CHAPTER 4
TEAM SITUATION AWARENESS IN AIRCRAFT MAINTENANCE

Mica R. Endsley, Ph.D.
Department of Industrial Engineering, Texas Tech University
and
Michelle M. Robertson, Ph.D.
Institute of Systems and Safety Management, University of Southern California

4.1 INTRODUCTION

Insufficient attention has been paid to human error in aircraft maintenance. While the numbers 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 issues can be identified.

1. The first involves shortcomings in the detection of critical cues regarding the state of the aircraft or sub-system. 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 & 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 supports 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. The Eastern Airlines incident at Miami Airport (National Transportation Safety Board, 1984) has been directly linked to a problem with coordination of information across shifts (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, or completed properly, important information not being communicated, and problems going undetected as responsibility for tasks becomes diluted.

4.1.1 Situation Awareness

All of these difficulties point to a lack of situation awareness. 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 mechanical 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 sub-system 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, systems not functioning properly, etc. 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. A technician with Level 1 SA might be aware that a particular subsystem is not working properly. A technician 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. A technician 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 technicians' 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, technicians 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 maintenance technicians, as they often receive little or no feedback on the effects of their actions, and thus may have difficulty developing an adequate mental model for making accurate predictions. The ability to project system status forward (to determine possible future occurrences) may also 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.

4.1.2 Team SA

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. Individuals need not only to 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. 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, 1989a). 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.

4.1.3 SA Errors

Marx and Graeber (1994) point out that many different taxonomies of errors have been proposed. The major question becomes translating the error classification into meaningful remediation within the maintenance context, an issue that is not trivial with many taxonomies. The primary advantage of characterizing maintenance errors in terms of situation awareness is that a taxonomy of causal factors at the level of human information processing mechanisms and characteristics has been developed for understanding the root causes of these errors (Endsley, 1994; Endsley, 1995), shown in Table 4.1. Thus specific remediation measures can be identified for addressing the root causes of the errors discussed previously. Situation awareness training concepts for individuals (Endsley, 1989b) and teams (Robertson & Endsley, 1995) can also be developed based on this formulation.

Table 4.1 SA Error Taxonomy (Endsley, 1994, 1995)

I. Level 1 SA - Failure to Correctly Perceive Situation
  A. Data not available
  B. Data difficult to detect/perceive
  C. Failure to scan or observe data
    1. Omission
    2. Attention narrowing/distraction
    3. High taskload
  D. Misperception of data
  E. Memory failure
II. Level 2 SA - Failure to Comprehend Situation
  A. Lack of or poor mental model
  B. Use of incorrect mental model
  C. Over-reliance on default values in model
  D. Memory failure
  E. Other
III. Level 3 SA - Failure to Project Situation into the Future
  A. Lack of or poor mental model
  B. Other

4.2 RESEARCH OBJECTIVE

The overall research objective is to address current situation awareness related difficulties in aircraft maintenance through the development of cohesive maintenance teams and the promotion of team situation awareness. 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, Dickinson, Converse, & Tannenbaum, 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. 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.

Within the framework of a team it is important to provide the members with the skills to function effectively. Specifically, it is proposed that training 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 for which they have been trained. Several related training programs have been successful within this domain. Drury (1993) has shown success in training maintenance personnel in visual inspection. Taylor, Robertson, Peck and Stelly (1993) were successful in improving high-level performance objectives (for example, dependability and safety) after instituting a program to train aircraft maintenance personnel in communication and coordination skills. While both of these examples may help SA, neither directly addresses SA as an over-riding objective. Other factors need to be considered to optimize Team SA, such as the skills needed to identify critical information and ensure that it is passed across teams and team members and interpreted based on a common framework across team members.

The objective of this project is to identify situation awareness requirements for aircraft maintenance teams, analyze how SA needs are currently being met in a typical maintenance environment, and establish concepts and requirements for training Team SA in this domain.

4.3 METHODOLOGY

Two major research initiatives were conducted towards the accomplishment of this goal:

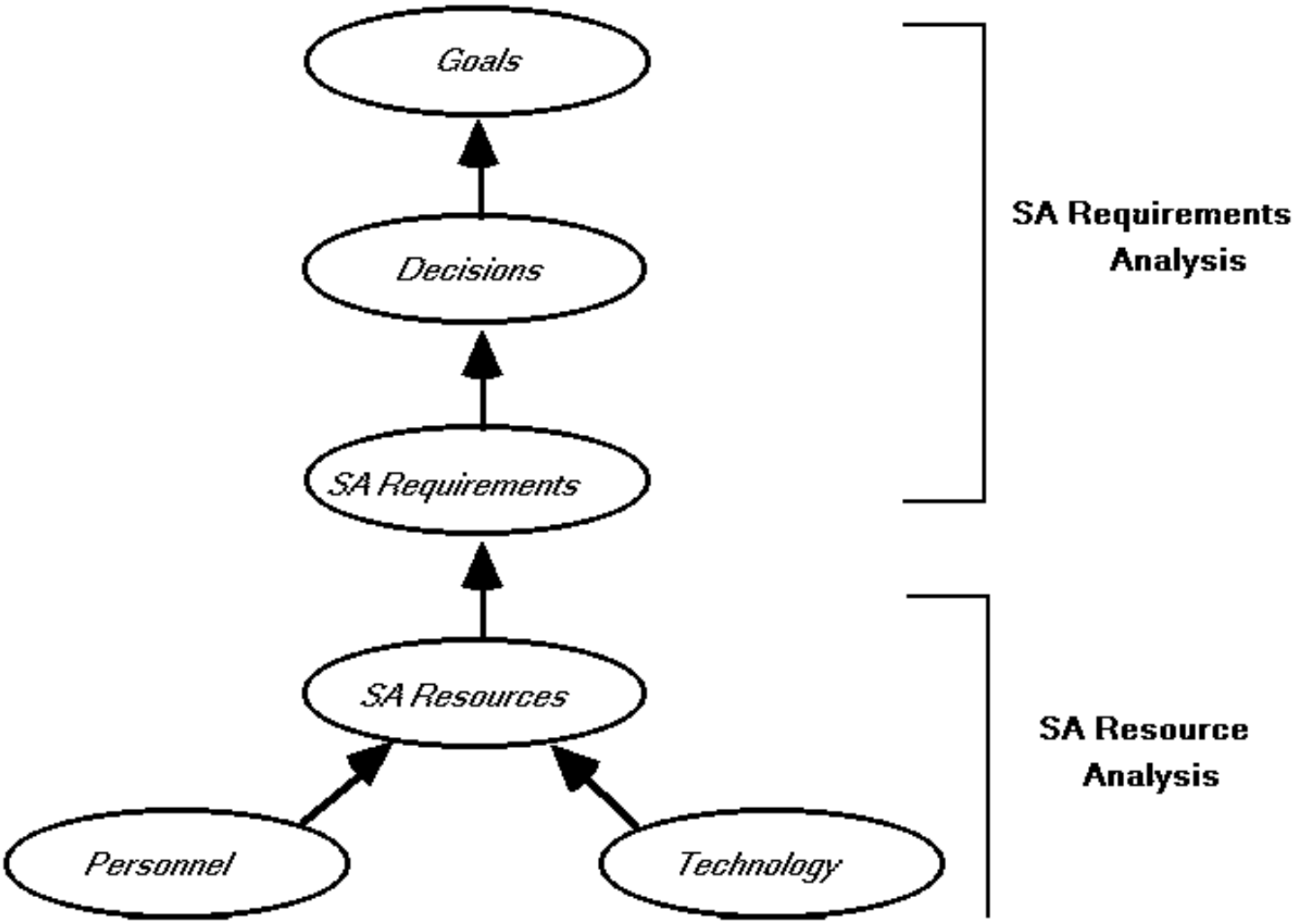
(1) A determination of the requirements and resources for Team SA in aircraft maintenance, and

(2) An assessment of training needs for Team SA.

Since it was not possible to review practices at all airlines or all locations, these activities were conducted at an aircraft maintenance facility for a major U.S. airline that served as a representative maintenance environment. The B-check maintenance operations at a major airport were selected to keep the project within a reasonable scope. The project was conducted by first identifying SA requirements and the resources used to support those requirements in the selected representative maintenance environment. Concepts for training Team SA were developed based on the analysis.

A Team SA Context Analysis methodology was developed for this project. This method consists of two parts: An SA Requirements Analysis and an SA Resource Analysis, as shown in Figure 4.1.

Figure 4.1 Team SA Context Analysis



4.3.1 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 conducted successfully for several classes of aircraft (Endsley, 1989a; Endsley, 1993), air traffic control (Endsley & Rodgers, 1994) and airway facilities maintenance (Endsley, 1993).

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. Discussions were conducted with three maintenance supervisors, four lead technicians and four A&P technicians. In addition, personnel in planning and stores, maintenance control, maintenance operations control and aircraft-on-ground at headquarters were involved in the discussions.

4.3.2 SA Resource Analysis.

The second part of the Team SA Context Analysis concentrated on identifying the SA Resources used in the current 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 existing personnel SA resources, an analysis of communications between organizations and individuals was conducted using a contextual inquiry approach. The contextual inquiry approach (Robertson & O'Neill, 1994) focuses on understanding and describing the communication patterns within and between teams as related to their performance goals. The contextual inquiries were conducted simultaneously with the discussions for determining the SA requirements. The contextual inquires involved semi-structured discussions 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 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 to identifying the SA requirements of teams working on each maintenance task, 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 Team SA 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 Team SA.

4.4. RESULTS

A hierarchy of goals in the maintenance environment was developed for several categories of job function within the maintenance team (supervisors, leads and technicians), 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). These are presented in Section 4.4.1. These goals were used to develop a list of SA requirements for each group, shown in Section 4.4.2. Next, the personnel resources used for meeting these SA requirements were determined and are presented in Section 4.4.3. The technology resources used for meeting the SA requirements were also surveyed and are discussed in Section 4.4.4. In addition, barriers and problems for achieving job goals were identified during the discussions and are documented in Section 4.4.5.

4.4.1 Goals and Functions

Goals for each job analyzed in the maintenance domain were derived from discussions with personnel as a part of the goal-directed task analysis. Job goals at all levels in this domain appear to be oriented towards the dual objectives of ensuring aircraft safety and delivering aircraft for service on time. A breakout of A&P technician goals is shown in Table 4.2. The goal break-outs for supervisors and maintenance team leads were identical, and so have been combined and presented in Table 4.3. (Supervisors also have significant administrative responsibilities which are outside the scope of this analysis and are not addressed here.)

Table 4.2 A&P Technician Goals

1.0 Aircraft safety
1.1 Deliver aircraft in airworthy, safe condition
1.1.1 Make repairs
1.1.1.1 Determine part availability
1.1.1.2 Placard problem
1.1.2 Service aircraft
1.1.3 Find potential problems
1.1.4 Solve problems
1.1.5 Provide quality workmanship
1.2 Keep area clean

2.0 Deliver aircraft on time
2.1 Prioritize tasks

Table 4.3 Lead & Supervisor Goals

1.0 Aircraft safety
1.1 Deliver aircraft in airworthy, safe condition
1.1.1 Assist mechanics
1.1.1.1 Make repairs
1.1.1.2 Service aircraft
1.1.1.3 Find potential problems
1.1.1.4 Solve problems
1.1.1.5 Provide quality workmanship
1.2 Keep area clean

2.0 Deliver aircraft on time
2.1 Prioritize tasks
2.2 Assign tasks
2.2 Assess aircraft status
2.3 Provide coordination

In general, the top level goals of supervisors and leads are very similar to those of technicians. They assume many of the same subgoals as the technicians in identifying and solving maintenance problems when needed to support technicians 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).

Specific tasks and functions included within the B-check operations were:

- avionics in cockpit: radar, radios, flaps, gauges,
- interior: lavatories, emergency equipment, seats, overhead bins, lap belts, emergency lighting
- exterior: tires, brakes, fuselage, leading edges and flaps, cargo bays
- right and left engines and wings
- right/left gear lubrication, nose gear lubrication and tail lubrication
- APU
- placards

Several internal organizations (teams) interact with the maintenance team and have a significant role in achieving maintenance goals. The goals and SA requirements for these organizations also were assessed. They included Material Services (Stores) (Table 4.4), Planning (Table 4.5), and Maintenance Control (Table 4.6). Maintenance Operations Control (MOC) (Table 4.7) and Aircraft-on-ground (AOG) (Table 4.8) are sub-organizations of Maintenance Control.

Table 4.4 Material Services (Stores) Goals

1.0 Minimize delays & placards
- 1.1 Have needed parts/tools/materials ready when needed
  - 1.1.1 Assess parts/tools/materials demands
  - 1.1.2 Assess parts/tools/materials availability
  - 1.1.3 Assemble kits
- 1.2 Supply parts/tools/materials to other stations

2.0 Minimize costs and time to obtain materials
- 2.1 Obtain parts/tools/materials in a timely/cost effective manner
  - 2.1.1 Order parts/tools/materials from vendors
  - 2.1.2 Order parts/tools/materials from other stations
  - 2.1.3 Borrow parts/tools/materials from other airlines

Table 4.5 Planning Goals

1.0 Set-up and print job cards for remain-over-night (RON) aircraft
- 1.1 Determine tasks to be done to aircraft
- 1.2 Assess ability to complete tasks
- 1.3 Re-schedule work

Table 4.6 Maintenance Control Goals

1.0 Eliminate out-of-service aircraft and avoid delays
- 1.1 Determine actions needed to get aircraft back to flight status

Table 4.7 Maintenance Operations Control Goals

1.0 Minimize number of placards on aircraft
- 1.1 Don't exceed mandated time limits on placards
  - 1.1.1 Get aircraft to desirable station
  - 1.1.2 Approve/disapprove re-routing requests

Table 4.8 Aircraft-on-Ground Goals

1.0 Deliver needed parts ASAP
- 1.1 Find parts
- 1.2 Minimize costs

Reviewing the goals of each of these organizations reveals significant interdependencies between teams. For instance, technicians are dependent on Material Services to "have parts/tools/materials ready when needed." Material Services is in turn dependent on Planners to provide relevant task information and on AOG to "deliver needed parts ASAP." These interdependencies, while not surprising, highlight the need for good transfer of information across teams. By examining in detail the situation awareness 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.

4.4.2 SA Requirements

A breakout of SA requirements for each goal and subgoal was derived from discussions and observations. This is presented in Table 4.9 (for technicians) and Table 4.10 (for supervisors and leads). The SA requirements for each goal and subgoal for the supporting organizations was likewise derived and are presented in Table 4.11 (for material services (stores)), Table 4.12 (for planning), Table 4.13 (for maintenance control), Table 4.14 (for maintenance operations control (MOC)) and Table 4.15 (for aircraft-on-ground (AOG)). The format of the SA requirements breakout is as follows:

X.X
Goal

X.X.X Subgoal

- *questions to be answered to meet the goal*
  - SA requirements
    - SA requirements

In general, the analysis identifies a number of SA requirements at all three levels (perception, comprehension and projection) that are important for meeting goals in this domain. There are a few guidelines that should be kept in mind when reviewing this analysis.

- At any given time more than one goal or subgoal may be operating, although these goals will not always have the same priority. The attached SA requirements breakout does not assume any prioritization among them, or that each subgoal within a goal will always come up.
- These are goals or objectives not tasks. The analysis should be as technology free as possible. How the information is acquired is not addressed here (e.g., directly through some system, from another unit, etc.). (This will be addressed in the SA Resource Analysis.)
- The analysis sought to define what technicians 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.
- 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 technicians perform their tasks.

Table 4.9 A&P Technician SA Requirements

1.0 Aircraft safety
1.1 Deliver aircraft in airworthy, safe condition
1.1.1 Make repairs
1.1.1.1 Determine part availability

- *Correct part supplied?*
- manufacturer's part number
- aircraft type, model, tail number
- maintenance and equipment list (M&E) number
- effectivity number
- *How long to get part here?*
- in-stock status
- manufacturer's part number
- aircraft type, model, tail number
- maintenance and equipment list (M&E) number
- effectivity number
- part & tooling availability
- where
- when it will be here

- delivered or pick-up
- arrival flight number
- arrival gate number

1.1.1.2 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

1.1.2 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?*
- 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

1.1.3 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

1.1.4 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 1.1.1.1)
- proposed repair authorized
- EC/RA Engineering Change Request Authorization number

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

1.2 Keep area clean

- *Area free of foreign objects?*
- loose objects (screws, parts, etc.)
- 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 1.1.1.1)
- problem deferability category (placardable, groundable)
- minimum equipment list (MEL) status
- availability of kits, tools, equipment, vehicles
- availability of personnel
- personnel skills

Table 4.10 Lead Technician & Supervisor SA Requirements

1.0 Aircraft safety

1.1 Deliver aircraft in airworthy, safe condition

1.1.1 Assist mechanics

1.1.1.1 Make repairs

(see A&P Technician requirements)

1.1.1.2 Service aircraft

(see A&P Technician requirements)

1.1.1.3 Find potential problems

(see A&P Technician requirements)

1.1.1.4 Solve problems

(see A&P Technician requirements)

1.1.1.5 Provide quality workmanship

(see A&P Technician requirements)

- *Procedures followed correctly?*
- required tasks completed properly
- tasks completed per manual
- paperwork complete

1.2 Keep area clean

(see A&P Technician requirements)

2.0 Deliver aircraft on time

2.1 Prioritize tasks

- *Best order for tasks?*
- tasks scheduled
- aircraft type
- check type
- placards
- non-routine problems
- task time requirements
- time available for tasks
- time due in
- time due out
- location in
- location out
- gate number
- flight number
- interdependence/sequencing requirements of tasks
- part availability
- problem deferability category (placardable, groundable)
- minimum equipment list (MEL) status
- availability of kits, tools, equipment, vehicles
- availability of personnel
- personnel skills

2.2 Assign Tasks

- *Task assignments?*
- personnel here/available
- experience/capability in task type
- speed at performing task
- ability to do job without supervision
- ability to sign off on job
- seniority
- housekeeping
- tasks to be done
- criticality for air safety

- time required to do task
- complexity of task
- how much needs to be disassembled to complete task
- ability to do task at same time as other tasks
- ability to do task at gate
- aircraft location

2.3 Assess aircraft status

- *where do we stand on tasks/non-routine problems?*
- *what help is needed?*
- *what problems are the technicians having?*
- *what parts are needed?*
- Impact on delivery schedule
- tasks completed
- tasks in progress
- non-routine problems encountered
- status of non-routine problems
- time required to do remaining tasks
- parts needed
- help/information needed
- personnel needed
- diagnostic support needed

2.4 Provide coordination

- *coordination/assistance needed?*
- tasks completed
- tasks in progress
- non-routine problems encountered
- status of non-routine problems
- time required to do remaining tasks
- parts needed
- help/information needed
- personnel needed
- diagnostic support needed

Table 4.11 Material Services (Stores) Goals

1.0 Minimize delays & placards

1.1 Have needed parts/tools/materials ready when needed

1.1.1 Assess parts/tools/materials demands

- *What parts/tools/materials are needed?*
- maintenance work forecast
- tasks planned
- aircraft type
- check type
- known placards
- date planned
- parts/tools/materials needed for each task
- aircraft type
- modifications/changes to aircraft
- part number
- effectivity number or mod number
- anticipated problems for aircraft type
- parts/tools/materials needed
- aircraft type

- modifications/changes to aircraft
- part number
- effectivity number or mod number

1.1.2 Assess parts/tools/materials availability

- *Can we meet demands?*
- state of internal inventory
- number of items per part number/effectivity number
- other parts that are interchangeable
- engineering authorization for substitution
- *Is item available elsewhere?*
- availability of parts/tools/materials at other stations
- availability of parts/tools/materials at other airlines
- availability of parts/tools/materials at vendors

1.1.3 Assemble kits

- *Kits ready?*
- kit complete/correct
- kit assembled prior to when needed
- Assess demands (1.1.1)
- Assess availability (1.1.2)
- Obtain items (2.1)

1.2 Supply parts/tools/materials to other stations

- *Can I supply this item?*
- requests for items
- urgency of need
- parts/tools/materials needed
- aircraft type
- modifications/changes to aircraft
- part number
- effectivity number or mod number
- Assess own demands (1.1.1)
- *Where to send item?*
- stations plane will R.O.N. in
- capabilities of station
- urgency of need
- *How can I get it there in a timely/cost effective manner?*
- shipment methods available
- cost
- timeliness

2.0 Minimize costs and time to obtain materials

2.1 Obtain parts/tools/materials in a timely/cost effective manner

- *can I get this item by the time its needed?*
- *what is the most cost and time effective method of obtaining?*
- availability of parts/tools/materials at other stations
- availability of parts/tools/materials at other airlines
- availability of parts/tools/materials at vendors
- urgency of need
- time item needed by
- shipment methods available
- cost
- timeliness

2.1.1 Order parts/tools/materials from vendors

- *What needs to be ordered?*
- *When should items be ordered?*
- lead time to keep inventory at levels needed

- state of internal inventory
- number of items per part number/effectivity number
- re-order points
- usage requirements (number of items per month)

2.1.2 Order parts/tools/materials from other stations

- *What needs to be ordered?*
- *Who has item?*
- *Who can deliver item quickest and cheapest?*
- cost
- time to acquire
- delivery method
- item availability

2.1.3 Borrow parts/tools/materials from other airlines

- *What needs to be ordered?*
- *Who has item?*
- *Who can deliver item quickest and cheapest?*
- cost
- time to acquire
- delivery method
- item availability

Table 4.12 Planning Goals

1.0 Set-up and print job cards for remain-over-night (RON) aircraft

1.1 Determine tasks to be done to aircraft

- *what needs to be done to aircraft?*
- *amount of time until work must be performed?*
- tasks to be completed
- routine work
- type of check
- standard check items
- known placards
- expiration date/time on placard
- non-routine work
- new placards
- expiration date/time on placard
- extra jobs (flight directives, etc.)

1.2 Assess ability to complete tasks

- *can work be done here?*
- *manpower available for tasks to be done?*
- time required to complete tasks
- number of man-hours required for tasks
- time available to complete work
- number of man-hours available
- *ability to perform work?*
- parts availability
- in-house
- being shipped
- time of arrival
- material availability
- tooling availability

1.3 Re-schedule work

- *can work be deferred?*
- *can plane be delayed?*
- *can aircraft be re-routed?*

- problems encountered in completing work
- new placards
- assess ability to complete work here (1.2)

Table 4.13 Maintenance Control Goals

1.0 Eliminate out-of-service aircraft and avoid delays

1.1 Determine actions needed to get aircraft back to flight status

- *Can aircraft be fixed?*
- problem diagnosis
- type of repairs needed
- parts needed
- estimated time to repair (ETR)
- aircraft model
- description of problem
- status of system parameters
- actions performed
- history of actions on systems/parts on aircraft
- estimated return to service time (RTD)
- confidence in RTD estimate
- estimated time to repair (ETR)
- time to acquire parts
- time to acquire people with skills
- *Is alternate action needed?*
- *Will current actions meet schedule requirements?*
- Estimated return to service time (RTD)
- Scheduled time aircraft due in service
- *Can problem be deferred?*
- M.E.L. list
- other system repairs currently deferred
- scheduled trips (cities, routes)
- weather forecast
- distance of trips
- fuel loads required
- altitude restrictions
- capabilities of stations on current schedule
- *Can aircraft be rescheduled?*
- alternate routes available
- capabilities of stations on alternate routes
- *Temporary repair possible?*
- type of repairs needed
- parts needed
- estimated time to repair (ETR)

Table 4.14 Maintenance Operations Control Goals

1.0 Minimize number of placards on aircraft

1.1 Don't exceed mandated time limits on placards

1.1.1 Get aircraft to desirable station

- *Which station should aircraft be sent to?*
- *Can necessary work be performed at stations on route?*
- *Impact of route on schedule?*
- Stations scheduled for R.O.N. on route
- placarded item
- number of days on limit
- type of repairs needed
- parts needed
- estimated time to repair (ETR)
- capability of stations
- availability of parts at stations
- availability of expertise/manpower at stations

1.1.2 Approve/disapprove re-routing requests

- *Okay to re-route aircraft?*
- *Can necessary work be performed at new stations?*
- *Impact of re-route on schedule?*
- Stations scheduled for R.O.N. on route
- placarded item
- number of days on limit
- type of repairs needed
- parts needed
- estimated time to repair (ETR)
- capability of stations
- availability of parts at stations
- availability of expertise/manpower at stations

Table 4.15 Aircraft-on-Ground Goals

1.0 Deliver needed parts ASAP

1.1 Find parts

- *Where can the part be acquired from as soon as possible?*
- part number/effectivity number
- reference used to determine part number
- interchangeability of parts
- quantity needed
- rotable/expendable
- station part needed at
- location of available parts
- other stations
- other airlines
- vendors
- priority
- time aircraft due back in service
- status of part delivery

1.2 Minimize costs

- *What is the least expensive place to get the part by the needed time?*
- *What is the least expensive way to get the part to the station by the needed time?*
- expedite fees
- volume discounts
- delivery method
- priority

- time aircraft due back in service
- cost of available parts
- other stations
- other airlines
- vendors

4.4.3 SA Resources: Personnel

The personnel resources and technology resources used within the organization to meet the situation awareness needs identified in Section 4.4.2 were ascertained through the contextual inquiry methodology. Personnel resources are presented in this section and the technology resources are in Section 4.4.4.

Results of the contextual inquiries are presented in Figures 4.2 through 4.11. The figures depict the personnel SA resources, in terms of the individuals or units within the maintenance technical operations, that are needed to achieve the team's performance goals. Figures 4.2, 4.3, and 4.4 show the organizations and individuals that the A&P technician, lead technician and supervisor interface with, respectively. Lines and arcs show communication patterns between organizations. Figure 4.5 shows the personnel requirements for the material services (stores) supervisor and Figure 4.6 for a lead in material services, Figure 4.7 for planners, Figure 4.8 for a maintenance control manager and Figure 4.9 for maintenance control controllers, Figure 4.10 for maintenance operations control, and Figure 4.11 for aircraft-on-ground. Supervisor SA resources were delineated for some organizations where available.

Figure 4.2 SA Resources: A&P Technician

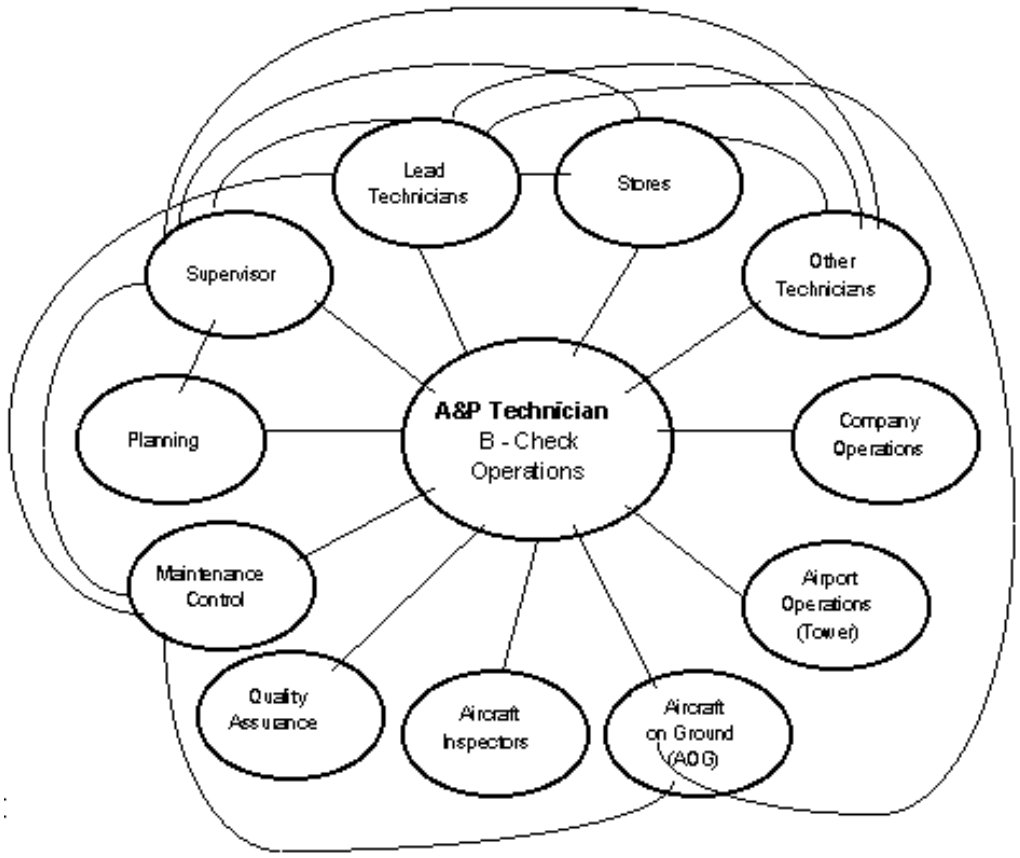


Figure 4.3 SA Resources: Lead Technician

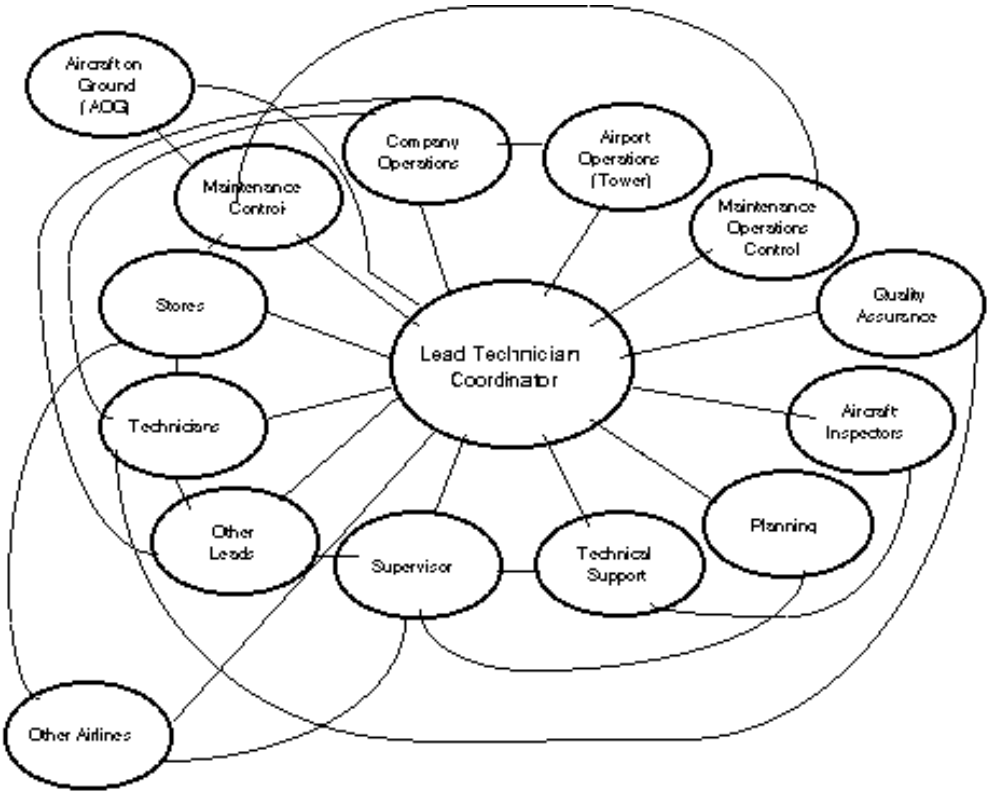


Figure 4.4 SA Resources: Supervisor

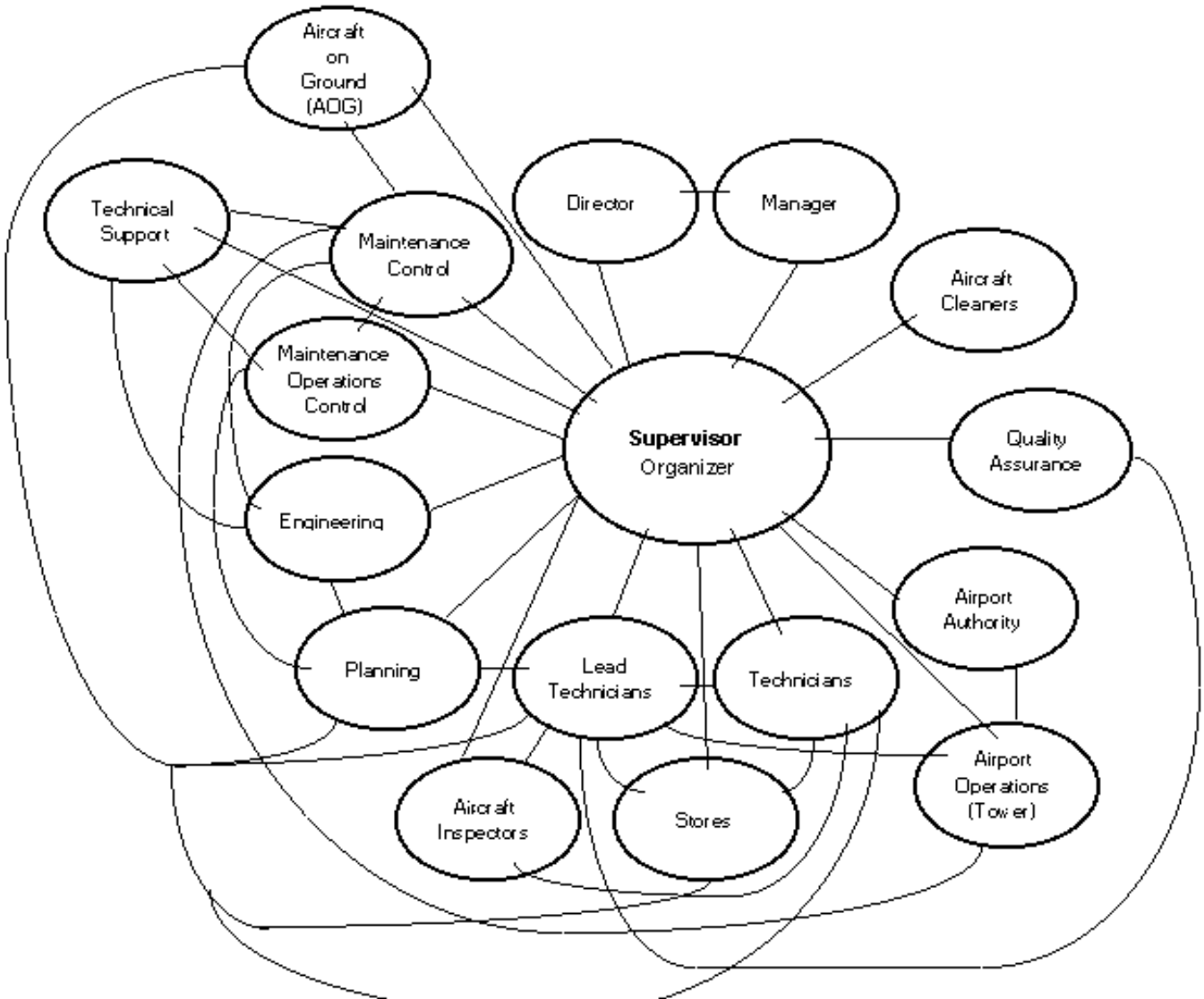


Figure 4.5 SA Resources: Material Services Supervisor

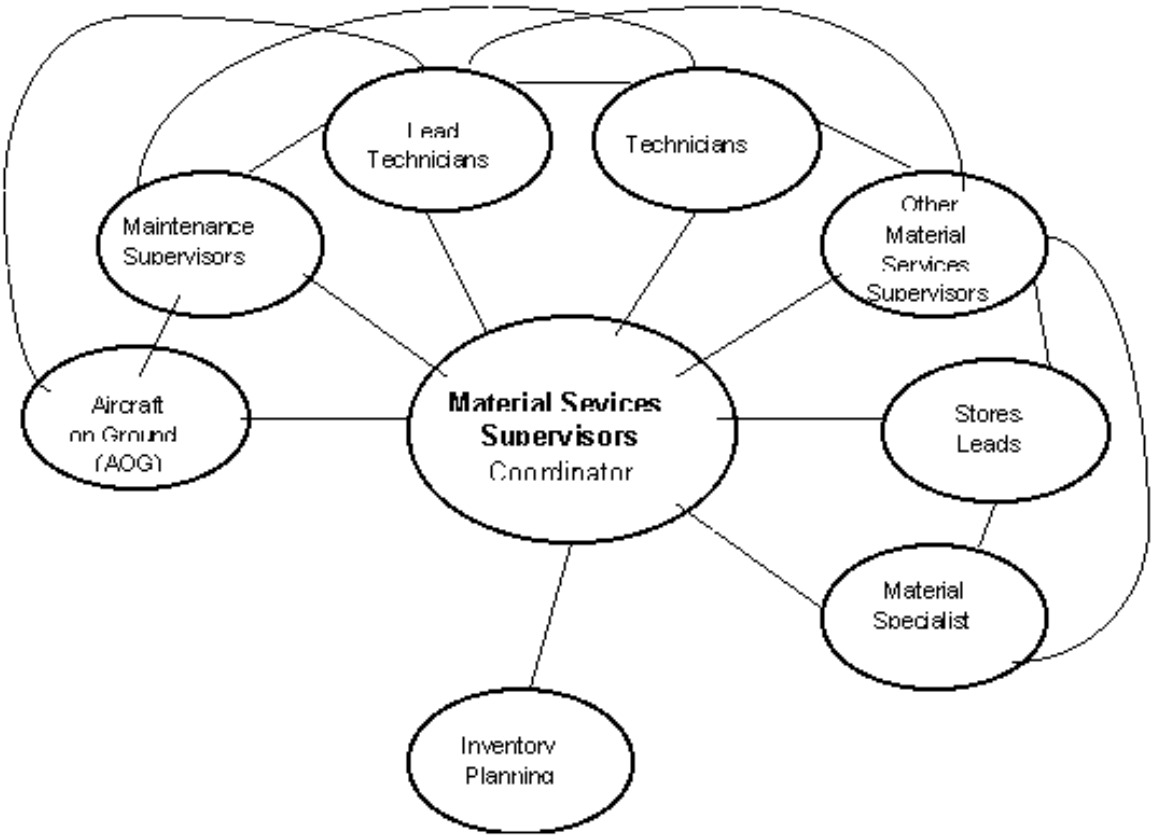


Figure 4.6 SA Resources: Material Services Lead

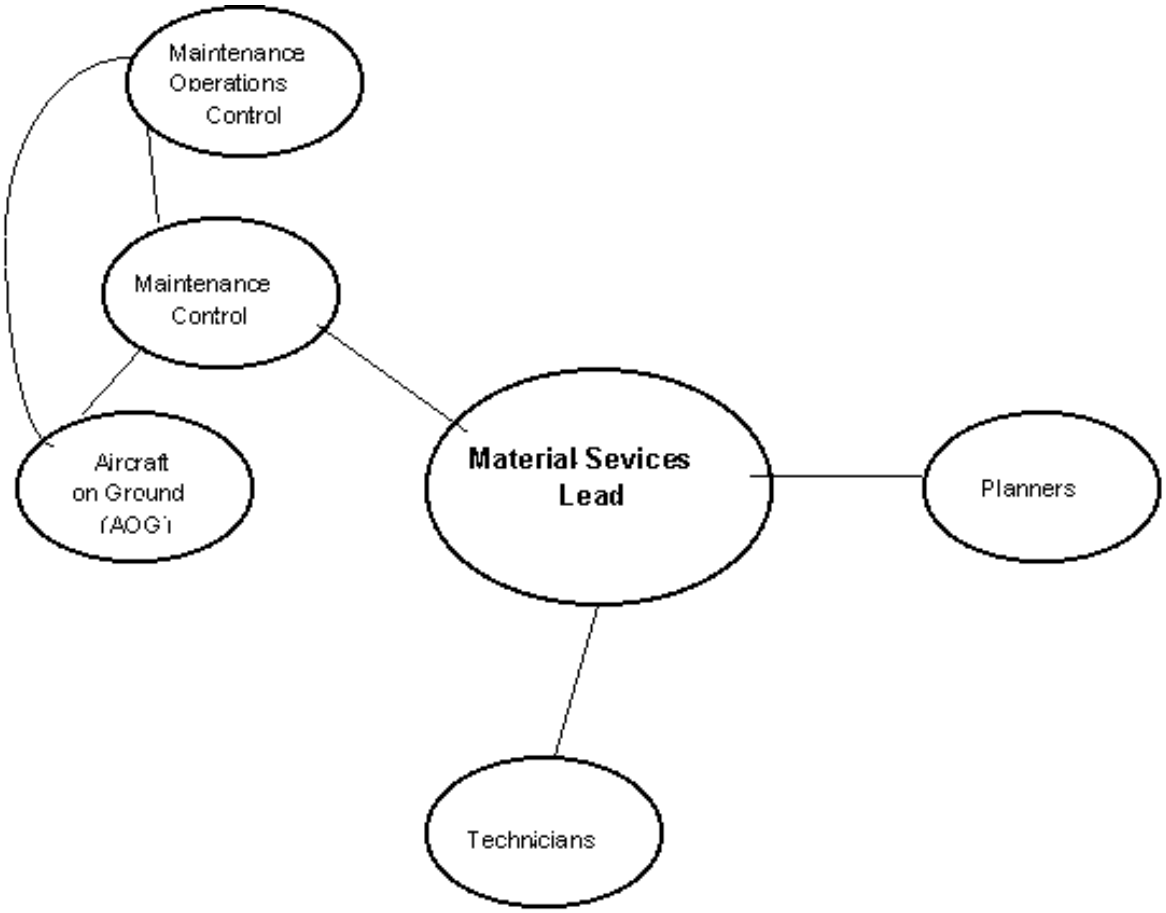


Figure 4.7 SA Resources: Planner

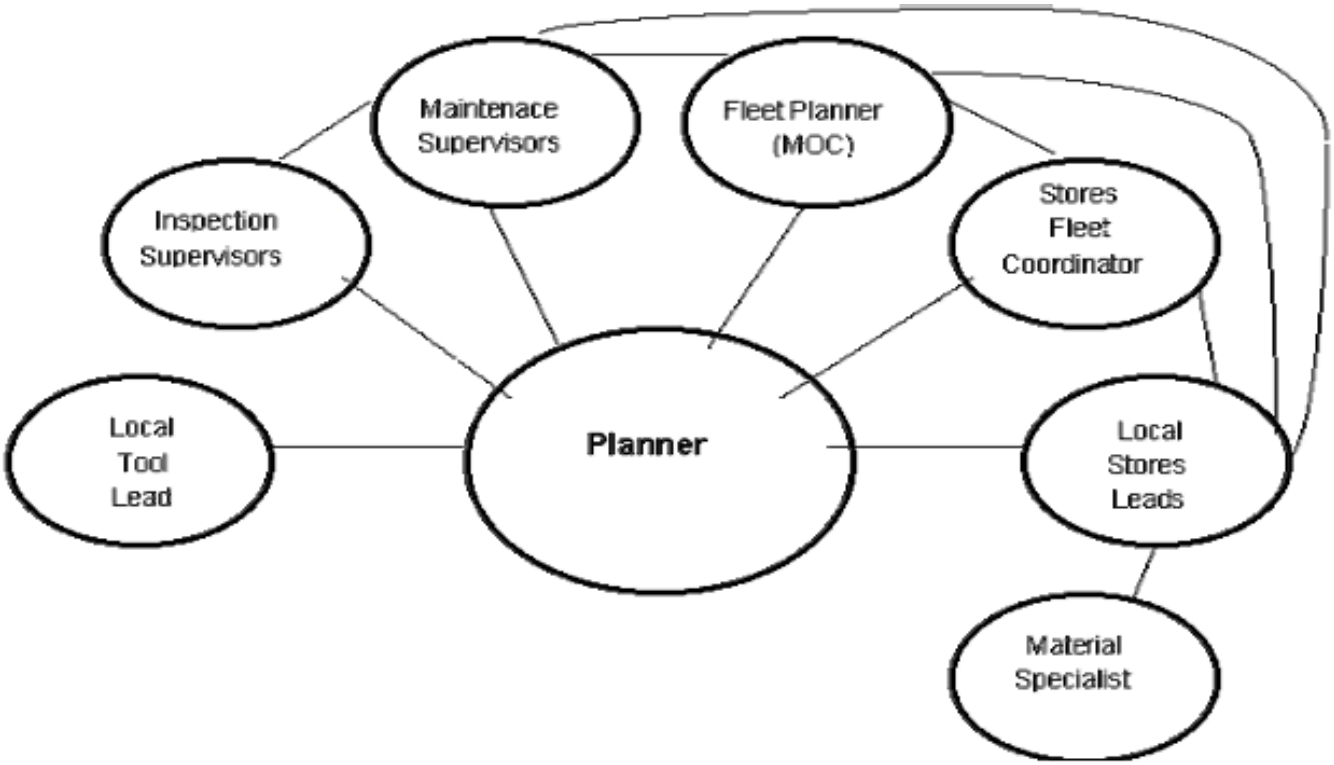


Figure 4.8 SA Resources: Maintenance Control Manager

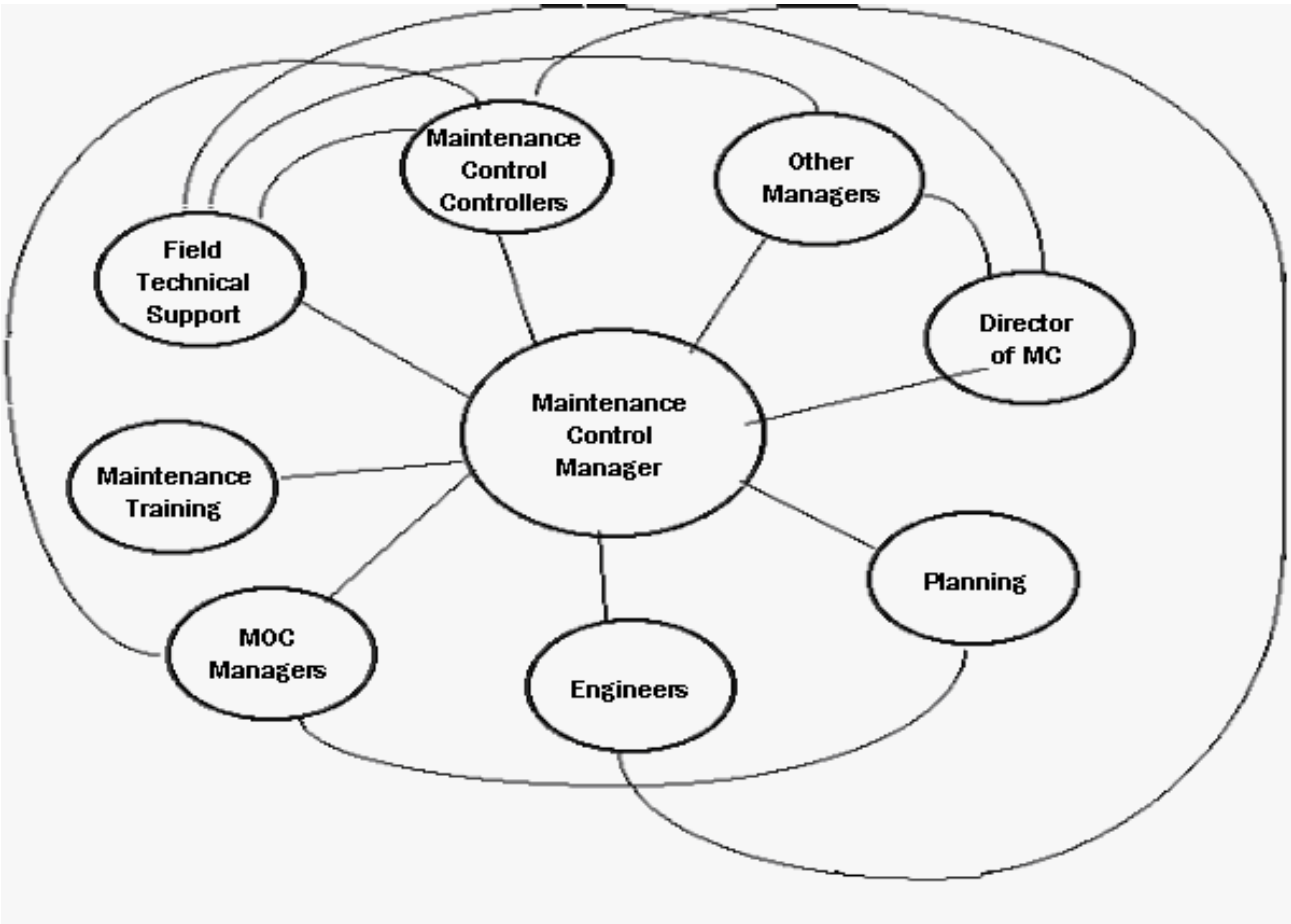


Figure 4.9 SA Resources: Maintenance Control Controllers

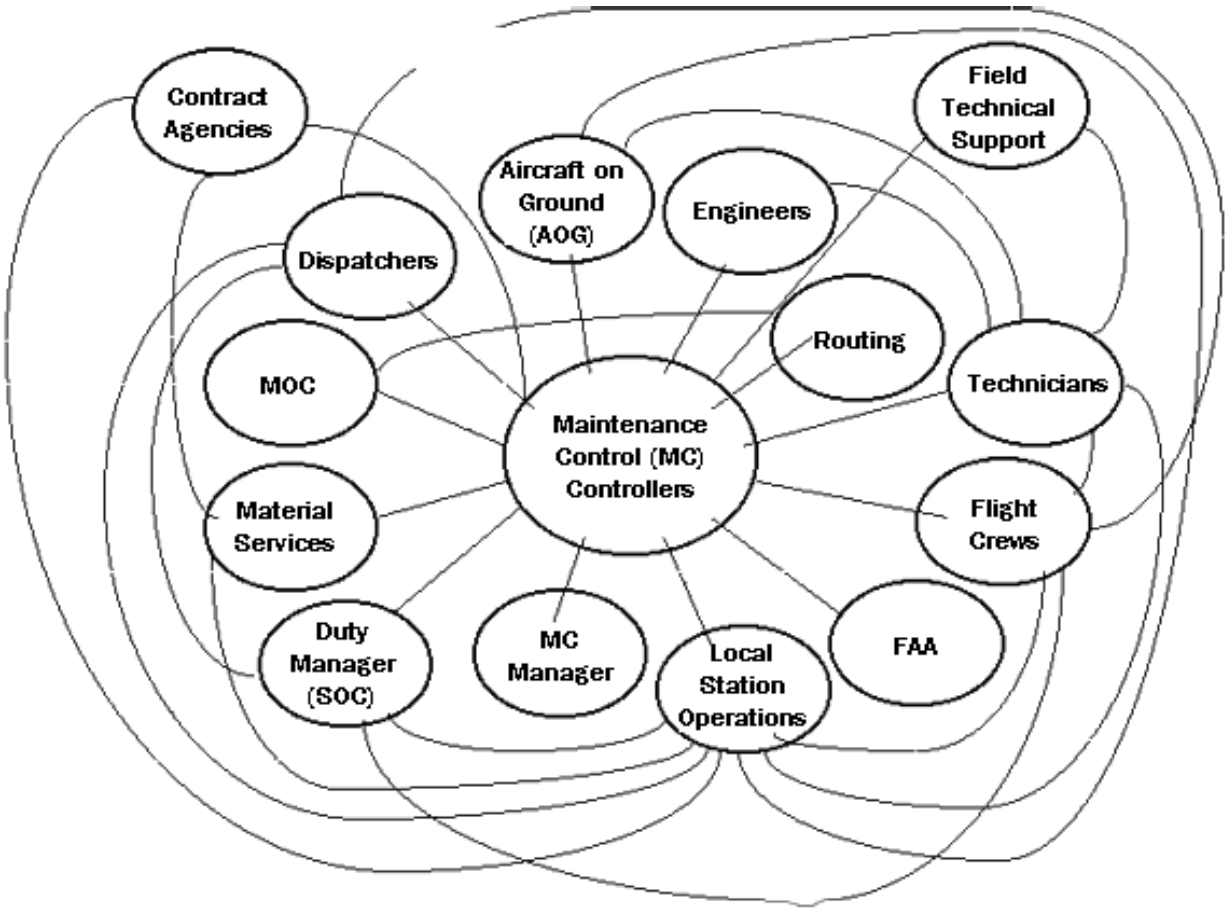


Figure 4.10 SA Resources: Maintenance Operations Control (MOC) Controller

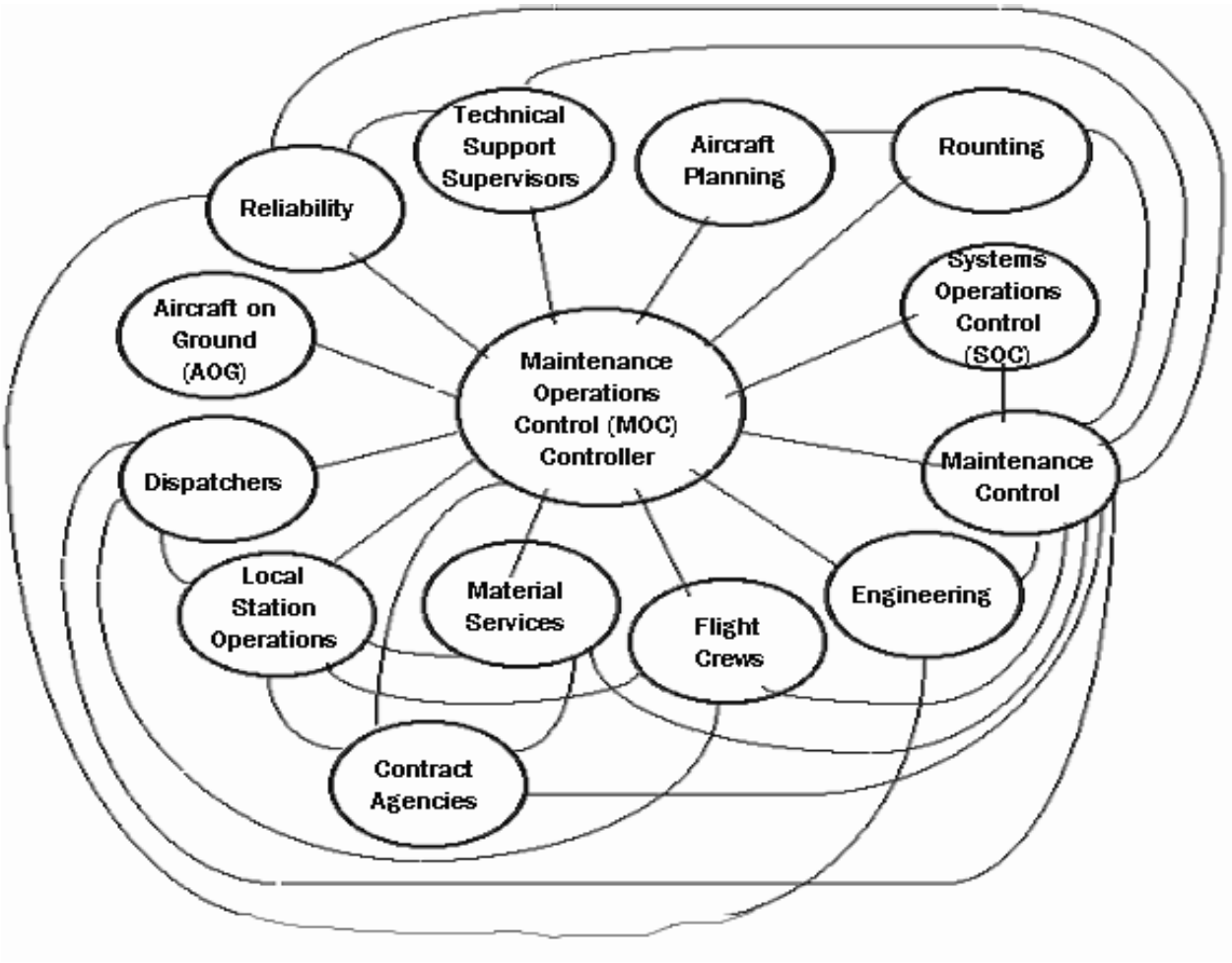
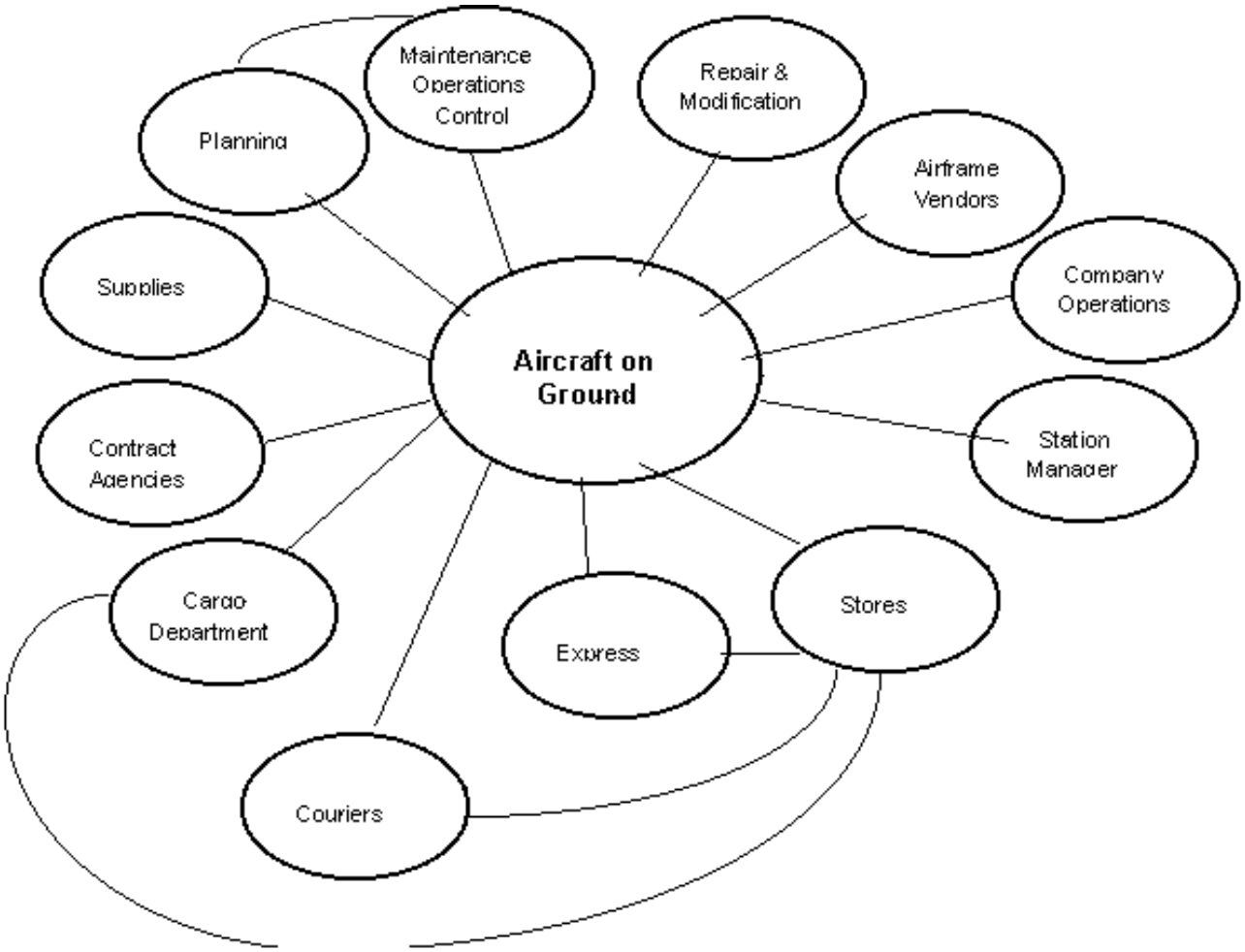


Figure 4.11 SA Resources: Aircraft-on-Ground



Estimates were made by each individual in the discussion concerning the overall frequency of communication with each maintenance unit and other team personnel. Each individual assigned a percentage (of 100%) to each unit that reflected the overall frequency of communication of each interchange. 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 communication interface 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 interfacing organizations depicted in each figure and are presented numerically in Tables 4.16 through 4.23.

Table 4.16 displays the personnel SA resources, mean importance, and mean frequencies for the communication interfaces from the perspective of the A&P technician. Several personnel and work units were indicated as very important knowledge resources necessary to accomplish the A&P technicians' jobs. These were the other technicians, airport operations (tower) and company operations (ramp personnel), closely followed by lead technicians and stores (material services). The highest reported frequency of communication was with the other technicians (54.50%), followed by lead technicians (26.75%).

Table 4.16 SA Personnel Resources: A&P Technicians

SA Resources: Personnel	*Mean Importance*	*Mean Frequency (%)*
Maintenance Control - Maintenance Operations Control Aircraft on Ground (AOG)	2.5	3.75
Lead Technician	1.5	26.75
Stores	1.5	8.25
Other Technicians	1.0	54.50
Airport Operations	1.0	< 1.00

Company Operations	1.0	< 1.00
Supervisor	3.2	2.25
Quality Assurance	2.5	< 1.00
Aircraft Inspectors	2.0	3.25
Planning	2.0	< 1.00

Table 4.17 displays the personnel SA resources, mean importance, and mean frequencies for the communication interfaces from the perspective of the lead technician. The most important knowledge resources necessary to accomplish their jobs were maintenance control, stores (material services) and technicians. The highest reported frequency of communication was with the technicians (45.3%), followed by maintenance control (13.3%), and the supervisor (13.3%).

Table 4.18 displays the personnel SA resources, mean importance, and mean frequencies for the communication interfaces from the perspective of the maintenance supervisor. The most important knowledge resources necessary to accomplish their jobs were maintenance control, lead technicians, technicians, quality assurance and the director. The highest reported frequency of communication was with the lead technicians (35.0%) and technicians (32.5%).

Table 4.17 SA Personnel Resources: Lead Technicians

SA Resources: Personnel	*Mean Importance*	*Mean Frequency (%)*
Maintenance Control - Maintenance Operations Control Aircraft on Ground (AOG)	1.3	13.3
Other Leads	3.0	6.0
Stores	1.3	10.0
Technicians	1.6	45.3
Airport Operations	2.0	< 1.0
Company Operations	3.5	3.3
Supervisor	3.0	13.3
Quality Assurance	3.6	< 1.0
Planning	2.0	1.6
Aircraft Inspectors	3.6	2.2
Other Airlines	2.0	< 1.0
Technical Support	2.0	3.6

Table 4.18 SA Personnel Resources: Supervisors

SA Resources: Personnel	*Mean Importance*	*Mean Frequency (%)*
Maintenance Control - Maintenance Operations Control Aircraft on Ground (AOG)	1.0	6.0
Lead Technicians	1.0	35.0
Stores	1.5	6.5
Technicians	1.0	32.5
Airport Operations	2.5	3.0
Quality Assurance	1.0	2.5
Director & Managers	1.0	6.0
Planning	2.0	7.5
Engineering & Technical Support	2.0	< 1.0

Aircraft Inspectors	3.0	< 1.0
Aircraft Cleaners	3.0	< 1.0
Airport Authority	3.0	< 1.0

Table 4.19 displays the personnel SA resources, mean importance, and mean frequencies for the communication interfaces for the material services supervisor. The most important knowledge resources necessary to accomplish this job was maintenance control, leads, and material specialists in Stores, as well as other supervisors in material services and in maintenance. The highest reported frequency of communication was with material specialists (30.0%) followed by leads in material services (20.0%).

Table 4.19 SA Personnel Resources: Material Services Supervisor

SA Resources: Personnel	*Mean Importance*	*Mean Frequency (%)*
Maintenance Control - Maintenance Operations Control Aircraft on Ground (AOG)	1	< 5.0
Lead Technicians	2	10.0
Technicians	2	10.0
Stores Leads	1	20.0
Material Specialists	1	30.0
Inventory Planning	2	< 5.0
Maintenance Supervisor	1	15.0
Other Material Services Supervisors	1	10.0

Table 4.20 displays the personnel SA resources, mean importance, and mean frequencies for the communication interfaces for the material services leads. The most important knowledge resources necessary to accomplish this job was maintenance control and technicians. The highest reported frequency of communication was also with these two groups.

Table 4.20 SA Personnel Resources: Material Services (Stores) Leads

SA Resources: Personnel	*Mean Importance*	*Mean Frequency (%)*
Maintenance Control - Maintenance Operations Control Aircraft on Ground (AOG)	1	40.0
Technicians	1	40.0
Planner	2	20.0

Table 4.21 displays the personnel SA resources, mean importance, and mean frequencies for the communication interfaces for planning. The most important knowledge resources necessary to accomplish this job was the maintenance supervisor, the planners, and coordinator for the fleet (at company headquarters) and the local tool lead. The highest reported frequency of communication was with the fleet planner and fleet stores coordinator.

Table 4.21 SA Personnel Resources: Planners

SA Resources: Personnel	*Mean Importance*	*Mean Frequency (%)*
Maintenance Supervisor	1	20.0
Fleet Planner (MOC)	1	30.0
Stores Fleet Coordinator	1	30.0
Local Material Services (Stores) Lead	3	10.0

Inspection Supervisor	2	5.0

Table 4.22 displays the personnel SA resources, mean importance, and mean frequencies for the communication interfaces for managers at maintenance control. The most important knowledge resources necessary to accomplish this job were the controllers and other managers in this organization, the director of the organization, and field technical support. The highest reported frequency of communication was with the director, controllers, and other managers.

Table 4.22 SA Personnel Resources: Maintenance Control Managers

SA Resources: Personnel	*Mean Importance*	*Mean Frequency (%)*
Maintenance Controllers	1	25
Maintenance Operations Control (MOC)	4	< 5
Planning	4	< 1
Director of Maintenance Control	1	20
Maintenance Training	2	5
Engineers	2	10
Other Managers	1	25
Field Technical Support	1	10

Table 4.23 displays the personnel SA resources, mean importance, and mean frequencies for the communication interfaces for controllers in maintenance control. The most important knowledge resources necessary to accomplish this job were the technicians, the SOC duty manager, engineers, and aircraft-on-ground. The highest reported frequency of communication was with technicians.

Table 4.23 SA Personnel Resources: Maintenance Control Controllers

SA Resources: Personnel	*Mean Importance*	*Mean Frequency (%)*
Technicians	1	23.5
Flight Crews	2	3.3
Local Station Operations	1.5	5.0
Duty Manager (SOC)	1	15.6
Material Services	2	10.0
Dispatchers	2	10.0
Contract Agencies	2	10.0
Aircraft on Ground (AOG)	1	15.0
Engineers	1	3.0
Routing	2	< 1.0
Field Technical Support	1.5	< 1.0
MC Manager	1.5	< 1.0
FAA	4	< 1.0
Maintenance Operations Control (MOC)	4	< 2.0

Table 4.24 displays the personnel SA resources, mean importance, and mean frequencies for the communication interfaces for maintenance operations control. The most important knowledge resources necessary to accomplish this job were aircraft routing, planning, and material services. The highest reported frequency of communication was with routing and material services.

Table 4.24 SA Personnel Resources: Maintenance Operations Control		
SA Resources: Personnel	***Mean Importance***	***Mean Frequency (%)***
Engineers	4	6.0
Maintenance Control	2	4.0
Systems Operations Control (SOC)	2	4.0
Aircraft Planning	1	10.0
Technical Support Supervisor	3	6.0
Reliability	2.5	6.0
Local Station Operations	1.2	10.0
Aircraft on Ground (AOG)	1.2	< 3.0
Dispatchers	2.2	8.6
Material Services	1	15.0
Contract Agencies	2	8.6
Flight Crews	2	< 3.0
Aircraft Routing	1	18.0

Table 4.25 displays the personnel SA resources, mean importance, and mean frequencies for the communication interfaces for aircraft-on-ground. The most important knowledge resources necessary to accomplish this job were stores, maintenance control, and maintenance operations control. The highest reported frequency of communication was with the same three organizations.

Table 4.25 SA Personnel Resources: Aircraft on Ground		
SA Resources: Personnel	***Mean Importance***	***Mean Frequency (%)***
Stores	1	25.0
Cargo Department	3	< 3.0
Express	3	< 1.0
Couriers	3	< 1.0
Station Maintenance	3	< 5.0
Operations	3	< 5.0
Airframe Vendors	4	< 1.0
Repair & Modification	4	< 1.0
Maintenance Operations Control (MOC)	1	20.0
Planning	4	< 1.0
Maintenance Control	1	25.0
Supplies	2	10.0
Contract Agencies	2	10.0

Overall, a great deal of interdependency can be seen between the organizations and personnel included in this study. Each job type involved interacting with between 3 and 14 different organizations to attain (or supply) the information needed to perform the job. In general two or three of these interactions were viewed as very important and constituted the majority of each function's interactions, however, for many of the functions there were also many organizations that were interacted with at least occasionally. Specific issues regarding these interactions that can have a significant impact on SA were uncovered during the analysis and are discussed in Section 4.5.

4.4.4 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 within the organization included Spectre, a system for logging maintenance activities, several non-integrated databases used across several organizations, and technical documentation that could be found in various hard copy manuals and micro-fiche.

From the standpoint of supporting situation awareness, several shortcomings exist within these technologies. First, Spectre, a computer program that supports maintenance activities at many large air carriers, is woefully deficient in supporting the SA needs of the technicians and others with whom they interact. The primary problem is that the database is based on very old 1970's computer technology that does not meet even basic human-computer interaction standards. Finding information within screens is difficult due to poor layout and presentation, and finding desired screens is quite confusing. These problems greatly increase the likelihood of making an error, spending excess time in trying to find needed information, and, most importantly, decrease the likelihood that the system will be utilized fully to share information across organizations. Particularly since the personnel using this technology are not necessarily high-level computer users, significant changes in this technology would be most beneficial. An upgrade is greatly needed to provide information that is organized around the user's needs (as outlined in the SA requirements analysis presented here). This information can be used to create a database interface that presents the information that is needed in a form that is integrated around the user's goals and corresponding SA needs. A Windows menu-based interface is recommended to provide ease of use for personnel whose main job is not programming computers but fixing aircraft.

Secondly, while Spectre serves as the main database for the technicians, several other computerized databases are also present in the system. These databases all run on separate systems, function in different ways and are non-integrated. This poses significant difficulties for personnel who must switch between several systems to find the information they need. It requires entering information multiple times, which is both time consuming and error prone. To support situation awareness, these databases need to be integrated. While different databases may be needed to support different functions, they should be designed along a common interface framework and links should be provided between databases so that personnel can easily pull up needed information from one system while working on another system. Without this type of functionality, it is very difficult for personnel to achieve an up-to-date picture of critical situation elements.

Thirdly, a large number of technical manuals are present throughout the organization. These manuals are very important for diagnostic activities, finding proper parts numbers and ascertaining information needed to conduct certain procedures. At present this information is widely distributed in various hard copy manuals and micro-fiche, which may not be up-to-date, and may not cover pertinent modifications or differences between particular aircraft even within a model (due to significant customization of aircraft at the time of purchase and subsequent modifications). This results in a system where personnel spend a considerable amount of time trying to find the information that is needed, often find incorrect information (regarding the needed part number for example), and which provide significant system inefficiencies. Frequently repairs are delayed when the wrong part is procured, for example, and unneeded work is conducted in disassembling and reassembling an aircraft system, upon finding that the repair cannot be made. Pertinent drawings, specifications and technical information needs to be computerized, linked to the aircraft tail number (so that it is correct relative to the customization and changes that have been made to that aircraft), and made directly accessible to the technician through a common interface. By linking this information to the database that technicians use to log information and pass information to other organizations, a significant improvement will be realized in the quality and correctness of information transferred. At present, the information passed within the database tends to be minimal (due to the poor interface and typing requirements). The ability to make direct reference to drawings, procedures and part-numbers will greatly help with this problem. It furthermore puts all needed information at the user's finger-tips which will greatly reduce confusion, errors and wasted time.

4.4.5 Barriers and Problems

During the discussion process, maintenance personnel were solicited to determine factors that created barriers to effective communication and performance. Barriers are issues that slow down or hinder performance. These are problems that maintenance teams have to routinely overcome in order to meet their performance goals. They encompass organizational, technical and personnel issues. Barriers that were mentioned by the maintenance personnel are listed in order of frequency in Table 4.26. In general, most people felt that the system worked quite well, however, almost all could name a few areas where improvement was possible.

The most frequently mentioned barrier was a lack of proper tooling for completing a job which is exacerbated by the fact that much of the repair work has been out-sourced thus 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 that 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 technician. 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 that 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 source 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 AOG.

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 Spectre, 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 (AOG). 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 and 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 MELs better and a database on parts reliability. The Spectre 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. This system needs significant revisions to provide pertinent information in a usable format.

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 maintenance technicians did not like having maintenance operations control (MOC) tell them what to do, when "they are not 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 technician's 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). The technicians, though, did not have 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 shiftwork (particularly among graveyard shift workers), concerns over organizational down sizing, lack of updating of the stores computer system to reflect the nuances of particular aircraft, need for more training on Spectre, a lag in updating workcards 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 involved more 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, 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.

The need also was expressed for streamlining the processes 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 method for getting a part and then when that method falls through the process must be started over again. Procedures that incorporate alternate parallel tracks and action plans when parts are needed are felt to be needed.

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 were described as a problem. Due to a number of layoffs, people with high seniority, but perhaps low experience levels in a particular job type are more common. This has a significant impact on scheduling the technicians 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 individuals might not be able to work with fellow team members as much as might be needed.

Table 4.26 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: Spectre	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 Spectre	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

4.5 DISCUSSION

Based on the analysis of the SA requirements and resources for each organization (Sections 4.4.2 through 4.4.4) and the barriers and problems expressed (Section 4.4.5) 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.

Maintenance technicians face several challenges to meeting their SA requirements that can be linked to team SA. First, technicians 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&P technician subgoal 1.1.1.1). A considerable gap exists between the technicians and the stores organization who often may supply the incorrect part (due to difficulties with effectively 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 technicians frequently must involve their leads and supervisors, maintenance control and aircraft-on-ground to achieve this subgoal. 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 (A&P technician subgoal 1.1.1.2). Technicians 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. Technicians 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 other 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 technicians report a need to ascertain job status and schedule progress (A&P technician subgoal 1.1.2), 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 technicians really needed information on how the other team members were doing in terms of progress on their respective tasks. Without this knowledge, the technicians have no way to engage in compensatory activities (for example, 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 technicians 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 technicians 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 already is 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 technicians, 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.) 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 AOG) 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 technicians 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 technician. If they only pass information regarding what the technician should do (the decision) but not regarding why the decision was made, this may lead to both a lack of understanding by the technician and may deny the technician the opportunity to volunteer information he or she may have that would be pertinent to the decision being 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 technicians 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 solution 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, both in terms of technical skill and documentation, at its disposal. Technicians 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 (MOC) is to minimize placards, it should be noted that it primarily focuses 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 MOC nor MC 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 technicians in the field. It may be that some organizational streamlining between MOC and MC 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 technicians 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 are the support organizations. These groups have an increased need to understand the other groups with which they interact. 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 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.

4.6 TRAINING RECOMMENDATIONS

Several training concepts should be explored for improving Team SA within the maintenance setting based on this analysis and discussion, in addition to the technology enhancements that were recommended in Section 4.4.4.

(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 enhanced greatly by the creation of a shared mental model that 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.

(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 be 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.

(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.

(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 on which technicians work. 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 technicians (and others) can also be trained to provide more feedback (either over the phone or through the computer system) on what worked and what didn't.

(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.

Results from the SA requirements analysis conducted here provide a firm foundation for identifying the knowledge, skills, and abilities (KSA) that maintenance personnel need to attain a high level of SA. The SA requirements identified in Section 4.2 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 Section 4.5. To address these gaps, the training concepts proposed here may be useful as a means of enhancing the skills and abilities needed for achieving a high level of SA in a team environment. This information will be used to develop the proposed training concepts into deliverable training programs in future efforts.

4.7 CONCLUSIONS

Overall, the applicability of the concept and importance of situation awareness in maintenance teams has been supported in this analysis. Teams of technicians 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 knowledge 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 later (placarded)), and their ability to correctly project into the future to make good decisions (e.g., time required to perform task, availability of parts, etc.).

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. In addition, concepts for improving SA among and between team members through training were identified. It is recommended that these concepts be prototyped and tested to determine whether team SA can be improved through the methods identified and organizational effectiveness thus enhanced.

4.8 REFERENCES

Drury, C. (1993) Chapter eight: Training for visual inspection of aircraft structures. In G. S. Corporation (Eds.), *Human Factors in Aviation Maintenance - Phase Three, Volume 1 Progress Report (DOT/FAA/AM-93/15)* (pp. 133-154). Washington, DC: Office of Aviation Medicine, Federal Aviation Administration.

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

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

Endsley, M. R. (1989b). Pilot situation awareness: The challenge for the training community. In *Proceedings of the Interservice/ Industry Training Systems Conference (I/ITSC)* (pp. 111-117). Ft Worth, TX: American Defense Preparedness Association.

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 dynamic human decision making: Theory. In R. D. Gilson, D. J. Garland, & J. M. Koonce (Eds.), *Situational Awareness in Complex Systems* (pp. 27-58). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

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

Endsley, M. R., & Rodgers, M. D. (1994). *Situation awareness information requirements for en route air traffic control* (DOT/ FAA/AM-94/27). Washington, DC: Federal Aviation Administration Office of Aviation Medicine.

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

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

Robertson, M. M., & Endsley, M. R. (1995). The role of crew resource management (CRM) in achieving situation awareness in aviation settings. In R. Fuller, N. Johnston, & N. McDonald (Eds.), *Human Factors in Aviation Operations* (pp. 281-286). Aldershot, England: Avebury Aviation, Ashgate Publishing Ltd.

Robertson, M. M., & O'Neill, M. J. (1994). *Development of contextual inquires for examining knowledge workers in technological office environments*. Zeeland, MI: Herman Miller, Inc.

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

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

Taylor, J. C., Robertson, M. M., Peck, R., & Stelly, J. W. (1993). Validating the impact of maintenance CRM training. In R. S. Jensen & D. Neumeister (Ed.), *Proceedings of the Seventh International Symposium on Aviation Psychology* (pp. 538-542). Columbus, OH: Department of Aviation, The Ohio State University.