Using Micro and Macro Studies of Tablets to Improve Maintenance

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ABSTRACT

Navy maintenance is becoming increasingly difficult with more complicated systems, reduced staffing, and efforts to reduce expensive training time. To improve maintenance readiness, the Navy is testing tablets by which technicians receive performance aids and directly connect with the larger Navy maintenance enterprise system. Technicians' performance can be improved by (1) micro controlled experiments which investigate interface details of accessing and presenting content via tablets and (2) macro field tests that illustrate the effect of technological tools in their deployed state. A comprehensive approach to improve productivity and decrease cost through tools is best informed by both micro and macro studies, and to integrate the results of both to create and promote Navy goals.

The micro element of our approach is the study of how a tablet-based presentation of procedures can be structured to provide technicians the support needed to maximize performance. We will report results from one such study, identifying difficulties introduced by tablets and how they can be overcome, and the capabilities now possible with interactive tablets.

The macro element of our comprehensive approach is the study of how the Navy maintenance technicians can benefit when connected to enterprise resources. Technician benefits include an ability to order components when technicians are in the field, access updated technical documentation, and automatically collect work performance data which reduces redundant paperwork and enables big-data analytics to identify interesting trends of previously unknown efficiencies and performance difficulties. We will report results from a recent field test that includes lessons learned from connecting technicians to the enterprise system.

Micro studies provide scientific verification of principles used to develop the solution, and macro studies reveal how well the solution improves work flow and productivity in the Navy context.

ABOUT THE AUTHORS

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INTRODUCTION

Maintaining complex Navy equipment is difficult. One approach to improving technician proficiency is providing maintenance technicians with advanced technology. When designing and implementing new technological tools, the Navy should assess how well the tools improve maintenance performance. We address questions of assessing effectiveness of new tools and analyzing how to apply them to be as effective as possible. We will illustrate how micro studies—controlled experiments conducted in laboratory-like conditions; and macro studies—field test observations of tools as they are deployed—can be combined to assess benefits of technology and recommend improvements. This paper will describe how micro and macro studies complement each other, and how both contribute to improving the work environment and capacity of maintenance technicians.

General Work Environment

The work environment we primarily studied is maintenance of radar systems (SPY) on destroyers and cruisers. This work environment is similar to many other Navy maintainers' jobs. Paper-based procedures specify step-by-step instructions that maintainers execute. While each printed procedure provides step-by-step instructions, the instructions address all variants of the SPY radar, as well as all ships, though ships have different test equipment and equipment configuration.. Technicians read the procedures, and follow the instructions specific to the type of radar and the test equipment available on their ship.

Many of the procedures involve aligning signals in the radar system. If a malfunction is detected, based either on self-test reports or characteristics of the radar operation, technicians are directed to a second class of procedures which diagnose faults and specify recommended repairs. Once a malfunctioning component is identified, technicians order parts, follow procedures to replace parts, execute procedures to re-align the system function affected by the replaced component, and provide administrative details regarding their maintenance activities, such as the duration of the maintenance activity.

Tablets for Maintainers

The Navy has invested in technological tools to improve maintenance and mission readiness. One tool involves tablets that provide technicians with (1) presentations of procedures and documentation that is only possible with computerized presentations and (2) maintenance and logistics databases by which technicians access the most current procedures and technical documentation and order parts. The Naval Ship Systems Engineering Station (NAVSSES) has developed the Reliability Engineers' Data Integration (REDI) tablet system. REDI tablets present step-by-step instructions that are tailored to the ship's (1) variant of the radar and (2) available test equipment. The tablets enable more interactions with the procedures than are available on paper. For example, if a technician is performing a procedure and identifies a component that must be replaced, the technician can order that component from the tablet.

REDI is browser-based, and therefore hardware agnostic. REDI is designed to operate both when it has a network connection and when it is offline. So once the tablet is synced, the technician has access to all available data. Specific interfaces include a calendar view showing scheduled maintenance, the presentation of procedures, identification of work candidates, record of work completed, access to the logistic system to order new parts, and access to technical documentation.

Underlying Structure of REDI Tablets

REDI (diPilla & Philip, 2013) uses an Enterprise Service Bus (ESB) along with other modern software architecture to reduce the complexity of integrating disparate applications. REDI leverages Service Oriented Architecture (SOA) principles and standardized packaging frameworks. SOA addresses shortcomings of other approaches by using standards and loosely coupled interfaces. An ESB is the central data aggregation point for all the distributed data sources in the maintenance and logistics chain. Each of the programs that the ESB communicates with has defined interfaces and Application Program Interfaces (APIs). Depending on the application and system, the interface could be a direct Open Database Connectivity (ODBC) connection, a web service connection, or a file based export. Because each system is unique the ESB allows for the presentation layers of the applications and the interfaces to third party algorithms to be agnostic to the specific applications. The tablets, through which technicians view maintenance procedures and access logistics information, communicate with the ESB through web services, and user interfaces are written in HTML and javascript.

REDI tablets promote user efficiency by reducing presentation of unnecessary information and removing duplicate actions. Business logic determines what each technician has access to, based on the technician's role. Manually aggregating key data into spreadsheets or other offline tools only needs be completed once, and users can access many databases through one login. Technicians can focus on key decisions instead of mundane tasks.

Challenges of Tablets

The use of tablet-based presentations of procedures and documentation presents a major challenge for interaction design: How should tablets present content so technicians can easily understand and follow step-by-step instructions? When following procedures, technicians currently see a whole sheet of step-by-step instructions on paper. On the tablet, the amount of display space is smaller, so technicians will not see as much. Should the presentation of procedures to technicians consist of only one step at a time, with technicians indicating when to proceed to the next step? Or should technicians see many steps that are functionally related at one time? If many steps are presented, will technicians be able to identify the current step?

Beyond the simple presentation of procedures, tablets make many interactions possible. These include viewing videos of step execution, identifying the location of each component described in the procedure, being able to order new parts, accessing diagrams, and using job aids that provide knowledge about to how to solve problems and understand equipment operations. Design of the tablets' interface should enable technicians to (a) unambiguously access each type of assistance and (b) present each type of assistance so it benefits technicians.

Technician Needs

When addressing these challenges, we should understand the needs of technicians and the needs of the overall Navy maintenance system. Psychological investigations of people performing complex tasks similar to those of technicians reveal that technicians should perform best when:

- They attend to what's important for them to perform well (Stroud and Cavalcanti, 2013), and
- They possess an understanding of the environment and the purpose of their actions (Margulieux, 2014).

Thus, tablets should

- Allow technicians to focus their attention on what is most important, and
- Train technicians to understand the function of the tests they are conducting, in both schoolhouse and on-the-job modes.

Role of technician in the maintenance system

Technicians maintain equipment so that it is mission ready. Technicians' execution of maintenance procedures is central to the correct functioning of the systems. The maintenance system has to supply the parts that need to be replaced; the maintenance system maintains the specification of the procedures and how long each procedure should take; the maintenance system supports central engineering services to the fleet and provides technicians with assistance when the technician needs support.

System Capabilities

While Navy technicians use paper-based presentation of procedures for most jobs, electronic procedures enables the following benefits:

- Easy update to revised procedures via electronic downloads.
- Tailor procedures to the actual equipment configuration and test equipment on each ship. While paper-based Mission Readiness Cards (MRCs) present procedures steps for all equipment variants, REDI presents the procedures tailored to the equipment on the technician's ship. Technicians can perform better when they can focus on their own procedures, rather than when they are distracted by instructions to skip over steps that are irrelevant to them.
- Providing more information about each component identified in the procedure.
    - Its location can be illustrated
    - Its function can be described
    - Its context within its larger circuit can be illustrated via a diagram and described
    - It can be ordered
- Showing videos of expert technicians executing complex procedures or steps;
- Presenting FAQs associated with common problems for completing a step or procedure;
    - Explaining system function pertinent to the tested equipment
    - Presenting and explaining diagrams of component functions
    - Presenting diagrams relevant to a particular step
- Anticipating and considering new capabilities when designing for future adaptations including:
    - Augmented Reality glasses, such as Oculus Rift
    - Prognostics of expected equipment malfunction
    - Difficulties that technicians experience can be observed based on time to complete each step.
    - Training videos or activities tailored to individual technicians can be integrated with procedures

As tablets enable greater access to a maintenance and logistics database, the Navy maintenance system provides more capabilities to users of the maintenance system. With constant monitoring of the maintenance system:

- The current mission readiness is continually monitored
- Notifications sent when a system is working correctly, but has no available back-up parts
- Replacements for malfunctioning components are ordered as soon as maintenance operations diagnose a fault
- Technicians' activities and time spent conducting procedures is automatically tracked, eliminating the need for technicians to track and report these inputs to the maintenance system

Focus of This Paper

The Navy seeks efficient maintenance systems to support readiness. Building an efficient maintenance system requires learning what works, what doesn't, and improving the system. The focus of this paper is how to conduct studies of systems like the REDI system. Studies should look at both details of technician interactions with user interfaces, and the effects of work patterns affected by technology. Questions to address include

- How does the communication from technicians on a ship to maintenance and logistic systems affect depot-level maintenance and logistic processes?
- How should the REDI interface for technicians be designed to support effective job performance?
- How might current platforms—REDI tablet and maintenance practice--prepare for potential elaborations of REDI?

LABORATORY STUDIES TO INFORM REDI (A MICRO-STUDY)

Some questions about REDI design are best answered by controlled experiments. For example, questions about difficulties users experience with tablet presentation of procedures can best be examined in laboratory studies. Questions such as

1. Do technicians review prior steps? If so, why?
2. On which steps do technicians get stuck?
3. Do technicians skip steps? If so, why?
4. Do technicians properly execute each step?
5. Are there any observable patterns related to steps that are improperly executed?

Results from studies investigating these questions can lead to improvements in the REDI system interface design and suggest capabilities to include in REDI. Some laboratory studies are described below, with implications for capabilities to include in REDI.

Training Within a Simulation

One study investigated how to train technicians while they practice maintenance procedures on simulated equipment. The training protocol uses principles from current instructional theory that speaks to the importance of

1. System understanding
2. Interactive instruction rather than lectures
3. Contextualized instruction.

The training module content was developed based on interviews with Subject Matter Experts (SMEs). These expert technicians had performed the procedures regularly, and understood the function of the procedures from a maintainer's perspective. The experts divided the procedure into functional sub-goals, and articulated, usually with a diagram, how each sub-goal of the procedure served the goal of the entire procedure.

The training consisted of the trainee executing a sub-goal, and then being asked a question about the just-accomplished sub-goal. The trainee answered the question; the trainee then was presented with an expert's answer to the question; finally the trainee specified which elements of the expert's answer was present in their own answer.

This training was tested with a 12-day training module. Half of the trainees in a class received the common practice of simply executing the steps on the procedural simulation; the other half executed procedures that had training modules occasionally inserted. The results of this study found that providing training modules that focused on function of system operations in an instructionally powerful way resulted in markedly better post-test performance (Pokorny, Haynes, Gott, Chi & Hegarty, 2013). Post-test results are shown in Figure 1. The increase in total training time across the 96 hour course was approximately 1 hour, which did not require a structural change to the course. The difference in post-test performance between the groups was 1.3 standard deviations, $p < 0.05$. The score was based on the number of points they received from an objective post-module knowledge test.

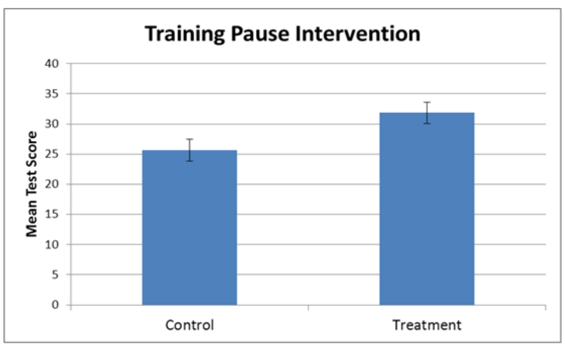

Figure 1. Results of training study

These results indicate that delivering training within simulation-based practice can greatly facilitate the acquisition of system understanding by technicians.

Job Aid Study

While the training study illustrated how to efficiently train technicians within simulation-based practice environments, the Office of Naval Research (ONR) sought an approach that would yield similar benefits as the training study, but help technicians while they are doing their job (rather than while they are in the schoolhouse). This led to ONR supported research at the Aegis Training and Readiness Center (ATRC) which investigated how the training content could be used as a job aid.

The presentation of content needed to be changed for one obvious reason: technicians should not be distracted by answering questions while conducting maintenance operations on real equipment. To address this concern, the content was transformed from training modules that asked technicians questions after they had completed procedural steps to advance organizers that presented technicians with the rationale for a set of steps before they executed the steps.

A study of the benefits of presenting advance organizers while technicians perform maintenance was conducted with a simulation of the Aegis system. As shown in Figure 2, the Aegis environment was presented on the right portion of the screen while a tablet-like display was presented on the left. To navigate between screens on the simulated tablet, technicians used mouse clicks (rather than finger swipes that would be used on a real tablet). The screens that technicians examined and the mistakes that technicians made were recorded and analyzed.

Method

The content from the training study was transformed into advance organizers with the assistance of SMEs from Sonalysts. We conducted the study with 12 technicians from ATRC at Dahlgren who had been trained on the transmitter before participating in the study.

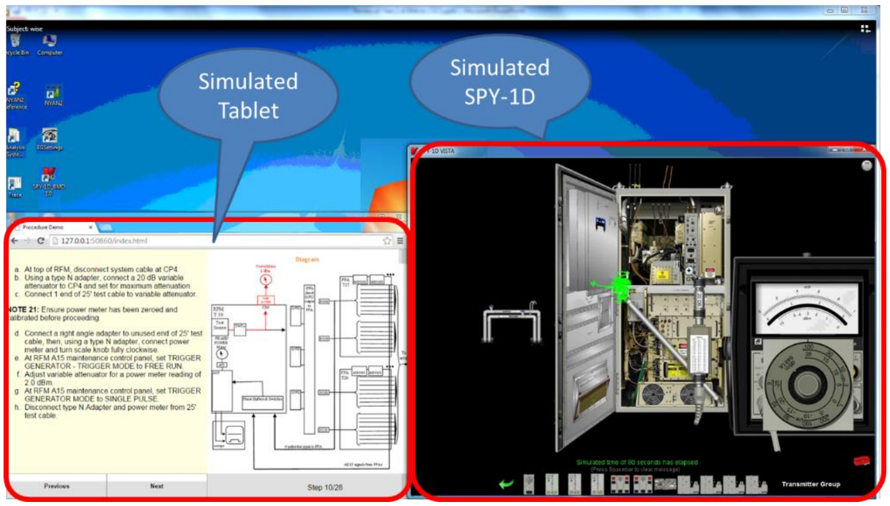

Figure 2. Screen layout for job aid study

Technicians were randomly assigned to either the control group (who were given procedures and executed them on the simulation) or the treatment group (who were given procedures and advance organizers of the upcoming procedural steps, and then executed them on a simulation).

Measures from the experiment included scores on a knowledge test, results from a usability questionnaire, number of errors, and an analysis of procedure pages observed by technicians on the tablet.

Stimuli

The presentation of the tablet was shown on the lower left of a computer screen; the simulation of the equipment was shown on the lower right. The presentation used an 18 inch wide screen as shown in Figure 2.

The simulated tablet showed a specific maintenance procedure. It was modified so that the procedure would show actions specific to the SPY-1D variant rather than the instructions for all SPY variants. This matches the presentation utilized by REDI. Technicians in the treatment condition were also presented with advance organizers.

Procedure

The experiment was conducted at Sonalysts' office near ATRC. Upon arriving at the experiment site, technicians were briefed on what they would be doing, and read materials on the purpose of and procedures for the experiment. They read and signed a consent form (as approved by the Navy Institutional Review Board, IRB). Before the experiment began, technicians practiced with the simulation, and passed a checklist on their ability to use the simulation. Technicians were told that they could ask questions of the experimenter at any time.

Each technician completed a set of maintenance procedures (with or without advance organizers depending on whether they were in the control or treatment group). At the conclusion of the session, technicians took (1) a knowledge test that asked them about the procedures they had just completed, and (2) a survey that asked them about the usability of the system. As technicians participated in the session, they were encouraged to express anything they were thinking about the process. These notes were collected for later analysis.

Results

The primary finding was that technicians who saw a measurement reading that was not in the expected range looked backward from the screen which showed the measurement procedure to try to understand how they might have configured the equipment incorrectly. The implication of this finding is that technicians should be supported to help them understand how to interpret measurements and how to review steps taken earlier to configure equipment. Further laboratory studies are planned to work with technicians to understand how the review of procedures should be presented to help technicians.

There were no statistically significant differences between performance of the control and treatment groups. Knowledge was assessed based on objective answers to a short knowledge test. Usability was rated on a scale of 1-5. Number of successful configurations was based on a review of performance collected during the procedure. The number of participants who successfully configured the primary test used in the procedure was counted. Six participants were in each group. Table 1 shows the results for each outcome measure.

Table 1. Quantitative results from job aid study

	Knowledge Test	Usability Score	# of Successful Configurations
Treatment group (with advance organizers)	4.6	4.42	2
Control group (no advance organizers)	3.8	4.17	4
Standard Deviation	1.1	3.3	

The usability results identified major problems that technicians had completing the procedures. This list of problems was identified from user comments and observations of performance.

Table 2. Usability results from job aid study

Problem	Potential modification to procedure presentation
Technicians lost track of which maintenance lines they had executed	Present an indicator of the current step. Display the current step as “selected.” Technicians can change the “selected” step by tapping a new step, or by tapping a next or back button.
Technicians didn’t know where a component identified in the procedure was in the real equipment	Allow technicians to highlight a component specified in the procedure, and access more information about it, such as (1) where it is, (2) how to order it, (3) how it works, or (4) which circuits it plays a role in (diagrams).
Technicians sometimes misinterpreted readings, e.g., used the wrong scale.	Show graphics of what readings should look like on common measurement devices.
Sometimes technicians read a line, but did not know how to execute the step.	Provide additional specifications for execution of some steps, such as graphics or video of performance execution.
Technicians wanted to add notes to the procedure for later performance support.	Allow technicians to add notes to the procedures (just as they currently write notes on the paper-based materials).
Technicians paid relatively little attention to the advance organizers until they experienced a problem, e.g., when they saw a reading they shouldn’t have gotten, they became very interested in understanding the procedure.	Develop a template presentation for assisting technicians when they get an unexpected measurement. Specific content can be tailored to each measurement taken, though the pattern guidance would be similar for each measurement.

Discussion

This study shows three kinds of results that inform potential improvements to REDI.

1. Usability test results show how the presentation of procedures on a tablet should be modified to provide better support for technicians.

2. The use of advance organizers did not improve technicians' performance, thus does not support including advance organizers in procedures. A caveat to this finding is that this study was conducted with young technicians. Young, less experienced technicians may apply all of their cognitive resources to simply following the procedures, and may not be able to use the advanced organizers as context that provides assistance to users as they follow procedures. More experienced technicians may be better equipped to take advantage of the advanced organizers. As technicians gain experience, they may have sufficient fluidity in following procedures to pay attention and use the advance organizers to supplement the step-by-step information of the procedures.
3. Technicians were very interested when readings from test equipment were outside expected limits. This observation leads to the possibility of providing technicians support when the technician has just taken an out-of-tolerance measurement. A future study could investigate if support for technicians when readings are out-of-tolerance improves performance.

This job aid study informs design of the interface and answers some questions raised when identifying benefits of micro studies. Technicians' performance is improved by both great clarity in presentation of step-by-step instruction and by system understanding of the equipment function and the rational of the test (Smith & Goodwin, 1984). This study revealed that students stopped executing steps when measurement readings were out-of-tolerance. They reviewed earlier steps to try to understand why the reading was not within expected limits.

Possible Studies of Other Capabilities for REDI

REDI enables the integration of many existing data sources that could help technicians. Laboratory studies could show if the capabilities improve technician performance and how (1) the information could be accessed and (2) the information could be presented. Of the many possible improvements that could be studied, we have identified four.

1. Providing technicians with videos of experts completing procedure steps. Studies of this capability could investigate
   - How should technicians access these videos so they are intuitively found?
   - How much do the videos improve performance?
   - Which form of step-by-step instruction is the most cost-efficient?

   Some concerns about cost of videos that show step-by-step performance include:
   - The verification of the procedures that are shown to technicians
   - The need to tailor the presentation for technicians with different variants of equipment
   - The need and costs of updating the video when a change is made to the procedure
2. Including prognostics information for technician activities. As equipment systems become more sophisticated, more data is collected about their operation, and prognostics can be used to recommend when components that are not yet failing but show the likelihood of upcoming need for replacement are targeted for replacement conveniently during related maintenance operations.
3. Providing access to information collected by the Port Hueneme Detachment (PHD) that provides a chat center to support complex maintenance activities. The PHD chat support provides Aegis technicians with support of difficult problems. Records of these calls from technicians could be collected and made available to technicians.
4. Using the tablets as a source of training. The training study described above (in "Training Within a Simulation" section) is one way that training could be provided using tablets. The Navy could provide simulation environments in which students learn and practice applications of concepts on tablets as a common mode of training.

FIELD TESTS TO INFORM REDI (A MACRO STUDY)

When conducting a field test, the primary purpose is to observe the use of the tablet in the conditions in which it will be eventually deployed, and to observe both expected and unexpected consequences. The REDI system has been field tested across a dozen ships: Littoral Combat Ships (LCS), destroyers (DDG), cruisers (CG), frigates (FFG), and Landing Platform Dock (LPD) ships.

Various questions were prepared for observation. Some of these included:

1. What was the effect of the tablet being online or offline as technicians used it?
2. What was the effect of the tablet on documentation of equipment failures?
3. What is the effect of tablets on need to print and move paper-based forms?

The data collected and analyzed for the questions above yielded the following results:

- The tablet worked as it was designed in both online and offline configurations. When REDI was online, the technicians had immediate access to the authoritative data and to provide results of tests (such as documentation of equipment failures). When offline, the tablets presented the most recently stored data, and collected information that was pushed to maintenance and logistics systems when the tablet was reconnected to its larger network.
- The tablet improved processing of equipment failures. One metric was that the percentage of accurate equipment failures documented was higher when the report came through the REDI system than when it was submitted on paper. Perhaps the REDI system provided guidance and processes (through tools) for reporting equipment failures.
- The REDI system enabled access to all technical manual references while negating the need for hard copy. The ability to access current maintenance documentation removes questions of applicability of paper based documentation. Having a database of a ship's assets increases the ability to search for desired components. The tablets reduce printing and manual labor of paper documentation. Many standard forms used for ship inspections, documentation of equipment and procedures, and reports of equipment readiness for the Ship captain and Lead Engineer have been nearly eliminated. Technicians no longer have to record their activity; instead, their activity is automatically tracked and recorded, thus reducing redundant paperwork.

In addition to the observations that were planned for, other observations were noted as well:

- Technicians were uncomfortable finding a place for the tablets as they read procedures from them. Perhaps they will get used to holding tablets rather than paper, or tablet holders will be added to the work center.
- While the tablet made the technician's job easier and they were able to complete their work more efficiently, some technicians expressed that they did not enjoy that their work process was being recorded and could possibly be monitored or analyzed later.

Both of these finding should be examined and addressed before full scale deployment of the tablets. The Navy could deal with these directly with policies and/or practices.

CONCLUSIONS

Transitioning research products and concepts into the field is never easy. We collected and analyzed data from both controlled, micro-study experiments and field tests to understand the benefits of technology. The controlled experiments focus on the ability of technicians to use the technololgy's interface. Micro-studies enable the quantification of potential benefits derived from changes in the interaction between the technician and the maintenance system. Careful observation and analysis of technicians using the interface yield suggested improvements to the interface which are designed to improve technician efficiency and which can be tested in later micro studies. The field tests address the effects of the technology on the entire maintenance system. The field tests yield results that cannot be observed in laboratory setting but that are critical to technology acceptance by users. While micro studies focus on the interactions between the technician and system, the field studies allow for observation of new work processes that result from the capabilities of the new technology. Finally the macro studies yield results that speak to the overall efficiency gains for the entire maintenance system process, of which the technician interacting with an interface is one part. In summary, the micro studies contribute to improving the usability of technicians' interface. The macro studies address the case for bringing the most powerful tools to the field.

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