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Including the Human Element in Design of Command and Control Decision Support Systems: The KOALAS Concept

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The rapidly developing technology of command and control and decision support systems requires improvement in the way the human element is integrated into the system. The limitations of human cognitive capacity must not be exceeded, or the system will fail. A properly designed decision support system should include provision for the heuristics that are likely to be employed by a decision maker when faced with a rapidly changing and information intensive situation and incomplete or questionable data.

Many measures to effectiveness have been proposed for battle management and C2 systems. In this paper, where systems consist of an integrated combination of a human decision maker and his decision support system, three measures of effectiveness are proposed and discussed. Improvements in performance of the total system can be made by improving the efficiency of information exchange between the DM and the support system.

The KOALAS architecture has been shown to be an effective implementation of a simulation and rule based expert system which can increase the efficiency of information exchange between the human decision maker and the decision support system. Potential improvements in KOALAS' architecture are discussed with recommendations for improving its employment and utility.

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CONTENTS

Foreword

CDR COLTON is a member of the Technology Mobilization Reserve component which supports the Office of Naval Research and the Naval Research Laboratory. He spent 14 years in the nuclear submarine force, and earned an M.S.E.E. degree from the Naval Post Graduate School specializing in Communications Engineering. He has over 20 years experience in Navy communications and is a part time instructor in the Information Systems Department at the University of Maryland, Baltimore County. He is also currently the Chief Scientist and a Program Manager on the Trident Integrated Radio Room for Data Decisions Incorporated.

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INCLUDING THE HUMAN ELEMENT IN DESIGN OF COMMAND AND CONTROL DECISION SUPPORT SYSTEMS: THE KOALAS CONCEPT

1.0 INTRODUCTION

In 1987 the Defense Science Board cited as a problem the lack of a "...useful conceptual framework for evaluating or specifying command and control systems..." [1]. The purpose of this NRL Report is to describe a conceptual framework which could help bridge the gap between the multidisciplinary science of human interaction with systems and the need to design, specify and analyze command and control (C2) systems.

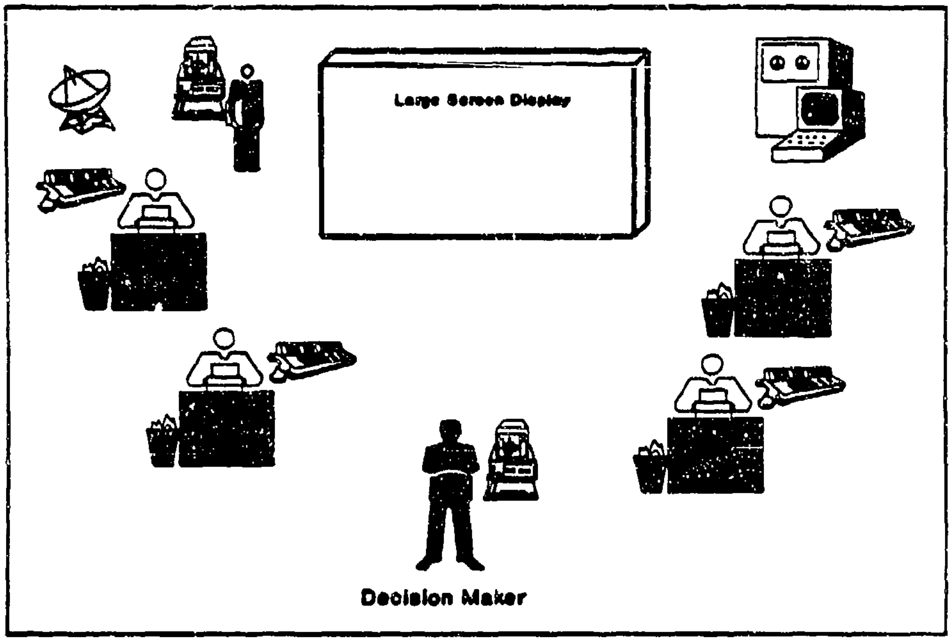

Figure 1 A Typical Command Center

The academic literature contains a great deal of research on human computer interaction, human cognitive styles and limitations, and other aspects of human performance applicable to command and control systems design. This report provides a conceptual framework for exploiting expert systems, simulation and heuristic modeling in command and control decision support systems (C2DSS).

Central to design of modern C2DSS are human decision makers [2], with their individual cognitive processes and biases [3]. The military decision maker (Figure 1) must perform in a stressful, information intensive, and dynamic environment. However, the human element of the system design has been relatively neglected [4], because of unrealistic expectations from automation and artificial intelligence. Most C2 system users and analysts have come to realize that "The benefits of

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automation will not eliminate the central element of command and control - the human commander" [5]. Therefore, in C2DSS design, account should be taken for human limitations, biases and heuristics. Most modern information systems are intended to speed human work processes by providing data and information in a flashy, fast manner without considering how the operator or information user will interact, interpret, or perceive the information.

Human-computer interactive system design has come to be recognized as an interdisciplinary science touching on many fields: cognitive science, cognitive psychology, artificial intelligence, expert systems, management science, decision science, control theory, and others [6,7]. Some topics found in literature applicable to the study of human cognitive processes in C2 include: 1) human cognitive style [8 thru 15], 2) decision/distributed decision support [16 thru 20], 3) knowledge representation [18,21,22], and 4) artificial intelligence [4,23,24,25,26]. Many of these are active research areas allowing more study to clarify their applicability to C2DSS design. Two areas with obvious applicability will be discussed further: 1) human cognitive capacity and 2) human decision making under uncertainty.

2.0 HUMAN COGNITIVE CAPACITY

A properly designed C2DSS should, if possible, account for any known weaknesses of the human component of the system. Only recently have designers and analysts begun to think of the human user as a system component, with preconceived biases and capacity limits. Fineberg [27] stated that rather than trying to rationalize human failure, we should account for the human operators' limitations, for when limits are exceeded the system fails. Boettcher and Levis [28] described a model for quantifying the decision maker's cognitive workload. Louvet, Casey and Levis [29] presented evidence supporting the existence of cognitive workload thresholds (sometimes referred to as the "bounded rationality constraint") for individual decision makers (DM) above which they become overloaded. A wide threshold variance among individuals was shown to exist. The results have real implications for C2DSS designers.

For example, the information amount and update rate shown on a large screen display contribute to the DM cognitive load. As a battle situation changes and decisions must be made, the rate at which the DM must evaluate alternatives and make decisions contributes to his cognitive work load. As the information presentation and the required decisions rates increase, there will certainly come a point where the DM cannot keep up. When the DM can no longer keep up, he has reached his bounded rationality limit and is overloaded.

A DSS should be designed such that the cognitive work load is properly shared among computers and human decision makers, so no one DM is overloaded. The cognitive workload will vary greatly among various battle situations. The workload variety combined with a large variance among individual thresholds, implies that considerable testing should be conducted with human subjects exposed to varying situations.

In addition to failure from overload, the human decision maker may rely on certain heuristics that can lead to erroneous decisions. Three particular heuristics impact on a decision makers choice during situations of uncertainty.

3.0 DECISION MAKING UNDER UNCERTAINTY

In addition to facing problems which could be handled by artificial intelligence (i.e. expert systems, with sets of rules) or by operations research methods (with analytical solutions), the battlefield commander needs a C2DSS that aids with uncertainty on the battlefield. In the words of General Carl von Clausewitz: "A great part of the information obtained in War is contradictory, a still greater part is false, and by far the greatest part is of doubtful character" [1].

A decision maker will, during the heat of battle, turn to a set of personal heuristics. While heuristics may often prove expedient and useful, they may also lead to gross errors in judgement. Tversky and Kahneman [30] describe three primary heuristics humans use in making judgements under uncertainty as: 1) representativeness, 2) availability, and 3) anchoring and adjusting. We discuss briefly these heuristics and their associated biases and potential fallacies.

3.1 Representativeness

Many of the probabilistic judgements that decision makers may be called upon to make are of the following types: What is the probability that object A belongs to class B? What is the probability that event A originates from process B? What is the probability that process B will generate event A? In addressing these types of judgements, operators typically rely on a representativeness heuristic [30,31], in which probabilities are evaluated by the degree to which A resembles B.

For example, consider the situation where the decision maker is given the information that an unidentified aircraft "is manuvering radically toward him, changing course, speed, and altitude"; and then is asked to assess the probability that the aircraft has a particular intent chosen from a list of possible actions. As Kahneman and Tversky [32] report, in experiments subjects will order their judgements of the probabilities and their judgements of the similarities in the same order. While this heuristic may be useful and expedient in ordinary circumstances, it has several fallacies which can lead to serious errors in judgement. In this case, insensitivity to prior distributions ignores the fact that there are many more airliners than there are hostile aircraft. In other situations additional logical fallacies may exist: insensitivity to sample size, and misconceptions about probabilities.

3.2 Availability

Another situation that a decision maker may encounter is one requiring him to assess the frequency of a class or probability of an event. When confronted with this situation, people typically use the availability heuristic [33], which is based on the ease with which instances or occurrences can be brought to mind. Again, while this heuristic may be useful under many circumstances, it ignores several important factors and can lead to serious errors. Some of the factors ignored are: 1) bias due to retrievability of instances, 2) biases of imaginability, and 3) illusory correlation.

The biases of retrievability and imaginability can be significant if the decision makers have been exposed recently to numerous reports, rumors and hysteria concerning hostile air attacks in their immediate vicinity. As in the USS Vincennes incident [37], this bias can be enough to cause decision makers to make a determination of hostile intent and ignore other clear evidence to the contrary. The bias of illusory correlation can be caused by oversimplifications, such as "when an aircraft turns toward you and ignores challenges, it has hostile intent".

3.3 Anchoring and Adjusting

The third common heuristic used in making judgements under uncertainty is that of anchoring and adjusting. This heuristic comes into play when the decision maker is required to make a judgement about a numerical value. In applying this heuristic the decision maker will start from an initial value and adjust it up or down.

In air, sea and submarine warfare an important target parameter is always target range. This value is important for two reasons. First, to determine when the target is within range for launching its weapons; and second, for determining when the target is within range of own ship's weapons.

Because of emission controls and other operational factors, range may not always be known, so an operator will intuitively anchor on a previously known value and make mental adjustments. Some battle managers call this "the old eyeball integrator". Slovic and Lichtenstein [34] showed that this heuristic is subject to two serious potential biases: 1) insufficient adjustment and 2) lack of calibration.

Examples of insufficient adjustment and lack of calibration occur frequently in submarine warfare. The fire control coordinator (FCC) has primary responsibility for determining the target's course, speed and range. As such, he is the DM for deciding when the target is within weapon range. After determining the target's range early in the torpedo firing approach, there may be insufficient information to update target range. The FCC will use a previously determined range and make mental adjustments based on elapsed time and assumptions about the target's actual course and speed. Delays in data analyses performed by members of the fire control party and in evaluation by the plot coordinator and FCC frequently cause the estimated target range to not be adjusted sufficiently, resulting in the target being within weapons range earlier than expected.

The FCC may also choose an unreliable anchor range from which to make adjustments. As the battle problem unfolds, he will naturally begin to place undue faith in his estimate of target range which is based on an uncalibrated anchor point.

4.0 COMMAND AND CONTROL DECISION SUPPORT SYSTEM DESIGN

Military decision makers are often unprepared to deal with sudden, unexpected changes and do not like to be surprised. Military analysts need access to facilities that identify the rapidly changing or nonlinear aspects of military behavior and that provide indications and warnings of the existence of conditions under which sudden changes may occur [35].

Decision Support System design for any type of system follows the same principles. It should be noted here that a DSS is merely a glorified version of an information system. The methodology employed to create the design is not as important as the overall implementation and the thought processes that go into the design. Standard methodology usually consists of requirements specification or "what the user wants or needs?", requirement evolution or analysis, software requirement documentation, system modeling, requirements definition, formal specification, and validation, prototyping, software design (top-down, object-oriented, function-oriented), user interface, design review/quality assurance, programming, data reduction, data base development, hardware requirements, configuration (hard and software), develop, test, document, integrate, test, and maintain. Prototyping and rapid prototyping encompass many of the middle steps in the methodology and are the only sensible way to design and develop systems intended to support interactive problem solving [36].

The most important step missing in the above methodology is human cognitive processes, biases, limitations, and heuristics. Placing human factors into the software engineering process is sometimes overlooked because of monetary or time constraints or plain development zeal. Because of varying personality traits or biases within each individual or decision maker, a system design may not be able to fully account for or offset the users biases. However, by using a knowledge based expert system, or artificial intelligence kernel embedded in the system, employing standard rules and prompting the decision maker, poor judgement or delayed reactions may be overcome or reduced.

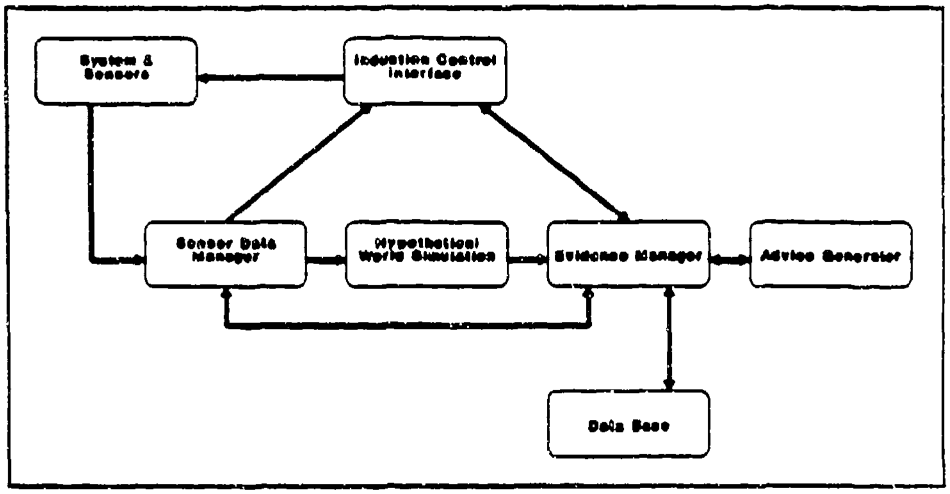

Figure 2 - KOALAS Architecture

The Knowledgeable, Observable Analysis-Linked Advisory System (KOALAS) is just such a system. KOALAS can be thought of as an intelligent control system or a knowledge processing system. Its main features are a simulation system, a rule-based expert system, an object attributes database and an induction control interface that allows the user to update the situation model being used by the simulation to estimate future system states. For instance, suppose a dynamic information management system (IMS) is being employed by a DM. The DM has a hypothesis in mind about the situation being enacted. But, the DM cannot enter his hypothesis into the IMS, nor can the IMS apply a set of rules to his hypothesis to advise proper action. The concept demonstration phase has shown KOALAS capable of accepting hypotheses, projecting system states and providing appropriate advice. KOALAS is a suitable foundation for further development and experimentation in knowledge processing in decision support systems.

New features in the KOALAS architecture contributing to timely reactions and decisions are the Evidence Manager and the Advice Generator shown in Figure 2. The Evidence Manager takes as inputs the current situation hypothesis, predicts future values for system state variables based on information stored in the database and deduced information from object models in the situation hypothesis (ie. rules), and makes it available to the Advice Generator, which then provides advice on actions to be taken. KOALAS development was originally centered around the outer air battle management environment, but has application in other C2 environments, such as submarine warfare, land battle management, surface warfare, and as well as air warfare.

5.0 C2DSS MEASURES OF EFFECTIVENESS

In the modeling and simulation discipline measures of effectiveness (MOEs) [38, 39] are usually dependent on the model's objective. In C2, MOEs are frequently tied to combat or mission outcome. There is truly no better measure than success in combat. When considering the battle management problem where the system consists of the human DM and his DSS several pertinent MOEs are relevant. The first one is "are decisions being made in a timely fashion?" The next MOE is "are the decisions correct?". Finally, "is the mission accomplished?" These MOEs should be quantifiable given the mission's objectives.

The KOALAS concept could help improve these MOEs in several ways. First, through the use of its Evidence Manager and Advice Generator, KOALAS could greatly improve decision timeliness and accuracy. The unobtrusive nature and the simplistic operation of the decision aid (KOALAS) could improve decision making processes and thus the MOEs. KOALAS provides a gentle reminder to the DM and prompts action early without imposing on the process or can be enabled to initiate action automatically should a situation warrant automatic response such as the need to immediately engage an incoming missile with a Close-In Defense System.

6.0 POTENTIAL FOR FURTHER DEVELOPMENTS INCLUDING THE KOALAS ARCHITECTURE

The following paragraphs describe briefly some areas considered worthy of further exploration for further development of the KOALAS architecture and eventual transition to operational C2DSS systems.

6.1 Look Ahead

The simulation built into KOALAS could easily be run faster than real time to provide a look into the future. While maintaining the real-time picture, the operator could open a window which shows what the situation would like at some time in the future if none of the object attributes (ie ships, aircraft, etc.) were changed. In this way both the decision maker and the built in expert system could better anticipate required tactical decisions. Even though advice given by the Advice Generator may not be different a few minutes in the future, it is important to emphasize the potential improvement in judgement that could result by giving notice of upcoming decision points. For example, knowing that "within the next three minutes the target will be within launch range" may give the DM just the extra minute or two he needs to carefully consider his decision to engage. The window into the future could show immediately the consequences or benefits of changes to object attributes or tactical decisions.

6.2 Distributed Simulation Techniques

APPENDIX A is an extensive bibliography of literature in the very broad subject of modeling and simulation. Many publications discuss techniques for performing simulations through distributed systems. For further exploration of the KOALAS concept, migration to a distributed simulation architecture [17] would provide several benefits. First, it would assure KOALAS's compatability with several major wargame simulations such as 1) AWSIM (Air Warfare Simulation), 2) GRWSIM (Ground Warfare Simulation) 3) TTSM (Theater Transition and Sustainment Model) and 4) other wargame simulations in use at the Unified and Specific Commands and planned for use in major coordinated training exercises linked through worldwide Battle Simulation Centers on distributed networks.

A distributed simulation architecture for KOALAS could facilitate improvements in computational power through links to other computers. The inclusion of other processors in the system could also promote experimentation with distributed decision making processes [18,40].

6.3 Other I/O Devices

Exploitation of new human-computer interface technologies such as voice synthesis and recognition, touch sensitive screen hardware, eye trackers, roller balls, etc. could improve user performance in using the system.

6.4 Experimental Designs

As mentioned in the beginning, there is a shortage of principles for the design and evaluation of command and control systems. Experiments should, therefore, be designed and conducted using human subjects and proper scientific methodology to develop valid generalizable design principles, which take proper account of the human element.

7.0 RECOMMENDATIONS

To include proper consideration for the characteristics of the human element of a command and control decision support system the following general guidelines are proposed.

First, quantify the cognitive workload which will be experienced by the decision maker under normal circumstances and under extremes that might be expected. Since there is a wide variance in the "bounded rationality" threshold, the design should provide, possibly through established procedures, for the fact that the decision maker may be overloaded during periods of peak load. KOALAS could be used in experiments to determine the bounded rationality limits for decision makers in various situations.

Second, it should be possible to design a command and control decision support system which combines aspects of operations research and expert systems in such a way that it could recognize which heuristic a decision maker is likely to use when faced with insufficient information. It could then help guide the decision maker in a way which minimizes the impact of potential heuristic fallacies. KOALAS has been shown to be an effective implementation of a combined expert system, simulation and decision support system. It is recommended that the KOALAS concept be used as the foundation for further development and testing.

8.0 CONCLUSIONS

This report is intended to increase the readers awareness of some of the human element characteristics and limitations within a command and control system. Two primary human limitations discussed were 1) cognitive capacity and 2) decision making under uncertainty. The potential benefits of further development of the KOALAS architecture have been discussed. For proper inclusion of human element characteristics in the design process, there are many unanswered questions such as "bounded rationality" limits, compensating for fallacies associated with commonly used heuristics, and an optimized Human-Computer Interface (HCI) for information flow between the DM and the support system (ie. computers). It is hoped that an increased awareness of these topics will stimulate additional research and eventual development of more intelligent and flexible decision support systems.

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APPENDIX A

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