ELSEVIER
International Journal of Industrial Ergonomics 26 (2000) 301–325
International Journal of Industrial Ergonomics
www.elsevier.nl/locate/ergon

Situation awareness in aircraft maintenance teams

Mica R. Endsley[a,*], Michelle M. Robertson[b]

[a]SA Technologies, 4731 East Forest Peak, Marietta, GA 30066, USA
[b]Liberty Mutual Research Center, Hopkinton, MA 01748, USA

Accepted 15 June 1998

Abstract

Research was conducted at a major airline to investigate factors related to situation awareness in aviation maintenance teams. Situation awareness has been found to be critical to performance and error prevention in many environments. Its role in the maintenance domain for the performance of both individuals and teams is discussed. Situation awareness requirements for aviation maintenance were determined as well as the technologies and personnel resources used to achieve situation awareness. Barriers and problems for situation awareness both across and within teams involved in aviation maintenance were revealed. Based on this analysis, recommendations for the development of a training program to improve situation awareness in aircraft maintenance at the individual and team level are presented.

Relevance to industry

The importance of situation awareness for preventing errors in maintenance is discussed as well as factors that contribute to problems with situation awareness across multiple teams. Specific recommendations for improving situation awareness through organization and system design and through training are made that are applicable to a wide variety of industrial settings.

Keywords: Situation awareness; Teams; Maintenance; Training; Error

1. Introduction

Insufficient attention has been paid to human error in aircraft maintenance. While the number of incidents due to mechanical failures that can be traced to maintenance problems are relatively few when compared to other causal factors (e.g. inflight human error), they do exist and can be systematically addressed. Marx and Graeber (1994), for instance, report that 12% of accidents are due to maintenance and inspection faults, and around one-third of all malfunctions can be attributed to maintenance deficiencies. In addition to its impact on safety of flight, the efficiency of maintenance activities can also be linked to flight delays, ground damage and other factors that directly impact airline costs and business viability.

In examining human error that may occur within the maintenance arena, several key issues can be identified.

(1) The first involves shortcomings in the detection of critical cues regarding the state of the

* Corresponding author. Tel.: + 1-770-565-9859; fax: + 1-770-579-1132.
E-mail address: mica@satechnologies.com (M.R. Endsley).

0169-8141/00/$ - see front matter
PII: S0169-8141(99)00073-6

aircraft or subsystem. Several accidents have been traced to metal fatigue or loose and missing bolts that should have been visible to maintenance crews. Incidents exist of aircraft being returned to service with missing parts or incomplete repairs. Frequent errors include loose objects left in aircraft, fuel and oil caps missing or loose, panels and other parts not secured, and pins not removed (Marx and Graeber, 1994). While several factors may contribute to this type of error, in all of these cases the state of the system (i.e. the defect, or the loose or missing item) was not detected prior to returning the aircraft to service.

(2) Often, even when important information is perceived, there may be difficulties in properly interpreting the meaning or significance of that information. For instance, Ruffner (1990) found that in more than 60% of avionics repairs, the incorrect avionics system is replaced in an aircraft. While the symptoms may be observed correctly, a significant task remains in properly diagnosing the true cause of the failure. While not much data exists regarding the impact of misdiagnoses of this type, there is a significant increase in the probability of an incident occurring when the aircraft undertakes the next flight with the faulty system still aboard.

(3) Problems in properly detecting the state of the system and diagnosing or interpreting cues that are perceived are compounded by the fact that many different individuals may be involved in working on the same aircraft. In this situation, it is very easy for information and tasks to fall through the cracks. The presence of multiple individuals heightens the need for a clear understanding of responsibilities and good communications between individuals to support the performance of shared tasks.

(4) In addition to the need for intra-team coordination, a significant task for maintenance crews is the coordination of activities and provision of information across teams to those on different shifts or in different geographical locations. For example, an Eastern Airlines aircraft nearly crashed when oil pressure was lost to all engines almost simultaneously due to a maintenance error in servicing the engines in which critical o-rings were left off (National Transportation Safety Board, 1984). This error has been directly linked to a problem with coordination of information across shifts and between maintenance departments (along with other contributing factors). In addition, considerable energy is often directed at coordination across maintenance sites to accommodate maintenance tasks within the flight schedule and part availability constraints. These factors add a level of complexity to the problem that increases the probability of tasks not being completed, tasks completed improperly, important information not being communicated, and problems going undetected as responsibility for tasks becomes diffused.

1.1. Situation awareness

All of these difficulties point to a lack of situation awareness (SA). Situation awareness has been found to be important in a wide variety of systems operations, including piloting, air traffic control and maintenance operations. Maintenance crews need support and training in ascertaining the current state of the aircraft system in addition to current training programs that concentrate on technical skills. Formally defined, "situation awareness is the detection of the elements in the environment within a volume of space and time, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988). In the context of aircraft maintenance, this means being aware of the state of the aircraft system (and the subsystem one is working on). Termed Level 1 SA, this would include perception of factors such as metal fatigue, loose or missing items, pins, or screws, oil or fluid leaks, tread wear, or systems not functioning properly. Level 2 SA would involve the technicians' understanding or comprehension of the significance of observed system states. Specifically this would include their diagnosis of the causal factors associated with observed symptoms. An aviation maintenance technician (AMT) with Level 1 SA might be aware that a particular subsystem is not working properly. An AMT with Level 2 SA also understands what is specifically wrong with that subsystem. Level 3 SA, the ability to project the state of the system in the near future, is considered the highest level of SA in dynamic systems. An AMT with Level 3 SA would be able to project what effect a particular defect might have on the performance of the aircraft in the future.

While SA has generally been discussed in terms of the operation of a dynamic system, such as an aircraft, the concept is also applicable to the maintenance domain. The complexity of aircraft systems and the distributed nature of equipment and system components posses a significant challenge to the AMT's ability to determine the state of the system (Level 1 SA) during diagnosis and repair activities. Putting together observed cues to form a proper understanding of the underlying nature of malfunctions (Level 2 SA) is a significant problem in diagnostic activities. In the maintenance domain, AMTs may need to be able to project what will happen to an aircraft's performance with (or without) certain actions being taken or with given equipment modifications/repairs/adjustments occurring (Level 3 SA). This task may be even more difficult for AMTs. As they often receive little or no feedback on the effects of their actions, they may have difficulty developing an adequate mental model for making accurate predictions. The ability to project system status forward (to determine possible future occurrences) also may be highly related to the ability to project system status backward, to determine what events may have led to an observed system state. This ability is particularly critical to effective diagnostic behavior.

1.2. Team situation awareness

In aircraft maintenance, as in many other domains, the requirement for situation awareness becomes compounded by the presence of multiple team members and multiple teams. Teams differ from a collection of individuals in that they are a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/object/mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership" (Salas et al., 1992). Thus, the major factors contributing to the concept of a team are shared goals, the interdependence of their actions, and the division of labor in terms of established responsibilities for meeting those goals. Based on this framework, teams will have some division of labor, and thus some of their SA requirements will be independent. However, they will also have shared goals and their actions will be interdependent, and thus they will also have shared SA requirements.

Team situation awareness can be defined as "the degree to which every team member possesses the situation awareness required for his or her responsibilities" (Endsley, 1989). In this context, the weak link in the chain occurs when the person who needs a given piece of information (per his or her job requirements) does not have it. Therefore, the concept of team SA embodies the need for each person on a team to have the information needed for his/her specific job. As shown in Fig. 1, if one considers the SA requirements of different team members, there will be some area of overlap between them. That is, there will be some SA requirements (at each of the three levels) that are pertinent only to a given individual, but also some SA requirements that are the same across one or more team members. Successful team performance requires that not only does each team member have good SA on his or her individual requirements, but

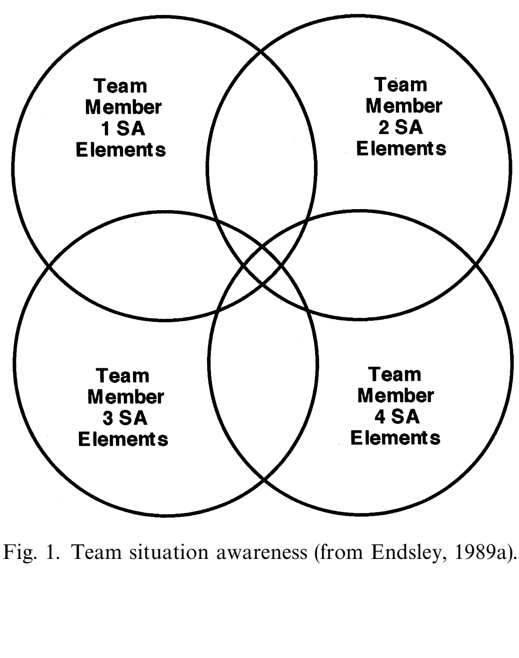

Fig. 1. Team situation awareness (from Endsley, 1989a).

also the same SA across shared requirements. This has been termed "shared SA".

In maintenance teams, as in teams in many other domains, errors frequently occur because information is not successfully transmitted from one individual to the next within a team, or from one team to the next. The failures may occur at Level 1 (information not transmitted successfully to a team or team member), Level 2 (information not comprehended properly or in the same way across teams or team members), or Level 3 (the implications of transmitted information for future events not understood or the same across teams or team members). The ways in which these failures might occur and the factors that contribute to such failures have not previously been examined from the perspective of situation awareness in the maintenance arena.

The objective of the present study was to address situation awareness related difficulties in aircraft maintenance. This information would be useful for supporting the development of cohesive maintenance teams and the promotion of team situation awareness. This is critical for the development of an environment in which people have a shared understanding of who does what when, reducing the probability of information or tasks going unattended. Individuals need to not only understand the status of the system they are working on, but also what other individuals or teams are (and are not) doing as well, as both factors contribute to their ultimate decision making and performance.

Within a team it is important to provide the members with the skills to function effectively. Specifically, training can be provided to assist teams in achieving situation awareness as this is the critical factor that will allow team members to carry out the maintenance tasks they have been trained for. Several related training programs have been successful within this domain. Drury (1993) has shown success in training maintenance personnel in visual inspection. Taylor et al. (1993) were successful in improving high-level performance objectives (e.g. dependability and safety) after instituting a program to train aircraft maintenance personnel in positive, assertive communication and teamwork coordination skills. While both of these training examples may help SA, neither directly addresses SA as an over-riding objective. In particular, other factors need to be considered to optimize team SA. For example, skills are needed for identifying critical information and ensuring that it is passed across teams (and team members) and then interpreted based on a common framework across team members. The present research therefore sought to identify SA requirements for various aircraft maintenance teams, analyze how SA needs are currently being met in a typical maintenance environment, and establish concepts and requirements for training to improve SA in maintenance teams.

Why examine the maintenance domain from the perspective of SA? First, based on a naturalistic model of decision making, we find that peoples' classification of the situation largely drives their decision making and performance (Endsley, 1995b; Klein, 1989). Studies of human error in the cockpit have found that the vast majority of errors are due not to poor decision making, but to problems with SA (Endsley, 1995a; Hartel et al., 1991). The present study specifically sought to determine whether SA was relevant in the maintenance domain and the way in which it serves decision making and performance in this, a very different, environment.

Secondly, examining SA may provide a unique perspective on the challenges and problems within the maintenance arena. The reasons for many errors and shortcomings in aircraft maintenance may not be apparent at first glance. By looking at SA, and the many challenges to SA in this domain, a better understanding of the causes of human error may be achieved. It is important to note that while many problems may occur due to challenges in information acquisition (e.g. noise, poor lighting, out-dated technology), the way in which information is used and understood by individuals within the maintenance organization, across its various teams, shifts and locales, may also underlie many problems in the system.

2. Methodology

Two major research activities were conducted towards the accomplishment of the research goal: (1) A determination of the requirements and resources for SA in aircraft maintenance teams, and (2) an assessment of training needs for improving team SA. The objective of the requirements analysis was to determine exactly what SA means within the maintenance environment: What is it that needs to be perceived by each person in his or her job, what is it that needs to be comprehended and what projections need to be made? Based upon an understanding of the actual requirements for SA in various parts of the organization, recommendations can be made for improving the technologies or organizational factors available for supporting SA and for creating a training program to enhance SA in aviation maintenance teams. While SA is critical for decision making and performance in many areas, developing appropriate methods for improving SA in any given domain is contingent on such an analysis.

Since it was not possible to review practices at all airlines or all locations, this research was conducted at an aircraft maintenance facility for one major US airline which served as a representative maintenance environment. Specifically, B-check maintenance operations at a major airport were analyzed. The B-check is conducted on a periodic basis for all aircraft and involves thorough checks of avionics systems and power units, various interior and exterior components, and lubrication and checks of engines, wings and gears.

The subject airline is a large US air carrier. It was believed that the selected airport B-check operation was fairly representative of the type of activities performed in aircraft maintenance, although obviously variations may exist due to differences between airlines or management practices at various maintenance stations. This airline, like many in the industry, had undergone a number of reorganizations in the previous five years which involved consolidating maintenance bases and out-sourcing some of its maintenance functions. While a significant impact to personnel within the organization and to the way of doing business, it was not felt that these factors would significantly affect the major goals of the study – determining the applicability of SA and team SA to aircraft maintenance, and designing intervention strategies for improving it.

The research was conducted by first identifying SA requirements and the resources used to support those requirements in the selected representative maintenance environment and operations. Concepts for training team SA were developed based on the results of the analysis. A team SA context analysis methodology was developed for conducting the analysis. This method consists of two parts: An SA requirements analysis and an SA resource analysis, as shown in Fig. 2.

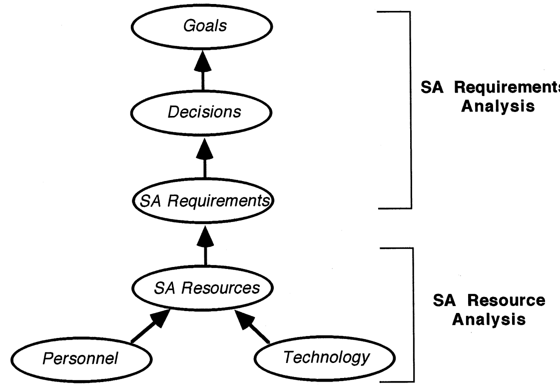

Fig. 2. Team SA context analysis.

2.1. SA requirements analysis

The first step was to determine the specific situation awareness requirements of individuals in the aircraft maintenance arena. This was addressed through a goal-directed task analysis which assessed (1) the goals and sub-goals associated with maintenance crews, (2) the decision requirements associated with these goals, and (3) the situation awareness requirements necessary for addressing the decisions at all three levels – detection, comprehension, and projection. This type of analysis has been successfully conducted for pilots in several classes of aircraft (Endsley, 1989,1993), air traffic control (Endsley and Jones, 1995; Endsley and Rodgers, 1994) and airway facilities maintenance (Endsley, 1994).

Analyses were conducted through expert elicitation with experienced maintenance personnel, observation of aircraft maintenance activities, and review of all available maintenance documentation. The analysis concentrated on B-Check maintenance activities. Interviews were conducted with three maintenance supervisors, four lead technicians and four AMTs. In addition, personnel in planning and stores, maintenance control, maintenance operations control and aircraft-on-ground in the company's technical operations were interviewed.

2.2. SA resource analysis

The second part of the team SA context analysis concentrated on identifying the SA resources used in the maintenance environment to achieve the SA requirements identified in the goal-directed task analysis. Two major categories of resources were considered: other personnel as a source of information and technologies used as sources of information.

To provide an assessment of the personnel SA resources, an analysis of communications between organizations and individuals was conducted using a contextual inquiry approach. The contextual inquiry approach (O'Neill and Robertson, 1996; Robertson and O'Neill, 1994) focuses on understanding and describing the communication patterns within and between teams as related to their performance and job goals. The contextual inquiries were conducted simultaneously with the interviews for determining the SA requirements. The contextual inquires involved semi-structured interviews in which each individual was asked to describe his/her major functions and goals and the organizations or individuals that served as resources in meeting those goals. A mapping was determined showing the communications and interactions among and between team members. Each individual was asked to make an estimate of the overall frequency of communication with each identified unit and the importance of the communication for achieving their goals. Finally, they were asked to identify barriers to effective communication and performance in the work setting.

In addition, the technologies for obtaining each requirement within the current system were documented. Based on this analysis, an assessment was made of the degree to which the current system supports SA in maintenance teams and the skills and abilities that are required for achieving good SA within this environment. This assessment was used to identify system design recommendations and training concepts for improving SA in maintenance teams.

3. Results

A hierarchy of goals in the maintenance environment was developed for several categories of job function within the maintenance team (supervisors, leads and AMTs), and for several organizations or teams that work closely with the maintenance team to achieve its goals: Material Services (stores), Planners, and Maintenance Control, including Maintenance Operations Control and Aircraft-on-Ground (an organization that deals with accelerated maintenance for aircraft that do not meet airworthiness requirements). These goals were used to develop a list of SA requirements for each group. Next, the personnel resources used for meeting these SA requirements were determined. The technology resources used for meeting the SA requirements were also surveyed and barriers and problems for achieving job goals were identified during the interviews. As these analyses were quite extensive, the results for only the AMT are shown here as an example. The analysis of SA issues across maintenance teams will also be discussed.

3.1. Goals and functions

Specific tasks and functions included within the B-check operations were identified to include: (1) avionics in cockpit: radar, radios, flaps, gauges, (2) interior: lavatories, emergency equipment, seats, overhead bins, lap belts, emergency lighting (3) exterior: tires, brakes, fuselage, leading edges and flaps, cargo bays, (4) right and left engines and wings, (5) right/left gear lubrication, nose gear lubrication and tail lubrication, (6) auxiliary power unit, and (7) addressing placards (notices placed in maintenance logs for non-functioning items, allowing the plane to be flown for a specified number of hours using redundant systems while repairs are completed).

An analysis of the AMTs' goals in performing their tasks revealed that they appear to be oriented towards the dual objectives of ensuring aircraft safety and delivering aircraft for service on time. A breakout of AMT goals is shown in Table 1. In general, the top level goals of supervisors and leads are very similar to those of AMTs shown in Table 1. They assume many of the same subgoals as the

Table 1
AMT goals

1.0	Aircraft safety
1.1	Deliver aircraft in airworthy, safe condition
1.1.1	Find potential problems
1.1.2	Solve problems
1.1.3	Make repairs
1.1.3.1	Determine part availability
1.1.3.2	Placard problem
1.1.4	Service aircraft
1.1.5	Provide quality workmanship
1.2	Keep area clean
2.0	Deliver aircraft on time
2.1	Prioritize tasks

AMTs in identifying and solving maintenance problems as needed to support AMTs when they run into difficulties. Supervisors and leads, however, also have additional subgoals associated with managing the maintenance teams (assigning and prioritizing tasks, assessing aircraft status and providing coordination).

Reviewing the goals of each of the other organizations involved in aviation maintenance revealed significant interdependencies between teams. For instance, AMTs are dependent on material services to have parts, tools, and materials ready when needed. Material services is in turn dependent on the planners to provide relevant task information and on the aircraft-on-ground organization to deliver needed parts as soon as possible. These interdependencies, while not surprising, highlight the need for good information transfer across teams. By examining in detail the SA requirements of each team, it should be possible to gain an understanding of the types of information required by each team and the ways in which the transfer of this information can be improved.

3.2. SA requirements

A breakout of SA requirements for each goal and subgoal identified for each maintenance team was derived from the interviews and observations. The goals, subgoals, major decisions and SA requirements for AMTs are shown in Table 2. The analysis identified a number of SA requirements at all three levels (perception, comprehension and projection) that are important for meeting goals in this domain. In reviewing Table 2, a few issues should be noted.

(1) At any given time more than one goal or subgoal may be operating, although these goals will not always have the same priority. The SA requirements in Table 2 do not assume any prioritization among them, or that each subgoal within a goal will always be present.
(2) These are goals or objectives not tasks. The analysis is as technology free as possible. How the information is acquired is not addressed in the SA requirements analysis. (This matter is addressed in the SA resource analysis).
(3) The analysis sought to define what AMTs would ideally like to know to meet each goal. It is recognized that they often must operate on the basis of incomplete information and that some desired information may not be easily available with today's system.
(4) Static knowledge, such as procedures or rules for performing tasks, is also outside the bounds of this analysis. The analysis primarily identifies dynamic situational information (information that changes from situation to situation) that effects how AMTs perform their tasks.

A similar analysis was conducted for each of the other maintenance teams (e.g. stores, inspectors, etc.) This analysis shows the factors that are important for SA in maintenance crews, not only in terms of the basic information that is needed, but also how that information is used, interpreted and

Table 2
AMT SA requirements

- 1.0 Aircraft safety
  - 1.1 Deliver aircraft in airworthy, safe condition
    - 1.1.1 Find potential problems
      - *Item within or beyond serviceable limits*?
      - *Item near limits needing preventive maintenance*?
        - reported problems
          - pilot reports
          - placards
        - new problems
          - worn tires/brakes
          - miswiring
          - dents/damage
          - loose items
          - fuel/oil leaks
          - items out of ordinary
          - functioning of convenience items
    - 1.1.2 Solve problems
      - *Fix problem or defer*?
        - potential impact of problem on flight safety
        - time required to solve problem
          - time required to get part
        - length of time item can be deferred without repair
        - location(s) aircraft is going to
          - facility maintenance capabilities
        - today's load
        - problem deferability category (placardable, groundable)
          - minimum equipment list (MEL) status
      - *How to solve problem?*
        - impact of potential approaches on time
        - impact of potential approaches on flight safety
        - impact of potential approaches on other tasks/jobs
          - possible methods
          - possible sources of problem
          - maintenance/failure history of item
          - part availability (see 1.1.3.1)
        - proposed repair authorized
          - Engineering Change Request Authorization number
    - 1.1.3 Make repairs
      - 1.1.3.1 Determine part availability
        - *Correct part supplied*?
          - manufacturer's part number
          - aircraft type, model, tail number
          - maintenance and equipment list number
          - effectivity number
        - *How long to get part here*?
          - in-stock status
            - manfacturer's part number
            - aircraft type, model, tail number
            - maintenance and equipment list number
            - effectivity number

Table 2 (Contd.)

- part & tooling availability
  - where
  - when it will be here
  - delivered or pick-up
  - arrival flight number
  - arrival gate number

1.1.3.2 Placard problem

- *Can problem be placarded?*
  - type of problem
  - Minimum Equipment List (MEL) status
    - Deferred information placard (DIP)
    - Open item list (OIL)
    - redundant systems available
    - control number
    - log page number
    - flight number
    - employee number

1.1.4 Service aircraft

- *Service activities needed?*
  - tasks to be done
  - fuel status
  - lavatory status
  - *Are we meeting schedule?*
    - time aircraft due at gate
    - delays to aircraft
      - estimated time of arrival at gate
      - aircraft repair status
  - *Where do we need to go?*
    - gate assignments
    - permission to taxi
    - permission to do high power run-up
    - taxi/runway clearances
  - *Current status of job?*
    - status of other tasks impacting own task
    - other tasks own task will impact
    - who can help
    - who needs help
      - tasks started
      - tasks completed
      - tasks/activities being done next
      - who is doing each task
      - activity currently being performed by others
    - major problems encountered

1.1.5 Provide quality workmanship

- *Activities performed correctly?*
  - tasks performed correctly
    - steps to be done
    - steps completed
    - location of designated components on system
    - system type
    - paperwork completed
    - parts installed correctly
    - inspection approved

Table 2 (Contd.)

- 1.2 Keep area clean
  - *Area free of foreign objects?*
    - loose objects (screws, parts, …), tools, trash
- 2.0 Deliver aircraft on time
  - 2.1 Prioritize tasks
    - *Best order for tasks?*
      - task time requirements
      - interdependence/sequencing requirements of tasks
      - part availability (see 1.1.3.1)
      - problem deferability category (placardable, groundable)
        - minimum equipment list (MEL) status
      - availability of kits, tools, equipment, vehicles
      - availability of personnel, skill level

Table 3
AMT personnel SA resources

SA resources: personnel	Mean importance	Mean frequency (%)
Supervisor	3.2	2.25
Maintenance control	2.5	3.75
–Maintenance operations Control		
–Aircraft on ground (AOG)		
Quality assurance	2.5	< 1.00
Aircraft inspectors	2.0	3.25
Planning	2.0	< 1.00
Lead technician	1.5	26.75
Stores	1.5	8.25
Other AMTs	1.0	54.50
Airport operations	1.0	< 1.00
Company operations	1.0	< 1.00

analyzed to make decisions and carry out required tasks. Any attempts to develop technologies or other changes to support the maintenance technician must directly impact on the accuracy or ease of achieving each of these requirements.

3.3. *SA resources: personnel*

The personnel resources and technology resources used within the organization to meet the SA requirements identified in Table 2 were ascertained through the contextual inquiry methodology. Results of the contextual inquiries for the AMT are presented in Fig. 3. The figure depicts the personnel SA resources, in terms of the individuals or units within maintenance technical operations, that are needed to achieve the AMTs' SA requirements and job goals. Lines and arcs show communication patterns between organizations.

Estimates were made by each individual who was interviewed concerning the overall frequency of communication with each of the other maintenance organizations and other team personnel. Each individual assigned a number to each organization which reflected the overall frequency of communication of each interchange (out of a total of 100%). For each of these SA resources, the importance of the communication also was rated on a four-point scale, where 1 represents a very important resource for achieving the team's performance goals and 4 represents a relatively low importance resource. Mean estimates of communication frequency and importance were determined for each of the maintenance organizations.

Table 3 displays the personnel SA resources, mean importance and mean frequencies for the communication interfaces from the perspective of the AMT. Several personnel and work units were indicated as very important SA resources necessary to accomplish the AMT's job. These were the other AMTs, airport operations (tower) and company operations (ramp personnel), closely followed by leads and stores (material services). The highest reported frequency of communication was with the other AMTs (54.50%), followed by lead technicians (26.75%).

Overall, a great deal of interdependency was found between the organizations and personnel

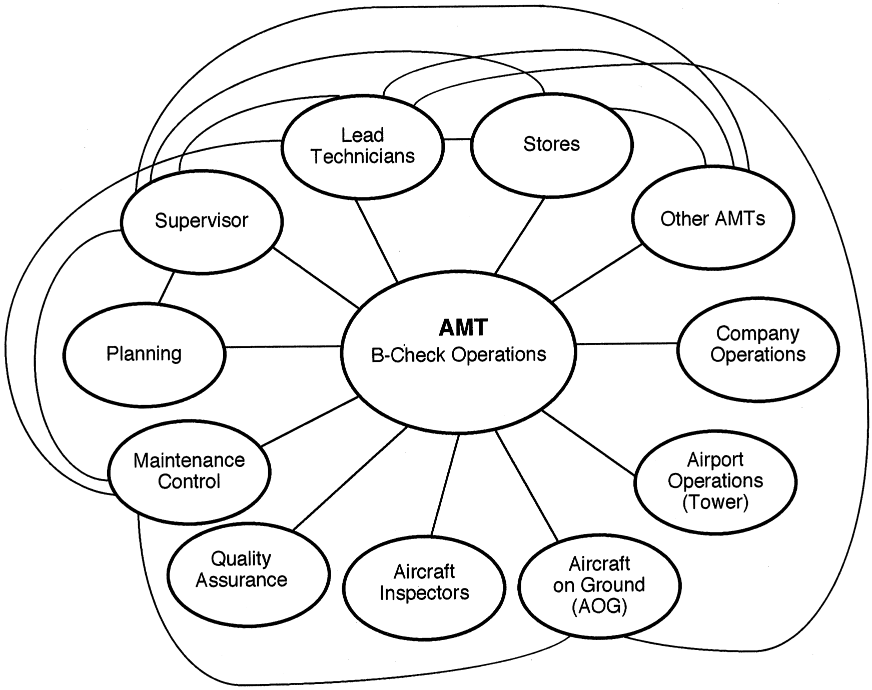

Fig. 3. AMT personnel SA resources.

included in this study. Each job type involved interacting with between 3 and 14 different organizations to attain (or supply) the information needed for good SA and job performance. In general, two or three of these interactions were viewed as very important and constituted the majority of each organization or team's interactions, however, for many of the teams there were also many organizations that were interacted with only occasionally. Specific issues regarding these interactions that can have a significant impact on SA were uncovered during the analysis and presented in the discussion section.

3.4. SA resources: technologies

In addition to ascertaining the personnel resources used for attaining situation awareness, the technologies used within the maintenance organization were also examined. The primary technologies used for passing information included a commercial information system for logging maintenance activities, several non-integrated databases used across several organizations, and technical documentation which could be found in various hard copy manuals and micro-fiche. (Issues and recommendations involving these technologies are addressed later.)

3.5. Barriers and problems

During the interview process, factors that created barriers to effective communication and performance were elicited. Barriers are issues that slow down or hinder performance. These are problems that maintenance teams must routinely overcome in order to meet their goals. They encompass organizational, technical and personnel issues. In general, most people felt that the system worked quite well, however, almost all could name a few areas where improvement was possible. These are listed in Table 4.

The most frequently mentioned barrier was a lack of proper tooling for completing jobs, a

Table 4
Barriers to performance

Barrier	Frequency
Lack of tooling; out-sourcing of parts	13
Parts availability; determining status of parts	10
No backlog of critical parts	10
Non-integrated databases; redundancy of tasks; hard to find needed information	10
Tracking the parts; getting the parts to the aircraft	8
Computerized database	8
Lack of support and feedback from management	8
Other organizations don't understand what we do, problems we face	8
Lack of teamwork; information being passed among & between team members	7
Personality conflicts	7
Instability of organization	7
Downsizing of organization	6
Shiftwork; fatigue	6
Computer system in stores	5
Workcards; changing of procedures with aircraft	5
Need for better information and communication to solve problems locally	5
Streamline engineering authorizations	4
Poor housekeeping and maintenance of tools	4
Computer system for customer service	3
Need more training on using computer system	3
Need for more proactive procedures	3
Need to develop consistent procedures for obtaining/borrowing parts	3
Need more explicit requirements for contract suppliers	3
Low experience levels of some personnel due to lay-offs and job changes	2

problem which is exacerbated by the fact that much of the repair work has been out-sourced to outside contractors, making rapid access to correct tooling and parts difficult. In addition to a certain lack of trust of these external organizations (probably stemming from lack of information), there was an expressed frustration with not being able to interact with personnel where the repair work had been out-sourced so that questions pertaining to specific items could be addressed. A decreased reliability of parts and quality control problems with parts coming from out-sourced vendors was also mentioned. Maintenance personnel expressed the need to be able to track parts by vendor names and to track the quality and reliability of these parts which the current system does not support.

The second most commonly listed problem was an unavailability of parts and difficulty in determining when the proper parts would be available to the AMT. Often the parts supplied would not be correct for the specific model and type of aircraft. This is a particular problem as the company has aircraft which were purchased from many different airlines, each with subtle differences between them. Parts supplied by stores often are not the correct ones due to these slight differences. This serves as a frequent sources of frustration, necessitating schedule delays or issuing a placard for repair at a later date. Related to this problem is the lack of a backlog of critical parts. Critical parts are frequently not available when needed, leading to having an aircraft down for an extended period or necessitating expensive and time consuming rush procurements through the aircraft-on-ground organization.

Tracking parts for a specific aircraft was frequently mentioned as a significant difficulty. Determining where parts are in the system (specifically in relation to items being obtained from outside the system, or in transit from somewhere) and getting the parts to the aircraft were described as common problems. In general, maintenance personnel experienced significant uncertainty regarding when, where and how parts would be delivered and spent extra time trying to get this information and to ascertain its reliability.

Significant problems in switching between the various information databases (such as the stores database and the customer service database among others) were noted. Maintenance personnel currently need to retrieve information from multiple sources, however, the ability to readily access and gain needed information from multiple systems at the same time is quite limited. For example, booking, monitoring bills, baggage handling, and tracking items and parts are all activities that need to be conducted by aircraft-on-ground. These activities require accessing and integrating information across several databases on an almost continual basis in order to keep up-to-date with the current situation. This situation also leads to redundant tasks between paperwork, manuals and the computer systems. Maintenance personnel expressed a need for an integrated computerized database system, allowing for more efficient monitoring of activities and parts thus facilitating getting the part to the aircraft in a more expeditious fashion. Other needs expressed included a ready list of "hot" parts and items, a means of tracking minimum equipment list (MEL) items better and a database on parts reliability. The commercial computer information database in particular was considered a significant barrier or problem. Personnel expressed considerable frustration with the system as it made data entry very difficult and the user interface was very clumsy.

Organizational issues were also mentioned. In particular, the feeling was expressed that management was not providing visible and active support, particularly in regard to feedback on how personnel were doing, improvements that could be made, and guidance on which direction personnel should go in and why. Maintenance personnel expressed a desire for better feedback or rewards when they make progress in the right direction.

Maintenance personnel also expressed a certain degree of frustration regarding other organizations. Many felt that other groups did not really understand what they did. For example, the AMTs did not like having maintenance operations control (MOC) tell them what to do, when "they aren't out here working in the cold and the dark". On the other hand, MOC personnel felt they were misunderstood as they all had worked in the AMT job before. They also felt they had the best information to be able to ascertain the impact of a given problem on changes in the system (e.g. scheduling). They did not feel the AMTs had this "big picture". The end result of these types of differences is misunderstandings between organizations, and inefficiencies in problem solving as neither group has the full picture and the same information possessed by the other group.

Several interpersonal issues were mentioned. While most personnel were considered to be "team players", others were considered to be deficient by not pitching in to help complete tasks. Problems with information not being transferred between team members both during a shift and between shifts were cited. Related to this, personnel conflicts were listed as a problem. The instability of the organization was also a significant concern. Just prior to the time period of this study, there were many reorganizations, changes in management, layoffs, and reassignments/relocation of many of the personnel.

Other problems mentioned included fatigue and problems associated with shift work (particularly among graveyard shift workers), concerns over organizational down sizing, lack of up-dating of the stores computer system to reflect the nuances of particular aircraft, a need for more training on the computer system, a lag in updating work cards to reflect changes in work procedures, and poor housekeeping and maintenance of tools.

People expressed the desire to be able to solve problems locally if only they had the information they needed. For example, a particular problem may be placarded and passed on to another station, when it could be fixed locally if information on scheduling and parts availability was shared better. People at the local level wanted to be more involved in the decision-making process in order to help meet the organizational goal of having the aircraft back in service as soon as possible. Related to this issue, personnel also expressed a desire for more proactive problem solving instead of waiting until a crisis situation develops. They felt they needed to get information sooner and to obtain earlier involvement of the respective parties in the problem solving process.

A need was also expressed for streamlining the process used for obtaining engineering authorizations and for developing consistent procedures that everyone could follow for borrowing and obtaining parts. Due to a lack of consistent procedures, a lot of time and effort may go into one particular strategy for obtaining a part and then when that method falls through, they have to try a new strategy having lost valuable time. Procedures that incorporate alternate parallel tracks and action plans when parts are needed are desired. Difficulty with contract suppliers was expressed. The feeling was that contract suppliers need to be given clearer expectations regarding what they are to deliver and quality requirements. Clearer procedures and processes need to be conveyed to them, particularly in light of significant culture and time zone differences.

Finally, the low experience levels of some personnel was described as a problem. Due to a number of layoffs, people with high seniority, but perhaps low experience level in a particular job type are more common. This has a significant impact on scheduling the AMTs on particular tasks and teams. With the perceived pressure to save money and do more with less, this issue was felt to have an impact on performance as more highly trained individuals might not be able to work with fellow team members as much as might be needed.

4. Discussion

Based on the analysis of the SA requirements and resources for each organization and the barriers and problems expressed, several observations can be made pertinent to team SA in the aircraft maintenance domain. The largest problem for team SA exists when gaps are present between organizations or individuals. These gaps may be the result of mismatched goals, lack of needed information on the part of one or both parties, lack of understanding of the exact information that another group needs, or different interpretations of information that is passed from another group.

AMTs face several challenges in meeting their SA requirements that can be linked to team SA. First, AMTs spend a great deal of their time and resources in ascertaining whether they have the correct parts or when and how they will get the correct parts. A considerable gap exists between the AMTs and the stores organization which often may supply the incorrect part (due to difficulties with effectivity number differences between different aircraft models, for instance) or may not have the correct part due to stocking limitations. These situations increase both the probability of error (incorrectly installing the wrong but very similar part) and may lead to considerable inefficiencies, waste and delays. When parts are not available, the AMTs frequently must involve their leads and supervisors, maintenance control and aircraft-on-ground. This necessitates the involvement of several organizations and personnel, all of whom need to be brought up to speed on pertinent situational information to make good decisions. This process is time consuming and may be prone to miscommunication errors, leading to SA problems.

The process of placarding also poses a significant problem. AMTs may spend a considerable amount of time disassembling a system and trouble-shooting to arrive at a diagnosis, only to find they cannot fix the problem due to an unavailability of parts or schedule constraints. This is a process which is fairly inefficient and which they find very frustrating due to lack of closure in addressing the very problems they are trained to fix. Completing repairs is a factor from which they derive their major job satisfaction. AMTs get very discouraged when they are not allowed to fix things that clearly need fixing. It is also a waste of time and human resources to have to reassemble a subsystem and placard it so that it can be unassembled again and fixed later on at another maintenance station. Although sometimes placarding is unavoidable, it is generally best if problems can be fixed immediately. The system does not appear to be currently optimized to avoid placarding, however. A review of the goals of supporting organizations, such as maintenance control and its sub-organizations, reveals that they place far more emphasis on remedying existing placards than avoiding new ones. This goal mis-match may be at the heart of considerable misunderstandings between groups.

While AMTs report a need to ascertain job status and schedule progress, they currently get only limited information concerning these issues. While they supply information regarding progress on their own tasks up the line on an ongoing basis, leads and supervisors frequently provide little information back down the line over the course of a shift. Leads reportedly did not feel that AMTs really needed information on how other team members were doing in terms of progress on their respective tasks. Without this knowledge, however, the AMTs have no way to engage in compensatory activities (e.g. pitching in to help each other), and may not be aware of ongoing activities of other team members that may have an effect on their own tasks (or vice versa). In some cases, tasks must be done in a certain order. In other cases, certain tasks can affect the activities of other AMTs in a way that creates a safety hazard unless both parties take precautionary measures. Thus, a lack of up-to-date knowledge on within team progress contributes to SA gaps within the maintenance team.

Although regulations are very specific regarding the criteria specifying when an item must be repaired or replaced, discretion is available in allowing AMTs to repair or replace items that might be nearing the acceptable limit. It may be both safer and more time and cost effective to promote this type of action in some circumstances (e.g. if a given subsystem is already disassembled for other work and the part is available). Discretion is also available on items that are placardable: they can be fixed immediately or placarded and sent to another station for later repair. Better sharing of information is needed in regard to these issues so that AMTs, leads and supervisors can make decisions that are in line with defined organizational priorities and realities. For example, they may need the information that a given aircraft will only be going to other stations that are not well equipped to fix the particular type of problem or that are overloaded. This would indicate that they should fix the problem instead of placarding it, even it means a slight schedule delay. Personnel need to understand what current organizational priorities are and why. A shared understanding of the cost and benefit tradeoffs in fixing things on the spot versus delaying repairs would allow them to form a better understanding of situations they encounter and make better decisions.

In reviewing the SA requirements and resources of the maintenance leads and supervisors, it is apparent that they serve largely in the role of coordinators and can become information "middle-men". In addition to administrative duties, they become involved when problems arise and assistance is needed, providing support themselves or interacting with other organizations (e.g. maintenance control or aircraft-on-ground) to get needed support. This role is very critical in the process of achieving good SA at the team level. When they become involved, supervisors and leads need to get a considerable amount of situational information from the AMTs or from others who may be in geographically distributed locations. This process can be highly prone to information falling through the cracks or can result in individuals not forming a full understanding of a situation. If supervisors do not have a complete understanding of all pertinent information, for instance, they may not pass information on that will allow maintenance control to make the best decision. In addition, leads and supervisors are frequently responsible for passing information back to the AMT. If they only pass information regarding what the AMT should do (the decision) but not regarding why the decision was made, this may lead to both a lack of understanding by the AMT and may deny the AMT the opportunity to volunteer information he or she may have that would be pertinent to the decision made. Leads and supervisors form a critical link in the SA chain between the various organizations and need to have a full understanding of what information other people really need and of how to get all the information they need themselves.

Stores (material services) appears to work primarily based on planned demands in order to obtain needed parts in advance. Some stores personnel, however, reportedly do not understand the unique differences between aircraft models and tail numbers that allow them to procure parts with the proper effectivity number. (This problem appears to be at least partially due to problems in documentation and the databases provided to them.) This situation leads to considerable problems with AMTs who complain of not having the correct parts. The lack of availability of needed parts has been identified as one of the most critical factors in determining whether an aircraft will be repaired or not. There also exist problems in keeping up with the status of the inventory when there are numerous people who have access to parts and may not keep databases up-to-date. The greatest SA need for this group is in determining methods to insure that they have correct information on needed parts and to provide them with a better ability to project parts requirements (Level 3 SA). While they do work with projections from planning and with typical part usage requirements, their ability to project requirements for parts could probably be enhanced through better system feedback and advanced planning.

Maintenance control (MC) and its sub-groups appear to function largely in a trouble shooting, reactive mode. They become involved when help is needed and primarily focus on expediting problem solutions by bringing resources (parts, expertise, routing) to bear on identified problems. They face several challenges in this role. Maintenance control has a great deal of general system knowledge at its disposal, both in terms of technical skill and documentation. AMTs in the field have the best situation knowledge, however, as they are on-site with the aircraft and have the most contact with pertinent aircraft data. The challenge is to combine these two sources of information most effectively to arrive at proper diagnoses and solutions. This gap between those with situation information and those with the best technical knowledge may be reduced with improved understanding between the two groups or from technologies that assist in the sharing of information between the two groups.

Although the stated goal of maintenance operations control is to minimize placards, it should be noted that they primarily focus on making sure existing placards do not exceed prescribed time limits. The process seems to be to first approve placards (if allowable) and then to work to remove them. Neither maintenance operations control nor maintenance control appear to focus on proactive tasks to avoid placards in the first place. This state of affairs also appears to form a gap between these organizations and the AMTs in the field. It may be that some organizational streamlining between maintenance operations control and maintenance control may also be of benefit, reducing the need to have distributed decision making in meeting their shared goal.

In reviewing the SA resources used by each group, several general comments can also be made. It appears that the AMTs interact mostly with other team members on site. Moving up in the organization, leads and supervisors are far more likely to interact with other groups (such as planning, stores, and maintenance control) and with maintenance units at other stations, as do the support organizations. These groups have an increased need to understand the other groups they interact with. For example, understanding the differences between maintenance sites (manpower availability and skill levels, load levels, parts and equipment availability) may be very important in allowing personnel to develop a good understanding of the impact of decisions or to understand why other organizations are making certain statements. These issues are very important to effective decision making, particularly when organizations are highly geographically distributed and such differences may not be evident. Each maintenance site also needs to be able to share relevant information (e.g. problems detected with certain aircraft or parts) across sites in order to allow the whole organization to achieve the highest knowledge level possible. Across the organization, members of each group need to develop an understanding of what information is needed by other groups and how to clearly pass on needed information about their own situations.

5. System and organizational recommendations

The issues unearthed by this analysis are myriad. Clearly, many different strategies can be proposed that would be helpful for improving information flow and SA within the organization. Table 5 shows several changes and improvements to both the technologies and organizational system that can be implemented to improve the distribution of information. While these factors are specific to this airline, many of these proposed solutions may also be applicable to the maintenance organizations of other airlines.

Improving situation awareness within a widely distributed organization such as aviation maintenance, however, will also require that personnel are able to properly utilize this information to form good higher level assessments of the situation (comprehension and projection) and are better able to communicate information within and across maintenance teams. For this reason, a program for training to improve team SA within aviation maintenance was also developed.

6. Team SA training recommendations

Several training concepts were identified for improving Team SA within the maintenance setting based on this analysis and discussion.

Table 5
Technological and organizational interventions

Information system improvements
• Support for information exchange with out-sourced maintenance organizations and vendors
• Support to insure proper parts are available and supplied for jobs
• Support for tracking parts on order
• Integration of multiple databases used within the maintenance organization
• Support for tracking MEL items, parts reliability information, and "hot" items
• Redesign of user interface/usability of computer support system
Organizational and personnel improvements
• Better feedback and guidance from management
• Better understanding between maintenance organizations
• Better teamwork
• Improved organizational stability
• Improved use of consistent procedures for engineering authorizations and obtaining parts
• More training and use of experienced personnel
• Organizational streamlining
• Increased involvement by personnel at all levels in problem solving

6.1. Shared mental models

From the analysis it was determined that different teams (organizations) do not have a good mental model of what other teams know, do not know or need to know. Good situation awareness at the team level depends on having a clear understanding of what information means when it is conveyed across team members. Thus, teams need to share not only data, but also higher levels of SA, including the significance of data for team goals and projection information. This process is greatly enhanced by the creation of a shared mental model which provides a common frame of reference for team member actions and allows team members to predict each other's behaviors. A shared mental model may provide more efficient communications by providing a common means of interpreting and predicting actions based on limited information, and therefore may form a crucial foundation for effective teamwork. When shared mental models are not present, one team may not fully understand the implications of information transmitted from another team and misunderstandings, errors and inefficiencies are likely to occur. By providing each team with better information on the goals of other teams, how they perform their tasks, and what factors they take into account in their decision processes, a better shared model can be developed. This should greatly enhance not only interpersonal interactions among teams, but also the quality of the decision processes.

6.2. Verbalization of decisions

There also exists a need for teams to do a better job of passing information to other teams regarding why they decide to (or not to) take a particular course of action (e.g. deferments, schedules, etc …). Unless the rationale and reasons are passed along, considerable misunderstandings may occur. In addition, this will deny the possibility of getting better information from the other team, who may have access to other pertinent information that would make for a more optimal solution. Conveying why a particular decision was made provides a much greater level of SA (particularly at the comprehension level). It allows other teams to either understand and accept the decision or to offer other solutions that may be better in achieving organizational goals. More information also needs to get conveyed on what diagnostic activities have been performed when passing aircraft to another station, and a need exists for better communications between stations and teams in general. Training that focuses on teaching people to verbalize the rationale behind decisions and provide greater detail regarding diagnostic activities should help improve team SA considerably.

6.3. Better shift meetings and teamwork

Team leads need to receive explicit training on how to (1) run a shift meeting to convey common goals for the team, (2) provide a common group understanding of who is doing what, (3) set-up an understanding of the inter-relationship between tasks and personnel activities and (4) provide expectations regarding teamwork. Shift meetings provide an excellent opportunity to provide this shared understanding among the members of a team. This information is crucial for allowing team members to have a good mental model regarding what everyone is doing and how tasks inter-relate so that they can have good SA regarding the impact of their actions and tasks on other personnel and on the overall goal. Team leads also need to receive specific training on the importance of passing information on job status within teams over the course of the shift. Without this type of feedback, people can easily lose sight of how they are progressing in relation to the other tasks being performed. This feedback is important for individual performance and SA, and also for fostering a team spirit in carrying out activities.

6.4. Feedback

Currently, personnel receive little feedback on how well a particular solution worked. A tricky diagnosis and repair may have been totally successful, or may have failed again a few days later at another station. At present, it is very difficult to track the performance of a particular action or part (partially due to the cumbersome nature of the computer system). Such feedback is crucial to the development of better mental models of the technical systems AMTs work on. Without such feedback, it is very difficult to improve one's diagnostic skills. While system enhancements are recommended to help with this problem, it is also recommended that people be trained to provide such feedback. Not only do managers and leads need to take an active role in providing this feedback, but AMTs (and others) can also be trained to provide more feedback (either over the phone or through the computer system) on what worked and what did not.

6.5. SA training

Common problems can be linked to SA failures in a number of systems, including (1) forgetting information or steps, frequently in association with task interruptions, (2) not passing information between shifts or team members, (3) missing critical information due to other task related distractions, and (4) misinterpreting information due to expectations. Training can be used to provide heightened awareness of these problems and ways of combating them. For instance, task interruptions are a common problem leading to SA errors. Frequently, such interruptions lead to skipping steps or missing activities. Personnel can be trained to take particular measures following a task interruption (double check previous work performed, double check area for loose tools, etc.). This type of training may be useful for helping maintenance personnel to insure that they are not missing critical information in the performance of their tasks.

6.6. Team SA training program

The team SA training course (Endsley and Robertson, 1997; Robertson and Endsley, 1997) was developed to address these five SA training goals and objectives. In addition, the course also provides a review of maintenance resource management (MRM) principles which are considered to be prior knowledge requirements for the trainees. The team SA training course was designed to be presented as an 8 h classroom delivery to personnel from across all maintenance operations departments. The course is best taught to a class composed of a mixed cross section from different maintenance operations organizations (e.g. stores, AMTs, inspectors, maintenance operations control, etc.). This is because the course focuses on helping to reduce the gaps and miscommunications that can occur between these different groups and it was anticipated that much of the course's benefit would come from the interaction that occurs when trainees share different viewpoints and information in going through the exercises.

An extensive set of Powerpoint® slides covering the five team SA training principles, group exercises, maintenance examples and case studies are included as part of the course to encourage active learning. The instructional strategy used for the course features adult inquiry and discovery learning. This allows a high level of interaction and participation amongst the trainees creating an experiential learning process. The team SA training course strongly encourages participation in problem solving, discussion groups and responding to open ended questions, thus promoting the acquisition and processing of information.

7. Evaluation of team SA training course

In order to assess the effectiveness of the course, an initial evaluation of it was conducted at the same subject airline.

7.1. Evaluation method

The team SA training course was delivered by the airline at four of its large maintenance bases. Most of the maintenance organization personnel in this airline had already received MRM training which is considered to be a precursor to the team SA training course. The course was delivered over a two-day period by this airline. (It was expanded from the original 8 h course design by this airline to allow for more group exercises, interaction and case studies.)

Seventy-two people from nine different maintenance locations attended the training sessions at which the present evaluation took place. Participation in the course was voluntary and participation in the course evaluation was also voluntary and confidential. Participants were present from a full cross-section of shifts. The majority of the participants were male (86%), however, 14% of the participants were female. The participants came from a wide range of technical operations departments and job titles. The most frequent job title was that of line mechanic (AMT), followed by leads and supervisors. A good cross sections of other organizations within the maintenance organization were also represented, including inspection, planning, and documentation support personnel. Attendees were very experienced at their jobs (mean = 10.41 yr) and within the organization (mean = 12.16 yr).

The evaluation process consisted of three levels: Value and usefulness of the training, pre/post training measures, and changes in behavior on the job. A questionnaire was administered immediately following the course to get participant's subjective opinions on the value and usefulness of the course. In addition, the amount of learning on attitudes and behaviors related to SA was also measured. An evaluation form was provided immediately prior to the training to assess knowledge and behaviors of the trainees related to SA. It was administered again immediately following the course to measure changes in attitudes and self-reported intentions to change behavior as a result of the training. The form was administered again 1 month later to assess changes in behavior on the job.

7.2. Results

7.2.1. Value and usefulness

The post-training course evaluation was used to measure the level of usefulness and perceived value of the course. Course participants scored each subsection of the course on a five-point scale which ranged from 1-waste of time to 5-extremely useful. On average, they rated each of the major topics as "very useful" (mean scores between 3.5 and 4.7). In addition to rating topics in the course, participants also answered several questions related to the course as a whole, shown in Fig. 4. The mean rating for the course overall was 4.3, corresponding to better than "very useful". A whopping 89% of the participants viewed the course as either "very useful" or "extremely useful", representing a high level of enthusiasm for the course. There were no low ratings of the course as a whole. Over 94% of the participants felt the course was either "very useful" or "extremely useful" for increasing aviation safety and teamwork effectiveness (mean rating of 4.4). Over 89% felt the course would be either very or

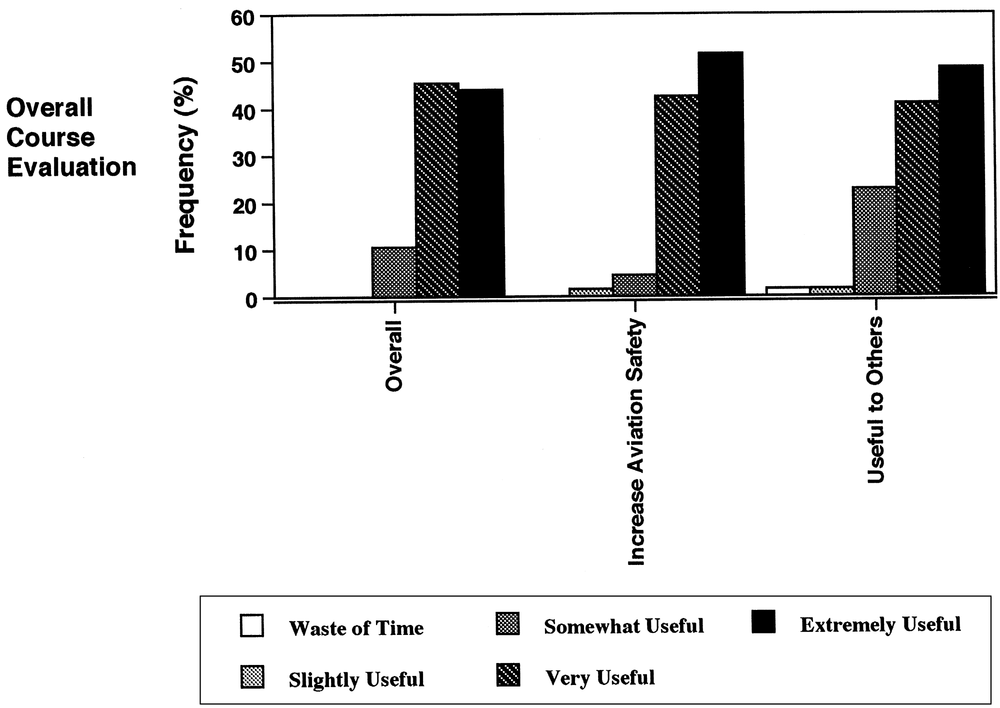

Fig. 4. Overall course evaluation.

extremely useful to others (mean rating of 4.3). When asked to what degree the course would affect their behavior on the job, 83% felt they would make a "moderate change" or a "large change", as shown in Fig. 5.

7.2.2. Changes in behavior and attitudes

The mean change in the post-test compared to the pre-test on each behavior described in the pre/post self-reported SA behavioral measure form was also assessed. A factor analysis on the questionnaire revealed a moderate degree of homogeneity. That is, responses on the items were somewhat interrelated, however, no large groupings of related factors were revealed to explain a large portion of the variance. (Only one factor accounted for more than 10% of the variance, with most accounting for less than 5%). The questionnaire was therefore treated as a set of independent items. Changes on each item were compared for each subject using a paired comparison analysis (pre-test to post-test).

The Wilcoxon non-parametric statistical analysis revealed that attitudes and self-reported behaviors changed significantly on seven of the 33 items ($p < 0.05$). Participants reported after the training they would be more likely to keep others up-to-date with their status as they go along in doing their jobs (an increase of 15%). They also were slightly more likely to report that they would try to keep up with which activities others were working on over the course of the shift (an increase of 10%). Both of these items relate to improved situation awareness across the team.

Participants reported they would be more likely to try to understand others' viewpoints when engaged in a disagreement with other departments (an increase of 15%). This relates to an effort to develop better shared mental models regarding other departments. In addition, participants reported changes in several behaviors related to improved communications and teamwork. They were more likely to report improved written communication when sending an aircraft with a MEL to

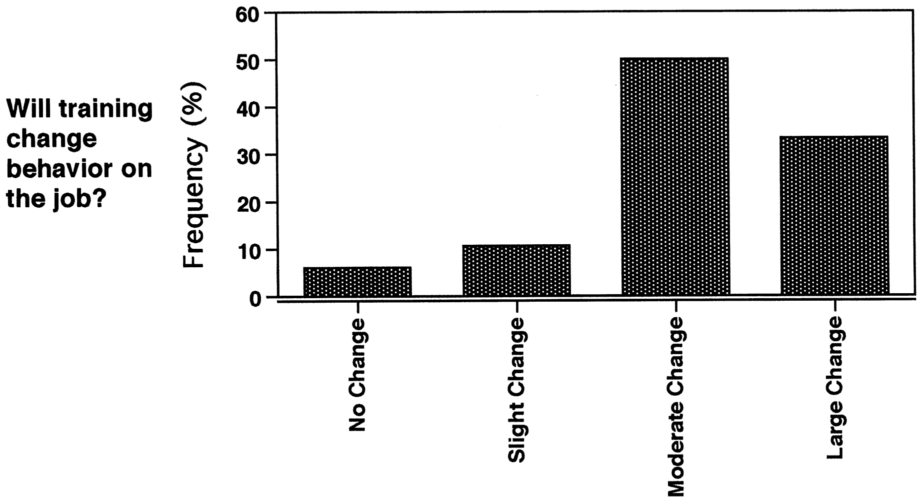

Fig. 5. Perceived affect of course on behavior.

another station (an increase of 21%). Participants were more likely to report that they would make sure to pass on information about an aircraft and work status to the next station (an increase of 13%).

They were also more likely to report making sure all problems and activities are discussed during shift meetings (an increase of 11%), and encouraging others to speak up during shift meetings to voice concerns or problems (an increase of 12%).

These differences between the pre-test and post-test measures on SA related behaviors and attitudes indicates that in addition to participants responding positively to the course, they reported actual changes in behaviors they would make on the job as a result of the course, thus improving SA on the job both between and within maintenance teams.

7.2.3. Changes on the job

In order to assess whether participants actually made the intended changes in their job behaviors following the course, the same form was again administered one month following the course. At the time of this analysis, the participants of only one course had been on the job for a full month after the training session. Of these participants (17), six responses were available for this analysis (representing a return rate of 35% which is typical of mail-in questionnaires). A paired comparison of responses on each item between the post-test questionnaire and the one-month questionnaire was made using the Wilcoxon test. This analysis revealed no changes on any of the test items at a 0.05 level of significance. Therefore, it would appear that the behaviors participants reported they would engage in following the training were carried out in practice, at least for this small sample.

7.3. Discussion of training evaluation

Overall the SA team training course was highly successful. The course content associated with all of the major training objectives was rated very highly with the vast majority of participants rating each area as "very useful" or "extremely useful". The course was viewed as between "very useful" and "extremely useful" overall, for increasing aviation safety and in terms of usefulness to others. The course training methods and media, including the case studies, videos and group exercises, were viewed as particularly successful and supportive in acquiring the learning objectives. In fact, the only suggestion many participants had for improvement was to use even more of these materials. Clearly, an instructional strategy that emphasized experiential learning and participation was effective for achieving the training objectives and facilitating the learning process.

The course was administered to a fairly experienced aviation maintenance group who represented a wide range of departments and skill areas within maintenance department of the airline. The fact that the course included such a mix of participants also was viewed as a key ingredient in its success. The mixed group allowed people from different areas to better understand each other's viewpoints, contributing to the development of shared mental models and open communications for future decision making.

The majority of participants felt that the course would result in making changes in their behaviors on the job. The results of the follow-up questionnaire, administered one month after the training course, supported these intentions. The self-reported behavior follow-up questionnaire showed that participants were making the changes they had intended to make following the training.

These results are very similar to those achieved in previous evaluations of MRM training programs which have been shown to be highly successful in improving safety and performance in aviation maintenance. Fig. 6 illustrates the enthusiast support for crew resource management (CRM) and MRM courses by flight operations and maintenance participants, respectively, as measured immediately following training (Taylor and Robertson, 1995). This is compared to the response measured in this study to the team SA training course. Nearly two-thirds of the flight operations groups reported that the CRM training was "very useful" or "extremely useful" (Helmreich et al., 1987). Even though this response is very strong, the response of maintenance personnel to the MRM training was even stronger. Ninety percent of the maintenance personnel sampled at two different airlines felt the course was "very useful" or "extremely useful" (Robertson et al., 1995; Taggart, 1990). The team SA training course, evaluated in this study, drew a response that was comparable to that found for the highly successful MRM Training program that was conducted at the same airline (Taylor and Robertson, 1995). Based on this result, it can be concluded that the team SA training course is viewed as highly useful at a rate that is

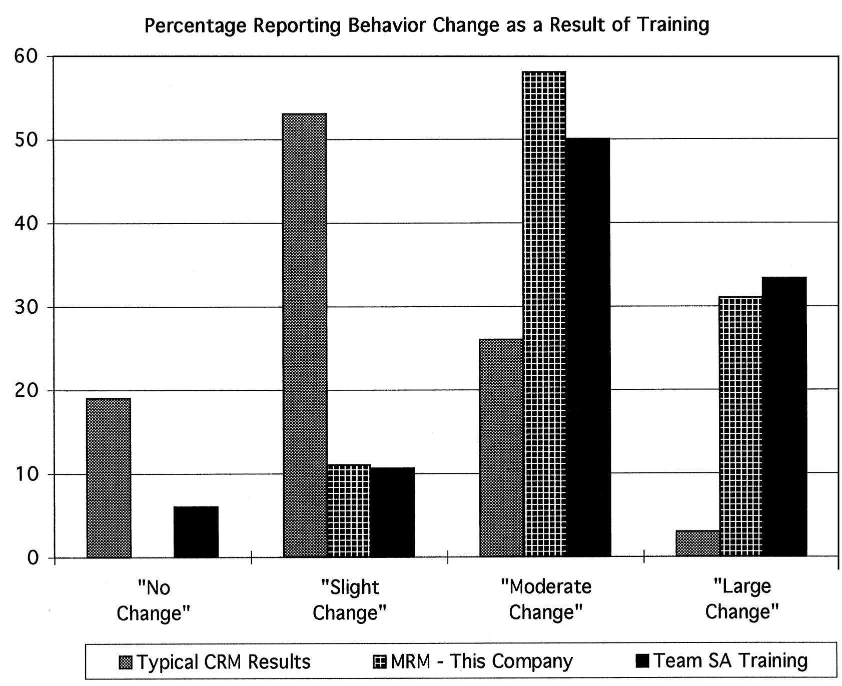

Fig. 6. Comparison of team SA training course usefulness to CRM/MRM courses.

favorably compared to previous courses in the MRM/CRM area.

These findings are based on the responses of an initial group of course participants. To further validate these findings, this evaluation should be continued with succeeding groups of trainees in the course. In addition, more follow-up research is needed to validate the results of the on-the-job behavior changes. At the time of this analysis, very few course participants had been back on the job for one full month. Therefore, the sample size for this analysis was very small; Probably, too small for much confidence in the results. By following up with the remaining participants at the one month point (and again at longer durations), more reliable results can be obtained regarding the degree to which the training effected job behaviors related to SA.

Finally, it would be highly desirable to ascertain the degree to which the training impacts critical maintenance performance measures at the airline. The bottom-line objective is to reduce maintenance errors, improve aviation safety and improve performance. Since the course had been administered to so few participants (scattered over 9 cities), making any meaningful assessment of the effect of the training on performance outcomes was not feasible in this study. In the future, however, the effect of the training implementation on several key safety and performance measures should be assessed.

8. Conclusion

Overall, the applicability of the concept and importance of situation awareness in maintenance teams has been supported in this analysis. Teams of AMTs are supported by many other personnel and organizational units to achieve their goals, each of which has a major impact on the attainment of the these goals. In this context it is necessary to examine how information flows between and among team members in order to identify system and personnel factors that will impact on the degree to which team members are able to maintain an accurate picture of an aircraft's status. This information appears to be crucial to their ability to perform tasks (as each task is interdependent on other tasks being performed by other team members), their ability to make correct assessments (e.g. whether a detected problem should be fixed now or placarded for later), and their ability to correctly project into the future to make good decisions (e.g. time required to perform task, availability of parts, etc.).

Results from the SA requirements analysis conducted here provide a firm foundation for identifying the knowledge, skills, and abilities that maintenance personnel need to attain a high level of SA. The SA requirements identified provide information on the specific knowledge that maintenance personnel need to achieve a high level of SA for completing their tasks. Providing personnel with knowledge is not enough, however. Maintenance personnel must also have the skills and abilities required to effectively communicate that knowledge, and need the ability to recognize which information needs to be exchanged among and between team members. Several gaps between teams were discussed.

In addition to specifying the role of SA in an aircraft maintenance environment, an assessment was made of systems and technologies used to support SA in this organization, and potential areas for improvement identified. The training concepts proposed here also show promise as a means of enhancing the skills and abilities needed for achieving a high level of SA in a team environment. These concepts were used to create a deliverable training program that was prototyped by a major airline. By enhancing the SA skills of the various maintenance teams, specifically focusing on areas where SA breakdowns are likely to occur, improvements in the efficiency and safety of the aircraft maintenance operations can be achieved.

The prototype implementation of the course was used to obtain an indication of the value of training of this nature. The idea of using training to improve SA is very new and no courses for training team SA have previously been developed. The evaluation presented here represents an initial evaluation of the team SA training course in its prototype implementation phase. It was the first time the course had been offered to a group of maintenance personnel. The fact that it was viewed so positively as useful to maintenance operations is highly indicative of its success. It is strongly recommended that the airline continue to implement the course and that additional airlines consider adopting the course to improve SA within maintenance organizations. Overall, the value of the team SA training program has been supported by this analysis and further implementation and evaluation of the course are recommended.

Acknowledgements

This work was performed under a sub-contract to Galaxy Scientific Corporation, Dr. William Johnson, Project Managers, for the Federal Aviation Administration Office of Aviation Medicine, Dr. William Sheppard and Ms. Jean Watson, Program Manger. We express our sincere appreciation to Ms. Karin Porter, Mr. John Stelly and Mr. Tom Kirwan at Continental Airlines for their support of this research and their innovative efforts to improve technical operations in aviation.

References

Drury, C., 1993. In: Corporation, G.S. (Ed.), Training for visual inspection of aircraft structures. Human Factors in Aviation Maintenance – Phase Three, Progress Report (DOT/FAA/AM-93/15), Office of Aviation Medicine. Federal Aviation Administration, Washington, DC, pp. 133–154 (Chapter eight).

Endsley, M.R., 1988. Design and evaluation for situation awareness enhancement. In: Proceedings of the Human Factors Society 32nd Annual Meeting, Santa Monica, CA, pp. 97–101.

Endsley, M.R., 1989. Final report: situation awareness in an advanced strategic mission. NOR DOC 89-32, Northrop Corporation, Hawthorne, CA.

Endsley, M.R., 1993. A survey of situation awareness requirements in air-to-air combat fighters. International Journal of Aviation Psychology 3 (2), 157–168.

Endsley, M.R., 1994. Situation awareness in FAA Airway Facilities Maintenance Control Centers (MCC). Final Report, Texas Tech University, Lubbock, TX.

Endsley, M.R., 1995a. A taxonomy of situation awareness errors. In: Fuller, R., Johnston, N., McDonald, N. (Eds.), Human Factors in Aviation Operations, Avebury Aviation. Ashgate Publishing Ltd, Aldershot, England, pp. 287–292.

Endsley, M.R., 1995b. Toward a theory of situation awareness. Human Factors 37 (1), 32–64.

Endsley, M.R., Jones, D.G., 1995. Situation awareness requirements analysis for TRACON air traffic control. TTU-IE-95-01, Texas Tech University, Lubbock, TX.

Endsley, M.R., Robertson, M.M., 1997. Team situation awareness training program. In: Human Factors Issues in Aircraft Maintenance and Inspection '97 CD-ROM. Galaxy Scientific Corporation, Atlanta, GA.

Endsley, M.R., Rodgers, M.D., 1994. Situation awareness information requirements for en route air traffic control. In: Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting, Santa Monica, CA, pp. 71–75.

Hartel, C.E., Smith, K., Prince, C., 1991, Defining aircrew coordination: searching mishaps for meaning. Paper presented at the Sixth International Symposium on Aviation Psychology, April.

Helmreich, R.L., Foushee, H.C., Benson, R., Russini, W., 1987. Cockpit management attitudes: exploring the attitude behavior linkage. Aviation, Space and Environmental Medicine 57, 1198–1200.

Klein, G.A., 1989. Recognition-primed decisions. In: Rouse, W.B. (Ed.), Advances in Man–machine Systems Research. JAI Press, Inc, Greenwich, CN, pp. 47–92.

Marx, D.A., Graeber, R.C., 1994. Human error in aircraft maintenance. In: Johnston, N., McDonald, N., Fuller, R. (Eds.), Aviation Psychology in Practice. Avebury, Aldershot, UK, pp. 87–104.

National Transportation Safety Board, 1984. Aircraft Accidents Report, Eastern Air Lines, Inc., L-1011, Miami, Florida, May 5, 1983, Author, Washington, DC.

O'Neill, M.J., Robertson, M.M., 1996. A participatory design process for developing ergonomic office design criteria. In: Brown, O., Hendrick, H.W. (Eds.), Human Factors in Organizational Design and Management – V. North-Holland, Amsterdam, pp. 209–215.

Robertson, M.M., Endsley, M.R., 1997. Development of a situation awareness training program for aviation maintenance. In: Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting, Santa Monica, CA, pp. 1163–1167.

Robertson, M.M., O'Neill, M.J., 1994. Development of contextual inquiries for examining knowledge workers in technological office environments. Herman Miller, Inc., Zeeland, MI.

Robertson, M.M., Taylor, J.C., Stelly, J.W., Wagner, R., 1995. A systematic training evaluation model applied to measure the effectiveness of an aviation maintenance team training program. In: Proceedings of the Eighth International Symposium on Aviation Psychology, Columbus, OH, pp. 631–636.

Ruffner, J.W., 1990. A survey of human factors methodologies and models for improving the maintainability of emerging army aviation systems. US Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA.

Salas, E., Dickinson, T.L., Converse, S., Tannenbaum, S.I., 1992. Toward an understanding of team performance and training. In: Swezey, R.W., Salas, E. (Eds.), Teams: their training and performance. Ablex, Norwood, NJ, pp. 3–29.

Taggart, W., 1990. Introducing CRM into maintenance training. In: Proceedings of the Third International Symposium on Human Factors in Aircraft Maintenance and Inspection, Washington, DC, pp.

Taylor, J.C., Robertson, M.M., 1995. The effects of crew resource management (CRM training in airline maintenance: results following three year's experience. NASA Ames Research Center Office of Life and Microgravity Sciences and Applications, Moffett Field, CA.

Taylor, J.C., Robertson, M.M., Peck, R., Stelly, J.W., 1993. Validating the impact of maintenance CRM training. In: Proceedings of the Seventh International Symposium on Aviation Psychology, Columbus, OH, pp. 538–542.