

AN INVESTIGATION INTO PROVIDING FEEDBACK TO USERS OF DECISION  
SUPPORT SYSTEMS FOR FAULT MANAGEMENT

by

JAMES ALLEN PHARMER  
B.S. University of Central Florida, 1994  
M.S. Florida Institute of Technology, 1996

A dissertation submitted in partial fulfillment of the requirements  
for the degree of Doctor of Philosophy  
in the Department of Psychology  
in the College of Arts and Sciences  
at the University of Central Florida  
Orlando, Florida

Fall Term 2004

Major Professor: Clint A. Bowers, Ph.D.

©2004 James Allen Pharmer

## ABSTRACT

Research in several domains has shown that the implementation of computerized decision support aids is often associated with issues of human-automation interaction, which can have disastrous consequences. One often-cited reason for these issues is the poor quality of the feedback that is provided to the operators through these tools. The objective of the proposed investigation is to examine how providing feedback through a decision support tool affects operator knowledge and performance in the context of a fault management task for naval gunfire support.

A one-way between-groups comparison was made to investigate differences between providing decision support feedback (logic trace, mission impact, both, no feedback) in a fault management task. Logic trace feedback was posited to provide users with a representation of the logic that the decision support tool used in reaching a conclusion about the best course of action to perform and is posited to support better diagnostic performance. Mission impact feedback was posited to provide the operator with a description of the potential effects that a taking a course of action will have on the pre-planned mission and is expected to support better prognoses of the outcome of a particular fault. Finally, providing both feedback types was posited to support better compensatory actions for fault situations. Results indicated that decision support feedback has potential improve diagnosis and decrease errors of commission in these tasks.

## ACKNOWLEDGEMENTS

The author would like to gratefully acknowledge several individuals without whom this work would not have been possible. First, sincerest gratitude go to Dr. Clint Bowers and Dr. Gwen Campbell, the chair and co-chair of the committee for their thoughtful insight and support in accomplishing this work. Their mentoring will always be remembered fondly. Thanks also to Dr. Jeanne Weaver and Dr. Mustapha Mouloua for their helpful comments, suggestions, and encouragement in the development and defense of this dissertation.

My gratitude further extends to those individuals who supported me in all of the tasks that needed to be performed to pull this investigation together. Hugh Carroll and Richard Plumlee provided unbelievable amounts of support and expertise in the domain and training. I owe much of what is in this investigation to them. David Holness and Jonathan Frye recruited and ran participants and provided support in the analysis and interpretation of the data. Tyson Griffin provided much of the expertise in setting up the testbed. Thanks very much. Further thanks go to all of the people who kept asking me when I was going to finish my dissertation. Without their often curt prodding, it is very likely that I would have never finished.

Finally, my wife, Lorrie deserves my greatest thanks for her patience, faith, and love. I love her right back. My kids Becky and Griffin, while part of the reason that this has taken so long, have provided the motivation for me to finish this, as I am sure they will find when they have kids of their own.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS .....	iv
TABLE OF CONTENTS.....	v
LIST OF TABLES .....	viii
LIST OF FIGURES .....	ix
INTRODUCTION .....	1
Background .....	1
Information Processing in Fault Management.....	3
Feedback for Fault Management .....	8
Context: Naval Surface Fire Support Domain .....	9
Resolution of Ambiguity: Logic Trace Feedback.....	12
Considering Ultimate Goals: Mission Impact Feedback .....	14
Purpose of the Study .....	16
HYPOTHESES .....	18
Hypothesis I .....	18
Hypothesis II.....	18
Hypothesis III.....	19
Hypothesis IV .....	19
METHOD .....	21

Participants.....	21
Materials .....	22
Naval Surface Fire Support Assistant (NSFSA).....	22
Jane's Fleet Command .....	23
Experimental Scenario .....	24
Fault Management Questionnaire .....	26
Pre-performance Test.....	29
Participant Reaction Questionnaire.....	29
Design .....	30
No Feedback .....	30
Logic Trace Feedback Condition.....	30
Mission Impact Feedback Condition .....	31
Combined Feedback Condition.....	31
Procedure .....	32
Training.....	33
Performance .....	36
Dependent Measures .....	37
Diagnoses .....	37
Prognoses .....	38
Compensation .....	39
Analysis.....	39
RESULTS .....	40
Random Assignment.....	40

Hypothesis I Results .....	41
Hypothesis II Results .....	43
Hypothesis III Results.....	44
Hypothesis IV Results.....	44
Trainee Reaction Questionnaire.....	46
DISCUSSION .....	48
Process Control and Military Decision Making Differences.....	48
Experimental Validity.....	50
Future Research Considerations .....	54
CONCLUSIONS.....	58
APPENDIX A: INFORMED VOLUNTARY CONSENT TO PARTICIPATE.....	59
APPENDIX B: PRIVACY ACT STATEMENT.....	64
APPENDIX C: SCENARIO TARGETS aND ATTRIBUTES .....	66
APPENDIX D: FAULT MANAGEMENT QUESTIONNAIRE.....	68
APPENDIX E: NSFSA KNOWLEDGE PRE-TEST .....	81
APPENDIX F: PARTICIPANT REACTION QUESTIONNAIRE .....	85
APPENDIX G: DEMOGRAPHIC QUESTIONNAIRE .....	89
APPENDIX H: SURFACE aND AIR SITUATION REPORT TEMPLATE.....	93
APPENDIX I: GUN CASUALTY REPORT TEMPLATE .....	95
APPENDIX J: CODING SHEET FOR NSFSA.....	97
REFERENCES .....	99

## LIST OF TABLES

1. Background Variables by Condition .....	41
2. Frequency of Correct Responses to Gun Casualties by Condition.....	42
3. Mean Trainee Reaction Questionnaire Ratings.....	47



## LIST OF FIGURES

Figure 1: Rasmussen's Decision Ladder.....	4
Figure 2: Fault Management Activities.....	6
Figure 3: Knowledge-based Fault Management Activities.....	7
Figure 4: Experimental Procedure .....	32

## INTRODUCTION

### Background

The United States Navy has recently established the ambitious goal of reducing manning on future Navy ships by as much as 75%. However, while the number of individuals aboard ships will certainly be smaller, naval warfare will only become more complex. For example, a new class of naval destroyers with a substantial reduction in manning levels will have the capability to perform land attack missions, a capability that was not required of previous destroyer classes. As a result, the operators aboard these new vessels, who already routinely operate under high workload, will be asked to perform more tasks than had previously been performed. One potential way of achieving these seemingly conflicting goals of reduced manning in a more complex domain is to increase the use of automated systems and decision support tools. However, a substantial body of research suggests that there are inherent pitfalls with the introduction of automation and decision support, primarily related to the interaction between the human and the automated system (Wiener & Curry, 1980; Wiener, 1989; Woods, 1996; Mouloua & Koonce, 1997). Parasuraman and Riley (1997) posit that, although automated systems do have potential to support reductions in cognitive and manual workload for operators, multiple factors influence the effectiveness of the interaction between the operator and

the automated system. In fact, the added complexity and changing role of the operator in many automated systems actually may, in fact, have the opposite of the intended consequence of workload reduction on the operator (Sheridan, 1970). Lee and Moray (1996) hypothesize that a complex interaction between factors including operator self-confidence, system accuracy (see Muir, 1987), perceived workload, and task complexity, and operator skill level influence operator reliance on automation. Parasuraman et al. (1997) submit that designers of these systems must consider the consequences on the human operator is a critical factor in the design of these systems and that among the risks of not making these considerations (abuse) are over-reliance (misuse), under-reliance (disuse). Consequently, it is crucial that we understand how to implement these systems such that they provide operators with the required knowledge to use them effectively.

The interaction between automation and decision support tools and the operator who utilizes them hinges primarily on the communication strategy that the designers of these tools implements. In fact, a frequently-cited reason in the literature for human-automation interaction failures is that the quality of the feedback that is provided to the operator is often very poor (Norman, 1990; Sarter & Woods, 1992; Mosier & Skitka, 1996; Woods, 1996). The objective of the proposed investigation is to examine how providing feedback through a decision support tool may affect operator knowledge and performance. More specifically, this investigation focuses on methods of tailoring feedback from a decision support tool to the informational needs of operators at various stages in the decision-making process. For reasons discussed in more detail in following sections, this investigation was performed within the context of a military fault management decision-making domain, naval gunfire support, in which operators must

respond quickly and accurately when there are mechanical faults within gun systems in an effort to minimize their impact on a pre-planned land attack mission.

Any approach to providing decision support should be rooted in an understanding of how decision-makers process information within a domain. The following section provides an integrated framework of human information processing for fault management tasks and proposes a comparison, based on this framework, between three forms of feedback that can be provided by a decision support tool for fault resolution.

### Information Processing in Fault Management

Rasmussen's (1986) 'decision ladder' (Figure 1) provides a useful framework from which to describe the information processing activities involved in fault management. The decision ladder describes human information processing in response to information from the environment. As the figure illustrates, human behavior can be represented as a three level hierarchy. At the lowest level of the hierarchy is skill-based behavior, which is characterized as volitional sensory motor acts, such as tracking tasks, for which performance takes place without conscious control. At the intermediate level, rule-based behavior is based on stored rules or procedures selected from previous successful experiences in similar situations. Finally, at the highest level is knowledge-based behavior or goal-controlled behavior for which no rules are available from previous encounters. At this level, individuals formulate behavioral responses based on the analysis of cues within the environment and the goals of the individual.

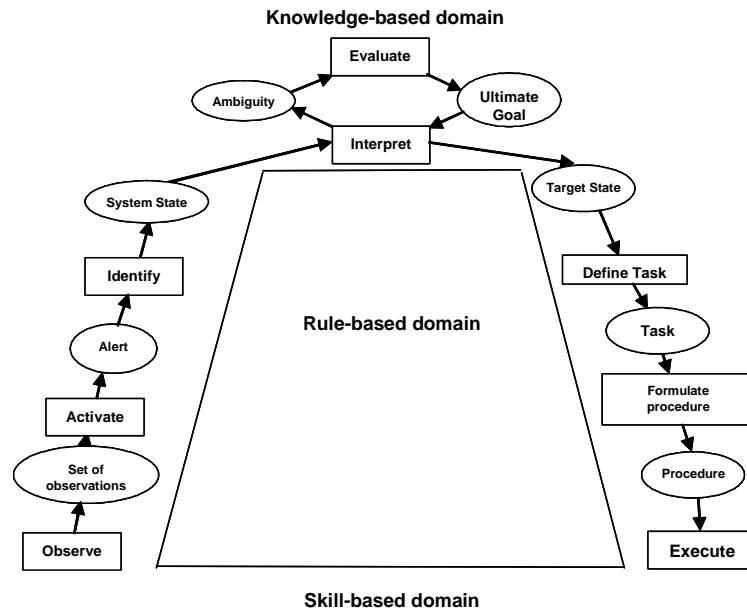


Figure 1: Rasmussen's (1986) Decision Ladder.

The decision ladder in Figure 1 depicts the relationship between these levels of cognitive control and decision phases. The boxes in the ladder illustrate the information processing activities involved in each decision phase and the circles represent the information or knowledge produced, which feed into the next decision phase. In general, data from the environment is observed and cues an evaluation and interpretation of the data. The individual's response to these environmental cues is formulated and an action is executed. It is well established in the literature that human decision making is often characterized by the use of heuristics, or shortcuts to this decision making process (see Tversky & Kahneman, 1974), such as availability and representativeness. The model

depicted here is a normative model in that it describes what people should do ideally and can be used as a frame of reference for fault management. Many decision support applications have been developed based on normative models, such as this (Edwards, 1987). More descriptive models of expert decision making strategies may have utility. However, they are beyond the scope of this investigation into a basic understanding of the feedback needed to support fault diagnosis.

The decision ladder discussed above can be applied across a variety of situations, activities, and decision types. For the purposes of this investigation, the focus is on fault management decision-making. In fault management, a fault represents an abnormal state of the system that has the potential to impact the successful achievement of the mission, in this case, the land attack mission. Rogers, Schutte, and Latorella (1996) describe fault management in terms of four operational tasks, or ‘threads of activity’. These are detection, diagnosis, prognosis, and compensation. Detection involves the recognition that an abnormality has occurred and that the operator must intervene in the process. Diagnosis is the activity that is performed to determine both the cause of the abnormality and the consequences of the failure. Prognosis is the activity that the operator performs to predict future states caused by the fault over time. Finally, the task of compensation utilizes the preceding task to determine the appropriate response to the fault. As is evident from the descriptions above, each of these fault management tasks require the operator to perform different information processing activities and each of these activities has different knowledge requirements.

Rogers and his colleagues have mapped each of these functions onto Rasmussen’s (1986) “decision ladder”, which depicts the relationship between skill-based, rule based,

and knowledge based control and the fault management ‘threads of activity’ described above (see Figure 2). As the figure shows, the operational tasks involved in fault management follow a path, which, in the initial operational stages of the fault, relies on bottom-up data (e.g., alerts, sensor data, etc.) to detect that there is a problem and to begin to diagnose what that problem is. The operator is then faced with the challenge of evaluating and interpreting the data so that he or she may perform the necessary compensatory actions. Key decisions are made at this point in fault management that determine how the operator predicts the impact of the fault on the mission (prognosis) and how to respond (compensation) to the fault.

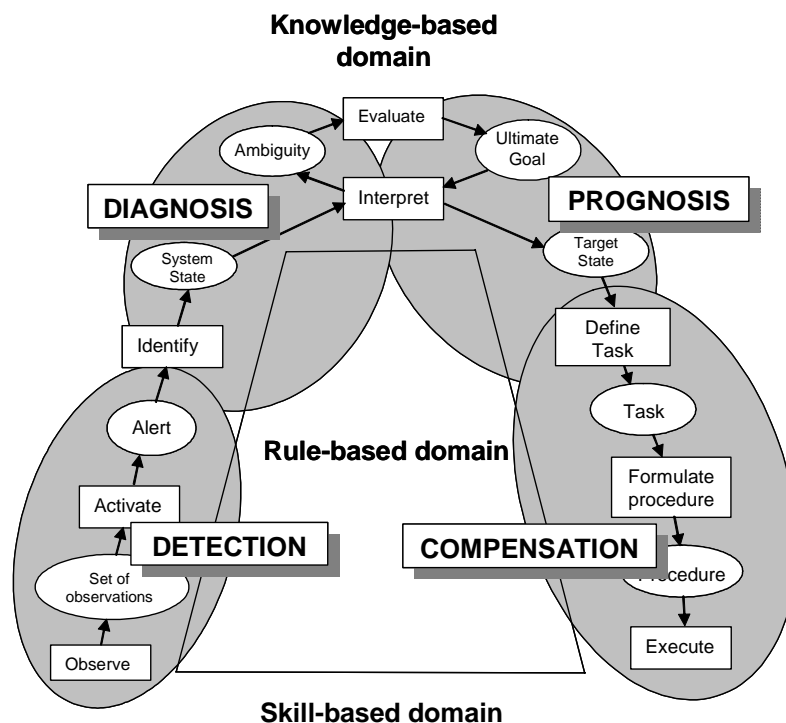


Figure 2: Fault Management Activities Mapped onto Rasmussen's (1986) Decision Ladder. From Rogers, Schutte, and Latorella (1996)

The application of human factors to the design of displays and controls can do much to support fault management at the skill-based levels and rule-based levels of detection and compensation. Activity at these levels is, in large part, based on familiar situation and internalized routines and rules. Arguably, it is at the knowledge-based processing level, diagnosis and prognosis phases of fault management that decision support tools can be of the most benefit during the (see Figure 3).

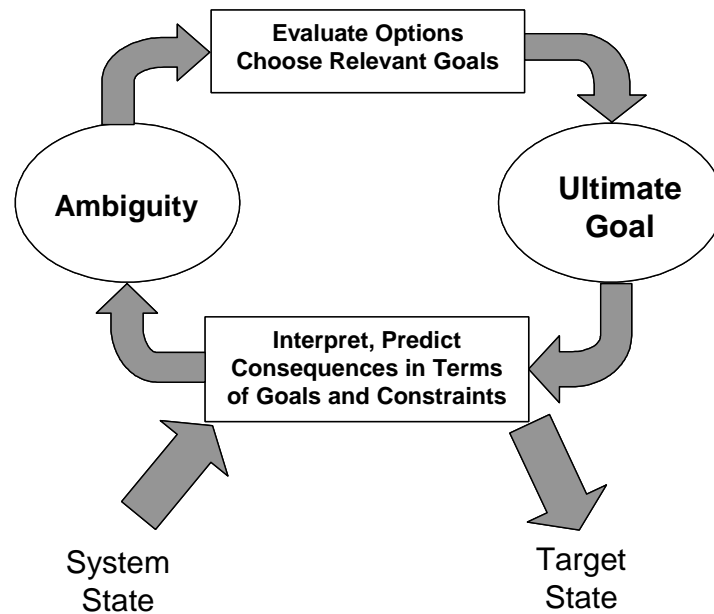


Figure 3: Rasmussen's (1986) Knowledge-based Fault Management Activities.

At this level, the situations are non-routine and rules are not available to the operator. In Rasmussen's (1986) model, the evaluation and interpretation that occurs



during these phases requires considerations of the ambiguity of the data for diagnosing and produces a goal for the operator of how to compensate for the fault. Once the target-state of the system is determined, the operator can then formulate the necessary tasks and procedures to compensate for the fault effectively.

The following section will focus on the processes that occur at the knowledge-based level and the information that is necessary, via feedback from a decision support tool, to successfully diagnose faults, develop prognoses, and determine compensatory actions in fault situations.

### Feedback for Fault Management

The models of fault management described above provide insight into the information that a decision support tool would need to provide for successful fault diagnosis and prognosis. Figure 3 illustrates the activities that occur and the information requirements at the knowledge-based level of the fault management hierarchy. A feedback loop of two information-processing activities occurs at the knowledge-based level: evaluation and interpretation. According to Rasmussen (1986), during the evaluation activity, the decision-maker evaluates options and selects a relevant goal. During the interpretation activity, the decision-maker predicts the consequences of taking an action in terms of the relevant goals and constraints of the mission and the current situation.

Within this loop, the decision-maker generally requires three types of knowledge or information. First, the current system-state is provided by identification of the

problem during the detection stage and early in the diagnosis stage and serves as input into the knowledge-based processing and predicting the consequences of the fault. The two remaining information sources that are required serve as the connections between evaluation and interpretation processes and can be provided to assist the operator through a decision support tool. These are (1) information on the mismatch between normal operation (ambiguity) and the current systems state and (2) information pertaining to the ultimate goal or target state (ultimate goal) of the system.

The following section will describe the domain of interest for the current investigation and a decision support tool designed to assist operators in decisions at the knowledge-based level of processing. This section will provide the context for further discussion on the appropriate information needed to support decisions made during both the diagnosis and prognosis (knowledge-based) stages in fault management.

### *Context: Naval Surface Fire Support Domain*

Historically, fault management investigation has been performed within the context of only a few domains characterized by complex systems consisting of tightly coupled physical components. Examples of these domains include nuclear power, process control, and aviation. However, the utility of fault management theories is not limited to these types of physical systems. The domain of interest in the current study, Naval Surface Fire Support, is one example of a system in which fault management theories can be applied to investigate what information is required by operators to successfully resolve a system fault.

The task of Naval Surface Fire Support involves firing on land targets within a pre-planned mission schedule to provide support for a land attack mission. Like the traditional domains of interest mentioned above, Naval Surface Fire Support consists of tightly coupled interacting components. However, these components can include both physical (i.e., mechanical) components such as guns, ammunition, transducers, and hydraulic systems as well as other system entities like friendly and enemy troops, aircraft, targets, and the gun commander. Further, Naval Surface Fire Support can be described as a process in that the role of the operator is to maintain a preplanned mission schedule despite faults that may occur within the system. Faults, in this case, are abnormal states, which threaten the mission schedule. These faults can include the physical breakdown of mechanical components of the guns. For example, a leaking hydraulic seal within a particular gun may render it inoperable for future targets and threaten performance within the mission schedule. System faults can also be brought about by entities within the battle. For example, friendly troops could move into proximity of an active target, making firing on a target risky and threatening adherence to the mission schedule. Moreover, these faults can interact with one another, as is the case when a particular gun problem makes it less accurate and the movement of entities in the environment makes accuracy critical to conforming to the mission schedule.

Not only do the elements of the Naval Surface Fire Support domain map to the elements of other domains traditionally studied in fault management tasks, but the activities of the operators within this domain are quite similar as well. Gun commanders follow the same ‘threads of activity’ described by Rogers et al. (1996) of detection, diagnosis, prognosis, and compensation.

In the current investigation, detection of a mechanical gun fault is a somewhat trivial task in that the decision support tool that is used as a testbed alerts the operator when it detects one. Detection of faults involving entities within the battle is a more complex task involving visual monitoring of the battlefield and auditory monitoring of a communication circuit. For these entities, the operator must detect when the movement of entities like aircraft and troops have the potential to change the firing plan and threaten the mission schedule.

In the more traditional fault management domains, diagnosis is a process of identifying the cause of abnormal states of the system and inferring the consequences of that aberration on other physical systems components. Operators of nuclear power plants and pilots of advanced automation aircraft often must identify which of a number of potential root causes are the source of a needle deflection and then interpret how the responsible component impacts other components. In contrast, the tasks involved in diagnosis of physical faults (gun casualties) in Naval Surface Fire Support faults, are not as heavily focused on identifying the cause of the fault. In fact, for the current investigation, this information is explicitly provided to the operator at the detection phase when they are alerted to a particular gun problem. Rather, the focus of diagnosis is more on the potential impact of the abnormality on other system components, which, as described previously may be either physical components or battle entities.

Like prognosis of more traditional fault management domains, the task of prognosis in Naval Surface Fire Support involves inferring the consequences of taking an action in response to a system fault on the success or failure of the mission. For example, one response to a gun problem may be to cancel firing on a specific target. However, if

that target is high priority and critical to the success of the mission, the operator may have to consider other alternatives.

Finally, the compensation task within the Naval Surface Fire Support domain is essentially the same as it is in the more traditional domains. Once the appropriate course of action has been determined, the operator implements the appropriate action. In the majority of cases in the current study, performing this course of action is accomplished through selection of an option within the decision support testbed.

### *Resolution of Ambiguity: Logic Trace Feedback*

Figure 3 shows that knowledge that resolves diagnostic ambiguity is a key component in the interpretation and evaluation process of fault management tasks. Results of several investigations have suggested that providing users with topographical information of the interrelationships of system components and failures can provide considerable benefit in knowledge-based processing and fault diagnosis. (Rasmussen, 1986; Kieras, 1992; Edlund & Lewis, 1994; Moore & Corbridge, 1996). For example, in a series of studies, Kieras (1992) obtained significant improvements in performance from participants in a malfunction diagnosis task by providing diagrammatic displays of the engineered systems. Kieras and Bovair (1984) made a somewhat similar manipulation in the context of training users of a complex device. Two groups of participants received identical training on the procedures to operate a control panel device (rote training) with no instruction on the interrelationships between components. In addition, one group (model group) also received approximately 15 minutes of ‘model training’ in which flow

diagrams and a simple description of how the components of the system interacted were presented. Their results showed that participants in the model group were able to learn a novel procedure 28% faster and showed significantly better retention when tested subsequently than the rote group. A major finding of these studies was that providing this type of information to participants in the diagnosis task significantly improved the quality of diagnoses.

Rasmussen (1985) suggests that the benefits of providing topographical information lie in providing the causal structure to the diagnostician. Yoon & Hammer (1988) propose that there are two further advantages to the use of topographical information in decision aiding in fault management. First, the representation is highly understandable to humans. Second, it provides a decomposition that allows the operator to make predictions and reason causally about the system. However, as the problem space increases in graphically displayed networks, operators are less able to perform optimally on a fault diagnosis task (Rouse, 1978). For the current investigation, topographical information will be provided to operators in a textual form, which provides the user with knowledge of which nodes in the process were considered by the decision support tool in determining a recommended course of action. For example, for a particular gun problem the feedback would take the following form:

*Pending target assigned to this mount? Y*

*Can pending target be cancelled? N*

*Conflicting target? Y*

*Is target time sensitive? N*

Feedback in this format would provide operators with a concise logical trace of only those decision nodes directly involved in the diagnosis and formulation of the recommended course of action for the particular fault.

Rogers, Schutte, and Latorella (1996) note that it is generally accepted that diagnosis is not only limited to identifying the cause of the failure, but it also encompasses the interpretation of the consequences of the system failure on other systems. This is the definition of diagnosis that is used in the current investigation. In fact, the decision support tool that is used in this study correctly and accurately identifies the source of the problem for the operator (e.g., hydraulic seal leaking). The task of the operator is to interpret what the problem means in the context of other systems and environmental entities (e.g., other guns, the battlefield, targets, friendly forces, low flying aircraft, etc.). For example, transducer damage is a particular gun casualty that degrades the accuracy of projectiles. If this problem arises, but it is not important that projectiles are accurate for the target to which the gun is assigned, then transducer damage does not represent a problem. However, if friendly troops are in the vicinity of this target, then the importance of being accurate is paramount.

### *Considering Ultimate Goals: Mission Impact Feedback*

A second type of information necessary in the knowledge-based processing level of fault management is information, which maps the consequences of following a particular compensatory action to the goals of the operator. This feedback supports prognoses by allowing the operator to predict the consequences in terms of the goals and

constraints of the mission. Shraagen (1997) emphasized the importance of providing information to predict future states in the development of a decision support tool for novice naval damage control (DC) officers. In a task analysis of both experts and novice DC officers, the novice officers were often unable to predict where fires were likely to spread aboard ship thus limiting their ability to take preemptive actions. Feedback, which allows operators to understand how their actions will affect future states, should always be useful because it would allow operators to understand how the actions that they perform now will impact the future and to compare their current goals to the predicted future states. Several researchers have maintained that the feedback provided by complex systems should map to the goals and expectations of operators. For example, Endsley (1996) has argued that, for operator situation awareness in automated systems, it is important that interfaces provide comprehensible information that maps to the operator's goals. Woods (1995) further argues that, in order to provide better representations to operators of complex systems, it is critical to put data into context of larger frames of reference, including the interests and expectations of the user. For the purposes of the current investigation, participants must manage the impact of performing a particular course of action in response to a fault on timely performance of the mission. Feedback that maps the impact of a particular course of action onto pre-planned mission goals should support prognoses by providing the information necessary to evaluate their options and choose relevant goals for compensation.



### Purpose of the Study

The purpose of this study is to better understand the role of feedback generated by a decision support tool on the knowledge-based processes in fault diagnosis. The normative fault management models of Rasmussen (1986) and Rogers, Smith and Latorella (1996) suggest fault managers require topographical information of the cause and effect relationships between systems to effectively diagnose faults and information on the impact of potential actions on mission goals to make fault prognoses. Both of these forms of information should, according to the models, support better decision-making, which should result in better compensatory actions in response to system faults.

A decision support tool for Naval gunfire support, known as the Naval Surface Fire Support Assistant (NSFSA), provides a unique opportunity to investigate the impact of providing each type of feedback described above, either alone or in combination. This tool was developed under the Office of Naval Research's Manning Affordability Initiative to demonstrate the capability of using a cognitive modeling approach as an architecture for a decision support tool. The iGen<sup>TM</sup> architecture behind this tool is derived from the GOMS (Goals, Operators, Methods, Selection Rules) work of Card, Moran, and Newell (1983) and utilizes notations for current problem representation, cognitive and behavioral representations of the human/system interaction, and representations of perceptual cues in the environment. A degree of context sensitivity is also built into this framework such that the order in which tasks are executed is dependent on the internal representation of the problem at a given point in time.

Using the iGen™ architecture, the NSFSA decision support tool has the capability to provide two types of feedback regarding gun casualties. First, it provides operators with the logic and procedures that were used by the decision support tool to arrive at a particular recommendation (logic trace feedback). The feedback provided to the operator can be stated in terms of the trace of logic that the NSFSA traversed to reach particular courses of action. Second, it can provide context specific feedback that elaborates on the impact of selecting a course of action in response to a particular gun problem on the mission in a reference scenario (mission impact feedback). This form of feedback can be said to map to the operators' goals in the context of the current state of the mission. .

The capability of the NSFSA to furnish operators with either of these two types of feedback allows for the investigation of three aspects of the normative models described above. First, it allows for the investigation of whether providing logic trace feedback supports better diagnoses in fault management. Second, it provides the opportunity to investigate whether mission impact feedback supports the formulation of better prognoses. Finally, it allows for the study of whether providing both forms of feedback supports better interpretation and evaluation of the situation, which results in better compensation activities. Thus, the proposed study will compare fault management performance for three methods of decision support feedback (logic trace, mission impact, both) to determine how they affect knowledge-based processing activities. The following sections will describe the predictions and approach that will be used to investigate these issues.

## HYPOTHESES

### Hypothesis I

It was expected that operators receiving either logic trace feedback, mission impact, or both types of feedback would perform better on fault management tasks than operators receiving only recommended courses of action. For this investigation, the predicted outcome was that operators receiving some additional feedback would make either a greater number of correct diagnoses on the effect of a gun casualty on the system or a greater number of correct prognoses on the impact of a gun casualty on the completion of a pre-planned Naval Surface Fire Support mission scenario in their gun casualty reports. Further, it was predicted that operators receiving no additional feedback would be significantly more likely to choose the ‘recommended’ course of action for each gun casualty than operators receiving no additional feedback. Finally, operators receiving feedback were predicted to have higher scores on the post-scenario fault management questionnaire.

### Hypothesis II

It was expected that operators receiving logic trace feedback would be better at fault diagnosis than operators receiving mission impact feedback only. For the purposes

of this investigation, it was predicted that individuals in the logic trace feedback only condition would make a significantly greater number of correct diagnoses in gun casualty reports during performance on a Naval Surface Fire Support Mission than individuals receiving mission impact feedback only. Further, it was expected that the participants in the logic trace only condition would have significantly more correct answers on the diagnostic portion of a post-scenario questionnaire.

### Hypothesis III

It was expected that operators receiving mission impact feedback would provide better prognoses of the faults on the mission than operators receiving only logic trace feedback. It was predicted that participants in this group will make a significantly higher number of correct reports on the impact of a gun casualty on the completion of a pre-planned Naval Surface Fire Support mission scenario than individuals receiving logic trace feedback only. Moreover, it was predicted that “mission impact only” participants would score more correct answers on the prognostic portion of a post-scenario questionnaire.

### Hypothesis IV

It was expected that operators receiving both logic trace feedback and mission impact feedback would be able to better compensate for system faults than operators

receiving either mission impact feedback alone or logic trace feedback alone. In the context of the current investigation, it was predicted that participants receiving both forms of feedback would make significantly more correct responses to gun casualties in the Naval Surface Fire Support scenario in significantly less time than participants receiving only one form of feedback. Finally, it was predicted that the participant receiving both forms of feedback would score higher on the compensation section of a post-scenario questionnaire.

## METHOD

### Participants

Sixty participants were recruited from introductory psychology classes at the University of Central Florida and chose to either be paid for their participation in this investigation or received course credit. Participants ranged in age from 17 to 31 years (median age=21 years) and were evenly split between males (n=30) and females (n=30). Participants were randomly assigned to one of four feedback conditions (no feedback, mission impact feedback, logic trace feedback, or both). While a more detailed analysis of the demographic data will be provided in the results section, it should be mentioned here that there were no significant differences between groups in age, class standing, computer or video game experience. There were no restrictions on who was able to participate in this investigation. An a priori rule was put into place that in the unlikely event that any participants had a background in naval gunfire support, the data collected from these participants would not be used in comparisons. However, no participants had prior experience in the domain. Finally, all participants were treated in accordance with ethical guidelines set forth by the “Ethical Principles of Psychologists and Code of Conduct” (American Psychological Association, 1992). Consequently, participants will read and sign informed consent (Appendix A) and Privacy Act statements (Appendix B).

## Materials

### *Naval Surface Fire Support Assistant (NSFSA)*

Two computer programs were utilized in this investigation. First was the Naval Surface Fire Support Assistant (NSFSA) which was initially developed by CHI Systems under the Office of Naval Research Manning Affordability Initiative to demonstrate the use of a cognitive modeling technique (iGen™) in the design of automation and decision support for future naval systems. The NSFSA is run on a standard personal computer and provides users with notifications of gun problems (e.g., hydraulic seals leaking, ammo low, etc.) and suggests a prioritized list of potential courses of action (cancel target, reallocate target to another gun mount, etc.). As mentioned previously, the NSFSA can provide feedback in two ways. First, the NSFSA software has been modified so that it can provide feedback containing the logic that the model used to arrive at the prioritized courses of action (logic trace). Second, it can provide explanation to the user of the impact of potential courses of action on the mission based on the mission schedule and target priority (mission impact). . For example, the explanation of a proposal to reallocate a target to another gun mount because a hydraulic seal is leaking might be explained to the user as “Reduces disruption to the original target schedule”. In contrast, for the “logic trace” conditions, feedback takes the form of yes/no reports of the logical nodes that the NSFSA traversed in arriving at its recommendations. Thus, feedback to operators for reallocating a gun mount based on a hydraulic seal leaking took the following form:

*Pending target assigned to this mount? Y*

*Can pending target be cancelled? N*

*Conflicting target? Y*

*Is target time sensitive? N*

The NSFSA has the capability to provide logic trace feedback, mission impact feedback, or both forms of feedback to the operator when a gun casualty occurs. As an experimental testbed the NSFSA collects time-stamped data on each screen element that the user clicks on during scenario runs and provides a spreadsheet of user actions for analysis of latency and accuracy.

### *Jane's Fleet Command*

The second software package, Jane's Fleet Command ® (JFC), a commercially available war game developed by Sonalysts Corporation, was run concurrently with NSFSA during the experiment. This software provided the actual Naval Gunfire Support Scenario on a standard personal computer. In essence, this is the 'knowledge of the external world' for the participants and dynamically displays the tactical situation with a view of the targets, surface ships and aircraft within the scenario using Naval Tactical Data Symbolology (NTDS). Participants had limited control of the JFC software during the scenario run. Control was limited to being able to zoom in and out and pan the display for better visibility of events within the scenario. This was accomplished through



commands to the keyboard. Participants had no control over the movements of displayed elements on the screen so that the scenario unfolded in the same way for each participant. Jane's Fleet Command and the NSFSA were run synchronously, providing the appearance that they were networked software.

### *Experimental Scenario*

Two subject matter experts, working at the Navair Orlando Training Systems Division developed an approximately one-hour land attack warfare scenario. This scenario simulates some of the tasks that may be required of a gun commander assistant onboard a future naval vessel providing surface gunfire support in a land attack mission. Participants were responsible for the firing of 2 gun mounts (MT51 and MT52) aboard own-ship on 30 ground targets. Appendix C contains a list of these targets and their attributes. Targets were classified in terms of their type (e.g., armor, command post, etc.), the category of target (e.g., accuracy sensitive, start time sensitive, etc.), and priority on a 10-point scale (1=low, 10=high). Each of these targets was to be fired upon at a pre-planned time with a given number of rounds. The participants could alter this firing schedule based on the priority and category of target and the current gun problem.

Within the scenario, participants were confronted with 5 major types of gun problems. Transducer damage negatively impacts the ability of the gun mount to fire accurately on targets. Two problems are associated with the hydraulic seal on the gun mount. A hot hydraulic seal does not in and of itself represent a problem unless accompanied by hydraulic seal leaking. In this case, the gun mount may be damaged and

not have the ability to service future targets. Recoil damage can also negatively impact the guns ability to service future targets. Finally, there may be low ammunition in the gun mount, which requires the participant to notify logistics and supply command for replenishment. So, for example, if the NSFSA has identified a problem with a particular gun mount, the participant may have to decide whether or not to cancel firing on a target, reallocate the target to the other gun mount, or fire until gun failure. This decision may be based upon target category, target priority and the context of the mission as displayed in Jane's Fleet Command ®. Contextual factors within the scenario, which affect decisions, include such things as whether or not troops or aircraft are in the area of the target.

In all, 28 gun problems were presented to participants during the scenario either alone or in combination with one another. For 16 of these gun problems, the correct course of action to take is that which is recommended by the NSFSA. However, for 12 of these problems, contextual factors within the scenario made selecting the recommended solution either wrong or sub-optimal. This was accomplished by inserting 10 key events into the scenario, which make system recommendations about whether to continue to fire on specific targets, to reallocate targets to another gun mount, to cancel targets, or to use different ammunition incorrect. For example, during the scenario, transducer damage occurs to a gun, which degrades its accuracy. The NSFSA recommends reallocating the target to the other gun because the target assigned is 'accuracy sensitive'. However, a 'Red Cross humanitarian effort' is also occurring in the vicinity of the target at the same time. Thus, while the recommended course of action by the decision support tool is to find a new way to fire on the target, the situational context

in the scenario makes the best course of action to cancel the target to minimize the risk of firing on humanitarian aid.

In some cases, these scenario events do not impact the correctness of the recommended course of action. One involves the appearance of a high-flying aircraft in the target area. During the training phase, participants are instructed that the ceiling for projectiles is 18,000 feet. The high-flying aircraft is actually above this ceiling and should not impact the mission. At this time, the NSFSA has made no recommendations to cancel the targets and the correct response to this event should be for the participant to report the high flyer to the TAO and accept the recommendation of the NSFSA to continue firing on targets.

### *Fault Management Questionnaire*

A 40-item fault management questionnaire was developed (see Appendix D), which was administered after participants completed the experimental scenario. This questionnaire was designed to assess participants' knowledge in four areas: general domain knowledge, diagnostic knowledge, prognostic knowledge, and compensatory knowledge.

### *General Domain Knowledge*

Ten questions within the questionnaire were designed to assess participant knowledge of the Naval Gunfire Support domain. In general, these questions focused on declarative knowledge to which the participants were exposed in early training. For example, this section contains questions about NTDS symbology, ammunition types, target types, and mission goals.

### *Diagnostic Knowledge*

Ten questions within the Fault Management Questionnaire focused on diagnosis of the impact of faults on physical components and entities within the land attack mission. Generally, these questions consisted of vignettes in which a fault is presented along with relevant contextual factors of a mission. Participants were then asked through multiple-choice questions to diagnose whether the fault represented a problem that needed to be evaluated. For example, the vignette provided a gun fault that causes rounds fired to be less accurate. The participant had to determine from the information presented whether it was particularly necessary to be accurate and whether it was possible to take specific courses of action recommended.

### *Prognostic Knowledge*

Ten questions in the questionnaire were designed to assess the ability of users to determine how particular gun problems would impact the mission. Like the diagnostic questions, these prognostic questions were in the form of brief vignettes followed by a series of multiple-choice questions. For example, a particular gun problem may damage the gun and make it unavailable to fire on future targets within the mission. However, it may be that the situation is such that damage to the gun is less important than firing on a specific target. The participant had to make a determination, based on the information provided as to whether or not taking the recommended course of action will presents a significant problem in terms of the goals for the mission and future targets.

### *Compensatory Knowledge*

Within the Naval Gunfire Support domain, there are often several actions that can be taken to achieve the same outcome. For example, if a gun problem degrades accuracy, the problem can be remedied by either reallocating a particular target to another gun mount or by using more accurate ammunition. Ten multiple choice questions within the Fault Management Questionnaire were designed to assess the knowledge of users to determine which compensatory actions may be appropriate for a given gun problem within the context of the mission.

### *Pre-performance Test*

Appendix E contains the pretest all participants took after training was completed. The 10-item pretest was developed to insure that the participants understand the important aspects of the Naval gunfire support mission. Specifically, the test addressed three areas. First, the pretest asks questions about each of the 5 potential gun problems that could be present during the scenario and what assumptions can be made about them. Second, questions address the nature of the ammunition that is available during the mission. The final questions deal with aspects of the mission itself and are designed to determine whether participants understood their role in terms of communication with the TAO and their responsibilities for firing on targets. Once the participants completed this pretest, the experimenter reviewed it and remediated the participants on any questions that they did not answer correctly.

### *Participant Reaction Questionnaire*

The Participant Reaction Questionnaire in Appendix F was designed to be administered following performance on the experimental scenario. The purpose of this 10-item questionnaire is to obtain participant feedback on aspects of the decision support tool, the training, and the scenario. Further, questions will address how much confidence participants had in the recommendations of the NSFSA and how well participants believed they performed the experimental tasks.

## Design

The experiment followed a one-way, between-subjects design. The between-subjects factor was the feedback condition consisting of four levels (no feedback, logic trace feedback, mission impact feedback, or both).

### *No Feedback*

The no feedback condition served as a control for this investigation and data were collected to determine whether, in fact, providing feedback in addition to recommended courses of action significantly improved diagnostic, prognostic, and compensatory performance in a fault management task. In this condition, no feedback in addition to recommended courses of action was provided on the Naval Surface Fire Support Assistant decision support tool to the operators when gun casualties arise.

### *Logic Trace Feedback Condition*

In the logic trace feedback condition, the same potential courses of action were provided to the participants as were provided in the mission impact feedback conditions. However, the feedback about each recommended course of action differed in that it was in the form of the logic that the NSFSA used to determine the courses of action. For example, a “hydraulic seal hot” in the gun mount might have yielded a recommended course of action to reallocate the target to another gun mount. The feedback for this

recommended course of action in this condition took the form: Is there a next pending target? Y, Did this mount have problem hydraulic seal leaking? Y, Can problem target be reallocated to another gun mount? N, etc.

### *Mission Impact Feedback Condition*

In the mission impact feedback condition, the NSFSA provided feedback about the impact of the recommended courses of action on mission schedule so that participants could make their decision about which course of action to select. So, for example, a recommendation to fire until gun failure might include feedback that tells the operator that selecting this course of action would mean that this gun mount would not be available to service a future target in the scenario.

### *Combined Feedback Condition*

Participants in the combined feedback condition receive the same recommended courses of action for each gun casualty but the NSFSA displays both the mission impact feedback and the logic trace feedback described above.



## Procedure

Figure 4 depicts the experimental procedure for this investigation. Initially, experimental runs consisted of administration of informed consent, a privacy act statement and a demographic questionnaire.

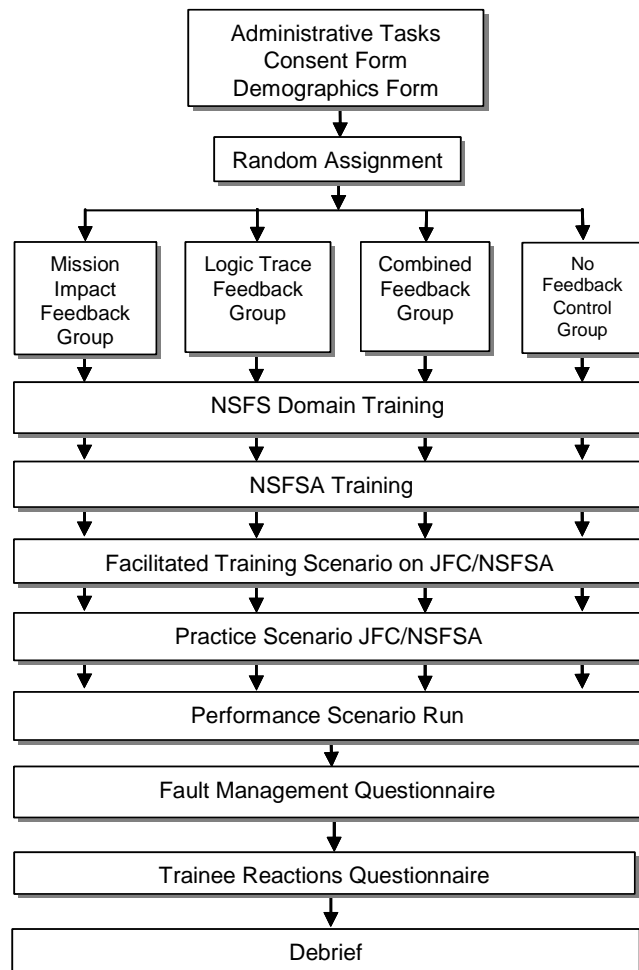


Figure 4: Experimental Procedure

Following random assignment to groups, all participants received the same training procedure with one exception. Displays of the NSFSA testbed software during the training presentations and practice scenarios were consistent with the feedback condition to which the participant has been assigned. In other words, Logic Trace participants were shown slides of the software with logic trace feedback shown, Mission Impact participants saw mission impact feedback, and participants assigned to the group receiving both feedback forms saw both in the training.

The training consisted of an initial familiarization with the NSFS domain and a familiarization with the software to be used. Next, participants had the opportunity to practice the task. Initially the experimenter facilitated this practice and then participants had the opportunity to perform tasks on a scenario without assistance. Participants then performed an experimental run followed by a knowledge test, and the administration of a trainee reaction questionnaire. Finally, participants were debriefed and thanked for their participation. The following sections will describe each part of this procedure in more detail.

### *Training*

#### *Domain Training*

Upon completion of informed consent and demographics forms, all participants began initial training on the Naval Gunfire Support domain utilized for the experiment.

This initial training consisted of two videotaped training modules and ‘hands on’ instruction with the JFC domain software. The first videotaped module consisted of approximately 10 minutes of instruction on the tasks of the Naval Gun Commander and the components of Naval Gunfire Support mission. During this training module, participants became familiar with the overall objectives of the mission, which included firing on tactical surface targets and reporting on contacts within the battle area. The primary responsibilities of the gun commander were to report gun problems to the Tactical Action Officer (TAO) and to recommend and execute courses of action based on the attributes of the mission such as the target schedule, and placement of friendly and hostile forces in the vicinity of targets. Following the initial training on the duties and responsibilities of gun commander, participants were trained via videotape to use the JFC software for the reference mission. This training included detailed descriptions of the display elements and the ‘button logy’ of the reference mission software. During this segment of training, participants became familiar with Naval Tactical Data Symbology (NTDS) and learned how to report attributes (e.g., altitude, bearing, and target type) of aircraft and surface ships displayed on Jane’s Fleet command with the aid of a template to the TAO. Further, participants were instructed on how to make recommendations (see Appendix D), to the TAO. During this phase of training, participants performed all of the tasks necessary to use the JFC software to zoom in and out, and to pan the screen.

### *NSFSA Training*

During the NSFSA phase of the training, participant were presented with a videotaped description of all of the elements of the tool. Participants were encouraged during this videotape session to ask questions of the experimenter. The videotape described the purpose of the tool and how to use it. Each screen element and actions for use at the mouse-click level were described in detail. During this tape, participants were instructed on each class of gun problem, target attributes and types of ammunition used in the scenario. During this time, participants were also provided with templates (see Appendix I) for the gun problem reports that they would make and given instruction on how and when to make these reports. All button actions that were required during performance on the scenarios were described. As mentioned previously, on slides that depict the NSFSA, the feedback that was shown was consistent with the condition to which the participant has been assigned.

### *Facilitated Practice*

After training on the domain and the software needed to perform the experimental task, participants were given the opportunity to perform a practice scenario with the aid of the experimenter. During this 15-minute scenario, participants used templates to make reports on events occurring on the JFC display and gun problems displayed on the NSFSA. The experimenter pointed out relevant aspects of the scenario when appropriate and answered any questions that the participant may have had during this time.

### *Individual Practice*

Following the facilitated practice, the participant performed the practice scenario solo. Again, the feedback provided by the NSFSA was consistent with the condition to which the participant was assigned. During this phase of the training, the participants were still encouraged to ask questions of the experimenter, but the experimenter did not actively point out relevant aspects of the mission or guide the process. The experimenter did, however, provide feedback to the participant following performance on the individual practice scenario. As a final performance check, the participant was asked to complete the Pre-performance Questionnaire at the end of this phase of training. The experimenter checked this 10-item questionnaire and provided any remedial information to the participant that was indicated by the responses.

### *Performance*

After participants completed the training, they performed the experimental scenario described above. During this phase of the experiment, participants used both software tools and made tactical reports and gun casualty reports to the experimenter, who acted as the Tactical Action Officer (TAO). The experimenter provided no information to the participant during the experiment except to acknowledge receipt of the report by responding, “TAO, Aye.” As the participant was performing the scenario, the experimenter was collecting dependent measures on a coding sheet, shown in Appendix

J. This coding sheet listed each of the thirty gun casualties that occurred during the scenario, the correct response, and the correct rationale for the response as determined by the subject matter expert designers. The experimenter coded whether or not the correct action was taken, and whether the rationale for the action was consistent with the rationale provided.

After performance on the scenario, participants were asked to complete the Fault Management Questionnaire (Appendix D) and the Trainee Reaction Questionnaire (Appendix F). Upon completion of both questionnaires, participants were debriefed, thanked for participating and excused.

### Dependent Measures

#### *Diagnoses*

Two main dependent measures were used to test the hypothesis that participants receiving logic trace only feedback would provide better diagnoses than participants receiving mission impact feedback. First, diagnoses obtained from gun casualty reports were assessed against an expert solution of the mission provided by the subject matter experts who designed the scenario. Part of the gun casualty report that users made was to describe why performing particular courses of action represented problems in terms of other components of the mission. For example, for a report of transducer damage to a mount, the report template required that the user report. “TAO, GUNS, I have TRANSDUCER DAMAGE to MT51. This (IS)/IS NOT a problem for us now because

IT DEGRADES THE ACCURACY OF PROJECTILES. I recommend

REALLOCATING TARGET 7 to MT52 because TARGET 7 is ACCURACY

SENSITIVE". The diagnosis that the "transducer damage degrades the accuracy of the

mount" would be considered a correct diagnosis of the problem and counted as such.

Thus, responses on the portion of the gun casualty report template that corresponds to the

information in the logic trace feedback was evaluated against the expert solution. As

such, the first dependent measure for diagnosis was the number of correct/incorrect

diagnoses made over the course of the mission.

The second dependent measure to test the diagnosis hypotheses was the number of correct responses to the diagnostic questions on the Fault Management Questionnaire.

### *Prognoses*

The second hypothesis for this investigation was that users receiving mission impact feedback would make better prognoses of the impact of the performing specific courses of action on the maintaining the mission plan. The dependent measures for prognoses were collected online via the gun casualty reports. The portion of the report that corresponds to mission impact, that a particular target was accuracy sensitive and therefore cannot be fired upon from that mount was evaluated against the expert solution for correctness and the frequency of correct/incorrect actions was used as a dependent measure. Second, scores on the prognosis questions of the Fault Management Questionnaire was used as a dependent measure.

### *Compensation*

The third hypothesis tested addressed whether users receiving both logic trace and mission impact feedback performed better compensatory actions than users who received one form of feedback alone. This hypothesis was primarily evaluated by the number of courses of action taken correctly/incorrectly and scores on the compensation section of the Fault Management Questionnaire. Further, the latency of performing correct actions was collected from the output files of the NSFSA to determine whether receiving both forms of feedback results in the ability to take the appropriate action more quickly. While participants will be required to read roughly twice as much feedback in the 'both' condition, the statements are relatively short. The time to read the additional feedback should be negligible and the advantages of having both forms of feedback readily available should result in faster decision times

### Analysis

The analyses of each of these measures were accomplished by performing one-way between-subjects a priori analyses of variance across the three conditions (logic trace, mission impact, both). These tests determined whether any observed differences between groups represented statistically significant main effects vice random differences that may be attributed to chance.

The major hypotheses stated that logic trace feedback would support better diagnostic decision making, mission impact feedback would support better prognoses,



and providing both would result in better compensation for gun problems. It was further predicted that providing some form of feedback would result in better performance than providing no feedback in addition to recommended courses of action. One way analyses of variance across the dependent measures described in the preceding sections will statistically determine whether these directional hypotheses are supported.

In addition to the analyses described above, analyses of variance were performed on the demographic data to determine whether randomly assigned groups were equivalent on variables such as age and computer experience. Similarly, responses to trainee reactions was analyzed using statistical tests appropriate to the data for investigation of how feedback condition may have impacted participant reactions to the testing.

## RESULTS

### Random Assignment

An analysis of the demographic data collected from questionnaires demonstrated no significant differences between the experimental conditions in gender, age, class standing, computer experience, or videogame experience. Table 1 provides detail of the participant demographics for median age, gender ratio, computer experience, and videogame experience.

Table 1: Participant Background Variables by Condition.

	Condition				p
	Combined Feedback	Mission Impact	Logic Trace	No Feedback	
Median Age (years)	21.5	20	22.0	21	> .05
Gender (M/F)	10/5	5/10	8/7	7/8	>.05
Computer Experience*	3.86	3.80	3.80	3.87	>.05
Videogame Experience**	2.79	3.20	2.60	2.67	>.05

\*1 to 4 scale. 1=What's a computer, 5=frequently use computers

\*\*1 to 5 scale: 1=Never play videogames, 5=play frequently.

Analysis of the class standing data also revealed no significant differences between the groups in the education levels of the participants. The majority of participants were junior level or above in class standing with 11 participants at the graduate level.

### Hypothesis I Results

It was expected that operators receiving either logic trace feedback, mission impact, or both types of feedback would perform better at fault management tasks than operators receiving only recommended courses of action. However, the results of a priori one-way analysis of variance did not support this hypothesis. This the accuracy data yielded no significant differences between the participants who did not receive additional feedback over and above a recommended course of action and those who did in the

average number of correct rationales for selecting a course of action. Table 3 shows the mean number of correct responses to gun problems for each of the conditions. While there were no statistically significant differences between groups in the mean numbers of correct actions, participants with no feedback were correct less of the time in the diagnostic reasoning that they provided for why they had chosen a particular course of action to take. Across the scenario, participants receiving some form of feedback provided, on average, 14.13 correct diagnostic rationales. This was compared to participants receiving no feedback, who, on average, provided 11.9 correct rationales across the scenario  $t(27)=1.82$ ,  $p<.05$ . This effect did not hold true for prognostic reasoning as there were no significant differences between feedback conditions in the frequency of correct reasons given on the impact of the gun casualty and the selected course of action on the mission.

Table 2.

Frequency of Correct Responses to Gun Casualties by Condition

	Mean Number Correct	Std. Dev
Combined Feedback	19.1	3.84
Mission Impact	20.0	3.25
Logic Trace	20.2	2.37
No Feedback	20.5	2.57

## Hypothesis II Results

It was expected that operators receiving logic trace feedback would be better at fault diagnosis than operators receiving mission impact feedback only. For the purposes of this investigation, it was predicted that individuals in the logic trace feedback only condition would make a significantly greater number of correct diagnoses in gun casualty reports during performance on a Naval Surface Fire Support Mission than individuals receiving mission impact feedback only. This was assessed by the number of correct rationales given across the scenario for the selection of courses of action in reports to the role-player supervisor in the investigation. A between groups t-test of the number of correct rationales provided by the logic trace group and the mission impact group did not yield support for this hypothesis. While the mean number of correct rationales given was greater for the logic trace condition (mean=14.1, std. dev.=5.07) than the mean number for the mission impact group (mean = 13.6, std. dev. 6.81), this difference was not statistically significant. Further, it was expected that the participants in the logic trace only condition would have significantly more correct answers on the diagnostic portion of a post-scenario questionnaire.

Of the ten diagnosis questions on the post-scenario fault management questionnaire, participants in the logic trace condition scored a mean of 9.8 questions correct (std. dev=1.15), while those in the mission impact group responded to a mean of 9.47 items correctly (std. dev. = 0.99). The high correct response rates to these questions, for these two groups as well as the other groups indicates that participants were highly aware of the correct reasoning for the selection of a particular course of action.

### Hypothesis III Results

It was expected that operators receiving mission impact feedback would provide better prognoses of the faults on the mission than operators receiving only logic trace feedback. Operationally this meant that participants in this group would make a significantly higher number of correct reports on the impact of a gun casualty on the completion of a pre-planned Naval Surface Fire Support mission scenario than individuals receiving logic trace feedback only. However, the data did not support this hypothesis. While the a priori one-way analysis of variance did not show the two groups to have significantly different frequencies of correct report, mission impact participants on average were slightly less correct in their reports than logic trace participants, with means of 15.2 and 15.8 correct reports, respectively. The same analysis was performed on the number of correct answers to the 10 mission impact items on the post-scenario fault management questionnaire. Mission impact participants, on average, scored 5.87 correct on the mission impact questions, while logic trace participants scored 6.4 correct. However, these results were not statistically significant.

### Hypothesis IV Results

The final hypothesis in this investigation was that operators receiving both the logic trace feedback and the mission impact feedback would be able to better compensate

for system faults than operators receiving either mission impact feedback alone or logic trace feedback alone. In the context of the current investigation, it was predicted that participants receiving both forms of feedback will make significantly more correct responses to gun casualties in the Naval Surface Fire Support scenario in significantly less time than participant receiving only one form of feedback. In fact, on average, these participants made slightly fewer correct compensatory actions (19.07 correct) than participants in the mission impact (20 correct), logic trace (20.2 correct), or no feedback conditions (20.5 correct), although this difference was not statistically significant. Further, there were no significant differences in the amount of time that it took for participants receiving combined feedback (115 seconds, std. dev.=55) to respond to a gun casualty than it did for participants receiving one form of feedback (118 seconds, std. dev. =28.7).

During observations of the data collection the researcher noted that, on several of the gun casualties related to transducer damage, which reduces the accuracy of the gun that participants were reallocating the target to the other gun and then switching ammunition to ERGM. Switching to ERGM was an unnecessary extra step, which was advised against in the training since it was an additional expense with no benefit to the accuracy in these cases. Consequently, analyses were performed to determine whether one or several groups performed this error of commission more often than any other group. Interestingly, participants receiving both forms of feedback (logic trace and mission impact) made significantly fewer of these errors of commission than the other groups  $t(27)=1.963$ ,  $p=.05$ .

Finally, it was predicted that the participant receiving both forms of feedback would score higher on the compensation section of a post-scenario questionnaire. This hypothesis was not supported by a priori one-way analysis of variance conducted on the questionnaire data. There were no significant differences between the groups in the number of correct responses to the compensation questions on the fault management questionnaire.

### Trainee Reaction Questionnaire

Table 3 provides the means to the overall participant reactions to the task and the training provided during the experiment. The actual questionnaire that was used to assess these reactions is provided in Appendix F. The ratings were anchored with 1 being 'not at all' and 7 being either 'very' or 'somewhat' (satisfied, well, etc.) in response to the questions. Results of the analyses of these data indicate that overall participants appeared to have no strong reactions to the dimensions above, neither feeling that they performed particularly well or poorly, that the training was particularly satisfying, or that the decision support tool helped in performing the task. Further analysis of these data by condition revealed no significant differences between the groups in response to any of the individual questions. Thus, only the mean ratings of these questions are offered to demonstrate that no strong feelings were evoked of the participants by the training, the scenario, the Naval Surface Fire Support Assistant or the difficulty of the task.

Table 3. Mean Trainee Reaction Questionnaire Ratings.

Question	Combined	Mission Impact	Condition		Overall
			Logic Trace	No Feedback	
Performance	4.00	3.80	4.07	3.87	3.93
Satisfaction with Training	4.60	5.13	5.07	5.00	4.95
Understood Task	4.20	4.60	4.73	4.60	4.53
NSFSA Helpfulness	4.80	5.73	5.60	4.73	5.22
Confidence in NSFSA	4.80	5.00	5.07	4.73	4.90
Decision support by NSFSA	5.53	5.53	5.60	5.07	5.43
Feedback supporting performance	5.20	5.47	5.53	5.00	5.30
Feedback supporting diagnosis	4.87	5.07	5.07	4.67	4.92
Feedback supporting mission impact understanding?	4.60	5.13	4.60	4.87	4.80
Feedback supporting COA	4.40	5.47	4.67	4.67	4.80
Feedback supporting accept/reject decision	5.00	5.13	5.13	5.20	5.12

This could be interpreted to mean that participants did not particularly feel negative about the experiment and were not particularly overworked or overstressed by the tasks that they performed.



## DISCUSSION

Several interpretations of the results of this investigation can be drawn from the lack of significant support for the hypotheses. First, it could be argued that the predictive capabilities of Rasmussen's (1986) fault management model do not generalize beyond the domains of process control into military fault management decision-making. An alternative interpretation is that the investigation was, in some manner, invalid and did not adequately test the hypotheses. The following sections will investigate these two possibilities to critically examine whether either possibility represents a plausible explanation of the results.

### Process Control and Military Decision Making Differences.

This investigation represents a first step toward the application of Rasmussen's (1986) fault management decision ladder to fault management in a complex military domain. While the origins of the model were heavily rooted in process control domains like the nuclear power and chemical process control plant operations, the validity of the model rests in its ability to predict fault management decision making across a range of domains. At first glance, the results of the current investigation could be interpreted as an indication that the Rasmussen (1986) fault management decision making model

focuses on traditional process control tasks and does not have application in complex military decision making tasks. In other words, the two domains are sufficiently different that the model does not apply. However, this view would be a very narrow interpretation of the capability of the model to predict fault management decision-making.

Fault management decision making within traditional process control domains are likely to share the same major decision making processes as those in complex military fault management decision making. Specifically, both domains share the processes of detection, diagnosis, prognosis, and compensation posited by Rogers et al. (1986). However, where the two domains differ most notably is in two of the factors, which influence how individuals evaluate and interpret faults during diagnosis and prognosis. These are the level of ambiguity in the data and the ultimate goal or target state. In general, well-defined and highly predictable physical processes govern process control tasks. The number and complexity of these predictable variables and the interaction between them drive ambiguity in process control (Moray, 1997; Woods and Hanes, 1986). The target state for this domain is often to reach some level of stability in often slow (long lag time) processes. Conversely, within military fault management decision-making, ambiguity is driven primarily by human behavior, of enemy, neutral, and friendly forces at a much faster pace. While the behavioral sciences continue to improve our capability to predict human performance and decision-making, the fact remains that our ability to make these predictions is not equivalent to predicting performance of physical processes.

The goal or target state is also less well defined in military fault management decision-making. A stable steady state is often neither possible nor desired. For

example, in several of the gun casualties in this investigation, the operator was given a choice between reallocating firing to another gun mount or firing until gun failure. Depending on the criticality of the target and the ultimate goals of the mission, firing until gun failure was the only reasonable option that could be taken. Thus, there are circumstances in military combat where it is reasonable and, in fact sometimes laudable, to allow a weapons system to be destroyed to meet the objectives of the mission or to save the lives of friendly combatants.

These two differences between process control and military fault management decision-making, differing degrees of ambiguity in the tasks and differing target or goal states, may explain the lack of support that the current investigation showed for the application of this model to the domain. Future investigations should focus on increasing the predictive validity of the model by refining the fault management model to account for these differences.

### Experimental Validity

A major goal of this investigation was to address the need for decision support tools to provide assistance to Navy warfighters in an increasing complex and uncertain domain perform their jobs effectively with fewer people. This real world problem required a premium to be placed on the external validity of this applied investigation. However, with this emphasis, come potential threats to other areas of experimental validity, which must be considered when undertaking an investigation of this type. Perhaps the most comprehensive review of these threats to validity, countermeasures

against them and the interactions between types of validity can be found in Cook and Campbell (1986). As these authors point out, applied research often has a different set of priorities than highly controlled laboratory research. As a result, tradeoffs often must be made to support generalization to a specific targeted setting or a particular group of interest. One could interpret the lack of statistical support for the hypotheses in this investigation to be the result of trading off or not considering some aspect of experimental validity to meet the objectives of high external validity. Given the lack of statistical support for the hypotheses in the current investigation, it was necessary to examine these validity issues to insure that they were not a factor in the results.

One possible threat to validity was considered to be “statistical conclusion validity,” which is concerned with the degree to which the investigation is sensitive enough to permit reasonable statements about covariation, cause and effect, and the strength of covariation. The authors cite several major threats to statistical conclusion validity that must be considered. Arguably the most common experimental errors made with respect to these threats are having low statistical power, violating the assumptions of the statistical tests, and error rate problems. However, a power analysis was conducted prior to this investigation indicating an 83% chance of detecting a medium effect size (0.65) given the levels of variability demonstrated in similar studies and a with a planned sample size of 60 participants. The largest effect size demonstrated in the current investigation (0.36) indicated slightly fewer correct responses (0.36) in the ‘combined feedback’ conditions than in the no feedback condition (19.1 versus 20.5). The result of a post-hoc power analysis of these data indicates that running approximately 3 times as

many participants would not significantly support the hypothesis that participants receiving combined feedback would provide more correct responses.

A second potential threat to statistical conclusion validity cited by Cook et al. (1986) relates to violation of the assumptions to statistical tests. The current investigation relied on analyses of variance using mean scores. Tests for normality and homogeneity of variance conducted in the data analysis revealed no violations to these assumptions. Moreover, the experimental design was such that observations were independent of one another. These factors lend confidence that the investigation was valid with respect to its statistical conclusions. Further, analysis of variance is a rather robust statistical test and would very likely have been able to account for any minor variations. Finally, careful attention was paid to insuring that there were no differences between participants on relevant demographics and, other than the experimental manipulations, in the way that each participant was run during data collection.

Construct validity is concerned with confounding variables and that variables have the potential to be construed in terms of more than one construct. Given the complexity of the task and constructs there was some danger that threats to construct validity may have manifest themselves in this investigation. However, Cook et al. (1986) recommend several countermeasures against threats to validity, which include thinking through the definitions of the constructs, differentiating between constructs, deciding which measures can be used to index these constructs, and developing multiple measures of the constructs, where possible. Much of the initial focus of the current investigation was on operationally defining the constructs of detection, diagnosis, prognosis, and compensation, determining their boundaries, and developing measures to index each of

these constructs. However, while there was careful planning, like most constructs in the behavioral sciences, there was still some room for subjective interpretation on the part of the investigator. Whether this interpretation was accurate, the boundaries were well defined, and the measures were adequate indices of the constructs always has some room for debate. Future research should focus on further refining the definitions, constructs, and measures involved in military fault management tasks.

The final area of potential threat to the validity of the investigation was internal validity, which is concerned with whether or not two or more variables are causally related. There are a number of threats, which fall under this category, many of which can be minimized through randomization and control procedures to insure that there are no systematic differences between participants and conditions across the investigation. It is unlikely that the current investigation fell prey to major threats to internal validity for several reasons. First, randomization was utilized and no major difference between relevant participant attributes was identified. Second, the investigation took place over a short period of time and within a laboratory setting, which did not change over the course of the data collection. Third, much of the training consisted of ‘canned’ presentations and the interaction between the participants and investigators was carefully scripted during the data collection. Further, even the format of participant responses was formatted according to report templates. These control mechanisms left little room for participants to have systematically different experiences across groups.

Clearly, no study exists without potential threats to validity. The current study is no exception. However, the preceding examination of these potential threats yielded no major areas of concern. Multiple steps were taken to insure that, while there was an

emphasis on the external validity of the study, statistical conclusion, construct, and internal validity were all considered to be critical factors as well. This lends credence to the interpretation that the lack of statistical support for the hypotheses in this investigation was not due to issues of experimental validity. Rather, the more likely culprit lies in the differences between process control and military fault management decision-making tasks in terms of ambiguity and target goal states. Future investigations should focus on refining of the Rasmussen (1986) model within the domain of military fault management decision support, as well as other domains, through a better understanding of how these two factors, ambiguity and goal states, may impact the predictions of the models.

The following section will describe several interesting findings from the current investigation that may be utilized as ‘lessons learned’ for future research in this area.

### Future Research Considerations

As discussed in the previous sections, none of the major hypotheses of this investigation were directly supported by statistical analysis of the dependent measures determined a priori. However, while not specifically hypothesized, two interesting results did arise in the data analyses. First, participants receiving any feedback at all were able to provide significantly more correct rationales for why a particular gun fault represented a problem to the successful to the gun mount. This result may suggest that additional information provided over and above an identification of the problem may assist operators in at the least understanding whether that problem is in reality a problem or

whether it is just noise. Further research in this area should consider focusing on the cues that operators use to develop a correct diagnostic rationale and how those can be instantiated in feedback from a decision support tool.

A second interesting finding from this study was that operators who received both logic trace and mission impact feedback made fewer errors of commission than those receiving only logic trace, only mission impact, or no feedback at all. It is likely that both forms of feedback taken together provided the participants with a better understanding of the specific type of task that the transducer damage problem represented. Of all of the gun casualties in this investigation, transducer damage was perhaps the most complex to resolve because there were multiple options the operators could take. Further, failure to respond correctly had very clear consequences. Operators could continue firing with decreased accuracy only at the peril of troops or friendly forces in the area. Finally, this particular gun casualty had very clear consequences in terms of cost. In the training, it was stressed that ERGM was an expensive solution to decreased accuracy and should only be used as a last resort. Since many of the errors of commission directly related to this particular gun casualty, future study should be directed toward gaining a better understanding how the variables of task complexity, perceived complexity, and decision support feedback may interact to produce errors of commission.

In addition to the factors examined in the previous section, several other factors may have contributed to the lack of statistical support for the four primary hypotheses offered in this investigation. First, while much effort was devoted to developing a rich scenario for hypothesis testing, the tasks of the participants themselves were not as robust



as might be imagined from the complexity of the scenario described previously. For most gun casualties, there were only a limited number of actions that were appropriate for the operator to take. The training that was provided to the participants covered each of the types of gun casualties, their causes, potential impacts on the mission, and the correct responses in great detail. Consequently, by the time participants were seated before the final scenario, they were very well trained in all aspects of the experimental task, where to obtain information, and how to report it. The relatively high scores across groups may be more testimony to the training the participants received and perhaps less related to the feedback that the Naval Surface Fire Support Assistant provided.

Second, as is the case in most investigations that seek to simulate some form of complex military decision-making task, there were a number of motivational factors that were missing from this investigation. In the Naval gunfire support domain, there are very real consequences to making mistakes. Actual gun casualties have consequences that cannot be adequately simulated in a laboratory environment. These include not just the potential loss of life but damage to one's career and reputation as well. Consequently, the participants in this investigation were highly likely to have had much less concern over the consequences of an erroneous action than would be seen in the actual domain. This interpretation is partially supported by the trainee reaction questionnaire, which showed few strong feelings about the elements of the investigation. If participants had felt high workload, uncertainty, or confusion, it would be expected that they would have provided data on the trainee reaction questionnaire to support their feelings. While this fact does not completely explain the lack of support for the hypotheses, it is one factor that probably contributed to participant performance. If possible, future studies of this type

should recruit from actual gun commanders in the fleet, who would have a better idea of the risks and would have more extensive training in the subtleties and complexities of the task as well. This would also allow for the development of a more realistic and robust scenario to challenge highly trained participants in a more externally valid environment.

## CONCLUSIONS

This study was performed to investigate the potential of tailoring decision support feedback to support the diagnostic, prognostic, and compensatory stages of fault management. While the strategies for feedback chosen appeared to have little effect on the prescribed outcome variables in this investigation, it is possible that Rasmussen's (1986) model, which was based in process control research may be in need of refinement to be of utility in a military fault management domain, in which variables and target outcomes are often more ambiguous. In addition, the results of this investigation suggest that several other factors may have been likely to account for some of the impact of decision support feedback in fault management. The results of this investigation do provide some clues to which of those factors may relate to the effectiveness of decision support feedback. Task complexity, motivational factors, consequences of failure, training, and the format of feedback clearly have some impact on decision-making and error in these situations. All of these factors have been cited as potential causal factors in poor performance on real-world fault management situations. The current study represents an initial investigation into using a fault management decision-making model to guide the development of decision support feedback in this domain. Future studies will seek to further understand the interaction of the above factors in fault management.

## APPENDIX A: INFORMED VOLUNTARY CONSENT TO PARTICIPATE

## INFORMED VOLUNTARY CONSENT TO PARTICIPATE

1. I am being asked to voluntarily participate in a research study titled, AN INVESTIGATION INTO PROVIDING FEEDBACK TO USERS OF DECISION SUPPORT SYSTEMS FOR FAULT MANAGEMENT. I will be asked to perform training on the use of the Naval Surface Fire Support Assistant, a computerized decision support tool for Naval Gun Commanders. This training will consist of watching several videotapes and slide shows as well as performing several practice scenarios with experimenter assistance on standard computers. Upon the completion of this training, I will be asked to perform a war game scenario in which I will make decisions about the mission with the aid of this tool. My duties during this scenario will be to solve gun problems and report events to an experimenter.

2. I understand that the investigators believe that the risks or discomforts to me are as follows:

There are no foreseeable risks to participating in this study over those that might be expected in the training of any computer software and playing a typical computer game.

3. The benefits that I may expect from my participation in this study are minimal. I understand that I will receive monetary compensation and/or course extra credit for my participation as well as the knowledge that participation in this study will aid efforts to improve the performance, safety, and/or the effectiveness of US Navy. I may have a copy of any publications resulting from the current study if I so desire.

4. My confidentiality during the study will be ensured by assigning me a coded identification number. My name will not be directly associated with any data. The confidentiality of the information related to my participation in this research will be ensured by maintaining records only coded by identification numbers. Video and photographic images of me will not be published or displayed without my specific written permission.

5. If I have questions about this study I should contact the following individuals:

James Pharmer, (Principle Investigator)

Code 4961

Naval Air Warfare Center Training Systems Division (NAWCTSD)

12350 Research Parkway,

Orlando, FL 32826-3275

(407)380-4771

[PharmerJA@navair.navy.mil](mailto:PharmerJA@navair.navy.mil)

Trish Hamburger, (Project Manager)

Naval Surface Warfare Center Dahlgren Division

17320 Dahlgren Road

Dahlgren , VA 22448-5100

(540)653-1119

[phambur@nswc.navy.mil](mailto:phambur@nswc.navy.mil)

Dr. Jerry Laabs(Acting Chair, Committee on the Protection of Human Subjects)

Code 4.9T

Naval Air Warfare Center Training Systems Division (NAWCTSD)

12350 Research Parkway,

Orlando, FL 32826-3275

(407) 380-4282

[LaabsGJ@navair.navy.mil](mailto:LaabsGJ@navair.navy.mil)

6. My participation in this study is completely voluntary.

7. My participation in this study may be stopped by the investigator at any time without my consent if it is believed the decision is in my best interest. There will be no penalty or loss of benefits to which I am otherwise entitled at the time my participation is stopped.

8. No out of pocket costs to me may result from my voluntary participation in this study.

9. If I decide to withdraw from further participation in this study, there will be no penalties. To ensure my safe and orderly withdrawal from the study, I will inform the Principal Investigator, James A. Pharmer.

10. Official government agencies may have a need to inspect the research records from this study, including mine, in order to fulfill their responsibilities.

11. I have received a statement informing me about the provisions of the Privacy Act (attached).

12. I have been informed that the CPHS Coordinator is responsible for storage of research records related to my participation in this study. My consent form will be stored under lock and key in compliance with NAWCTSD Policies and Procedures for the Protection of Human Subjects.

13. I have been given an opportunity to ask questions about this study and its related procedures and risks, as well as any of the other information contained in this consent form. All my questions have been answered to my satisfaction. I understand what has been explained in this consent form about my participation in this study. I do not need any further information to make a decision whether or not to volunteer as a participant in this study. By my signature below, I give my voluntary informed consent to participate in the research as it has been explained to me, and I acknowledge receipt of a copy of this form for my own personal records.

Volunteer:

Name (Please Print): \_\_\_\_\_

Signature: \_\_\_\_\_

SSN: \_\_\_\_\_

Date: \_\_\_\_\_

Investigator:

Name: \_\_\_\_\_

Signature: \_\_\_\_\_

Date: \_\_\_\_\_



## APPENDIX B: PRIVACY ACT STATEMENT

## PRIVACY ACT STATEMENT

1. Authority. 5 U.S.C. 301
2. Purpose. Performance speed and accuracy information will be collected in an experimental research project titled, "AN INVESTIGATION INTO PROVIDING FEEDBACK TO USERS OF DECISION SUPPORT SYSTEMS FOR FAULT MANAGEMENT" to investigate the effectiveness of different feedback training techniques on performance.
3. Routine Uses. The data collected will be used for analyses and reports by the Departments of the Navy and Defense, other U.S. Government agencies, and authorized government contractors. Additional use of the information may be granted to non-Government agencies or individuals by the Navy Surgeon General following the provisions of the Freedom of Information Act or contracts and agreements. I voluntarily agree to its disclosure to the agencies or individuals identified above, and I have been informed that failure to agree to this disclosure may make the research less useful.
4. Voluntary Disclosure. Provision of information is voluntary. Failure to provide the requested information may result in failure to be accepted as a research volunteer in an experiment, or removal from the program.

Attached: Informed Voluntary Consent To Participate for this experiment, signed by the research volunteer.

## APPENDIX C: SCENARIO TARGETS AND ATTRIBUTES

## Targets and Attributes in Performance Scenario

Time sent	Target#	Target Type	Sensitivity	Round Type	# of Rounds	Priority
10	1	COMMAND_POST	#ROUNDS	HE	5	6
10	2	ARMOR	START TIME	HE	15	8
10	3	BRIDGE	AMMO TYPE	ERGM	5	9
25	4	AIRFIELD	START TIME	HE	5	9
25	5	GUNS	START TIME	HE	5	9
25	6	TROOPS	AMMO TYPE	HE	5	9
40	7	ARMOR	AMMO TYPE	HE	5	1
530	8	COMMAND_POST	START TIME	HE	10	9
530	9	COMMAND_POST	#ROUNDS	HE	5	9
530	10	GUNS	ACCURACY	HE	5	9
530	11	AIRFIELD	ACCURACY	HE	5	9
530	12	TROOPS	START TIME	HE	10	9
530	13	GUNS	START TIME	HE	5	9
1250	14	AIRFIELD	START TIME	HE	5	9
1250	15	COMMAND_POST	END TIME	HE	5	9
1500	16	TROOPS	ACCURACY	HE	5	9
1500	17	AIRFIELD	ACCURACY	HE	5	9
1900	18	GUNS	ACCURACY	HE	5	9
1900	19	TROOPS	ACCURACY	HE	10	9
2100	20	COMMAND_POST	#ROUNDS	HE	10	6
2100	21	BRIDGE	START TIME	HE	5	8
2350	22	ARMOR	START TIME	HE	5	9
2350	23	TROOPS	START TIME	HE	10	2
2550	24	GUNS	ACCURACY	HE	10	9
2550	25	AIRFIELD	#ROUNDS	HE	5	9
2850	26	GUNS	START TIME	HE	10	9
2850	27	AIRFIELD	START TIME	HE	5	9
3050	28	COMMAND_POST	ACCURACY	HE	10	9
3050	29	ARMOR	ACCURACY	HE	5	9

## APPENDIX D: FAULT MANAGEMENT QUESTIONNAIRE

1. What is the gun commander's mission?

- A. To support an air assault by destroying or neutralizing enemy defenses
- B. To support an amphibious assault by destroying or neutralizing enemy defenses
- C. To provide appropriate guidance and feedback to Naval officers
- D. To report friendly submarine contacts to Marine Amphibious Units.
- E. None of the above

2. What is the Combat Information Center (CIC)?

- A. A land-based information center that provides assistance to the gun commander
- B. A satellite network system that the gun commander is able to access when emergency information is required
- C. A space where the ships weapons and sensors are employed
- D. A Naval communications center, located in Norfolk, VA
- E. None of the above

3. Who will you (the gun commander) make reports to?

- A. The Tactical Action Officer (TAO)
- B. The Commander Amphibious Task Force (CATF)
- C. The Combat Information Center (CIC)
- D. The Air Spotter (AS)
- E. None of the above

4. T or F Target scheduling occurs in the Combat Information Center (CIC)?

5. The target position is expressed in:

- A. Kilometers
- B. Meters
- C. Miles
- D. Grid Coordinates

E. None of the Above

6. Who assigns responsibilities and schedules the amphibious assault?

- A. The Tactical Action Officer (TAO)
- B. The Commander Amphibious Task Force (CATF)
- C. The Commanding Naval Officer (CNO)
- D. The Air Spotter (AS)
- E. None of the above

7. Which of the following does not describe a spotter?

- A. Gives CIC corrections to the aim point
- B. Provides feedback as to mission success
- C. Is able to see the target
- D. May provide information on movement of enemy forces
- E. None of the above

8. The battle space should be thought of as a 3-dimensional box with a ceiling of

- A. 24,000 feet
- B. 5,000 feet
- C. 16,000 feet
- D. 18,000 feet
- E. None of the above

9. The presence of friendly forces near a target will make that target

- A. Useless
- B. Very low priority
- C. Very high priority
- D. Accuracy sensitive
- E. None of the above

10. On Jane's Fleet Command, hostile contacts are displayed in the color

- A. Blue
- B. Yellow



- C. White
- D. Black
- E. None of the above

11. T or F Unknown contacts are displayed in the color blue.

12. A "speedleader" gives what?

- A. A quick indication of the course only of each contact
- B. A quick indication of the speed only of each contact
- C. A quick indication of the course and speed of each contact
- D. An elaborate explanation of the course only of each contact
- E. None of the above

13. In Jane's Fleet Command, targets are identified with the symbol

- A. 
- B. X
- C. 
- D. F
- E. None of the above

14. For the NSFSA and for Jane's Fleet Command, prehook information can be obtained by

- A. Right clicking on the contact
- B. Pressing the F4 key
- C. Pressing the Enter key
- D. Placing the mouse over the contact
- E. None of the above

15. The gun commander is able to see text for messages received by

- A. Right clicking on the contact
- B. Pressing the F4 key
- C. Pressing the Enter key
- D. Placing the mouse over the contact
- E. None of the above



16. T or F The NSFSA is able to incorporate information gained through Jane's Fleet Command when making recommendations about courses of action.

17. In NSFSA, a target that is displayed as partially red and partially green

- A. Has not yet been fired on
- B. Is in progress
- C. Is very high priority
- D. Has already been fired on
- E. None of the above

A target with a priority of 1

- A. Is very low priority
- B. Is neither high nor low priority
- C. Is very high priority
- D. Has already been fired on
- E. None of the above

When firing, the gun commander should use \_\_\_\_\_ rounds only when there is no alternative.

- A. High Explosive (HE)
- B. Smoke
- C. Extended Range Guided Munitions (ERGM)
- D. Illumination
- E. None of the above

T or F Transducers are sensors in the gun mount that help improve firing accuracy.

In which order are courses of action (COAs) presented?

- A. Alphabetical order
- B. Least appropriate first
- C. Most appropriate first
- D. Chronological order
- E. None of the above

What does a green check mark next to a COA mean?

- A. That COA is high priority
- B. That COA is low priority
- C. That COA is not recommended at this time
- D. That COA has been chosen
- E. None of the above

Hydraulic Seal Hot is only a problem when

- A. The gun commander is using high explosive rounds
- B. There is a green check mark next to a COA
- C. The gun mount also has a hydraulic seal leaking
- D. The other gun mount is incapacitated
- E. None of the above

T or F The recoil suppressor's primary purpose is to ensure the accuracy of ERGM rounds.

What does it mean if a gun problem is presented, but no COA's are recommended?

- A. A gun problem exists, but there is not a target scheduled for this gun
- B. The NSFSA does not know how to prioritize the COA's
- C. A gun problem exists making it impossible for the gun commander to follow the appropriate COA
- D. A gun problem exists and the other gun mount is incapacitated
- E. None of the above

T or F You should not make a "Firing Complete Report" to the Tactical Action Officer (TAO) unless you have already decided on a recommendation. You are firing on a low priority, accuracy sensitive target with MT51. The NSFSA alerts you to the gun problem "Transducer damaged MT51." This is your only gun problem. MT52 is not currently firing on a target and is not scheduled to fire on a target for 5 minutes.

How does "transducer damaged" affect the gun?

- A. Causes the gun to get too hot
- B. Degrades the accuracy of the gun
- C. Slows the firing rate of the gun
- D. Renders the gun inoperable
- E. None of the above

How might this problem impact the mission?

- A. May cause a hydraulic seal leak
- B. May cause start time sensitive targets to begin being fired on too late
- C. May require changes in scheduling of or rounds used for accuracy sensitive firing
- D. May cause the hydraulic seal to get hot
- E. None of the above

In this situation, what would you do?

- A. Continue firing on the target, while being aware of other system conditions
- B. Cancel the target
- C. Switch to ERGM rounds
- D. Reallocate the target to MT52
- E. None of the above

You are firing on a high priority, time sensitive target with MT51. The NSFSA alerts you to the gun problem "Recoil Damaged MT51." This is your only gun problem. MT52 is currently firing on another high priority, time sensitive target.

How does "Recoil Damaged" affect the gun?

- A. Causes the gun to get too hot
- B. Degrades the accuracy of the gun
- C. Slows the firing rate of the gun
- D. Continued firing renders the gun inoperable
- E. None of the above

How might this problem impact the mission?

- A. The mission schedule will likely be altered
- B. This will likely have no effect on the mission
- C. I will likely run low on ERGM rounds

- D. I will likely run low on high explosive (HE) rounds
- E. None of the above

In this situation, what would you do?

- A. Continue to fire MT51
- B. Reallocate the target to MT52
- C. Cancel the target allocated to MT51
- D. Cancel the mission
- E. None of the above

You are firing on a low priority, time sensitive target (Target 4) with MT51. The NSFSA alerts you to the gun problem "Ammo Low MT51." This is your only gun problem. MT51 is scheduled to begin firing on a high priority, time sensitive target (Target 6) immediately following Target four's completion. MT52 is currently firing on a time sensitive, high priority target (Target 5) and has another time sensitive, high priority target (Target 7) scheduled immediately following completion.

How does "Ammo Low" affect the gun?

- A. Causes the gun to get too hot
- B. Degrades the accuracy of the gun
- C. Slows the firing rate of the gun
- D. Continued firing renders the gun inoperable
- E. None of the above

How might this impact the mission?

- A. May cause an inability to fire on accuracy sensitive targets
- B. May have to cancel some target(s) or fall behind schedule
- C. Will likely have to cancel mission
- D. Will likely have no impact on the mission
- E. None of the above

In this situation, what would you do?

- A. Reallocate Target 4 to MT52
- B. Continue firing on Target 4 as scheduled

- C. Reallocate MT51 to help with Target 5
- D. Cancel Target 4
- E. None of the above

You are firing on a high priority, accuracy and time sensitive target with MT52. The NSFSA alerts you to the gun problem "Transducer damaged MT52." This is your only gun problem. MT51 is also currently firing on a high priority, accuracy and time sensitive target.

How might this problem impact the mission?

- A. May cause a hydraulic seal leak
- B. May cause start time sensitive targets to begin being fired on too late
- C. May alter schedule or ammunition used for accuracy sensitive firing
- D. May cause the hydraulic seal to get hot
- E. None of the above

In this situation, what would you do?

- A. Continue firing on the target, while being aware of other system conditions
- B. Cancel the target
- C. Switch to ERGM rounds
- D. Reallocate the target to MT51
- E. None of the above

You are firing on a low priority time sensitive target with MT52 and on a high priority, accuracy sensitive target with MT51. The NSFSA alerts you to the gun problem, "Hydraulic Seal Hot MT52." This is your only gun problem. The next scheduled target for MT52 is in 2 min 30 sec. The next scheduled target for MT51 is in 4 min.

How does the problem, "Hydraulic Seal Hot," affect the gun?

- A. This degrades the accuracy of the gun
- B. This slows the rate of fire of the gun
- C. This makes a hydraulic seal leak more likely
- D. This renders the gun inoperable
- E. None of the above

How might this impact the mission?

- A. May prevent the time sensitive target allocated to MT52 from being completed
- B. May prevent the accuracy sensitive target allocated to MT51 from being completed
- C. No immediate impact, but will have to watch for a hydraulic seal leak
- D. May prevent firing of the next scheduled target for MT51
- E. None of the above

In this situation, what would you do?

- A. Continue to fire on the target with MT52
- B. Cancel the mission
- C. Cancel the target allocated to MT52
- D. Switch MT52 to ERGM rounds
- E. None of the above

You are firing on a low priority, time sensitive target with MT51. The next scheduled target for MT51 is high priority. The NSFSA alerts you to the gun problem, "Hydraulic Seal Leak MT51." There are no targets currently scheduled to MT52.

How does "Hydraulic Seal Leak" affect the gun?

- A. Causes the gun to get too hot
- B. Degrades the accuracy of the gun
- C. Slows the firing rate of the gun
- D. Causes the gun to require ERGM rounds
- E. None of the above

How might this impact the mission?

- A. The mission schedule will likely be altered
- B. This will likely have no effect on the mission
- C. I will likely run low on ERGM rounds
- D. I will likely run low on high explosive (HE) rounds
- E. None of the above

In this situation, what would you do?

- A. Continue to fire MT51
- B. Reallocate the target to MT52
- C. Cancel the target allocated to MT51
- D. Switch to ERGM rounds
- E. None of the above

You are firing on a low priority, time sensitive target (Target 9) with MT52. This is the last scheduled target for MT52. The NSFSA alerts you to the gun problem "Recoil Damaged MT52." This is your only gun problem. MT51 is currently firing on another high priority, time sensitive target.

How might this problem impact the mission?

- A. It may not be possible to complete Target 9
- B. This may interfere with other targets allocated to MT52
- C. MT52 may need to be reallocated to another target
- D. I will likely run low on ammo
- E. None of the above

In this situation, what would you do?

- A. Reallocate Target 9 to MT51
- B. Cancel Target 9
- C. Switch to ERGM rounds
- D. Continue firing on Target 9 as scheduled
- E. None of the above

You are firing on a high priority, time sensitive target (Target 5) with MT51 and on a high priority, time sensitive target (Target 6) for MT52. On Jane's Fleet Command, you see that friendly troops have just moved close to Target 6. The NSFSA alerts you to the following problems: "Ammo Low MT51," and "Transducer Damaged MT52." You have no other gun problems.

How might these problems affect the mission?

- A. It is likely that these problems will have no impact on the mission
- B. It is likely that a hydraulic seal will get hot
- C. It is likely that a hydraulic seal will get hot and leak
- D. It is likely that both guns will become inoperable

E. None of the above

In this situation, what would you do?

- A. Cancel Target 5 and switch to ERGM rounds for MT52
- B. Switch to ERGM rounds for MT52 and continue firing MT51 on Target 5
- C. Reallocate MT52 to Target 5 and cancel Target 6
- D. Reallocate MT51 to Target 6 and MT52 to Target 5
- None of the above

You are firing on a high priority target (Target 3) with MT52. This target is not time sensitive. The NSFSA alerts you to the following gun problems: "Hydraulic Seal Hot MT52," and "Hydraulic Seal Leak MT52." There are no other gun problems. MT51 is currently firing on a high priority, time sensitive target, but has no targets scheduled after its completion.

How might these problems affect the mission?

- A. It is likely that these problems will have no impact on the mission
- B. It is likely that it will not be possible to fire on an accuracy sensitive target
- C. It is likely that MT52 will run out of ERGM rounds
- D. It is likely that both guns will become inoperable
- E. None of the above

In this situation, what would you do?

- A. Reallocate Target 3 to MT51
- B. Continue firing on Target 3 with MT52
- C. Cancel Target 3
- D. Reallocate Target 3 to MT51 and Target 4 to MT52
- E. None of the above

---

18. T or F All gun problems should be reported to the TAO

19. T or F A hydraulic seal that gets hot very early in a mission is still not likely to impact the mission



20. T or F Transducer damage degrades the accuracy of a gun

T or F Recoil damage is not a serious gun problems

21. T or F A leaking hydraulic seal degrades the accuracy of the gun

22. T or F Unless it leads to other problems, a hot hydraulic seal has no affect on the gun

T or F As ammo becomes low, the maximum firing rate of the gun slows

## APPENDIX E: NSFSA KNOWLEDGE PRE-TEST

NSFSA PRETEST RUN # \_\_\_\_\_

THERE MAY BE MORE THAN ONE CORRECT ANSWER.

1. What can you assume with the gun problem Transducer Damaged?
  - A. The next scheduled target for this gun cannot be fired.
  - B. This gun is no longer accurate enough to shoot an accuracy sensitive target.
  - C. This gun can be fired unless it also has a hydraulic seal hot.
  - D. Continuing to fire this gun mount could cause serious gun damage.
  - E. None of the above.
  
2. What can you assume with the gun problem Hydraulic Seal Leaking?
  - A. The next scheduled target for this gun cannot be fired.
  - B. This gun is no longer accurate enough to shoot an accuracy sensitive target.
  - C. This gun can be fired unless it also has a recoil suppressor damaged.
  - D. Continuing to fire this gun mount could cause serious gun damage.
  - E. None of the above.
  
3. What can you assume with the gun problem Ammo Low?
  - A. The next scheduled target for this gun cannot be fired.
  - B. This gun is no longer accurate enough to shoot an accuracy sensitive target.
  - C. This gun can be fired unless it also has a hydraulic seal leaking.
  - D. Continuing to fire this gun mount could cause serious gun damage.
  - E. None of the above.
  
4. What can you assume with the gun problem Recoil Damage?
  - A. The next scheduled target for this gun cannot be fired.
  - B. This gun is no longer accurate enough to shoot an accuracy sensitive target.
  - C. This gun can be fired unless it also has a transducer damaged.
  - D. Continuing to fire this gun mount could cause serious gun damage.
  - E. None of the above.
  
5. What can you assume with the gun problem Hydraulic Seal Hot?
  - A. The next scheduled target for this gun cannot be fired.

- B. This gun is no longer accurate enough to shoot an accuracy sensitive target.
  - C. This gun can be fired unless it also has a hydraulic seal leaking.
  - D. Continuing to fire this gun mount could cause serious gun damage.
  - E. None of the above.
6. How high can we expect projectiles to go in today's gun shoot?
- A. 33,000'
  - B. 18,000'
  - C. 16,500'
  - D. 1,500'
  - E. 12,000'
7. What is the advantage of using High Explosive (HE) projectiles?
- A. They make a bigger bang than ERGM.
  - B. There are lots of them onboard.
  - C. They cost less than some other rounds.
  - D. They are easier to shoot.
  - E. None of the above.
8. What is the advantage of using Extended Range Guided Munitions (ERGM)?
- A. They make a bigger bang than HE rounds.
  - B. There are lots of them onboard.
  - C. They cost less than some other rounds.
  - D. They are easier to shoot.
  - E. None of the above.
9. What can you assume with friendly forces in the area of a scheduled target?
- A. The next scheduled target for this gun cannot be fired.
  - B. The gun shooting this target can not have a Transducer Damaged problem.
  - C. Friendly forces will not be so close to the target that they will be in danger.
  - D. Regardless of the target category selected, the target is also accuracy sensitive.
  - E. None of the above.
10. When should situation reports be made to the TAO?
- A. When you have a gun problem.
  - B. When contacts near the battle space first appear or become a threat to safety.

- C. When messages are received that may effect the gunfire mission.
- D. When firing on scheduled targets is complete.
- E. None of the above.

## APPENDIX F: PARTICIPANT REACTION QUESTIONNAIRE

Participant # \_\_\_\_\_ Condition \_\_\_\_\_

Training Questionnaire

Note: "Feedback" pertains to the information given by the NSFSA in support of the recommended course of action (COA).

1. How well do you feel you performed the task?

1	2	3	4	5	6	7
Not well at all						Extremely well

2. How satisfied were you with the training experience?

1	2	3	4	5	6	7
Not at all satisfied						Very satisfied

3. How well did you feel you understood what you were doing?

1	2	3	4	5	6	7
Not well at all						Extremely well

4. How much did the feedback provided by the NSFSA help you to perform the scenario?

1	2	3	4	5	6	7
Not at all						Very much

5. How confident are you in the ability of the NSFSA to recommend the most appropriate course of action (COA)?

1	2	3	4	5	6	7
Not at all confident						Very confident

6. How much did the feedback you were provided by NSFSA help you to make a decision on which course of action to choose?

1	2	3	4	5	6	7
Not at all						Very much

7. Overall, how much did the feedback provided by the NSFSA help you to perform the scenario?

1	2	3	4	5	6	7
Not at all						Very much

8. How well did the feedback help you to understand why each gun casualty was a problem?

1	2	3	4	5	6	7
Not at all						Extremely well

9. How well did the feedback help you to understand the impact of gun problems on the mission?

1	2	3	4	5	6	7
Not at all						Extremely well

10. How satisfied were you with the feedback given as to why each recommendation was made?

1	2	3	4	5	6	7
Not at all satisfied						Very satisfied

11. Did the feedback given by the NSFSA help you to determine whether to accept the recommendation?

Yes	No
-----	----



12. Overall, how easy was it to understand the feedback given by the NSFSA?

1	2	3	4	5	6	7
Very difficult						Very easy

## APPENDIX G: DEMOGRAPHIC QUESTIONNAIRE

Participant # \_\_\_\_\_

Demographic Questionnaire

Age \_\_\_\_\_ Gender \_\_\_\_\_

Describe your education:

Class:    Freshman    Sophomore Junior    Senior  
         Graduate

Major: \_\_\_\_\_

Highest Degree Held?

High School Diploma    Associates Degree  
Bachelors Degree

Are you currently or have you ever been enrolled in the  
military?

Yes                      No

If, yes:

Which branch? \_\_\_\_\_ Rank: \_\_\_\_\_

Years of service: \_\_\_\_\_ Dates: \_\_\_\_\_ to \_\_\_\_\_

Billet: \_\_\_\_\_

Please provide any other relevant military details below.

---

Computer Experience

Circle the statement that best applies to you

What's a computer?	Never use computers	Sometimes use computers	Frequently use computers
-----------------------	------------------------	----------------------------	-----------------------------

How often do you play video games?

Never      Rarely      Occasionally      Often      Very Often



Please circle the computer applications that you use

Video games  
Internet

E-mail

Word Processing

Spreadsheet

Programming Languages

## APPENDIX H: SURFACE AND AIR SITUATION REPORT TEMPLATE

TAO, GUNS

I HAVE A \_\_\_\_\_ (SURFACE OR AIR) \_\_\_\_\_ CONTACT

TO THE \_\_\_\_\_ (NORTH, SOUTH, SOUTHWEST, ETC.) \_\_\_\_\_

HEADED TOWARD THE \_\_\_\_\_ (NORTH, SOUTH, SOUTHWEST, ETC.) \_\_\_\_\_

SPEED \_\_\_\_\_ KNOTS

ALTITUDE \_\_\_\_\_ FEET

MY RECOMMENDATION IS TO \_\_\_\_\_ (MONITOR, ALTER COURSE, ETC.) \_\_\_\_\_

## APPENDIX I: GUN CASUALTY REPORT TEMPLATE





## APPENDIX J: CODING SHEET FOR NSFSA

Time	MT	Gun Casualty	Det	Diag	Prog	Comp
95	MT51	HYDRAULIC_SEAL_HOT				
97	MT52	TRANSDUCER_DAMAGED				
276	MT52	HYDRAULIC_SEAL_HOT				
306	MT51	AMMO_LOW				
515	MT52	RECOIL_DAMAGED				
517	MT51	RECOIL_DAMAGED				
756	MT51	HYDRAULIC_SEAL_LEAKING				
757	MT52	AMMO_LOW				
995	MT51	HYDRAULIC_SEAL_HOT				
997	MT52	HYDRAULIC_SEAL_HOT				
1235	MT51	TRANSDUCER_DAMAGED				
1236	MT52	AMMO_LOW				
1475	MT51	TRANSDUCER_DAMAGED				
1476	MT52	HYDRAULIC_SEAL_HOT				
1715	MT51	AMMO_LOW				
1716	MT52	TRANSDUCER_DAMAGED				
1955	MT51	TRANSDUCER_DAMAGED				
1956	MT52	HYDRAULIC_SEAL_HOT				
2195	MT51	TRANSDUCER_DAMAGED				
2196	MT52	HYDRAULIC_SEAL_LEAKING				
2437	MT51	RECOIL_DAMAGED				
2438	MT52	TRANSDUCER_DAMAGED				
2676	MT51	HYDRAULIC_SEAL_LEAKING				
2677	MT52	HYDRAULIC_SEAL_HOT				
2915	MT51	TRANSDUCER_DAMAGED				
2916	MT52	AMMO_LOW				
3155	MT51	TRANSDUCER_DAMAGED				
3157	MT52	TRANSDUCER_DAMAGED				

## REFERENCES

American Psychological Association (1992). Ethical principles of psychologists and code of conduct. American Psychologist, 47, 1597-1611.

Card, S., Moran, T., & Newell, A. (1983). The Psychology of Human Computer Interaction, Hillsdale, NJ: Lawrence Erlbaum.

Cook, T. D., & Campbell, D. T. (1979). Quasi-experimentation: Design and analysis issues for field settings. Boston: Houghton-Mifflin.

Edlund, C. & Lewis, M. (1994). Comparing ecologically constrained and conventional displays in control of a simple steam plant. Proceedings of the Human Factors and Ergonomics Society 38<sup>th</sup> Annual Meeting (pp.486-490). Santa Monica, CA: Human Factors and Ergonomics Society.

Edwards, W. (1987). Decision making: In G. Salvendy (Ed.). Handbook of Human Factors (pp. 1061-1104). New York: Wiley.

Endsley, M. R. (1996). Automation and situation awareness. In R. Parasuraman & M. Mouloua (Eds.) Automation and Human Performance: Theory and Applications. pp.163-181. Mahwah, NJ: Lawrence Erlbaum Associates.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors, 37(1). 32-64.

Kieras, D. E. & Bovair, S. (1984). The role of a mental model in learning to operate a device. Cognitive Science, 8-255-273.

Kieras, D. (1992). Diagrammatic displays for engineered systems: Effects on human performance in interacting with malfunctioning systems. International Journal of Man-Machine Studies, 36, 861-895.

Klein, G. A. Orasanu, J., Calderwood, R., & Zsombok, C.E. (Eds.)(1995). Decision Making in Action: Models and Methods. Norwood, NJ: Ablex.

Klein, G. A.. ( 1995). A recognition-primed decision (RPD) model of rapid decision making. In Klein, G. A., Orasanu, J., Calderwood, R., & Zsombok, C.E. (Eds.). Decision Making in Action: Models and Methods, pp. 138-147.. Norwood, NJ: Ablex.

Lee, J., & Moray, N. (1992). Trust, control strategies and allocation of function in human-machine systems. Ergonomics, 35, 1243-1270.

Moray, N. (1997). Human factors in process control. In G. Salvendy (Ed.). Handbook of Human Factors and Ergonomics 2<sup>nd</sup> Edition (pp. 1944-1971), New York: John Wiley & Sons.

Mosier, K. L., & Skitka, L. J. (1996) Human decision makers and automated decision aids: Made for each other? In R. Parasuraman & M. Mouloua (Eds.), Automation and Human Performance: Theory and Applications. pp 201-220 Mahwah, NJ: Lawrence Erlbaum Associates.

Moore, P., and Corbridge, C., (1996). Designing mimic diagrams: Moving from art to science. Proceedings of the Human Factors and Ergonomics Society 40<sup>th</sup> Annual Meeting (pp. 328-332). Santa Monica, CA: Human Factors and Ergonomics Society.

Mouloua, M., & Koonce, J. M.(Eds.) (1997) Human-automation interaction: Research and practice. Mahwah, NJ: Lawrence Erlbaum Associates.

Muir, B. M. (1987). Trust between humans and machines, and the design of decision aids. International Journal of Man-Machine Studies, 527-539.

Norman, D. A. (1990). The “problem” with automation: Inappropriate feedback and interaction, not “overautomation”. Philosophical Transactions of the Royal Society of London, B, 327.

Parasuraman, R., & Riley, V. (1997) Humans and automation: Use, misuse, disuse, and abuse. *Human Factors*, 39(2), 230-253.

Rasmussen, J. (1983) Skills, rules and knowledge; Signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. SMC-13(3).

Rasmussen, J. (1985). The role of hierarchical knowledge representation in decision making and system management. . *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. SMC-15(2), pp. 234-243.

Rasmussen, J. (1986). Information processing and human-machine interaction: An approach to cognitive engineering. New York: North-Holland.

Rogers, W. H., Schutte, P. C. , & Latorella, K. A., Fault management in aviation systems. In R. Parasuraman & M. Mouloua (Eds.) Automation and Human Performance: Theory and Applications. pp 281-318. Mahwah, NJ: Lawrence Erlbaum Associates.

Rouse, W. B. (1978). Human problem solving performance in a fault diagnosis task. *IEEE Transaction on Systems, Man, and Cybernetics*, vol. SMC-8(4), pp. 258-271.

Sarter, N. B., Woods, D. D., & Billings, C. (1997). Automation surprises. In G. Salvendy (Ed.), Handbook of human factors and ergonomics, 2<sup>nd</sup> Edition. (pp. 1926-1943). New York: John Wiley & Sons

Sarter, N. B., & Woods, D. D. (1999). Team play with a powerful independent agent: Operational experiences and automation surprises on the Airbus A-320. The Journal of the Society for Human Performance in Extreme Environments 4(2), pp. 60-71.

Sarter, N. & Woods, D. D. (1992). Pilot interaction with cockpit automation: Operational experiences with the Flight Management System. International Journal of Aviation Psychology, 2(4), 303-321.

Sarter, N. B. & Woods, D. D. (1995). "How in the world did we ever get into that mode?" Mode error and awareness in supervisory control. Human Factors, 37, 5-19.

Shraagen, J. M. Discovering requirements for a naval damage control decision support system. In C. E. Zsombok & G. Klein (eds.), Naturalistic Decision Making(pp. 227-232)., Mahwah, NJ: Lawrence Erlbaum

Sheridan, T. B. (1970). On how often the supervisor should sample. IEEE Transactions on Systems Science and Cybernetics, SSC-6, 140-145.



Vincente, K. (1991). Supporting knowledge-based behavior through ecological interface design (Tech Report EPRL-91-1). Urbana-Champaign, IL: Engineering Psychology Research Laboratory and Aviation Research Laboratory. University of Illinois.

Vincente, K., & Rasmussen, J. (1990). The ecology of human-machine systems II; Mediating “direct perception” in complex work domains. *Ecological Psychology*, 2(3), 207-249.

Waterman, D. A. (1985). *A guide to expert systems*. Reading, MA. Addison-Wesley.

Weiner, E. (1989). Human factors of advanced technology (‘glass cockpit’) transport aircraft (Technical Report # 117528). Moffett Field, CA; NASA Ames Research Center.

Weiner, E. L., & Curry, R. E. (1980). Flight deck automation: Promises and problems. *Ergonomics*, 23(10), 995-1011.

Wickens, C. D. (1992). *Engineering Psychology and Human Performance* (2<sup>nd</sup> Ed.). New York: Harper Collins

Woods, D. D., & Hanes, L. (1986). Human factors challenges in process control: The case of nuclear power plants. In G. Salvendy (Ed.), Handbook of Human Factors, New York, John Wiley.

Woods, D. D. (1995). Towards a theoretical base for representation design in the computer medium: Ecological perception and aiding in human cognition. In J. Flach, P. Hancock, J. Caird, & K. Vincente (Eds.) An Ecological Approach to Human-machine Systems I: A Global Perspective (pp. 157-188). Hillsdale, NJ: Lawrence Erlbaum Associates.

Woods, D. D. (1996). Decomposing automation: Apparent simplicity, real complexity. In R. Parasuraman & M. Mouloua (Eds.) Automation and Human Performance: Theory and Applications. pp 3-17. Mahwah, NJ: Lawrence Erlbaum Associates.

Yoon, W. C., & Hammer, J. M. (1988). Aiding the operator in novel fault diagnosis. *IEEE Transactions on Systems, Man, and Cybernetics*, 18(4), 659-675.