MODELING THE USE OF COMPUTER AND BROADBAND TECHNOLOGY IN THE AIRCRAFT LINE MAINTENANCE WORKPLACE

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ABSTRACT

Five models of the aircraft line maintenance process were created after shadowing line maintenance crew at a major air carrier maintenance facility over a period of several months. These models include: (1) the physical layout of the facility, including arrangement of artifacts and the distances between them; (2) the artifacts used by technicians along with a quantification of the steps required to use them; (3) the cultural relationships between participants in the maintenance process; (4) the flow of information between participants; and (5) a computer simulation of the sequence of steps required to service an inbound aircraft: including routine inspections, scheduled maintenance, deferred items, squawks reported by the flight crew, and squawks discovered during inspections. The five models are used to make specific recommendations about how computer and broadband can successfully impact safety in the line maintenance workplace.

Introduction

Casner and Puentes (2003) surveyed the marketplace of computer and broadband technologies as well as the use of these systems at aircraft maintenance facilities. Computer/broadband technologies were found at every maintenance facility surveyed. While some systems enjoyed regular use among maintenance technicians, other systems were regarded as having little practical use. Interviews were conducted with both managers who acquired computer/broadband systems as well as with maintenance technicians who would ultimately use (or not use) the systems. It was found that computer/broadband technology was viewed differently by these two groups. Managers' views of technology were often based on efficiency and costs concerns, while maintenance technicians' views were based on learnability and practical usability of the technology. In many cases, benefits were not realized in everyday practice because maintenance technicians did not feel that the technologies directly addressed their needs while working on the ramp, or suffered from design flaws that made the technology inconsistent with the way they do their jobs.

Casner, Encinas, and Puentes (2004) explored the issue of practical use of computer/broadband technology by creating a task analysis: a sequential, step-by-step description of the process that line maintenance technicians use when handling an aircraft in need of maintenance. An analysis of this sequential task analysis revealed that computer/broadband systems were used during most phases of the line maintenance process with one important exception. Other than providing technicians with electronic copies of existing documentation, the task analysis showed that no technology was available to support the problem of troubleshooting and solving maintenance problems. Technicians' responses to a questionnaire further indicated a mismatch between the capabilities offered by existing computer/broadband applications and the needs of the maintenance technician while performing their job. The task analysis and questionnaire responses also pointed to the need for an analysis that goes beyond the simple listing of steps in the existing work process. A key limitation of that approach is that is overlooks many of the features of a work environment that influence the work process. At one maintenance facility we surveyed, technicians made reference to a technician, who no longer worked there, who had an unusual degree of familiarity with the MD-11 aircraft. Resolving a puzzling problem was often a simple matter of talking to that technician when he was on duty.

This study extends our previous modeling work beyond the simple detailing of work process steps. We use a technique prescribed in Beyer and Holtzblatt (1998) that attempts to make explicit more of the features of the work environment that influence the work process. Beyer and Holtzblatt (1998) argue the need for designers to create five types of analyses, called *work models*, for every workplace in which technology is to be introduced. These five models look at the work environment in different ways and attempt to capture the constraints under which workers do their business.

Flow Model: Details the division of labor in a work environment and shows how workers communicate or transfer the results of their work between each other to orchestrate a finished product.

Cultural Model: Makes explicit the constraints imposed by human relationships between all people involved in the maintenance process.

Artifact Model: Describes the tools that workers currently use to do their jobs.

Physical Model: Details the physical layout of the workplace: the arrangement of workers, the artifacts they use, and the distances between them.

Sequence Model: Outlines the individual steps in each task performed by each worker.

Collectively, Beyer and Holtzblatt describe these models as the "five faces of work" and stress how the five models inform each other to define the work environment. For example, the flow model and the physical model can be used to discover inefficiencies in the layout of a workplace or the steps used to complete a task. For example, if two artifacts are used in sequence but are separated by a great distance, the workplace might be rearranged or the steps in the task reordered.

Five Models of the Line Maintenance Workplace

Five models were created to describe the operation at one major air carrier line maintenance facility.

Flow Model: Questionnaire responses from Casner, Encinas, and Puentes (2004) indicated that technicians place heavy emphasis on communication between technicians while troubleshooting. The flow model shown in Figure 1 suggests several immediate ways that technology might improve communication between maintenance technicians.

Technicians who work during the same shifts currently talk to each other by traveling around the ramp or by using personal cell phones. Traveling to other areas on the ramp uses time and draws techncians away from the job they are currently working. Cell phones typically only allow two technicians to talk at once unless special conferencing capabilities are purchased. Setting up a conference call typically requires more work than is practical for short information exchanges. One application of computer/broadband technology might be a device that allows technicians to easily talk in groups.

Technicians at work are currently unable to use expertise of technicians that are not currently working on shift. The flow model make explicit how computer/broadband technology could be used to enrichen the flow of information between technicians in two ways. First, technology could be used to expand entries that are left in "passdown logs": notes left by technicians who were unable to resolve a maintenance problem during their own shift. Second, questionnaire responses from Casner, Encinas, and Puentes (2004) indicated that technicians felt the need for some type of archival database of previous maintenance problems and solutions. Passdown logs only allow for the transfer of knowledge between technicians who work on the same aircraft, usually on censecutive shifts.

The flow model also raises the question of how well technicians' expertise is known to other technicians. It is an open question of how many times do technicians call an off-site maintenance control facility with a question that might quickly be answered by someone working on the ramp.

Cultural Model: The cultural model shown in Figure 2 diagrams some of the relationships between the people who interact during the maintenance process. At the facility we surveyed, the relationship between technicians and the lead technician was highly functional. The lead technician's job was to support other technicians. The lead technician had expertise and the time to share that expertise with others. The lead technician often did the preliminary work for technicians so that they could start in immediately on technical problems.

The relationship between technicians and flight crews was somewhat less functional. Flight crews wrote up maintenance issues in the aircraft logs and left them for technicians to read. Since this information was the starting point for technicians' problem-solving, technicians often wanted more information. Technicians reported that flight crews did not understand how valuable pilots' verbal inputs were in the troubleshooting process. Flight crews often came off of a tiring flight or were in a hurry to make another flight and seldom had enough time to talk to technicians to answer all their questions. This suggests the need to improve the flow of information between flight crew and technician. Barshi and Chute (2001) have suggested co-training for workers in different jobs who must work cooperatively (e.g., pilots and air traffic controllers). Casner at al (2005) provides ASRS reports that detail instances of breakdowns between flight crews and technicians.

Another interesting relationship identified by the cultural model is that between technicians and the central maintenance control facility. An important function of maintenance control is to support technicians in resolving maintenance problems. Getting help from maintenance control is often more time-consuming than seeking help from a colleague on-site. Since maintenance control has the goal of ensuring efficiency company-wide, technicians are often told to simply follow all prescribed maintenance procedures and use maintenance control as a secondary resource. A more efficienct process that allows technicians to tap expertise of maintenance control might impact safety as well as efficiency. An archival database of stubborn maintenance problems might also address this problem.

Artifact Model: The artifact model in Figure 3 shows the computer hardware, software systems, software tasks routinely performed by maintenance technicians, and non-computer artifacts. There are two types of software tasks: (1) retrieving and printing needed information; and (2) making entries into the systems. We measured the average time to complete each software task and listed these times with the tasks in Figure 3. The times show that while some software tasks are performed quickly, others require lengthy interactions with the computer. A review of the steps required to complete each software task indicate that many tasks could be easily streamlined. The information needed to streamline a software system such as these is a quantification of the frequency at which the tasks are performed. With this information in hand, frequently-performed tasks could be quickly accessed from top-level menus, while less-frequently-performed tasks could be buried deeper in the system. Quantifying the frequency at which tasks are performed is precisely the goal of the sequence model. The safety impact of system interaction times might lie in how they affect technicians' decisions about whether or not to use the system to seek further information.

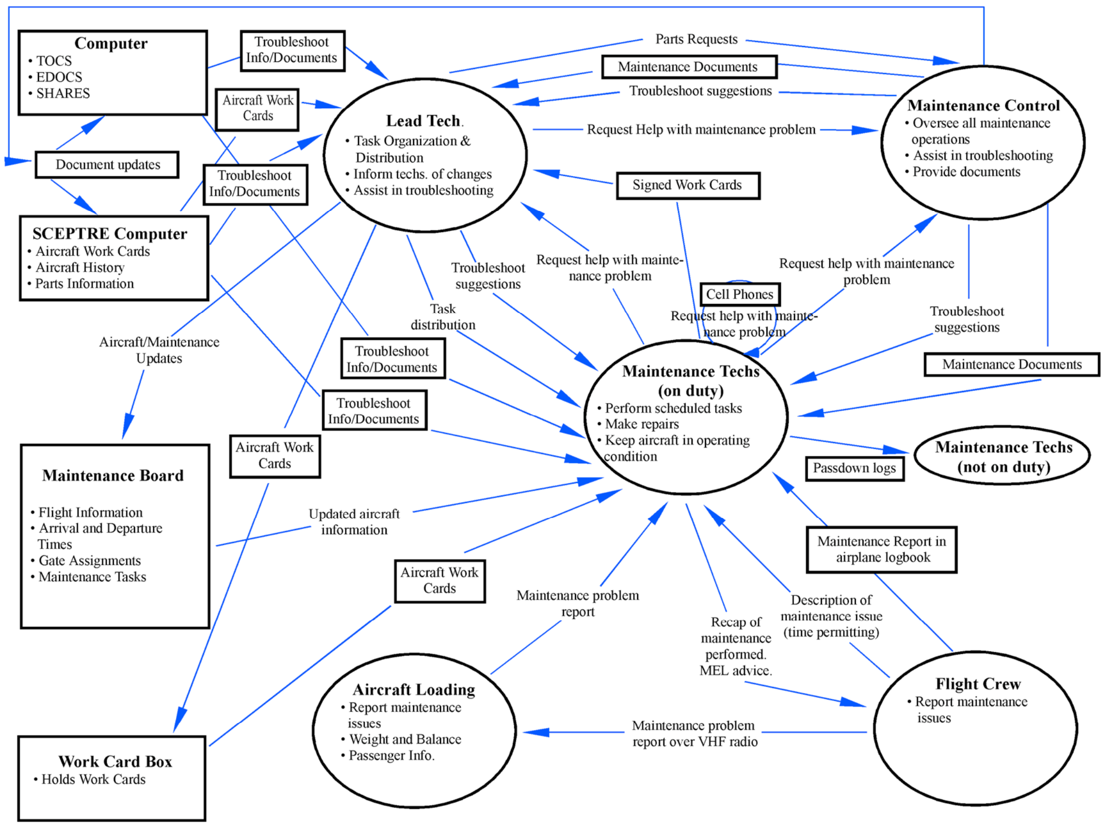


Figure 1: Flow model showing how information flows between entities.

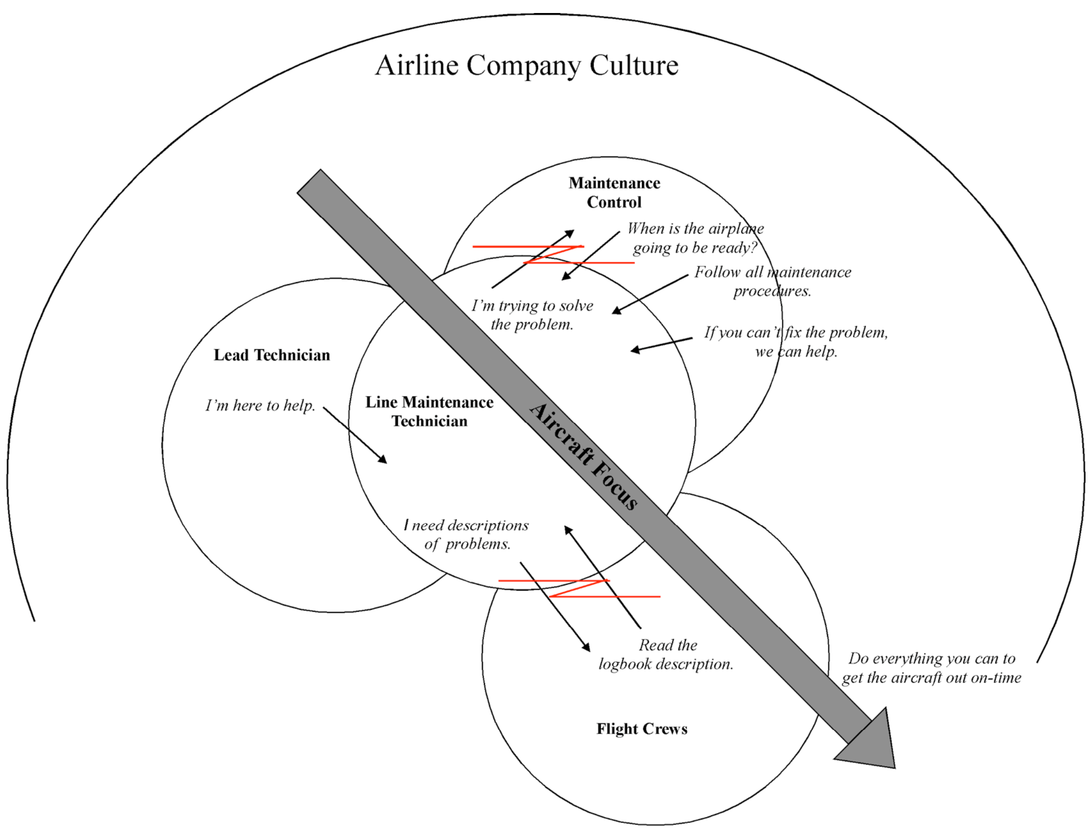


Figure 2: Cultural model detailing relationships between entities.

Technicians made extensive use of the printer, preferring to work with paper documents at the airplane.

Physical Model: The physical model in Figure 4 shows the geographical layout and the location of artifacts in the line maintenance workplace we studied. We used a simple measuring wheel to measure the distances between all important artifacts and locations at the maintenance facility. The layouts and measurements in the physical model are of little interest when considered alone. The arrangement of artifacts only becomes meaningful when we consider the sequence in which the artifacts is used.

Sequence Model: The sequence model is a more detailed rendering of the task analysis performed by Casner et al (2004). To make the sequence model more concrete and accurate, we developed our model as a runnable computer simulation. A sample run of the simulation is shown in Figure 5. The sequence model accepts a collection of aircraft with predefined maintenance issues and simulates, in a step-by-step fashion, the steps followed by maintenance technicians to resolve each maintenance issue. The sequence model uses the task performance times given by the artifact model (Figure 3) and the distances given by the physical model (Figure 4), and tallies the amount of time that technicians spend walking around the facility and the amount of time spend interacting with the computer systems in search of needed information. The sequence model performs all routine maintenance inspections, and attempts to resolve all maintenance problems reported by the crew, problems that have been deferred from previous flights, and all problems discovered during the routine inspection. The sample run shown in Figure 5 required one routine inspection and the handling of five maintenance issues: two problems reported by the flight crew (intermittent PTT switch and a broken seat), two deferred problems (inoperative CSD and a cracked landing gear door), and one problems discovered during the routine inspection (inoperative landing light). Performing all of the tasks required a technician to walk a total of 2,035 feet (0.39 miles) and spend a total of 13 minutes and 36 seconds interacting with the computers to retrieve information.

The sequence model suggests a number of ways in which computer/broadband technology could improve the work process. A first result generated by the model is the tiresome distances that technicians must walk during the course of working an airplane. In the simulation in Figure 5, technicians had to make several trips back to the maintenance office to access electronic documents. In some cases, these trips were required to gather significant amounts of information to perform a job (work cards, manual pages, etc.), and seem mostly justified. In other cases, trips had to be made to look up a single part number in an illustrated parts catalog so the technicians could then make a trip to the parts inventory to retrieve the part. It is clear that a device that allows technicians to remotely access this information, and print out pages from the ramp would be beneficial. Aside from the efficiency issue, the ASRS database contains many reports of documents and information being mishandled when time pressures are present and the effort required to retrieve information is significant [Casner et al, 2005]. Casner and Puentes (2003) found wireless laptops at one maintenance facility. However, technicians seldom used them complaining of intermittent wireless connections, limited battery life, and the lack of printers. This further suggests the need for modeling the specifics of the artifacts to be used: simply demonstrating the need for such an artifact is not enough.

A second result generated by the model is the amount of time that technicians spent interacting with the computer systems, validating the observations gleaned from the artifact model in Figure 3. Indeed, long interactions required for individual tasks result in tediousness when the systems are deployed in practical use.

A last issue made explicit by the sequence model is the inefficiency of fault isolation manual (FIM) approach to resolving maintenance problems. Using the FIM, technicians replace one part after another until the problem is resolved. Responses to questionnaire items in Casner, Encinas, and Puentes (2004) indicated that technicians felt that the FIM process often overlooks technicians' own expertise as a troubleshooting resource. Technicians described the parts-replacement strategy (i.e., "shotgunning”) as sometimes wasteful. Prescribed procedures such as those found in the FIM have a safety consideration as well. If technicians rely constantly on prescribed procedures and do not exercise their own troubleshooting knowledge, that knowledge will surely atrophy.

Conclusions

A five-dimensional model was developed to further analysis opportunities for the use of computer and broadband technology in the aircraft maintenance workplace. By going beyond a simple breakdown of steps in the maintenance task, the model was used to make several safety and efficiency recommendations.

The flow model suggested the need for technology that improved the way technicians share expertise with one another: not only while working together on-shift, but also across shifts or even careers. The survey of technology in use by Casner and Puentes (2003) suggests that the capabilities afforded by computer and broadband technology to enrichen the transfer of information between workers has yet to be realized.

The cultural model suggested the need to improve communication about maintenance problems between flight crews and maintenance technicians. This could be accomplished either by co-training pilots and technicians or by enrichening the means by which flight crews record maintenance squawks.

The artifact model suggested the need to redesign the inter-

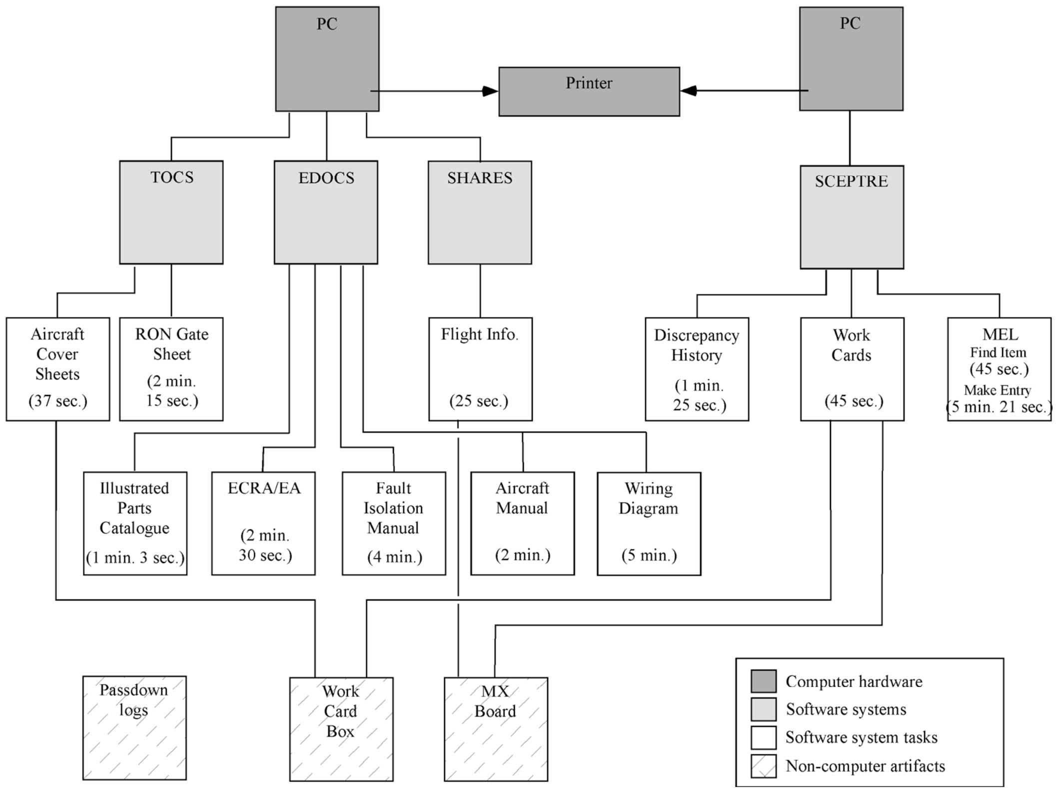


Figure 3: Artifact model showing computer and non-computer artifacts used by technicians. Task completion times are shown for all software functions.

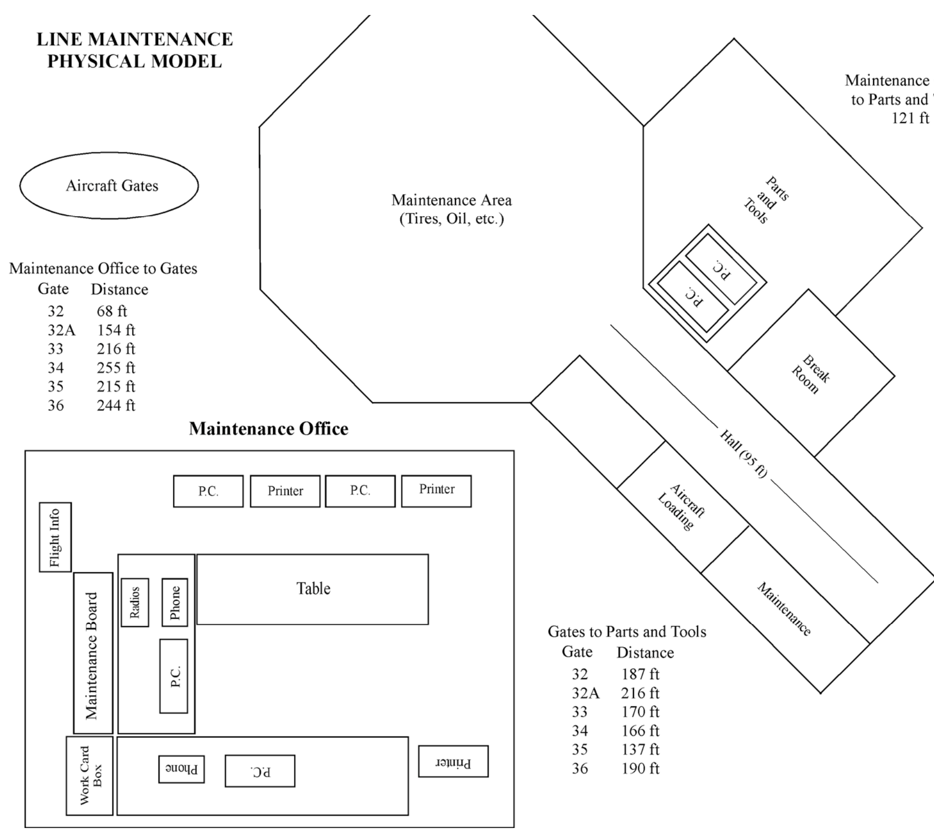
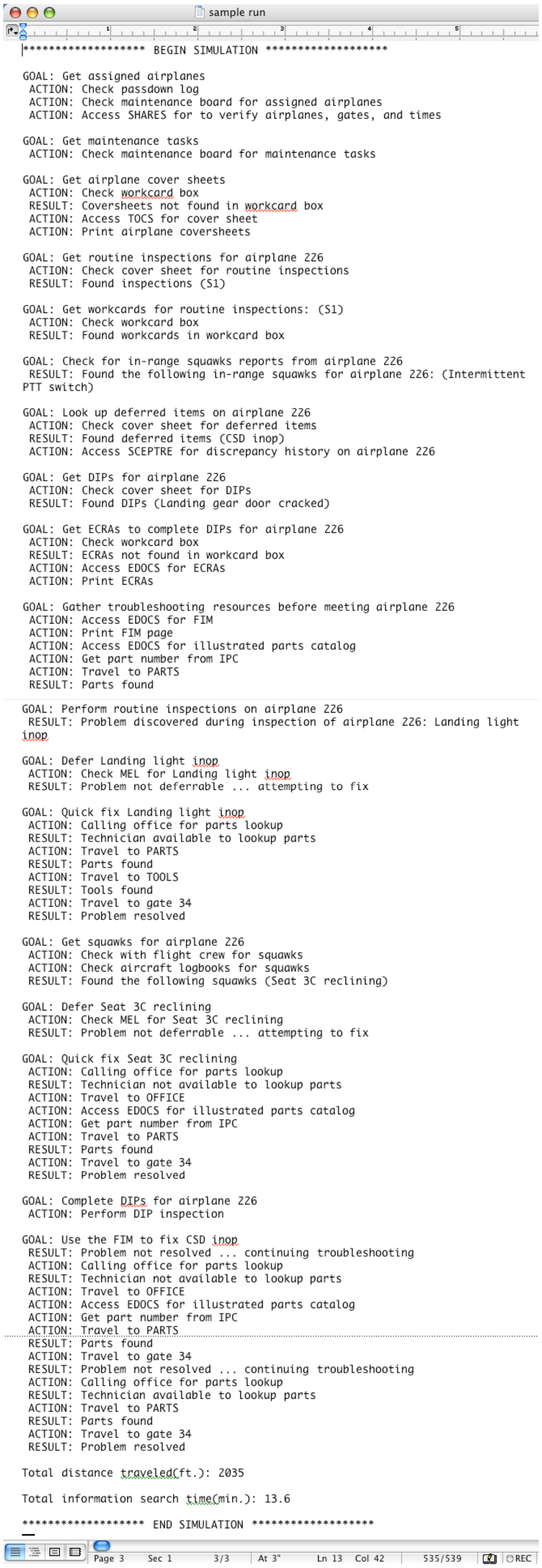


Figure 4: Physical model showing arrangement of artifacts at the line maintenance facility, including measured distances between them.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sample run
******************* BEGIN SIMULATION *******************

GOAL: Get assigned airplanes
 ACTION: Check passdown log
 ACTION: Check maintenance board for assigned airplanes
 ACTION: Access SHARES for to verify airplanes, gates, and times

GOAL: Get maintenance tasks
 ACTION: Check maintenance board for maintenance tasks

GOAL: Get airplane cover sheets
 ACTION: Check workcard box
 RESULT: Coversheets not found in workcard box
 ACTION: Access TOCS for cover sheet
 ACTION: Print airplane coversheets

GOAL: Get routine inspections for airplane 226
 ACTION: Check cover sheet for routine inspections
 RESULT: Found inspections (S1)

GOAL: Get workcards for routine inspections: (S1)
 ACTION: Check workcard box
 RESULT: Found workcards in workcard box

GOAL: Check for in-range squawks reports from airplane 226
 RESULT: Found the following in-range squawks for airplane 226: (Intermittent
PTT switch)

GOAL: Look up deferred items on airplane 226
 ACTION: Check cover sheet for deferred items
 RESULT: Found deferred items (CSD inop)
 ACTION: Access SCEPTRE for discrepancy history on airplane 226

GOAL: Get DIPs for airplane 226
 ACTION: Check cover sheet for DIPs
 RESULT: Found DIPs (Landing gear door cracked)

GOAL: Get ECRAs to complete DIPs for airplane 226
 ACTION: Check workcard box
 RESULT: ECRAs not found in workcard box
 ACTION: Access EDOCS for ECRAs
 ACTION: Print ECRAs

GOAL: Gather troubleshooting resources before meeting airplane 226
 ACTION: Access EDOCS for FIM
 ACTION: Print FIM page
 ACTION: Access EDOCS for illustrated parts catalog
 ACTION: Get part number from IPC
 ACTION: Travel to PARTS
 RESULT: Parts found

GOAL: Perform routine inspections on airplane 226
 RESULT: Problem discovered during inspection of airplane 226: Landing light
inop

GOAL: Defer Landing light inop
 ACTION: Check MEL for Landing light inop
 RESULT: Problem not deferrable ... attempting to fix

GOAL: Quick fix Landing light inop
 ACTION: Calling office for parts lookup
 RESULT: Technician available to lookup parts
 ACTION: Travel to PARTS
 RESULT: Parts found
 ACTION: Travel to TOOLS
 RESULT: Tools found
 ACTION: Travel to gate 34
 RESULT: Problem resolved

GOAL: Get squawks for airplane 226
 ACTION: Check with flight crew for squawks
 ACTION: Check aircraft logbooks for squawks
 RESULT: Found the following squawks (Seat 3C reclining)

GOAL: Defer Seat 3C reclining
 ACTION: Check MEL for Seat 3C reclining
 RESULT: Problem not deferrable ... attempting to fix

GOAL: Quick fix Seat 3C reclining
 ACTION: Calling office for parts lookup
 RESULT: Technician not available to lookup parts
 ACTION: Travel to OFFICE
 ACTION: Access EDOCS for illustrated parts catalog
 ACTION: Get part number from IPC
 ACTION: Travel to PARTS
 RESULT: Parts found
 ACTION: Travel to gate 34
 RESULT: Problem resolved

GOAL: Complete DIPs for airplane 226
 ACTION: Perform DIP inspection

GOAL: Use the FIM to fix CSD inop
 RESULT: Problem not resolved ... continuing troubleshooting
 ACTION: Calling office for parts lookup
 RESULT: Technician not available to lookup parts
 ACTION: Travel to OFFICE
 ACTION: Access EDOCS for illustrated parts catalog
 ACTION: Get part number from IPC
 ACTION: Travel to PARTS
 RESULT: Parts found
 ACTION: Travel to gate 34
 RESULT: Problem not resolved ... continuing troubleshooting
 ACTION: Calling office for parts lookup
 RESULT: Technician available to lookup parts
 ACTION: Travel to PARTS
 RESULT: Parts found
 ACTION: Travel to gate 34
 RESULT: Problem resolved

Total distance traveled(ft.): 2035

Total information search time(min.): 13.6

******************* END SIMULATION *******************
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Figure 5: Sequence model showing a computer simulation of the handling of an inbound aircraft with multiple maintenance issues.

face to electronic documentation systems so that the most frequently performed or most important information-seeking tasks are the easiest and quickest to perform. The artifact model points out that the acceptance of any particular application might depend on interface design issues such as ease-of-access and reliability. The ability for technicians to access and print documentation while out on the ramp would benefit technicians.

The sequence model showed how technicians often spend excessive amounts of time traveling about the facility, and accessing information from electronic documentation systems. This finding echoes the need for remote access to these systems.

Casner and Puentes (2003) found that the delivery of computer and broadband technology to the marketplace has been largely driven by concerns of efficiency and operational costs. Perhaps the most important next step for the FAA and community is to incentivize the design, evaluation, and use of specific information-sharing tools that are designed to impact safety. At least one air carrier we surveyed had informal effort to devise a database system that archived difficult maintenance problems. Clearing the way for efforts like these to be developed and used in practice could be the next important step for technology in the aircraft maintenance workplace.

References

Barshi, I., and Chute, R. (2001). Crossed wires: What do pilots and controllers know about each others' jobs? Flight Safety Australia, May-June.

Beyer, H. and Holtzblatt, K. (1998). Contextual design: Defining customer-centered systems. San Francisco: Morgan Kaufmann Publishers, Inc.

Casner, S. M., Puentes, A., Encinas, C., and Heraldez, D. (2005). The use of computer and broadband technology in the aircraft maintenance workplace. NASA Technical Memorandum.

Casner, S. M., Encinas, C. M., and Puentes, A. (2004). Computer and broadband technology in aircraft line maintenance: A task analysis and questionnaire. FAA General Aviation, Aviation Maintenance, and Vertical Flight Program Review, November 2004, Washington, D. C.

Casner, S. M., and Puentes, A. (2003). Computer and broadband technology in the aviation maintenance workplace. FAA General Aviation, Aviation Maintenance, and Vertical Flight Program Review, September 10-11, Reno, NV.