to accomplish the final goal. While various formats can be used to describe a task, in the current case a hierarchical and column format was used in conjunction. Figures 2 and 3 show a sample hierarchical task analysis (HTA) for the shift change operation. Each step was later described in detail using a column format similar to that used by FAA (1991). The column format identifies the specific human subsystem required for the completion of each step. The specific subsystems are attention, sensing, perception, decision, memory, control, feedback, communication, and output (Table 1). The format enabled analysts to clearly identify the specific cognitive and manual processes that were critical in the performance of the tasks. A summary of all sub-tasks revealed the critical processes identifying the opportunities for error. As an example, for Sub Task 1.3, Memory was identified as a critical sub process; observable errors were tabulated for all technicians for the specific sub-component occurring over various shifts at different sites (see data in Table 2.). Follow-up interviews, questionnaires and observational techniques were used to identify and isolate error-causing mechanisms. This was later mapped using Rouse and Rouse's (1983) error taxonomy to identify the error genotypes. Having this information, expert human factors knowledge was brought to bear upon the sub-task to identify specific interventions (e.g., provide job-aids) to minimize the ill effects due to specific error shaping factors (see Table) and improve performance on the sub-task.

The entire shift change process was analyzed using an integrated approach that combined the classic information transmission model and the system model of human error in maintenance and inspection (Drury et al, 1990). Figure 1 provides a graphical description of the shift change process using these two approaches. The shift change is essentially a hand-over process wherein information on work activity including information on job status, personnel status, material/tools, and equipment as well as the work itself is transferred from one shift (the personnel on Shift A) to another (the personnel on Shift B). In order for shift change to be successful, it is critical that the work and information be correctly transferred. When viewed within the context of the information transmission model, this transmission can be ineffective or inefficient because of two reasons: information loss and system noise. Thus, any system designed to promote should try to eliminate these two causes so that information and work from the input side, Shift A, is correctly transferred to the output side, Shift B. Moreover, an understanding of errors during shift change can be obtained only by understanding the impact of various system-level components on shift change. The specific components considered were those identified by FAA (1993) as described in Figure 1.

Following the analysis of shift change, a comprehensive error classification scheme was developed to classify the potential errors by expanding each step of the task analysis into sub-steps and then listing all the failure modes for each sub-step using the Failure Modes and Effects Analysis (FMEA) approach (Hobbs and Williamson, 1995). Following this, a classification scheme for errors was developed based on Rouse and Rouse's (1983) human error classification scheme.

Human Error in Shift Change – Development of a Taxonomy

The error taxonomy development was a two-step process. Initially, the Failure Effects Modes Analysis (FEMA) Approach was applied to develop the taxonomy of errors. A sample error taxonomy is shown in Table 2. Table 2.2 shows only the observed violations for sub-tasks 1.2 through 1.5 s. These represent the error phenotypes (Hollnagel, 1989), the specific, observable errors that provide the basis for error control. Error prevention and the development of design principles /interventions for error avoidance rely on genotype identification, associated behavioral mechanism and system interaction. The phenotypes were characterized by the relevant aspects of the system components (e.g., human, task, environment, etc.) with which they interact. The resulting list of phenotypes, error correctability and type and the relevant error shaping factors, enable designers to recognize these errors and design control mechanism to mitigate their effects. To this affect the Rouse and Rouse's (1983) behavioral framework was used to classify errors during a shift change process and to identify the genotypes associated with each phenotype. This methodology yielded the mechanism of error formation within the task content. This error framework, which classifies human errors based on causes as well as contributing factors and events, has been employed to record and analyze human errors in several contexts such as detection and diagnostics, trouble-shooting and aircraft mission flights.

Observations and Discussions

Following observations and discussions with various shift teams and a detailed task analysis of the shift change processes, the following general observations were made about the shift hand-over procedures between an outgoing and an incoming shift. These observations were in addition to those identified using the error taxonomy.

Issues Addressed

Shift Protocol Related Issues

In general, the shift hand-over procedures did not follow any defined protocol. The procedures were informal and often ad hoc. The discussions relied primarily, and in some cases heavily, on oral communication. The level of detail and discussion was dependent on the inspectors, maintenance technicians, and supervisors. Although companies have outlined basic shift change procedures, these often were not strictly adhered to. Moreover, these procedures are often difficult to locate. Detailed procedures need to be developed for situations where continuing work is transferred from one shift to the next: for example, when

--work is started on one shift but has to be stopped and continued on the next one because of various circumstances such as personnel availability, non-availability of parts or equipment, parallel work, reassignment of work

--work is started but partially completed with some items completed but not signed off

--work is started and partially completed with all completed items signed off

<u>Meeting Location</u> The task meetings between inspectors and technicians often did not take place in designated areas. Meetings would often be held in a noisy environment with parallel work in progress, causing distractions.

<u>Meeting Times</u> Meeting times would vary based on the task and individuals involved in the meeting.

Shift Meetings Shift meetings and face-to-face meetings between personnel often did not follow specific protocol. They often included non-technical information not associated with work. Moreover, the level of detail and the content of the meetings varied based on the personnel conducting the meeting. The approach to shift change differed between shift supervisors. In addition, they had no formal training and guidance in what did and did not constitute a good shift hand-over.

Awareness and Enforcement Related Issues

Discussion with personnel revealed that they were not aware and consistent in reporting the company's written procedures on shift hand-over, although all emphasized the importance of a proper shift hand-over. It should be mentioned that all personnel we interviewed were open, sincere, and genuinely interested in assisting the research team. Although personnel were aware of the need for face-to-face debriefings during shift change, often these were not adhered to. Moreover, the nature of the debriefing between individual personnel at work sites for work-in-progress was left to individual personnel. Thus, there existed a large variability in shift change protocol based on:

- the level of detail discussed
- the quality and relevance of the discussion to the task at hand

Information Related Issues

Transference of work information (written communication): Written communication on work in progress is not standardized. Personnel provide different levels of detail on work completed and work in progress. There exists a need for an efficient and effective system that will facilitate the transfer of information on work in progress from one shift to the next. Often personnel have to retrieve written information on work in progress from various sources and access an involved/complicated/complex route of procedures.

Transference of other information (Material, Tool and Equipment and Personnel Information): Systems to transfer information from one shift to the next are not well developed in some cases. Moreover, several problems in accessing necessary information were identified. For example, status information on tools borrowed and returned was not easily available, and personnel had to rely on jotted notes recorded in a diary.

Training

Shift change training on the use of correct shift change procedures and the importance of following correct protocol is not a part of regular training at most facilities. The lack of training on shift change procedures could be because of the following reasons:

- Lack of a well-developed shift change protocol,
- Lack of support staff to conduct training,
- Lack of management commitment emphasizing the importance of shift change in promoting safety, and
- Lack of detailed guidelines and an industry-wide accepted standard for shift change.

Organizational Support

A critical component missing was the lack of management support for a standardized shift change protocol. In the absence of an industry-wide standard, organizations have developed their own standards. Moreover, enforcement by management of the existing shift change protocol was often found to be lacking. The protocol was not communicated to various personnel involved in shift change. In the absence of such communication, individuals had developed their own internal procedures. Thus, there exists much variability in the way shift change was accomplished.

MRM Related Issues

Following discussions and analysis, it was clear that personnel need training on MRM-related issues such as communication, interpersonal relationships, leadership, and decision-making. These skills are critical for facilitating a smooth shift change, but most organizations do not have programs in place to train personnel on them. The links between them and efficient teamwork in the aircraft maintenance environment has been well-documented in previous FAA reports and MRM research.

Lack of Useful Job-Aids

Shift change is an information intensive task that is particularly critical in ensuring that personnel conducting the task have the right information on hand. Shift change tasks can be aided through the provision of decision support tools and job aids. Often, supervisors had to rely on memory, experience and judgment to decide on work assignments, organize shift meetings, and estimate work status. Similarly, technicians had to rely on memory and experience during task debriefings and status report updates. There is potential value in assessing the role that modern information technology can play in supporting access to information.

Standardized Shift Change Protocol

The error taxonomy was analyzed using a systems approach espoused by Czaja and Drury (1981), which not only considers the traditional interaction of the operator and the task requirements but also includes operator interactions with equipment, documentation, and other personnel within the constraints imposed by the system. Table 3 displays a sample list the errors and identifies error-causing factors based on this systems approach. Following this analysis, specific interventions to prevent shift change errors were considered with the objective of identifying specific interventions leading to an error-tolerant system and to the development of a standardized shift change process.

Shift Change Protocol

Analysis of the shift change operations clearly indicated the need for a detailed protocol for work transfer that will help minimize errors. The development of such a protocol will ultimately lead to a standardized shift change process that will serve as a benchmark for the industry. In order to provide the industry with guidelines, this research has outlined the critical elements for such a protocol. A flowchart for the shift change protocol is provided in Figure 4, and a detailed description of the critical elements follow. Individual organization can take the basic tenets of this protocol and implement it to suit their organizational and operational settings.

<u>Protocol for Work Transfer Conducted at the End of the Shift</u>

The following is a suggested generic protocol for transfer of work during shift change. The protocol with modification can be used by inspectors, mechanics, line maintenance, and component shops.

For work started and completed on one shift with all items signed off, personnel should

1. Complete the appropriate work card (WC)/task information.
2. Stamp and return the WC to work center.
3. Enter status of tools and equipment borrowed
4. Return tools and equipment to stores
5. Report status of work to shift supervisor.

For work started on one shift and partially completed before the end of shift with some items completed and some incomplete, personnel should

1. Complete work card and sign off on items completed.
2. Enter status of partially completed items, those for which work has been started but not signed off, using the shift change status report.(Figure 5)
3. Enter status of tools and equipment borrowed and their locations.
4. Stamp the shift status report and return WC and shift status report to work center.
5. Report status of work to the shift supervisor.

For work started on one shift and stopped before the end of shift, personnel should

1. Complete work card information for items completed.
2. Enter status on partially started items using the shift status report and indicate reasons for work stoppage.
3. Enter status of tools and equipment borrowed and their locations.
4. Stamp the shift status report and return WC and the shift status to the work center.
5. Report status of work to the shift supervisor.

Protocol for Shift Status Report (Written Communication)

In addition to completing the work card and non-routine cards (for inspectors), it is critical that all personnel, both inspectors and mechanics, involved in shift change complete a written shift status report for continuing work. A blank shift change status report form indicating the different elements is shown in Figure 5. This report solicits information on (1) Work Status – items partially completed but not signed off, items completed but awaiting approval (e.g., a mechanic fixes a part but the inspector needs to conduct a buy-back inspection to ensure that it meets specifications), reasons for delay, and critical items; (2) Equipment and Tools – status and location and (3) General Comments. On completion of the shift status report, personnel should stamp the report.

Protocol for Shift Supervisor Debriefing (Oral Communication)

In preparation for the debriefing meeting, the shift supervisor coordinates with each personnel and receives a written update on the work status prior to the shift change. For the work completed, the supervisor reviews the completed work card returned to the work center; for the continuing work, the supervisor reviews the completed work card for the items completed and signed off and the shift status report for partially completed items.

Once personnel have filed the work card and the shift status report in the case of continuing work, shift supervisors conduct the debriefing at a site free from distractions. They should use a checklist to solicit information to ensure consistency in information gathering.

Following this meeting the supervisor and the personnel should visit the job site to ensure that previously completed work has been appropriately signed off and the shift status report on continuing work has been correctly completed.

Protocol for Meeting Location

It is necessary to have dedicated space that is free from the distractions of both noise and parallel work to conduct meetings. In addition to these meetings, the final turnaround and debriefing on the work should take place at the work site.

Protocol for Meeting Times

It is critical that organizations allow sufficient time for conducting a proper shift change. In the case of rotating shifts, there should be a sufficient overlap between shifts--1/2 an hour for inspectors and technicians and 1 hour for shift supervisors--to ensure that the work transfer takes place properly and employees are not pressured into adopting shortcuts. In case of organizations that do not have continuous shifts, it is critical that all information on continuing work be clearly documented using the shift status report and communicated in both written and oral form to the shift supervisors.

Protocol for Shift Supervisor’s Meeting

Prior to shift change, supervisors from both shifts need to meet to discuss the status of the completed and continuing work. Supervisor of Shift A (ending shift) should transfer a written status report on the work conducted during the shift to the next supervisor (Shift B). An example of a report to be completed for each aircraft is shown in Figure 6. The report provides detailed information on the following:

Overall Status

1. Aircraft – type, location-hangar bay, type of check
2. Job Completion Times for OTD
3. Arrival Date/Time and Departure Date/Time

Job Status

1. List of jobs to be worked on a particular aircraft with estimated completion times
2. List of jobs currently being worked on a particular aircraft
3. Assignment of personnel to jobs
4. Status of jobs – completed, in progress, stopped/delayed/deferred items (indicate status of jobs at the beginning and end of shift)
5. Time and shift job started and completed
6. Estimated number of hours spent on each activity
7. Cumulative time spend on each activity

8. Reasons for delay or work stoppage
9. List of critical items – parts on order, equipment on order, tools
10. Equipment and tool status report

Personnel Report

1. Status of personnel on shift (available, absent, in-training, injured)
2. Qualification of personnel available on shift
3. Job and number of hours worked

Housekeeping

1. Clean office area
2. Clean work area
3. Safety

After completing the shift status report, the supervisor signs off on the report, ascertaining the information and transferring it to the supervisor on the next shift. In the case of a rotating shift, the supervisor orally debriefs the next supervisor on the status of the work completed. The oral debriefing should follow the format outlined in the shift status report so that all elements relevant to the work are covered. It is critical at this stage that Supervisor B seeks answers to all pertinent questions that might affect work and personnel on the new shift.

Protocol for Shift Meeting

Shift meetings should be held in designated areas that are free from distractions. Attendance at them must be mandatory for all the personnel involved. They should be conducted by the shift supervisor in a formal setting following a definite protocol, which guides their content and conduct. They should cover the following broad topics:

1. Goals to be accomplished by personnel on Shift B**,** focusing on the status of the aircraft in the hangar
2. Problems and possible critical items that can affect work
3. Work assignment
4. Question/Answer period

It is critical that shift meetings maintain a focus on purpose by describing the status of the work, the critical aspects of timely completion, and the adherence to safe work practices. It is important that the supervisor emphasizes the crews' role and performance in achieving the goal.

Protocol for Work Turnover Conducted at the Beginning of the Shift

Starting New Work

In the case of newly assigned work, Shift B personnel should conduct a review of the work card and associated information, for example the manufacturer's manual and Airworthiness Directives, in a designated area. Following this step, questions about assigned work should be discussed with the Shift B supervisor.

Continuing Work

In the case of continuing work, personnel from shift B should review the work status with appropriate personnel from Shift A. Work turnover should proceed as outlined below**:**

1. Initial Review: As part of this review, Shift B personnel should review all written information in a designated meeting area. This includes the work card information/associated information and the shift status report. Shift B personnel should ensure that all previously completed work has been correctly signed off.

2. Job Site Review: Upon completion of the initial review, personnel from Shift A and B should review the work at the work site. This review should include items completed and signed off, items partially completed, items not started, and information corresponding to entries in the shift status report. Once the review has been completed and Shift B personnel is satisfied that they have all the necessary information, they should stamp the shift status report

Following the two reviews, the Shift B personnel should discuss any questions on assigned work with their supervisor.

In the case of conflicting information about the continuing work, either in the oral meeting or in the written information, personnel should discuss the work with their supervisors so that it is resolved at the supervisor-level.

Allocation of space and time

Analysis of the shift change operation clearly indicated that to ensure a proper shift change, organizations must provide dedicated space and time for its facilitation. Dedicated space needs to be provided to (1) conduct shift meetings, and (2) to hold personnel meetings/debriefings. The space should (1) be clean and comfortable, (2) be free from other distractions and noise, (3) be equipped with appropriate office furniture, and (4) provide access to company computer systems and other information sources. It is important that organizations provide sufficient time and overlap at the beginning and end of each shift to ensure that all personnel follow the outlined protocol.

Training

An obvious strategy in improving shift change performance is through training. Training for shift change can take two forms: (a) Protocol Training and (b) Team Training (also referred to as Maintenance Resource Management (MRM) Training).

<u>Protocol Training</u> This training should essentially focus on the correct steps to conduct a shift change so that various personnel are correctly trained in adopting the above-mentioned protocol. The essential elements of such training should focus on the following:

- The steps to be followed by various personnel to conduct a proper shift change
- The use of checklists, shift status reports, computers, data retrieval, and other job aids that support the standardized protocol.
- The communication norms (written, oral and feedback information)
- The protocol for attending and conducting meetings and debriefings
- The rules (e.g., what steps to follow in different situations, violations of procedures**).**

<u>Team Training</u> The analysis of shift change showed it to be a task requiring team work between various personnel (inspectors, technicians, supervisors, stores from one shift and the next). Gramopadhye, Kraus, Rao and Jebaraj (1996) have identified the following skills critical to team work in the aircraft maintenance environment: communication, leadership, interpersonal relationships, and decision- making. The content of the Aircraft Maintenance Team Training (AMTT) and the Team Training software (Kraus and Gramopadhye, 2001) provides a good starting point for team training for all personnel involved in shift change operation.

While training for the procedural portion of the task is relatively straight-forward[17], most of the opportunities for error occur in the cognitive aspects of shift change. The current state of shift change is such that very little emphasis has been paced on both protocol training and team training. Most personnel learn company shift change protocol by working with senior personnel. This type of training, while realistic, is uncontrolled. In such an environment the trainees do not get rapid, accurate feedback about the correctness of their approach. The literature on training provides guidance in designing programs to provide sufficient control. Embrey (1979) states that for any training program to be effective, it should address the following three issues: the attitude of the trainee at work, the knowledge required to perform the job, and the specific skills required to perform the task. Specific training methods, which can be used, for inspection training have been outlined by Drury et al (1990) and Gramopadhye et al (1996).

Environmental Changes (Organizational and Physical)
The following changes need to be implemented at the organizational level.

Organizational Commitment In order to ensure a smooth shift change, organizational commitment to a standardized process is critical. This commitment needs to come from all levels – management, supervisory and hangar floor personnel. Only then will we see the benefits of implementing a standardized shift change protocol.

Infrastructure/Resource Support It is critical that the personnel involved are supported with resources dedicated to conducting a shift change. These include meeting rooms, access to computers, and designated times at the start and the end of the shift. In addition, organizations need to invest in the development of training and retraining programs.

Awareness Programs It is critical that organizations implement awareness programs that communicate the importance of shift change to all personnel. This can be accomplished through regular refresher courses, bulletins/circulars, and electronic communications. Moreover, each company and maintenance organization should have a statement of values emphasizing teamwork. These values should link with management practices with the rationale for them.

Enforcement It is critical that organizations have systems in place to ensure strict adherence to shift change protocol. This adherence should be strictly monitored, and violations should be reported and corrected.

Physical Environment Organizations have to ensure that the physical environment provides easy access to computers, instructional manuals, and job-aids as well as being clean and free from distractions from parallel work and noise.

Job Aids and Advanced Technology

The shift change operation can be tremendously aided by the use of advanced technology tools. Shift change is an information intensive task and information technology has a very important role to play in this environment. Examples of how shift change operation can be assisted through the use of technology are described below.

<u>Form Fill-in Interfaces using hand free technology</u> The task of aircraft maintenance personnel can be tremendously aided by use of intelligent interfaces that rely on voice recognition system. Thus freeing the operator from the mundane task of keying in information. Also, personnel can request various information without having to key in information.

<u>Use of Electronic Data Management/Product Data Management Systems</u> Over the years EDM/PDM systems have come of age that Commercial of The Shelf Software can be used to implement various EDM/PDM based solutions. The objective of these systems is to make data available to the right person at the right time. PDM/EDM systems are specifically designed to address the information demands of process industries, like maintenance. PDM systems allow for faster and more accurate updates to manuals, regulations and other written documentation, managing information transfer; improving completeness and accuracy of information entered on forms, making referenced information more readily and easily available, etc. Moreover, a recent study conducted by Millians and Johnson (2000) successfully demonstrated the improvements in performance resulting from the implementation of an EDM/PDM based solution for a specific aircraft maintenance process. They concluded that PDM solutions have the potential to improve the integrity of aircraft maintenance process and ultimately aviation safety.

<u>Job-Aiding and Training</u> Specific decision support tools can be used to aid the task of supervisors (for e.g., decision support system to aid supervisors make decisions on worker assignment, managing shift meeting and allocating resources). Similarly, personnel can be trained using computers by incorporating multimedia features (using simulations, video, audio, graphics and text) and by incorporating principles of training which, we know work.

However, it should be emphasized that although computer technology provides us with tremendous potential to improve performance we should be pragmatic in its use. It should not be thought as a complete solution but be thought as complementing existing strategies to improving safety and reliability.

Conclusions

The research presented here represents the results of task analysis of shift change operations conducted at representative aircraft maintenance facilities. Although the sample size was restricted to the team partners, the results here can be generalized so that they can be used and applied by other organizations. The development of the error taxonomy followed by the identification of human factor interventions has lead to the development of a standardized shift change protocol. It is anticipated that the adoption and use of the protocol by the aviation industry will lead to a reduction in errors ultimately leading to a safer and more effective and efficient shift change. Having outlined interventions for improvement it is critical that we evaluate the effect of these interventions and measure the effectiveness of these changes. The following are logical extensions to this work.

Protocol Implementation: It is critical to implement and test the developed protocol using industry partners at representative sites. Data obtained from this study can be used to further refine and standardize the protocol, which can serve as a benchmark for the industry.

Controlled Study: Following protocol implementation, a controlled study needs to be conducted which will evaluate the existing shift change practices in relation to the “standardized protocol.” This study should evaluate and document the effect of the standardized protocol in improving the effectiveness and efficiency of maintenance operations, the adherence to regulations, the subjective satisfaction, and in the measurement of changes in attitudinal performance.

Development of Training Programs/Dissemination: It is critical that appropriate training programs are developed that will train various personnel in adopting the protocol. Moreover, workshops need to be developed and presented at professional meetings attended by the aviation community to help disseminate the protocol to the general aviation community.

Development of Job Aids and Advanced Technology Tools: The protocol can be assisted by the use of job aids and advanced technology tools. It is critical that we develop prototype tools and demonstrate their use to the aviation industry.

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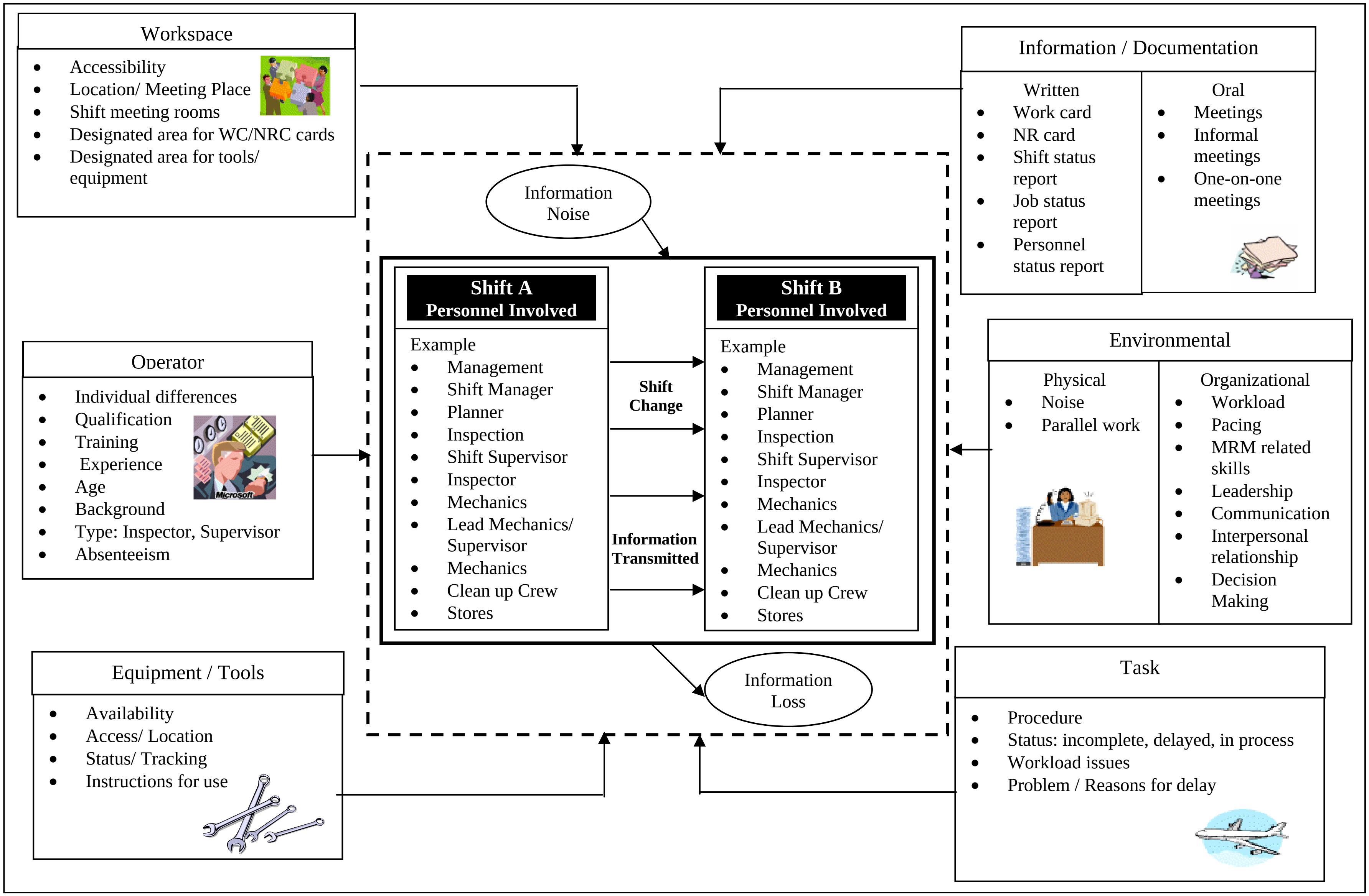

Figure 1: A model for understanding Shift Change

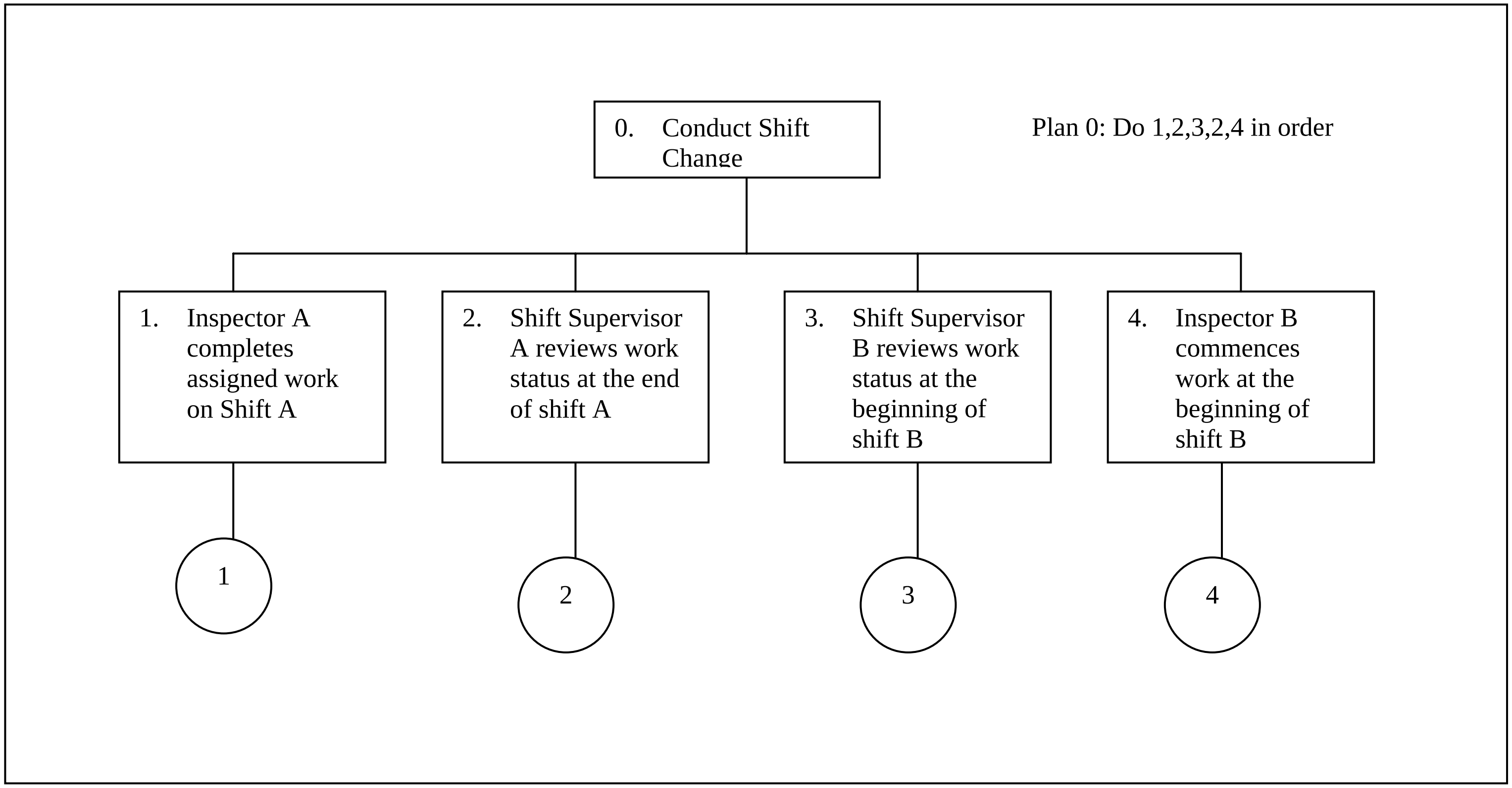

Figure 2: Hierarchical description of the shift change process (0)

Plan 1: Do 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8 and 1.9 in order

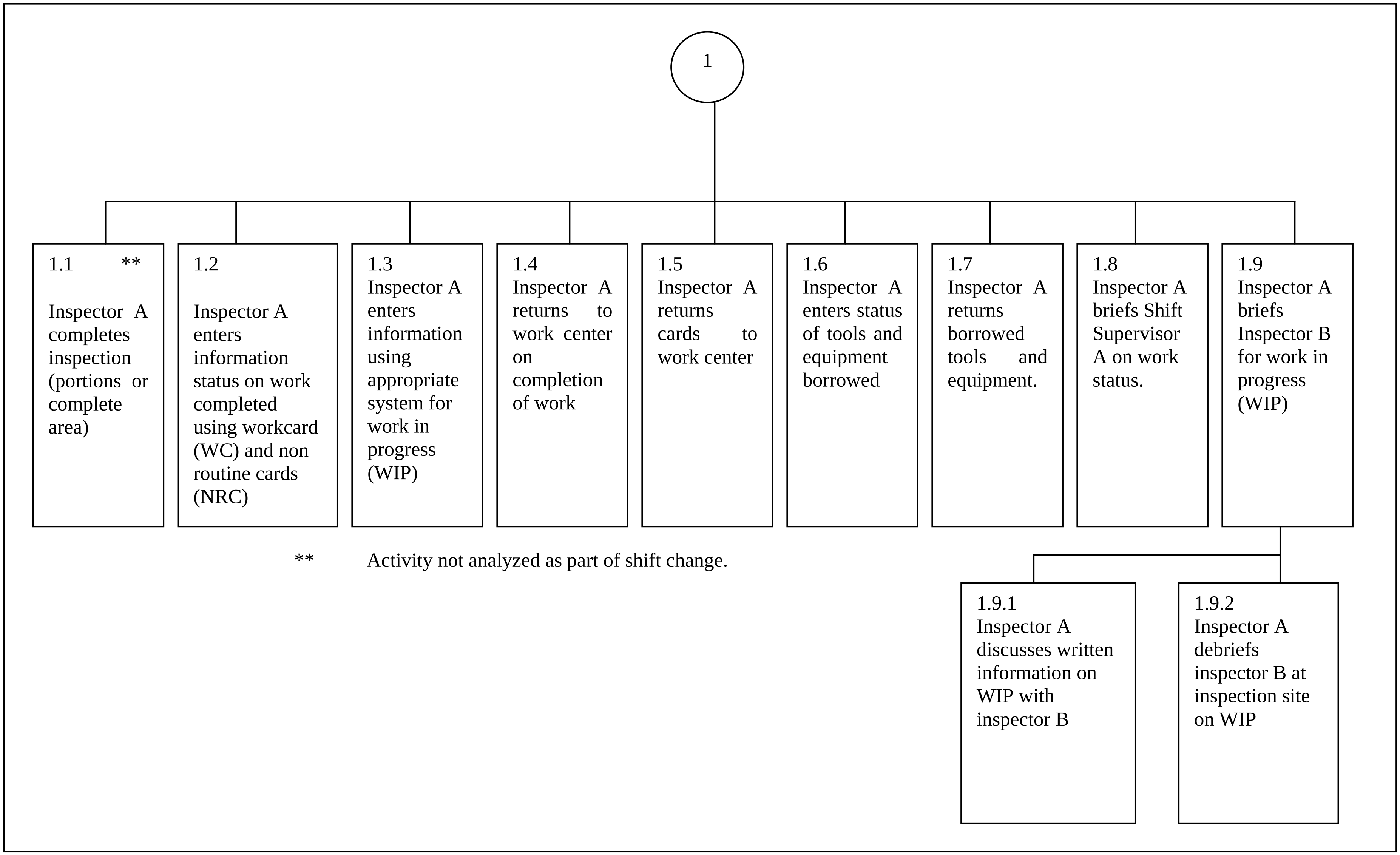

Figure 3: Hierarchical description of the shift change process (1)

Table 1: Sample Task Analysis of the Shift Change Process

	Task Analysis								
TASK DESCRIPTION	A	S	P	D	M	C	F	O	OBSERVATIONS
1.0 Inspector A completes assigned work on shift A.									
1.1Inspector A completes inspection (portions or complete area)**									
1.2 Inspector A enters information status on work completed using work card (WC) and non routine cards (NRC)	*	*	*	*	*			*	
1.3 Inspector A enters information using appropriate system for work in progress (WIP)	*	*	*	*	*				Inspector completes information on items not completed, items started but not signed off.
1.4 Inspector A returns to work center on completion of work	*							*	
1.5 Inspector A returns cards to work center.	*							*	

** Activity not analyzed as a part of shift change.

A: Attention S: Senses P: Perception D: Decision Making M: Memory C: Control F: Feedback O: Others

Table 2: Sample Error Taxonomy (1)

TASK	ERRORS	OUTCOME
1.Inspector A completes assigned work on shift A		
1.1 Inspector A completes inspection (portions or complete area) **		
1.2 Inspector A enters information on status of work completed	E1.2.1 Inspector A enters incorrect information E1.2.2 Inspector A enters incomplete information E1.2.3 Inspector A does not enter any information	Inspector A enters correct and complete information of work completed.
1.3 Inspector A enters information using system for work in progress (WIP)	E1.3.1 Inspector A enters incorrect information E1.3.2 Inspector A enters incomplete information E1.3.3 Inspector A does not enter any information	Inspector A enters correct and complete information for work in progress (WIP)
1.4 Inspector A returns to work center on completion of work	E1.4.1 Inspector A does not return to work center on completion of work	Inspector A returns to work center
1.5 Inspector A returns cards to location in the work center	E1.5.1 Inspector A does not return work card E1.5.2 Inspector A places card in incorrect location	Inspector A returns cards to correct location in the work center

** Activity not analyzed as part of shift change.

Table 3: Error Shaping Factors and Interventions (Example)

Errors from task analysis	**Error Shaping Factors**						**Suggested Improvements**
	Human	**Task**	**Work Space**	**Equipment/ Tools**	**Documentation**	**Environment (Organizational And Physical)**	
E1.2.1 Inspector A enters incorrect information	Memory slip, overconfidence, incomplete knowledge, recall error, lack of knowledge, familiar shortcut					Lack of training, Loose adherence to system procedures	• Training, Job Aid • Procedure development • Enforcement
E1.2.2 Inspector A enters incomplete information	Memory slip, overconfidence, incomplete knowledge, recall error, lack of knowledge, familiar shortcut					Lack of training, Loose adherence to system procedures	• Training, Job-Aid • Procedure development • Enforcement
E1.2.3 Inspector does not enter any information	Memory slip, overconfidence, incomplete knowledge, recall error, lack of knowledge, familiar shortcut				Lack of procedures	Lack of training, Loose adherence to system procedures	• Training, • Procedure development • Enforcement

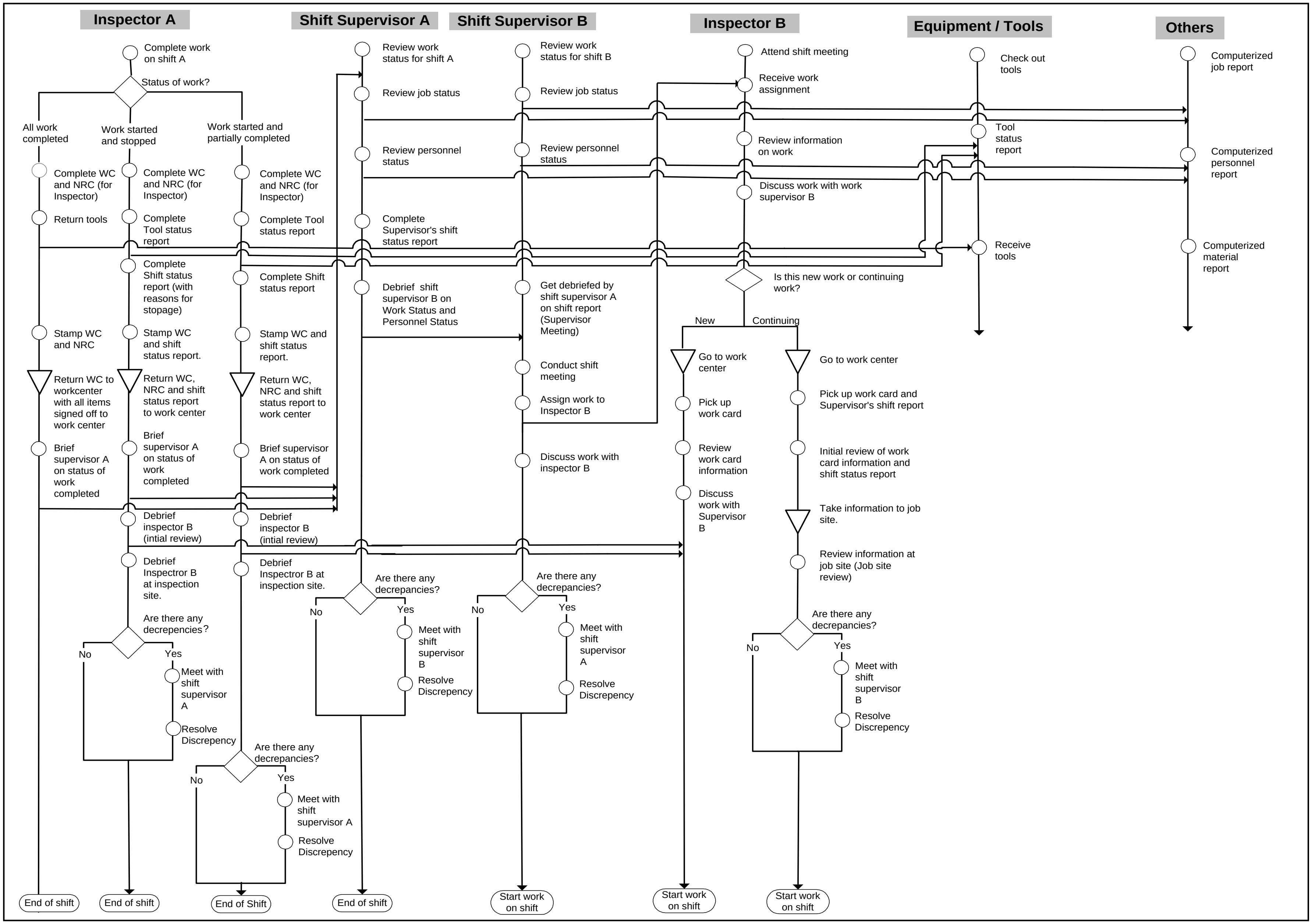

Figure 4: Standardized Shift Change Protocol

Shift Change Status Report

Aircraft:	Aircraft Location:	Shift Time:	Date:	Prepared By:	Stamp:

Job Number:____________ Job Description:____________________

Continuing Work

Item Number (WC)	Partial Items Description	Comments	Stamp

Completed Items

Item Number	Completed Item Description	Comments	Stamp

Stopped work

Item Number	Partial Items Description	Comments	Stamp

Material Status

Ordered Parts	Ordered By	Ordered Time/ Date	Comments	Stamp

Equipment / Tool Status

List of Equipment	List of tools	Status	Checkout time	Comments	Stamp

General Comments:

____

Figure 5: Shift Change Status Report

Supervisor's Shift Report

Shift Time:	Shift Date:	Prepared By:	Stamp:

Overall Status

Type of Aircraft	Location (Hangar)	Arrival Time	Departure Time	Type of check	Comments

Job Status

Job Number	Job Description	Job Status (New / Continuing) Beginning of shift	End of shift	Number of Assigned Hours	Time Started	Time Completed	Assigned Personnel	Comments

Personnel Status

Personnel Name	Qualifications	Availability (A, P, T, I)	Job Number	Hours Worked on Job	Comments

Equipment / Tool Status

List of Equipment	List of tools	Status	Assigned to Job Number	Assigned to Personnel	Comments

A: Absenteeism
P: Present
T: Training
I: Injury

Housekeeping

Work Area (Time Cleaned)	Office Area (Time Cleaned)

General Comment

Report any safety related issues:

Figure 6: Supervisor's Shift Report