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DECISIONMAKING IN MILITARY COMMAND TEAMS: AN EXPERIMENTAL STUDY

by

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This study examines the role of resource allocation in naval command teams. The experiment is based on the Composite Warfare Commander - Distributed Dynamic Decisionmaking (CWC-DDD) paradigm and investigates the impact of uncertainty in neutral/enemy discriminability, team information structure, and leader's involvement in resource coordination. Seven four-member teams, consisting of military officers, used the CWC-DDD to combat a pre-programmed air threat to a naval battle group. Results show that increased average resource effectiveness and higher average identification confidence lead to greater final team strength. However, increased upward communications lead to lower final team strength. Functional (tactical vs. non-tactical) variations in military background have a significant impact on team performance. Teams that are predominantly tactical develop more coherent strategies, more effectively utilize their resources and have better team performance. Teams that are non-tactical develop limited strategies, assign lower confidence to their target identifications and have more upward communications.

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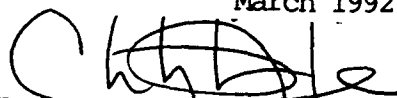Submitted in partial fulfillment
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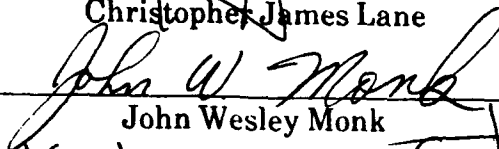## MASTER OF SCIENCE IN INFORMATION SYSTEMS

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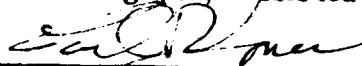Christopher James Lane

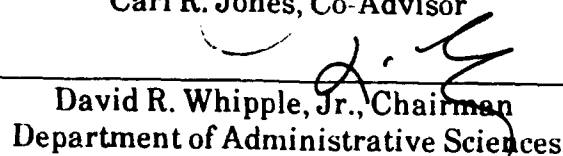_____
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ABSTRACT

This study examines the role of resource allocation in naval command teams. The experiment is based on the Composite Warfare Commander – Distributed Dynamic Decisionmaking (CWC-DDD) paradigm and investigates the impact of uncertainty in neutral/enemy discriminability, team information structure, and leader's involvement in resource coordination. Seven four-member teams, consisting of military officers, used the CWC-DDD to combat a pre-programmed air threat to a naval battle group. Results show that increased average resource effectiveness and higher average identification confidence lead to greater final team strength. However, increased upward communications lead to lower final team strength. Functional (tactical vs. non-tactical) variations in military background have a significant impact on team performance. Teams that are predominantly tactical develop more coherent strategies, more effectively utilize their resources and have better team performance. Teams that are non-tactical develop limited strategies, assign lower confidence to their target identifications and have more upward communications.

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I. INTRODUCTION

A. CONTEXT OF THE STUDY

Large scale computer systems of today have a tremendous impact on the way modern battles are fought. Air defense weapons can locate, identify and engage an enemy target automatically without human intervention. Ground surveillance radars can locate a target, designate it with a laser, and send the target description to a fire direction computer located miles to the rear of the front line. This fire direction computer analyzes the target, decides the best ammunition mix to use and picks the weapons to fire. The message to fire is sent to a firing element located miles from the fire direction center and the mission is fired. This process can be completed in seconds and can be accomplished without human intervention.

> Despite this explosion of information, communication and computer technology the human remains the focal point for decision making in large scale systems (Kleinman and Serfaty, 1989).

Humans bring to a system there own ideas and adaptability. In many cases this flexibility to adapt to changing situations is essential to the systems proper operation. These skills cannot at this time be programmed into a computer system. Also in many cases it is not

politically feasible to place complete control of our country's weapons systems in the hands of computers. Therefore, human control is an integral part of weapons systems employed by the United States.

The controversy surrounding the USS Vincennes incident points out one of the problems that remain to be solved by systems designers. The Fogarty report concluded that "The AEGIS combat system's performance was excellent - it functioned as designed" (Hill, 1989). The report went on to say that "mistakes made by the Vincennes CIC crew contributed to the commanding officers belief his vessel was in danger of attack" (Hill, 1989). This conclusion was disputed by Martin Hill in an article in San Diego Magazine (Hill, 1989). He maintains that the designers of the AEGIS system failed to incorporate enough human engineering in their design. Without addressing the fault of this incident it seems clear that there exists a need to better understand the process of human decision making as it interfaces with large information systems.

The AEGIS system is only one example of a large scale military weapons system. These systems include large databases, communications networks, automatic firing systems, several different information gathering systems (radar, sonar,

observers, etc) and human decision makers. More importantly these systems tend to have many human decision makers.

> A characteristic feature of these systems is the presence of a team of human decisionmakers who may be geographically separated, but who must coordinate to share their information, resources and activities in order to attain their goals in what is generally a dynamic and uncertain task environment (Kleinman and Serfaty, 1989).

The study of the dynamics of this distributed decision making was the purpose of the research sponsored by the Office of Naval Research in 1985.

B. RESEARCH BY THE OFFICE OF NAVAL RESEARCH (ONR)

The weapons of modern warfare are both accurate and lethal. They can destroy cities, sink ships and wipe out entire formations in seconds. The ability of modern info. nation systems places an enormous amount of data about potential targets for these weapons in the hands of tactical decisionmakers. Additionally the effects of these weapons can be felt almost immediately. Thus, although a modern commander has extremely destructive weapons at his disposal and massive amounts of information about where to use these weapons, employment decisions have to be made in seconds. Ship commanders of today have precious few seconds to identify an approaching aircraft and determine a course of action. Typically in military organizations these decisions are made by teams.

Specifically, in the case of the battle fought by naval ships the team is composed of the Composite Warfare Commander(CWC) and his immediate subordinates: the Anti-Air Warfare Commander, the Anti-surface-Warfare Commander, and the Anti-Submarine Warfare Commander. Each of the subordinates makes decisions and passes along information to the commander. He makes decisions about the overall battle and passes down information and instructions to his subordinates. Elaborate and integrated information systems have been developed to assist these commanders make their decisions. How commanders make decisions in this computer assisted environment is a growing concern in military organizations.

In order to understand the dynamics of team decisionmaking in the Navy the Office of Naval Research has initiated the Distributed Tactical Decision Making (DTDM) program. (Vaughn, 1990) The purpose of this study is to understand the problems of distributed command and control. The program was initiated to look at a wide range of methodologies. The normative – descriptive method and lab simulation forms the basis for the current research.

A computer based paradigm designed to simulate "real world" Navy engagements has been developed by a research team at the University of Connecticut and the research corporation of Alphatech. (Kleinman and Song, 1990) The Composite Warfare Commander – Distributed Dynamic Decisionmaking (CWC-DDD) paradigm was the basis of an experiment conducted at the

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Naval Postgraduate School during August 1991. The Resource Allocation in Naval Command Teams (RAINCOAT) experiment was designed to study the impact of decision making variables using military personnel as the decision makers.

C. THE RAINCOAT EXPERIMENT

The study of distributed decision making is more then a study of the decision making steps that individuals go through to make decisions. In this case the sum of the parts can be more then the whole or if things are going wrong the sum can definitely be less then the whole. Serfaty and Kleinman summarized the state of the art in the study of distributed decision making at the beginning of their study as follows:

> The scientific study of distributed human decision problems has long been hindered by several objective factors. The inherent complexity of the mathematical formulation and solution of decentralized problems in control. detection, data fusion, and resource allocation theories has prevented the development efficient and practical models that could be used as a basis to predict actual team performance in a distributed environment.... Another hampering factor is the lack of psychological or cognitive models of team decisionmaking behavior.... Finally the lack of comprehensive empirical data has prevented the development of essential scientific hypotheses related to team decisionmaking performance. (Kleinman and Serfaty, 1989)

The recognition of these deficiencies in this field of study and the real world need to better understand the dynamics of team decisionmaking lead to the initiation of this study by ONR. As stared earlier, the study concentrates on solving the types of problems encountered in naval command

and control systems which involve distributed decisionmaking. The scenarios developed thus far use computer simulations modeling the composite warfare commander (CWC) doctrine employed by naval battle groups. However, the results of the study conducted so far have application in many different military and civilian situations involving command and control of distributed resources.

The RAINCOAT experiment sought to study the dynamics of team decisionmaking as it was practiced by teams of military officers. The Composite Warfare Commander - Distributed Dynamic Decisionmaking (CWC - DDD) paradigm was used to present each four person team with an abstracted military situation in which they must respond to an enemy air attack. The teams were presented with unidentified targets which they must identify as enemy or neutral. Each team received at least four hours of training prior to recorded trials of the experiment. The goal of this training was to create expert teams with a complete understanding of the mechanics of the simulation. A more complete description of the experimental procedures used in the experiment is contained in chapter III of this document.

II. CURRENT RESEARCH

A. DEVELOPMENT OF DDD

The current Composite Warfare Commander - Distributed Dynamic Decisionmaking (CWC - DDD) paradigm is the result of five years of study involving the performance of model driven basic experimental research. The development has been a joint effort between the University of Connecticut and Alphatech Inc. working under a grant from the Office of Naval Research. The paradigm is designed to support empirical research and laboratory simulation examining distributed decision making issues in four-person hierarchial teams of naval commanders. The players plan, coordinate, and allocate resources in a simulated naval battle situation.

The paradigm is implemented as a computer driven interactive game in which four team members attempt to defend a naval battle group. The paradigm can be manipulated to expose the decision makers to different situations of information processing and resource allocation under different organizational hierarchies and information structures. The decision makers are expected to manipulate limited shareable resources to process a variety of targets in a changing environment. Each decisionmaker sits at a different

workstation which displays the situation as seen by each decisionmaker. (Kleinman and Song, 1990)

B. PAST EXPERIMENTAL RESEARCH IN TEAM DECISIONMAKING

1. Experimental Efforts in Hierarchial Team Decisionmaking

A compilation of the results of current studies of team decisionmaking dynamics is contained in Table 1. This table gives a brief summary of the experimental research that has been conducted under the sponsorship on the Office of Naval Research.

2. Summary of Experimental Results

a. Hierarchical Information Processing (HIP)

This experiment was an essential part of a coordinated study analyzing team situation assessment and information coordination. The experiment studied situation assessment in three-person teams. A team leader was forced to assimilate information gained from subordinates with his own information and opinions to determine if a contact was a neutral or an enemy. The study was designed to look at the effects of feedback (in the form of subordinates opinions and 'onfidence in their opinions) on the leaders assessment of the situation. The experimental results supported the hypothesis that the feedback mechanism helped to insulate teams against the lose of a critical element of information. The results hint that with feedback team members form a mental model of

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the other decision makers and thus are able to coordinate team

actions with less communication. (Burton and Kleinman, 1990)

TABLE 1

EXPERIMENTAL RESULTS IN TEAM DECISIONMAKING

EXPER IMENT	VARIABLES	SUBJECTS	RESULTS
HIP	Information Feedback	3 Person Teams	Feedback insulates team from information losses
HRA	Tempo	4 Person Teams	Leaders pool resources and positively affect task division
INCO	Information	4 Person Teams	Shared opinions among subordinates reduces need for leader and increases effective use of information
HITEC	Time Stress Leader Involvement Commo Structure	4 Person Teams	Explicit coordination is most greatly affected by tempo increases
REST	Reward Structure	2 Person Flat Team	Differing goals in teams forced an increase in explicit coordination and increased perceived workload.
CREST	Performance Feedback Expertise Overlap	2 Person Team	Performance feedback did not greatly enhance team performance
ICS	Information structure Tempo Command Strategy	4 Person Team	Increase in external load increases the leader role. Leader can suffer information overload

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b. Hierarchical Team Resource Allocation (HRA)

This experiment was the concluding experiment in a series of studies looking at team resource allocation, action selection, and team coordination. This experiment examined the role of a leader in resource allocation problems. The experimental goal was to determine if a teams performance increased with the introduction of a team leader and a hierarchical structure. The leader became the resource allocator with the ability to force transfers of resources among subordinates. The researchers concluded that the introduction of a leader had a positive effect on the teams ability to coordinate an overall pooling of resources. They also concluded that the team was better able to coordinate actions to process high value tasks. These studies (HIP and HRA) served as the base of information at the beginning of the research effort sponsored by the Office of Naval Research. (Miao, Luh, and Kleinman, 1990)

c. Information Coordination in Human Teams (INCO)

This experiment was designed to study information coordination in hierarchical teams. The experiment used four-person teams. The team leader was asked to identify a contact as friend or foe based on information passed to him by his subordinates and on his own information. The subordinates were asked to either identify the contact and pass this information to the team leader or request additional

information. This additional information cost the team and reduced their overall score. The team goal was to maximize that score. The experiment found that when team members share their opinions the team uses information more effectively and the leader's involvement is much less critical. The researchers also found that when the subordinates did not share information the team performed better with active leader. (Kleinman and others, 1991)

d. *Hierarchial Team Coordination (HITEC)*

This experiment manipulated the time available for decisions, the leader's role and the communication structure. The experiment revealed that with a 35% increase in the game tempo there was a 10% drop in team performance, a 25% drop in the number of communication messages and a 10% drop in the database (task status) updates. The communication messages with the longest planning horizon were reduced the most. The tasks that required more coordination were the first to be dropped. (Wang and others, 1991)

e. *The Reward Structure Experiment (REST)*

This experiment measured task processing in two person teams under an individual reward system and under a team reward system. The different goals at the local levels forced more explicit coordination, increased the perceived workload, reduced the number of cooperative team actions and lowered the overall performance. In other words the teams

that sought a team goal performed better at both the individual and team levels. (Kleinman and others, 1991)

f. Conflict Resolution in Teams (CREST)

This experiment investigated conflicts in resource sharing in two person teams. The team was confronted with a series of air and subsurface targets/tasks. The team was required to identify and then track each of these tasks for a specified period of time. DM1 was required to track air tasks while DM2 was responsible for subsurface tasks. The results suggested performance feedback does not significantly effect team performance. Rather it reduces the degree of cooperative behavior in a team. The experimenters concluded:

> Feedback helps correctly calibrate the mutual models that decisionmakers hold of each other and that feedback is filtered and interpreted more so at an individual level then at a team level. (Nodoushani, Kleinman and Serfaty, 1989)

g. Information and Command Strategy (ICS)

This experiment was designed to investigate the effect of different information structures and command strategies upon resource allocation in hierarchical teams. Four-person teams consisting of a leader and three subordinates are given limited resources to process tasks within a given area. The independent variables in this experiment were leader information, command options, and the external load applied. The experiment showed that if a leader has too much authority and not enough information they tend to

intrude into lower level processes. Additionally it showed that too much information can lead to information overload. (Shi, Luh and Kleinman, 1990)

C. A VIEW OF TEAM DECISIONMAKING IN COMMAND AND CONTROL

1. The Command and Control Environment

Tasks assigned to command and control elements are dynamic in nature; they can be diverse and completely unpredictable. The teams that are assembled to perform command and control are often separated geographically and into different functional responsibilities. They make decisions in an uncertain environment where there is not a easily defined correct answer. Typically there is an adversary who will work to confuse the decisionmakers of the team. In these situations the team's tasks can be broken into two distinct areas. They are situation assessment and resource management.

Situation assessment involves a continuous analysis and estimate of the current situation. It requires that the team control information gathering resources and place them in positions that will maximize their effectiveness. This assessment requires that the team have a complete understanding of the strengths and weaknesses of the resources available to them. In a military situation this involves the use of radars, detection devices, IFF devices to identify friendly forces, special operation forces and many other

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intelligence gathering forces and equipment. In business this can involve a study of the market, surveys of potential buyers, research of local newspapers, or even lobbying of the government.

Once this information is gathered it must be processed to present a clear picture of the situation. This process involves statistical hypothesis testing, pattern recognition and in many cases judgement of the decisionmakers. This step can be one of the most difficult to implement because huge amounts of data can be collected in a very short time. The decisionmaking team must find a way to extract the pertinent data and assemble it into a clear picture of the situation in time to affect a rapidly changing situation.

Resource management is the control and allocation of an individual's resources in order to utilize them in a effective and efficient manner to achieve organizational goals. When allocating resources the team must remember that the situation assessment is ongoing and the situation may be changing. Therefore, the teams must allow for a strategic reserve of resources to meet new demands. Teams must use their judgement, experience, and obtained data to decide when and where to use this reserve.

The execution of the team tasks is influenced by the goals that the individual members of the team perceive as their own and those of the team as a whole. The REST experiment showed that those teams that were able to integrate

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individual goals into the team goal attained much higher performance levels. The leader in this case is challenged to find common goals for his subordinates and to define them in a way that everyone understands.

   2. **Team Coordination - The G.R.I.T. View**

Serfaty and Entin present a model of team decisionmaking that defines a task as a general coordination problem. They define coordination as the "process of managing the overlap (interdependencies) among co-acting decisionmakers" (Kleinman and others, 1991). Furthermore Serfaty and Entin maintain that this coordination is an essential element of the team decisionmaking process.

Serfaty and Entin define four components of coordination: goal coordination (G), resource coordination (R), information coordination (I) and task/action coordination (T). Goal coordination involves the team in the reconciliation process between individual and team goals. Resource coordination involves an accounting of available resources; when and where they will be available. Information coordination involves the deciphering of incoming data. It can also be as simple as everyone agreeing on a common set of symbols to depict actual items. Task/action coordination involves the deconflicting of action. For example, two members of an air defense team should not inadvertently process the same target at the same time.

The present line of research is investigating how this coordination is facilitated by different environments. Specifically, the research is looking into how coordination is affected by the team's communication methods, the team's information sharing, preplanned rules or procedures, and the team's hierarchial structure.

3. Summary of Conclusions from Current Research

a. *Team Limitations and Biases*

Strategies developed by decisionmakers have a short planning horizon; two to three stages of decisionmaking appear to be the limit. Decision strategies developed by teams tend to be different then strategies developed by individuals. Individual decisionmakers tend to believe that their judgement of the situation is the best and that their task is the most important. When possible, teams tend to overuse communication channels in an attempt to reduce future uncertainty. This is particularly true when the workload is light. Finally, teams tend to underestimate their ability to coordinate implicitly. (Wang, Serfaty, Luh and Kleinman, 1991)

b. *Team Adaptation to Time Stress*

The level of stress that a team encounters influences the their performance in different ways. As the external load began to increase the teams prioritized their tasks and eliminated those with a low priority (Miao, Luh and Kleinman, 1990). At this stage the teams seemed to prefer

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processed information to raw data. Additionally, the amount of communication among the team members tended to decrease sharply. Decisionmakers shrank their planning cycle and eliminated tasks that required extensive coordination. Although the teams were beginning to encounter problems, the level of performance usually remained fairly high.

As the external load increased even further the teams performance decreased significantly. The teams tended to disintegrate into a collection of individual decisionmakers instead of a cohesive team. The load was spread unequally in order to reduce the amount of coordination required between members of the team. This is unfortunate for the decisionmaker who happens to be in the busy sector. Additionally, the error rate showed a significant increase as team performance decreased. (Wang and others, 1991)

c. Communication Strategy

As the tempo of the external load increased from a low tempo to a moderate tempo the teams explicit coordination and resource transfer rates tended to increase. However, as the tempo increased to a high rate, the explicit coordination dropped to a rate significantly lower then the low tempo rate. The researchers concluded that the high tempo forced the team members to behave more like individual decisionmakers then as a coordinated team. (Wang and others, 1991)

d. *Team Leader*

The role of the team leader diminishes as the subordinates are provided with communication methods for cross coordination or if information sources are shared throughout the team. The team leader is affected by the type and amount of information received. The team leaders authority must be consistent with the information that is available. Blanket authority without information causes the team leader to intrude on the decisionmaking of his/her subordinates. However, too much information can quickly overload the team leader and render decisionmaking impossible. (Shi, Luh and Kleinman, 1990) Leaders at different levels tended to hold different perceptions of the team problem. These perceptions caused internal conflict in the team and forced differing coordination methods at the different hierarchial levels in the team. (Wang and others, 1991)

4. Research Questions

The goal of the RAINCOAT experiment is to provide further information into the dynamics of team decisionmaking as practiced by teams of military decisionmakers. The research question is: what is the impact of uncertainty, differing information flows and different leader roles on team performance and team decisionmaking procedures.

III. METHODOLOGY

A. EXPERIMENTAL DESIGN

The purpose of this study was to examine the effects of certainty of target identification, the command structure, and the role of the leader on team performance, team strategy, and team coordination. A double 2 x 2 repeated-measures within-subject design was used. As Figure 1 indicates the design allows us to examine three main effects (U, I, and L) and two interaction effects (U x I and I x L).

1. Independent Variables

The independent variables for this study were (1) Neutral/Enemy Discriminability Uncertainty (2) Team Information Structure and (3) Leader's Involvement in Resource Coordination. Neutral/Enemy Discriminability Uncertainty (U) was established by having all enemy aircraft fly at either 0.4 kft (low uncertainty) or 0.5 kft (high uncertainty). In both the low and high uncertainty environments neutral aircraft flew at 0.7 kft. In both cases sensor noise caused readings to fluctuate with a standard deviation of 0.2 kft and the scale was truncated at two standard deviations. So, for example, 100% of enemy aircraft in a low uncertainty situation would have readings from 0.0 to 0.8 while neutral aircraft in the same situation would have readings from 0.3 to 1.1. These
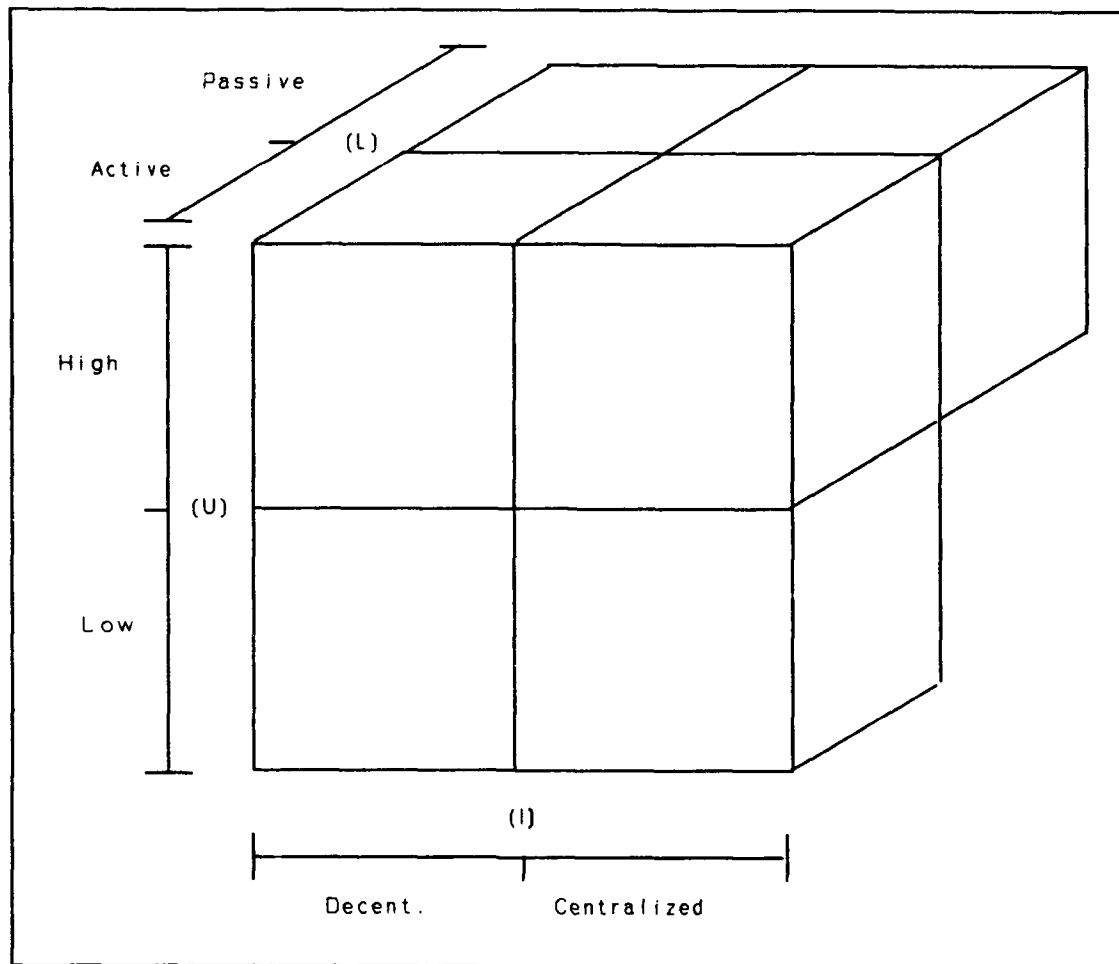
Figure 1 –   Experimental Design

numbers show that readings from 0.3 to 0.8 could be either enemy or neutral showing how uncertainty is built into the study (see Figure 2).

Team Information Structure (I) was termed either Centralized or Decentralized. The leader's information set always included all targets (enemy, neutral, and unidentified). This independent variable pertains only to the subordinates' information structure. In a Decentralized environment the subordinates' information set includes targets

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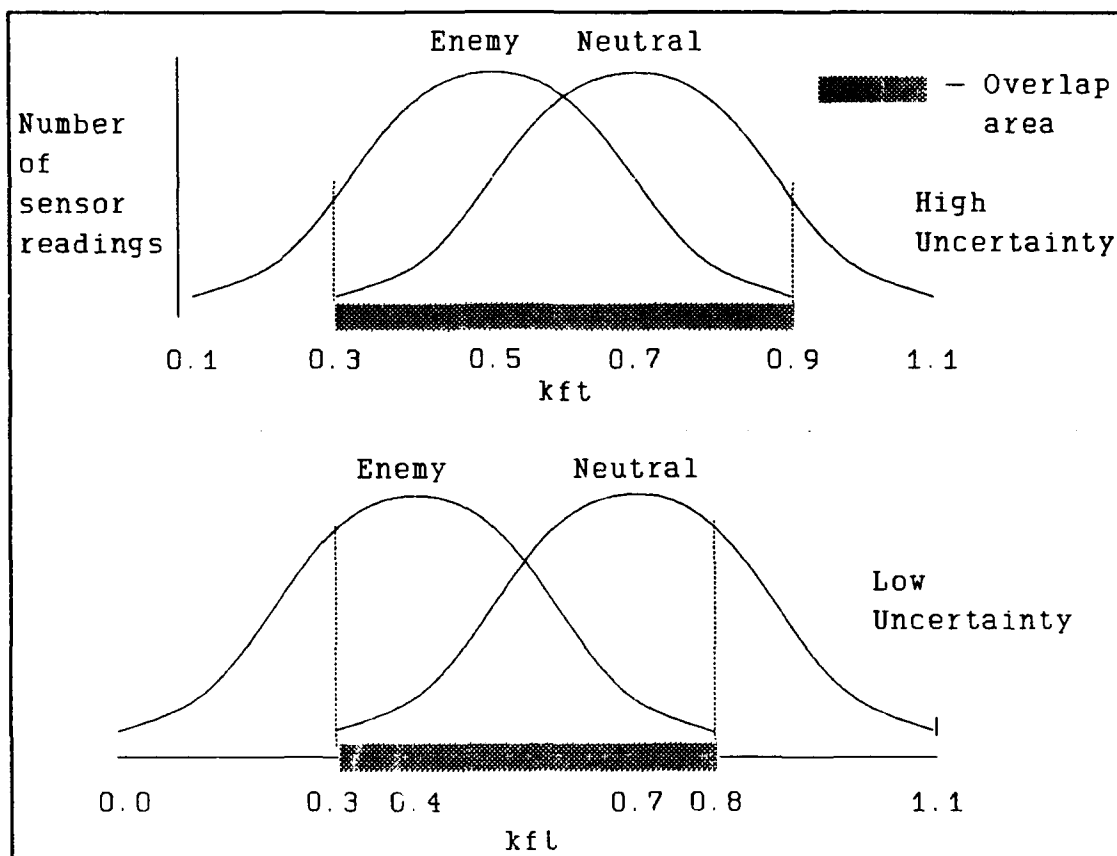
Figure 2 - Neutral/Enemy Discriminability Uncertainty

in their own area of responsibility (including own overlap areas) only. In a Centralized environment the subordinates' information set includes targets in their own area of responsibility and any enemy identified as such in all three areas.

Leader Involvement in Resource Coordination (L) was termed either Active or Passive. In an Active leader role, the leader was involved in situation assessment and enemy attack determination, and was allowed to take an active part in resource coordination and platform transfer among the

subordinates (including advice on transfers and forced transfers).

In a Passive leader role the leader was only involved in situation assessment and enemy attack determination, but was not allowed to take part in resource coordination and platform transfer among the subordinates.

2. Raincoat Counter-Balanced Design

Six basic scenarios were designed, with an embedded two-level variable: team coordination requirement. Depending on the direction of the main enemy attack, either resource or task coordination is being stressed. The scenarios were randomized across teams and experimental conditions in such a way that every Exam was treated once by each of the six experimental conditions and by each scenario once. Three of these scenarios stressed resource coordination by placing the primary attack in the middle of a DM's own area of responsibility (each DM was given one primary attack). Resource coordination requires the DM to basically work on his/her own and request additional resources as required. The other three scenarios stressed task/action coordination by placing the primary attack in an overlapping sector (each overlap sector was given one primary attack). Task/action coordination requires two adjacent DM's to work together in deciding who is going to work on which target(s). Table 2 shows how the design was counter-balanced for this experiment.

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TABLE 2

COUNTER-BALANCED DESIGN

SCENARIO						
	1	**2**	**3**	**4**	**5**	**6**
Experimental Condition (U, I, L)	11	12	13	21	22	23
111	A	B/G	D	C	E	F
121	F	D	C	E	A	B/G
211	E	F	B/G	D	C	A
221	D	E	A	F	B/G	C
212	C	A	F	B/G	D	E
222	B/G	C	E	A	F	D

B. SUBJECTS

Subjects for the experiment consisted of 27 active duty military officers and one civilian employee of the National Security Agency enrolled in the Command, Control, and Communications (C^3 curriculum at the Naval Postgraduate School, Monterey California. Five of the subjects were female

and 23 male. The subjects were allowed to freely divide into seven teams of four members each. Within each group, one person was picked to be the leader (DM0) and the other members played the roles of three subordinate decisionmakers (DM1, DM2, and DM3). During the training and practice sessions the team members were allowed to freely change positions to get a feel for what was required of each position. Once the real experimental sessions began changing of positions was prohibited. The level of experience was controlled by using the Composite Warfare Commander - Distributed Dynamic Decisionmaking (CWC-DDD) experimental paradigm. None of the subjects had previously used the CWC-DDD simulation.

C. APPARATUS

In our experiment the CWC-DDD simulation software was set-up to run on a Sun Microsystems SPARC 1+ server with four SPARCstation SLC diskless workstations, each having a monochrome monitor and an optical mouse, all linked together through an ethernet. The software was written to run under SunOS and the Sunview operating environment. Team members participated in the simulation using the workstations while the server ran the simulation. The network and experiment were in a room where noise was kept to a minimum and distractions that might influence the outcomes were minimized. Each DM had adequate room and was kept from seeing the other DM's monitors.

D. TASKS

The tasks carried out by the subjects were conducted using the CWC-DDD experimental paradigm. The CWC-DDD simulation creates a tactical environment that replicates, with a considerable level of abstraction, decisionmaking problems encountered by commanders in naval battle groups. It was developed by a research team at the University of Connecticut for use in the CREST and ICS experiments to provide a rather abstracted military environment. Certain features of the CWC-DDD simulation were greatly simplified or even removed to allow us to focus on a particular aspect of the team decisionmaking process for purposes of the RAINCOAT (Resource Allocation In Naval Command Teams) experiment.

1. Problem Domain

The problem domain constructed for the RAINCOAT experiment consisted of three parts:

- Anti-Air Problem (Inner/Outer Air Battle). The objective of the blue team is to defend a defined area around an aircraft carrier against an orange air threat.

- Four-Person Blue Teams. A leader (Anti-Air Warfare Commander – DM0) and three subordinates (DM1, DM2, and DM3) responsible for three geographical sectors (see Figure 3).

- Orange Attack Scenario is pre-programmed in the simulation (there were six pre-programmed scenarios used for this experiment). Targets are maneuvering in the theater of operations. However, the targets are not reactive to the actions of the blue team.

2. Phases

Each experimental session is broken down into three phases: Planning (PL), Situation Assessment (SA), and Threat Prosecution (TP).

a. Planning (PL) Phase

During the PL phase the blue team receives a detailed description of their own resource capabilities (how many and what type of platforms and subplatforms), their relative emplacement in future operations, a brief intelligence assessment of the overall situation (whether the enemy is expected to attack), and a general description of the probable enemy attack tactics (that the enemy will use a primary and diversionary attack path). The job of the blue team is to prepare a coordinated defense plan based on this preliminary information, answer a few questionnaires, preposition their platforms, and wait for the start of the SA phase.

b. Situation Assessment (SA) Phase

During the SA phase the job of the subordinates is to allocate their sensors (platforms and subplatforms) and to take sensor readings in order to make a neutral or enemy assessment on a target-by-target basis, in their sector of responsibility. Figure 3 presents an example situational display for a subordinate commander showing the division of responsibility using pie-shaped geographical sectors for a
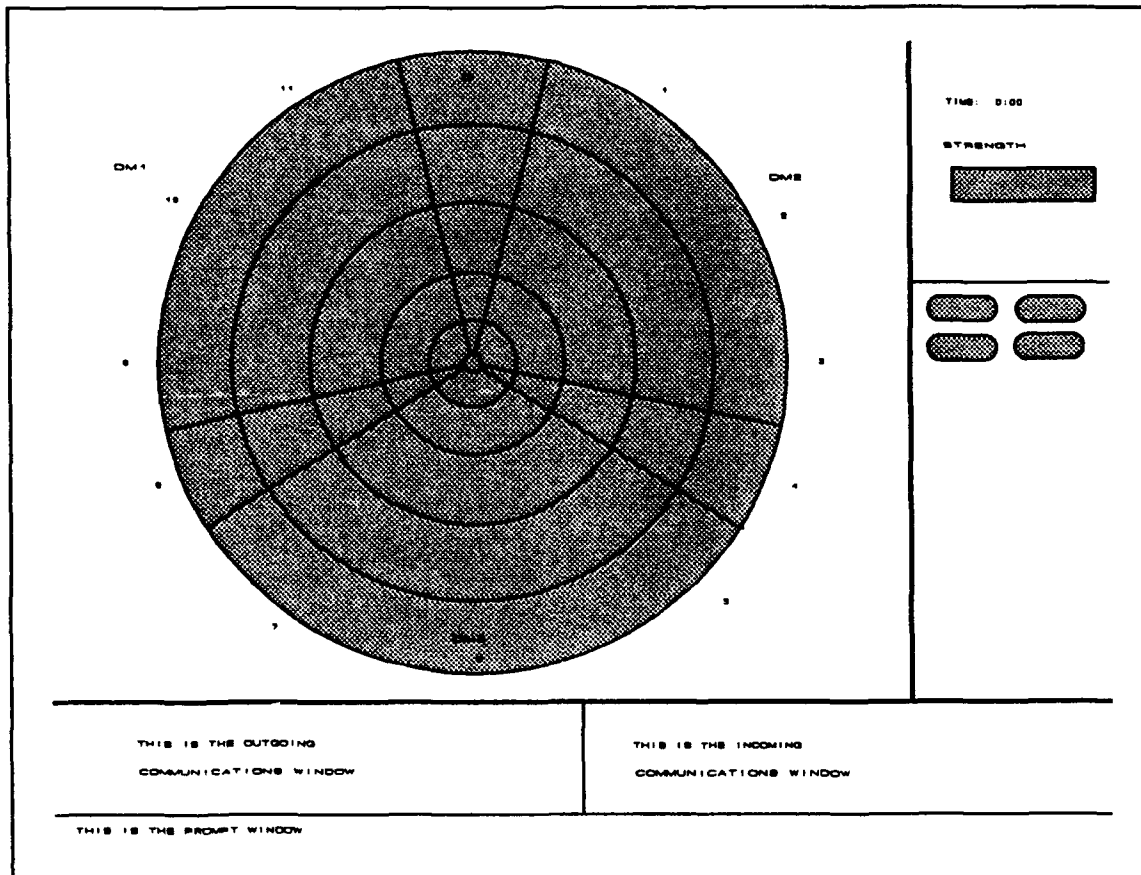
Figure 3 - Typical Screen

typical CWC-DDD simulation. In the next step the subordinates
report their assessment to the team leader (interpret their
sensor readings as either enemy or neutral, what size or
damage-inducing potential the target has, and how confident
they are in their decision). The job of the leader is to
request more information on a particular target if necessary
and once satisfied with the accuracy of all subordinates'
reports, to look at the global situation and make an attack
determination. He should decide if the blue forces are under
attack, where is the main avenue of attack or threat axis (in

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what sector), where is the eventual secondary or diversionary attack, and when the blue team should start threat prosecution for the purpose of self-defense.

c. *Threat Prosecution (TP) Phase*

During the TP phase the job of the subordinates is to allocate their subplatforms to engage the threat as defined by the leader. Each subplatform has a radius of lethality where an attack can be undertaken with a certain probability of kill. To do their job most effectively they must transfer resources (subplatforms) to the heaviest attack area and under the responsibility of that area commander. They may have to cooperate on some defense missions by pooling their resources together against a certain threat type. The job of the team leader is to ensure that the main goal of defending the carrier is achieved. To do so, he may have to enforce resource transfer among subordinates, set priorities on threats, and coordinate the subordinate's actions. A certain number of strength points are taken away from the team when a threat penetrates the inner defense zone, the blue team attacks a neutral, or the blue team does not allocate the proper amount of resources when attacking an enemy target. The objective of the team is to maximize the number of strength points remaining at the end of a scenario. At the completion of the trial a subjective workload assessment is

completed by each member of the team and finally a post-engagement questionnaire is distributed to team members.

E. EXPERIMENTAL PROCEDURE

Initial exposure to the experiment was accomplished through a briefing which covered very general characteristics of the simulation. Scheduling and other coordination was accomplished during this session so that each team would be able to provide a minimum of two hours per week for five consecutive weeks to the experiment. Each team was required to provide a minimum of ten hours to the experiment, four hours for training/practice and six hours for actual data collection.

1. Training and Practice Sessions

The first part of team training involved a walk through using hard copy screen dumps from an actual session. This method was used to explain each component of the screen to all members simultaneously. Different screen dumps showed various stages of the scenario and each window that a DM might see was fully explained. This portion of the first session lasted from 45-60 minutes. After completion of the walk through, each team member was seated at a station and the simulation was started (using training scenarios). During this first (and all subsequent practice sessions) run of the simulation two tutors were present to show different techniques and answer any questions posed by the subjects.

This part of the session lasted 35 minutes. Finally, to complete the first two hours of training, a practice session was started and the team was allowed to play freely, asking questions as necessary and having particular points stressed by the tutors. During the training/practice sessions team members were allowed to freely discuss anything about the simulation. The second training/practice session normally started with a review of the previous session. The remainder of the session consisted of running consecutive trials until the two hours was completed. By this point, most teams were confident in their ability to continue on with the data collection sessions. However, one team asked for another training session to work on some areas with which they were having trouble.

2. Data Collection Sessions

These sessions started out with briefings on the various parameters of the current session and pre-engagement questionnaires. During these trials no talking was allowed between DM's except through communications provided in the simulation. Each trial lasted approximately 35 minutes; however, 60 minutes were allotted for pre- and post-engagement questionnaires, a short break between trials, and any strategy discussions that the team conducted during the planning phase. Data was collected by the network and stored for later analysis.

3. Post Data Collection

After completion of all data collection sessions a short demographic questionnaire was completed by each subject and team strategies were discussed.

F. DEPENDENT VARIABLES

The dependent variables for this experiment were collected in order to capture the team behavior during each experimental scenario. They can be divided into three categories: Performance, Strategy, and Coordination.

1. Team Performance Measures

- Final Team Strength [%]. This is the most global measure of team performance. It is the one that each team attempts to maximize. At the start of the scenario (time=0), the team is given an initial strength S_0, representing some aggregate value of the defensive strength of the battle group. As the battle progresses, the team strength is being reduced by the damage caused by enemy forces as well as by mistakes made by the blue team, such as attacking a neutral task. The relative team strength at any time is computed as:

$$\frac{S_0 - \Delta S}{S_0}$$

  where ΔS is the loss at time t. This loss is a function of the number of threats that penetrated the inner defense, the number of neutral tasks attacked by the blue force, and the number of enemy targets that were attacked with inadequate resources by blue forces.

- Number of False Alarms []. This reflects a Type II misclassification error (target identified as enemy when it is really neutral).

- Number of Correct Enemy Identifications [].

- Number of Misdetections []. This reflects a Type I misclassification error (target identified as neutral when it is really enemy).

- Number of Correct Neutral Identifications [].

- Correct Enemy Classification Ratio [%]. This measure is computed as the ratio of correctly classified enemies (Low, Medium, and High damage-producing capability) to the total number of enemy targets that are identified as such.

- Number of Targets Unidentified [].

- Correct Primary Attack Determination [0/1]. If the leader correctly identifies the axis of the primary attack P (+/- 1 sector), then this variable takes a value of 1, otherwise it is 0.

- Correct Diversionary Attack Determination [0/1]. If the leader correctly identifies the axis of the diversionary attack D (+/- 1 sector), then this variable takes a value of 1, otherwise it is 0.

- Primary/Diversionary Attack Confusion [0/1]. If the leader incorrectly determines the axis of the primary attack p on the true diversionary attack D axis (+/- 1 sector), then this variable takes a value of 1, otherwise it is 0.

- Diversionary/Primary Attack Confusion [0/1]. If the leader incorrectly determines the axis of the diversionary attack D on the true primary attack axis P (+/- 1 sector), then this variable takes a value of 1, otherwise it is 0.

- Average Attack Score on Enemy Targets [points]. This score is the function of the value of the enemy target (damage-inducing potential) and the amount of attack resources used on the target. For enemy target k, the score is computed as

$$SC_K - VAL_K * REF_{K'}$$

where VAL is the target value (Low=1-4, Medium=4-6, and High=6-8), and REF is the resource effectiveness for target k. REF is defined in Average Resource Effectiveness.

- Total Number of Attacks of Enemy Targets [].

- Number of Attacks of Enemy Targets in the Primary (P) Attack Axis [].

- Number of Attacks of Enemy Targets in the Diversionary (D) Attack Axis [].

- Total Leakage [%]. Number of true Enemy targets that penetrated the Inner Defense Zone/Total number of threats.

- Total Leakage in (P) [%].

- Total Leakage in (D) [%].

- Total Number of Attacks of Decoys [].

- Total Number of Attacks of Neutrals [].

- Number of Attacks on Low Threat Targets [].

- Number of Attacks on Medium Threat Targets [].

- Number of Attacks on High Threat Targets [].

2. **Team Strategy Measures**

- Average Resource Effectiveness (AREF) [%]. An enemy target requires the allocation of a pre-determined amount of resources (weapons) to be attacked with maximum effectiveness (i.e., completely destroyed). The amount of

required resources is a function of the damage-producing capability of the target. This capability is indicated by the second attribute of the target, i.e., its value (Low=2-4, Medium=4-6, and High=6-8). Taking into account that each X subplatform contains 1 resource, and each Y subplatform contains 2 resources, Table 3 describes the resource requirements for attacks.

TABLE 3

RESOURCE REQUIREMENTS

ENEMY TARGET CLASS	LOW (2-4)	MEDIUM (4-6)	HIGH (6-8)
RESOURCES REQUIRED	1	2	3
SUBPLATFORMS NEEDED	1X or 1Y	2X or 1Y	3X or 1X+1Y

- The resource effectiveness of an attack on an enemy target is computed as the square of the ratio of resources allocated/resources required. For example, suppose that a high-valued enemy has been identified. Three resources are required for a complete kill. If a DM allocates 1X + 1Y platforms (three resources), the resource effectiveness (REF) is $(3/3)^2=100\%$. If a DM allocates only 1Y platform (two resources), the REF is $(2/3)^2=44\%$. There is no bonus or penalty for an over-allocation of resources. For instance if, in the case described above, the DM allocates 4X platforms when on three are required, the REF will still be 100%. The AREF is computed as the average of all REF on attacks on enemy aircraft by the blue team.

- AREF on Low Threat targets [%].

- AREF on Medium Threat Targets [%].

- AREF on High Threat Targets [%].

- Number of Attacks by Platforms [].

- Average Number of Platforms used for Identification []. Averaged across all targets identified.

- Average Team Latency [sec]. Delay between the appearance of a target and the very first team action on that target (communication, identification, or attack). When averaged across all targets, it represents a measure of the overall reaction time of the team.

- Average Identification Delay [sec]. Delay between the appearance of a target and the first team identification of that target. Averaged across all tasks identified by the team.

- Time of First Primary (P) Attack Determination [sec].

- Time of First Diversionary (D) Attack Determination [sec].

- Number of Attack Determinations [].

- Ratio of Targets Identified as Enemy but not Attacked [%].

- Number of Direct Attacks by Team Leader [].

- Average Attack Location [nm]. Distance between an attack location and the center of the battle group (A/C). Averaged across all tasks attacked by the team.

- Average Identification Confidence [].

- Average Number of Identification Actions per Task Identified [].

3. Team Coordination Measures

- Total Communication Rate [msg/min]. Total team communication traffic average over the length of the scenario. (Note: each broadcast counts as three messages).

- Number of Messages per Target Attacked [].

- Number of Platform Requests [].

- Number of Advices []. Number of "advise transfer" messages issued by the leader to transfer a platform between subordinates.

- Vertical Downward Communication []. Number of messages issued by the leader to the subordinates.

- Vertical Upward Communications []. Number of messages issued by the subordinates to the leader.

- Horizontal Communication []. Number of messages issued by a subordinate to another subordinate.

- Number of Platform Transfers by Subordinates [].

- Number of Platform Transfers by the Leader [].

- Number of Wasted Attacks []. A wasted attack may occur in the overlap sectors if a DM attempts to attack a target already under attack by another DM. This measure is indicative of a lack of planning and attack coordination among the team members.

IV. RESULTS

A. DATA ANALYSIS

Due to the large quantity of dependent variables in the data set it was necessary to reduce the number to a more manageable size. The experiment began with 49 dependent variables and through heuristic methods was reduced to 15. The original data set contained several dependent variables that were subsets of other dependent variables. These subsets provided redundant information that was of limited value and were eliminated from further consideration. The values of several other dependent variables were discovered to depend upon the experimental design and were also eliminated. An examination of the means of the remaining variables showed that the values of several of the variables changed little regardless of the independent conditions and were removed from consideration. Two variables were not considered because their values were affected by mechanical or software error.

Table 4 shows the dependent variables that remained, what they represented, their means, and their standard deviations. The data that remained were analyzed using an univariate analysis of variance (ANOVA) computed using the General Linear Models Procedure of the SAS statistical software program (SAS Institute Incorporated, 1988).

TABLE 4

FINAL DEPENDENT VARIABLE LIST

NUMBER	DEFINITION	MEAN	STDEV
1	Final Team Strength	64.67	21.84
2	Number of False Alarms	5.12	3.30
5	Number of Correct Neutral Identifications	19.71	3.27
6	Correct Enemy Classification Ratio	0.80	0.16
24	Average Resource Effectiveness	0.88	0.10
30	Average Team Latency [sec]	278.84	81.72
32	Time of First P Attack Determination [sec]	962.07	222.42
38	Average ID Confidence	1.92	0.26
39	Average Number of ID Actions per Task Identified	2.68	0.82
40	Total Communication Rate	0.67	0.48
41	Number of Messages per Target Attacked	1.69	1.36
44	Vertical Downward Communication	9.12	12.60
45	Vertical Upward Communications	4.05	4.19
46	Horizontal Communications	10.24	6.98
47	Number of Platform Transfers by Subordinates	1.95	1.85

The ANOVA procedure produces a value, p, which represents the probability of making an error in claiming that a dependent variable is affected by different levels of an independent variable. A value of $p \leq 0.05$ is considered significant. A value of $0.05 \leq p \leq 0.1$ is considered marginally significant. The ANOVA method also identifies significant interactions between two or more independent variables. (Miao, Luh and Kleinman, 1990)

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B. EXPERIMENTAL RESULTS

Two different approaches were taken in conducting the ANOVA. The first approach considers between cell interactions (see figure 1), while the second approach involves between team comparisons. A third approach was conducted using correlation techniques and an analysis of the processes which affected team performance.

1. Between Cells Analysis

a. Summary Statistics

Summary statistics (means and standard deviations) for each of the 15 dependent variables are given in table 5. The highest final team strength were attained in situations with an active leader and low uncertainty. In situations with an active leader and high uncertainty there was a significant difference in final team strength between a decentralized information structure and a centralized information structure (54.00 vs. 63.29)(See figure 4). Teams in the former situation (high uncertainty, decentralized information structure, and active leader cell) also showed considerably less team latency when the information structure was decentralized as opposed to all other cells. Under conditions of high uncertainty the first primary attack determination took longer when the leader was passive and the information structure was decentralized (1063.43 sec) or if the leader

TABLE 5

SUMMARY STATISTICS – BETWEEN CELLS ANALYSIS
MEANS
STANDARD DEVIATIONS

	CELLS					
	LOW DECENT ACTIVE	LOW CENT ACTIVE	PASS DECENT HIGH	PASS CENT HIGH	HIGH DECENT ACTIVE	HIGH CENT ACTIVE
1	73.00 24.30	70.71 25.36	61.86 21.90	65.14 20.92	54.00 13.87	63.29 25.44
2	2.29 1.89	3.14 1.35	5.86 2.67	6.29 3.59	7.14 4.60	6.00 2.45
5	22.57 1.90	21.71 1.25	19.14 2.67	18.57 3.46	17.86 4.60	18.43 2.37
6	0.84 0.17	0.69 0.15	0.81 0.14	0.77 0.18	0.77 0.21	0.84 0.10
24	0.89 0.09	0.89 0.00	0.85 0.13	0.91 0.09	0.07 0.00	0.85 0.11
30	289.70 95.96	289.20 79.32	272.89 86.23	278.00 83.95	255.18 74.58	287.98 95.05
32	966.71 133.23	1001.43 209.14	1063.43 261.91	848.14 288.95	887.29 229.21	1003.43 185.57
38	2.15 0.22	2.13 0.17	1.82 0.26	1.79 0.23	1.77 0.23	1.84 0.16
39	2.55 0.81	2.58 0.85	2.89 0.87	2.72 0.93	2.57 0.92	2.76 0.85
40	0.71 0.38	0.86 0.63	0.57 0.52	0.42 0.24	0.62 0.65	0.83 0.37
41	1.68 0.75	2.28 2.06	1.93 2.07	0.93 0.57	1.40 1.15	1.93 0.78
44	11.14 9.60	11.57 14.23	7.43 15.89	3.00 4.36	10.29 17.75	11.29 11.69
45	3.57 2.82	5.71 5.88	2.86 3.34	3.14 2.91	3.86 4.67	5.14 5.34
46	10.14 8.74	12.86 10.35	9.57 5.74	8.57 2.70	7.57 5.44	12.71 9.14

was active and the information structure was centralized
(1003.43 sec) as opposed to a passive leader with a
centralized information structure (848.14 sec) or an active
leader with decentralized information structure (887.29
sec)(See figure 5). Under high uncertainty, with an active
leader more identification actions were taken per task with
centralized information than with decentralized information;
however, with a passive leader more identification actions
were taken per task with decentralized information than with
centralized information (See figure 6). With a passive leader

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FINAL TEAM STRENGTH
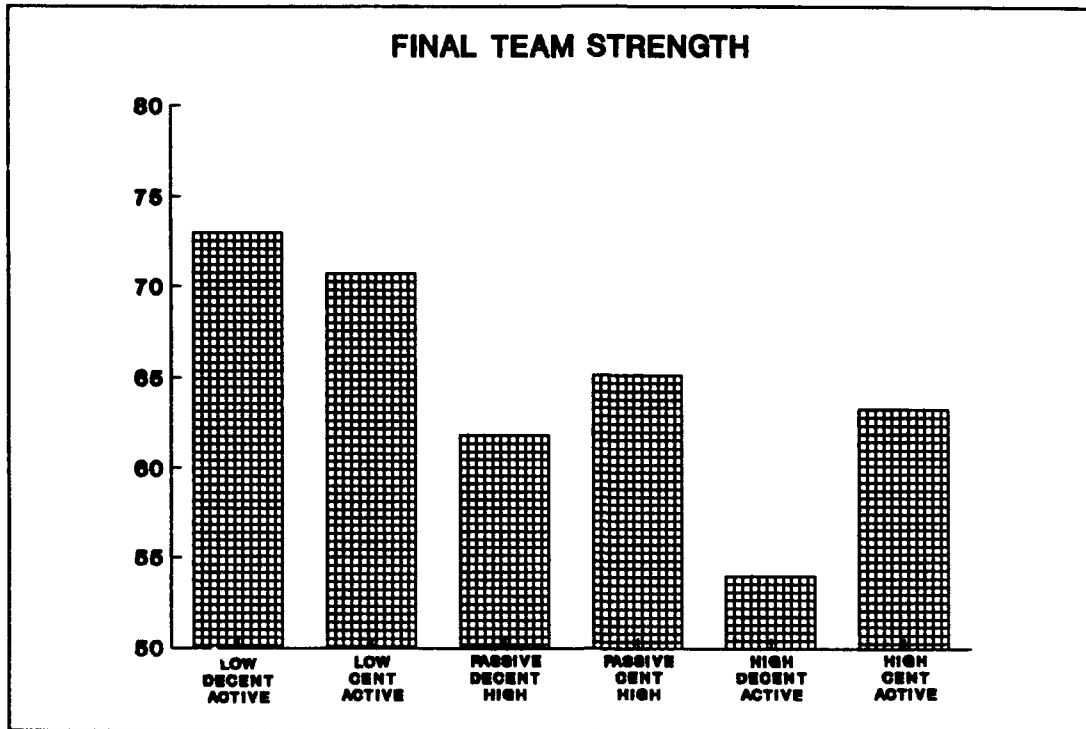
Figure 4 – Final Team Strength

and high uncertainty there were significantly more vertical communications in decentralized (7.43) as opposed to centralized (3.00) information structures. With an active leader there were more horizontal communications with centralized information than with decentralized information; however, with a passive leader there were more horizontal communications with decentralized information than with centralized information (See figure 7).

b. Analysis of Variance

Table 6 summarizes the results of the univariate analysis of variance (ANOVA) for the selected dependent variables. There was a difference in the number of false

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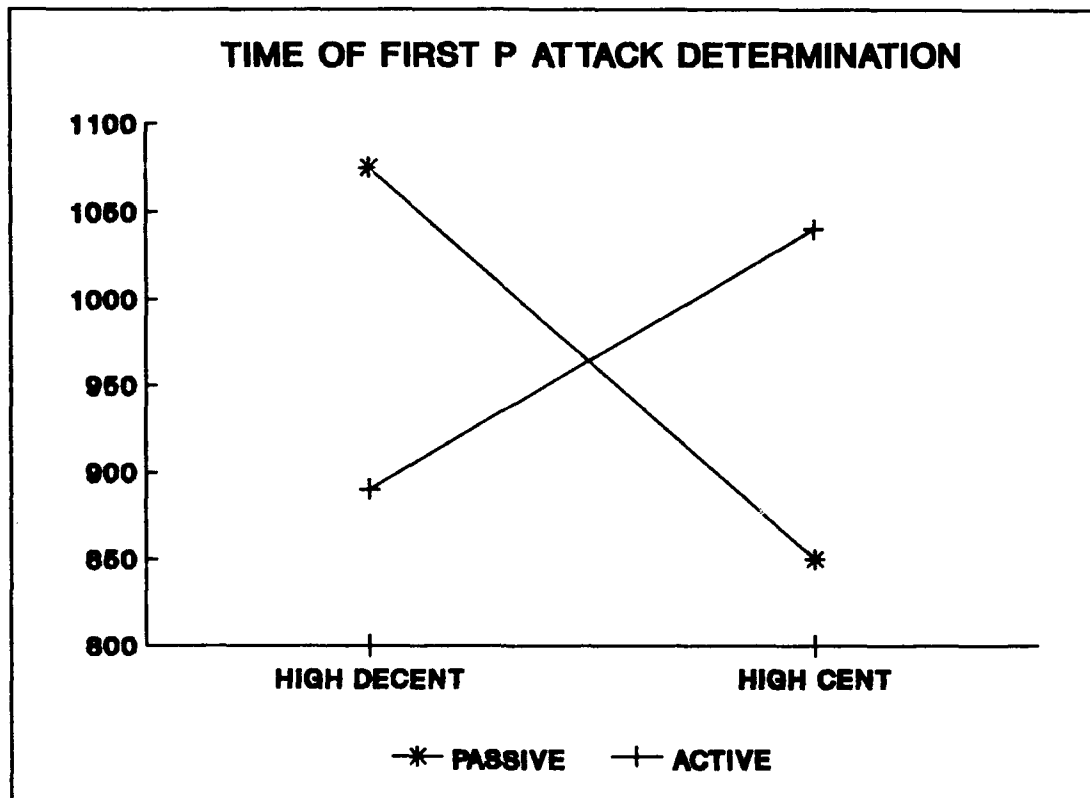
Figure 5 – Time of First Primary Attack Determination

alarms found in each of the cells at the 0.0234 significance level. This shows that in low uncertainty situations the number of false alarms is markedly less than in high uncertainty situations. Supporting the same hypothesis is the fact that the number of correct neutral identifications was significant at 0.0196 significance level. This shows that in low uncertainty situations teams were better able to identify neutral tasks than in high uncertainty situations regardless of the information structure or leader role. Average identification confidence was found to be significant at the 0.0020 level. This shows that in low uncertainty situations teams had higher average identification confidence than in
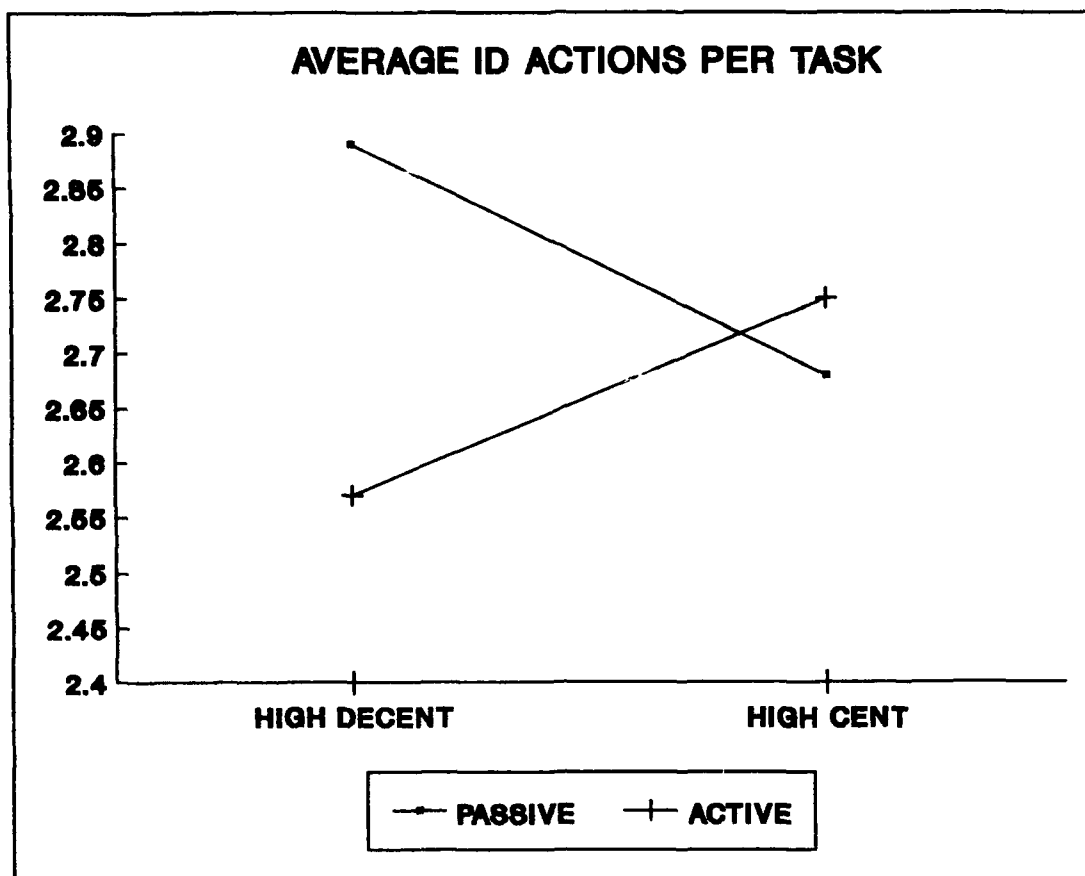
Figure 6 – Average ID Actions per Task Identified

high uncertainty situations. The dependent variables which showed significance in the between cells analysis all measured an impact of uncertainty. Dependent variables measuring impacts of the other independent variables did not show significance as measured by the ANOVA's. This supports the hypothesis that only uncertainty has a significantly different impact between the cells.

c. Team Composition Summary

Table 7 shows the composition of each team participating in the experiment. This table shows time-in-
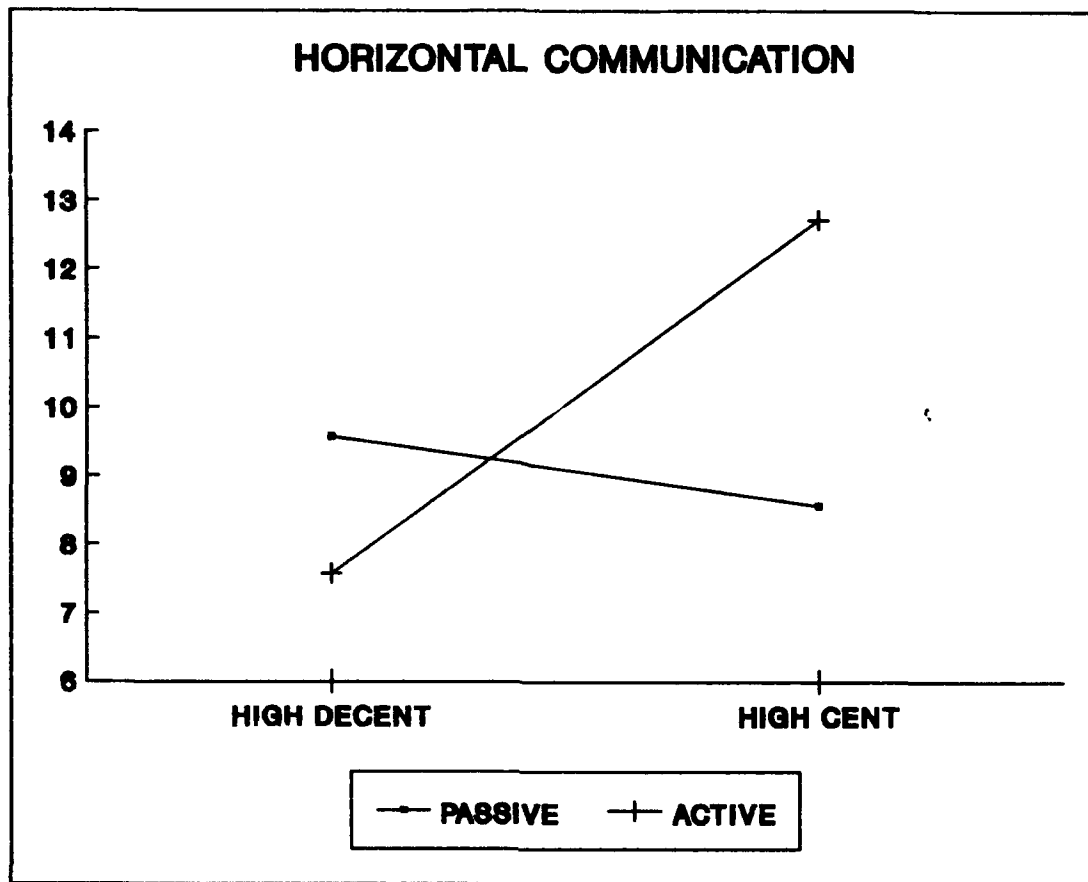
Figure 7 – Horizontal Communication

service, branch of service, specialty, team average time-in-service, tactical rating, and strategy rating. Tactical rating is a percentage of the team members that are trained to serve in tactical positions. This includes Surface Warfare Officer (SWO), Naval Flight Officer (NFO), Air Defense Artillery Officer (ADA), Pilot/Electronic Warfare Officer (EW), Anti-Air Warfare Officer (AAW), and Infantry Officer (INF). The non-tactical positions included Computer Related Specialty Officer (COMP), Communications Officer (COMMS),

TABLE 6

ANOVA - BETWEEN CELLS ANALYSIS

DEPENDENT VARIABLE	SUM OF SQUARES	F VALUE	Pr > F
1	1608.76	0.65	0.6668
2	130.97	2.99	0.0234
5	132.28	3.11	0.0196
6	0.03	0.26	0.9309
24	0.02	0.42	0.8332
30	6333.03	0.17	0.9719
32	225045.93	0.90	0.4926
38	1.09	4.73	0.0020
39	0.63	0.17	0.9733
40	0.98	0.83	0.5382
41	7.98	0.84	0.5271
44	395.26	0.47	0.7990
45	45.23	0.48	0.7860
46	163.33	0.64	0.6703

Instructor (INST), and Public Affairs Officer (PAO). The strategy rating information was gathered through team debriefings following their last experimental trial. Each team was asked to describe their strategy for handling overlap areas, transferring resources, and assigning confidence levels to identified tasks. Some of the teams had a coherent strategy while others did not.

d. Summary Statistics

Summary statistics (means and standard deviations) for each of the 15 dependent variables are given in table 8.

TABLE 7

TEAM COMPOSITION

TEAM	DM #	TIME	BRANCH	PRIMARY TRAINING	AVG TIME	TACTICAL	STRATEGY
A	0	6.5	USN	SWO	10.6	50%	YES
	1	6	USN	SWO			
	2	13	USAF	COMP			
	3	17	USAF	COMP			
B	0	8	USAF	COMMS	10.3	50%	NO
	1	12	USN	NFO			
	2	5	USN	SWO			
	3	16	USAF	COMMS			
C	0	5.75	USMC	ADA	6.1	75%	YES
	1	6	USN	EW			
	2	5	USAF	COMP			
	3	7.5	USN	AAW			
D	0	7	USN	INST	9.0	0%	NO
	1	16	USAF	COMMS			
	2	7	USAF	COMMS			
	3	6	USAF	COMMS			
E	0	11	USN	NFO/AAW	10.4	100%	YES
	1	16	USMC	INF			
	2	6.5	USN	SWO			
	3	8	USA	INF			
F	0	6	USN	SWO	6.75	75%	YES
	1	7	USAF	COMMS			
	2	6	USN	SWO			
	3	8	USN	SWO			
G	0	6	NSA	COMMS	6.1	50%	NO
	1	4	USN	SWO			
	2	5.5	USN	SWO			
	3	9	USN	PAO			

The three teams with high tactical ratings (75%+) showed significantly higher final team strength, higher correct enemy classification ratios, and better average resource effectiveness. The two teams with the lowest final team strength (A and D) had poor resource effectiveness, lower

average identification confidence levels, and significantly more vertical upward communications.

e. Analysis of Variance

Table 9 summarizes the results of the univariate analysis of variance (ANOVA) for the selected dependent variables. In the between teams analysis all of the selected dependant variable ANOVA's showed a significance level less than 0.05. This shows that significant differences existed between each of the teams' performance, strategy, and communication methods.

2. Process Analysis

As was stated before in Chapter III the dependent variables were broken into three categories; Measures of Performance, Measures of Strategy, and Measures of Communication. Final Team Strength, Number of False Alarms, Number of Correct Neutral Identifications, Correct Enemy Classification Ratio, and Average Resource Effectiveness are all measures of performance. Average Team Latency, Time of First Primary Attack Determination, Average Identification Confidence, and Average number of ID Actions per Task Identified are all measures of strategy. Total Communication Rate, Number of Messages per Target Attacked, Vertical Downward Communication, Vertical Upward Communication, and

TABLE 8

SUMMARY STATISTICS – BETWEEN TEAMS ANALYSIS
MEANS
STANDARD DEVIATIONS

TEAMS							
DVAR	A	B	C	D	E	F	G
1	44.33 22.07	61.33 26.81	85.00 22.75	41.17 19.46	71.33 14.05	80.67 6.95	68.83 17.11
2	4.83 2.94	4.67 3.20	3.33 1.76	4.50 1.17	4.17 5.79	5.00 3.00	9.33 2.35
5	19.83 2.94	20.17 3.15	21.50 1.76	20.50 0.82	20.83 5.58	19.83 3.00	15.33 2.46
6	0.84 0.06	0.76 0.13	0.92 0.17	0.67 0.06	0.94 0.23	0.93 0.08	0.57 0.17
24	0.80 0.13	0.86 0.11	0.98 0.07	0.78 0.07	0.90 0.06	0.96 0.06	0.85 0.08
30	375.03 59.10	338.02 25.58	260.29 98.21	303.25 110.48	131.28 45.68	307.56 60.49	236.42 71.60
32	879.83 229.74	951.17 141.47	836.50 119.88	708.83 176.31	956.33 83.55	1201.33 167.12	1200.50 21º.25
38	1.64 0.27	1.97 0.13	2.03 0.26	1.73 0.14	2.11 0.21	1.96 0.15	1.98 0.14
39	1.66 0.70	1.54 0.30	2.92 0.67	2.36 0.38	3.78 0.38	3.43 0.87	3.07 0.54
40	1.25 0.24	0.39 0.28	0.65 0.50	0.71 0.61	0.90 0.39	0.18 0.14	0.60 0.27
41	3.04 0.69	1.10 0.51	1.38 1.28	1.53 2.28	2.51 1.21	0.49 0.96	1.80 0.73
44	26.33 1.51	1.83 3.33	4.17 12.83	7.33 17.95	20.50 3.02	0.33 12.20	3.33 7.88
45	9.33 3.10	2.33 4.59	4.83 3.67	7.33 2.10	3.50 0.84	0.67 4.42	0.33 2.93
46	8.00 6.57	9.33 8.33	13.67 7.82	10.17 2.40	7.67 11.62	5.33 6.31	17.50 4.83

Horizontal Communication are all measures of communication. A correlation analysis was performed using the correlation procedures in the SAS statistical analysis software which produced a correlation matrix showing interactions between the variables (SAS Institute Incorporated, 1988).

TABLE 9

ANOVA - BETWEEN TEAMS ANALYSIS

DVAR	SUM OF SQUARES	F VALUE	Pr > F
1	10248.33	6.42	0.0001
2	135.23	2.54	0.0382
5	146.90	2.94	0.0199
6	0.74	16.67	0.0001
24	0.20	7.15	0.0001
30	228545.90	29.44	0.0001
32	1205442.62	8.55	0.0001
38	1.03	3.45	0.0088
39	26.45	107.54	0.0001
40	4.29	4.81	0.0011
41	26.55	3.13	0.0146
44	3703.90	7.72	0.0001
45	406.90	7.58	0.0001
46	605.95	2.54	0.0382

An analysis of the correlation matrix showed a moderate negative correlation (-0.35, P< 0.0217) showing that increased Vertical Upward Communications leads to decreased Average ID Confidence. Furthermore, there exists a moderate correlation (0.42, P<0.0057) indicating that decreased Average ID Confidence resulted in reduced Average Resource Effectiveness. Additionally, there is a strong correlation (0.82, P<0.0001) demonstrating that reduced Average Resource Effectiveness caused a lower Final Team Strength. This analysis is supported by the summary statistics of the between teams analysis.

Further analysis of the correlation matrix demonstrated that a moderate correlation (0.36, P<0.0197) existed showing that an increase in the Average Number of ID Actions per Task Identified led to an increase in the Average ID Confidence level. Also, a there was a moderate correlation (0.42, P<0.0057) indicating that an increase in the Average ID Confidence level caused an increase in the Average Resource Effectiveness. As indicated before increased Average Resource Effectiveness results in higher Final Team Strength. This analysis is also supported by the summary statistics of the between teams analysis.

A moderate negative correlation (-0.41, P<0.0073) indicates a decrease in the Vertical Upward Communication led to an increase in the Average Number of ID Actions per Task Identified. A further moderate correlation exists (0.45, P<0.0027) demonstrating that an increase in the Average Number of ID Actions per Task Identified led to an increase in the Final Team Strength.

V. CONCLUSIONS AND FUTURE RESEARCH

A. GOAL

The goal of this study was to determine the impact of (1) Neutral/Enemy discriminability uncertainty, (2) Team information structure, and (3) Leader's involvement in resource coordination upon four person teams consisting of military decisionmakers.

B. CONCLUSIONS OF STUDY

Three approaches were taken in the analysis of the experimental results; between cells analysis, between teams analysis, and an analysis of the processes that affected team performance. The between cells analysis showed that of the three independent variables the level of uncertainty had the most significant impact on team performance. With an active leader there was an increase in Horizontal Communications, Average ID Actions per Task, and Time of First Primary Attack Determination when moving from a decentralized information structure to a centralized information structure. The opposite was true when the leader was passive. These variables showed a decrease when moving from a decentralized information structure to a centralized information structure. The ANOVA only showed three dependent variables to be significant; Number of False Alarms, Number of Correct Neutral

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Identifications, and the Average ID Confidence. The first two of these are very closely related while the third is closely related to the level of uncertainty.

The between teams analysis shows that the level of tactical training within a team directly influenced the performance of that team. Teams with a more tactical background developed a more coherent team strategy. Average time-in-service appeared to have little or no impact on team performance. The two teams with the lowest Final Team Strength demonstrated poor resource effectiveness, lower confidence levels, and significantly more upward communication.

The process analysis demonstrated an association between communication methods, team strategy, and team performance. There were more significant correlations between strategy measures and performance measures than communication measures and performance measures, although the communication measures were highly correlated to each other. This analysis showed that the subordinates who tried to pass a large amount of information up the chain of command tended to assign that information much lower confidence levels causing less effective use of resources by the team and subsequently lower team strength. Conversely, the subordinates who passed less information up the chain-of-command were able to take more sensor readings and attained a higher team strength. Additionally, teams which took multiple sensor readings on

unidentified targets were able to assign a higher confidence level to each task leading to better resource effectiveness and finally a higher final team strength.

C. LIMITATIONS AND FURTHER RESEARCH

There were five primary limitations in the conduct of this experiment. First, communications were severely limited. Each decisionmaker was limited to a pre-established set of messages which was very restrictive. A recommendation would be to include either plain-text messages that can be entered from the keyboard or to establish voice communications.

Second, the workspace was very confined and the decisionmakers were not adequately separated from each other. A recommendation would be to ensure physical separation of all decisionmakers.

Third, during the conduct of the experiment it was discovered that sometimes the leader was unable to engage targets due to a problem in the software. After several discussions with the primary programmer it was decided that the software repair would have to wait until after the conclusion of this experiment. This led to removing one of the dependent variables from the data set (DVAR 36 - Number of Direct Attacks by Team Leader).

Fourth, the hardware that was used for this experiment included monochrome monitors. The use of color monitors would

enhance the decisionmakers ability to decipher information from the screen.

Fifth, decisionmakers were unable to filter the information presented on the screen. The ability to look at only targets identified as enemy or neutral would reduce clutter and increase readability leading to less confusion. This is especially true for the team leader.

Several follow-on studies are suggested by the results provided here. First, a study of the impact of implicit coordination, as a strategy, on communications and team performance. In the RAINCOAT experiment it became evident that some of the teams developed very comprehensive team strategies. They developed rules for assigning confidence levels to task identifications, resource allocation in the overlap areas and, types of communication methods. The impact of these rules showed up in the RAINCOAT experiment as improved team performance. Future studies could concentrate on analyzing this implicit coordination as an independent variable in order to quantify its impact.

Another enhancement to this study would be to move the decisionmakers into a more tactical setting and introduce external noise as an added pressure. The experiment was conducted in a quiet office setting. The decisionmakers were isolated from external interference and even prevented from talking to each other. Future studies could focus on introducing noise into the environment in order to analyze its

impact on the decisionmaking process. This would move the paradigm closer to a real life setting.

Third, subjective workload assessment data was gathered for this experiment. An analysis should be done to determine the impact of perceived workload on team performance. Data exists for each decisionmaker and for each team.

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