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13. ABSTRACT *(Maximum 200 words)*

Observations from fleet exercises indicate that access to reliable information is vital to timely, coordinated decision making. Under conditions of degraded tactical information, decisions are often delayed and alternate sources of relevant data are ignored; hence decisions are often based on an incorrect assessment of the situation. Common ways in which tactical information can be degraded include (a) periodic loss of data and/or voice communications, (b) conflicting or delayed reports from different sources, and (c) erroneous data mixed with veridical data. Empirical results concerning the specific impact of these factors are needed as a basis for modeling teams of decision makers.

In order to overcome many of the limitations of collecting data in fleet exercises, the RESA simulation laboratory at the Naval Ocean Systems Center was used for the studies reported here. RESA simulations are large-scale, event-driven battle simulations in which warfare commanders are presented with highly realistic, prescripted information streams to which they must respond. RESA provides high fidelity simulation of platform, weapon, jamming, and other environmental and hardware parameters.

A series of man-in-the-loop simulation experiments was conducted in the RESA facility to investigate the impact of degraded communications on tactical decision making. These experiments focused on the naval antiair warfare (AAW) commander during an outer air battle scenario. Naval officers who were experienced in battle group AAW participated in the experiments, serving as the commander. Each officer was presented with several battle simulation trials. Tactical information degradation was varied in these different trials. The primary responsibilities of the officers were to integrate and disseminate tactical information from different sources and to oversee and control the engagement of enemy aircraft. Several types of performance measures were collected during each simulation run, including the officers' ongoing verbalizations of their evolving decision process.

Overall findings indicated that periodic interruptions in data and tactical voice communications degrade battle effectiveness. This was largely the result of delays in the decision to launch additional interceptor aircraft as needed to counter the threat. The results suggested that the decision delays in launching interceptors were attributed to the commander's uncertainty about the tactical situation due to the interruption in updates of his geographical situation display. Few attempts to compensate for the communications losses were observed. Individual differences were noted in the extent to which the commanders relied on various kinds of tactical information and in their tendency to anticipate enemy actions. When multiple AAW decision makers (E-2 commanders) were dealing with overlapping sectors in the same simulations, few attempts to coordinate their activities were noted. Rather, each decision maker functioned independently for the most part, as though leaving coordination decisions to their superior.

These findings suggest that normative modeling efforts should characterize AAW decision making teams as tending to require confirmation of threats before reacting with well-defined response sequences. Interruption of the flow of tactical communications is especially disruptive, since this denies the commander data that he uses to trigger particular responses. Aiding techniques that help the commander to define and structure his response options may be of potential value. Such techniques could help to minimize the effects of interrupted communications by alerting commanders to the dynamic nature of the tactical situation.

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COMMUNICATION INTERRUPT EFFECTS ON TACTICAL DECISIONS

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Abstract

Observations from fleet exercises indicate that access to reliable information is vital to timely, coordinated decision making. Under conditions of degraded tactical information, decisions are often delayed and alternate sources of relevant data are ignored; hence decisions are often based on an incorrect assessment of the situation. Common ways in which tactical information can be degraded include (a) periodic loss of data and/or voice communications, (b) conflicting or delayed reports from different sources, and (c) erroneous data mixed with veridical data. Empirical results concerning the specific impact of these factors are needed as a basis for modeling teams of decision makers.

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A series of man-in-the-loop simulation experiments was conducted in the RESA facility to investigate the impact of degraded communications on tactical decision making. These experiments focused on the naval anti-air warfare (AAW) commander during an outer air battle scenario. Naval officers who were experienced in battle group AAW participated in the experiments, serving as the commander. Each officer was presented with several battle simulation trials. Tactical information degradation was varied in these different trials. The primary responsibilities of the officers were to integrate and disseminate tactical information from different sources and to oversee and control the engagement of enemy aircraft. Several types of performance measures were collected during each simulation run, including the officers' ongoing verbalizations of their evolving decision process.

Overall findings indicated that periodic interruptions in data and tactical voice communications degrade battle effectiveness. This was largely the result of delays in the decision to launch additional interceptor aircraft as needed to counter the threat. The results suggested that the decision delays in launching interceptors were attributed to the commander's uncertainty about the tactical situation due to the interruption in updates of his geographic situation display. Few attempts to compensate for the communications losses were observed. Individual differences were noted in the extent to which the commanders relied on various kinds of tactical information and in their tendency to anticipate enemy actions. When multiple AAW decision makers (E-2 commanders) were dealing with overlapping sectors in the same simulations, few attempts to coordinate their activities were noted. Rather, each decision maker functioned independently for the most part, as though leaving coordination decisions to their superior.

These findings suggest that normative modeling efforts should characterize AAW decision making teams as tending to require confirmation of threats before reacting with well-defined response sequences. Interruption of the flow of tactical communications is especially disruptive, since this denies the commander data that he uses to trigger particular responses. Aiding techniques that help the commander to define and structure his response options may be of potential value. Such techniques could help to minimize the effects of interrupted communications by alerting commanders to the dynamic nature of the tactical situation.

Objective

Command performance and system effectiveness have been measured during a series of experiments examining the ability of naval battle force commanders to monitor and control air defense activities during information degradation (delay, conflict, and interruption). The research program uses these measures, along with results of fleet exercises and small-scale experiments, to develop improved guidelines for naval C^3 and weapons systems and to evaluate decision aids and decision support tools. Specific objectives of these experiments were to:

- Examine the effect of degraded information states on a critical decision in air defense.
- Describe how information use changes as the air defense scenario evolves.
- Explore individual differences in tactical information use and decision making.
- Examine the cognitive structures associated with tactical decision making.

Introduction

One of the first steps in establishing the architecture of a navy C^3 system and developing its design guidelines is to understand the communication needs of the commander. Unfortunately, command decision making is not well understood, and commanders' requirements for information are not easily specified. The description of the tactical situation available to a commander is incomplete, evolves with variable time delays, and contains noise and false signals. The consequences of noise, error, delay, and information interruption on combat decision processes have not been determined, because information use by humans in these complex environments has not been systematically measured or analyzed. In order to determine how commanders monitor, classify, and integrate the large amounts of information in C^3 systems, the following cognitive factors need to be examined: (a) the types of information used by the commander, (b) the frequency of use of that information, and (c) how the pattern of information use changes with the tactical situation. Documentation of the cognitive processes of the decision maker in battle is prerequisite to designing support tools and aids that can enhance combat system performance and improve battle outcome. Specifications for combat C^3 systems must be based on as complete a description of these cognitive processes as possible.

This paper summarizes the results of the first four simulation experiments of a series that was begun in 1988 in the RESA laboratory at the Naval Ocean Systems Center, San Diego. The RESA laboratory presents large-scale, event-driven battle simulations with realistic scenarios. High fidelity simulation is available for multiple platforms, sensors, and weapons under a complete range of tactical and environmental situations. The RESA laboratory has been used primarily for training naval battle force staffs and for studies of advanced sensor and weapons concepts. Our interest was to use the RESA facility for man-in-the-loop studies to determine the cognitive and decision processes of warfare commanders during battle.

Initial experiments in this series of simulations have dealt with one or two commanders responsible for the air defense of the battle force against a large raid of enemy aircraft. The experiments measured the overall effectiveness of the system with the performance of the commanders as its principal determining factor.

Technical Approach

The tactical scenario for the experiments has been the air defense of a two carrier battle force against a large raid of enemy bombers carrying air-to-surface missiles. The battle force included eight Aegis cruisers, four destroyers, and a fast combat support ship. The principal weapon employed was the F14D fighter-interceptor armed with modern air-to-air missiles. A hot war situation was assumed throughout. The simulation runs consisted of two hours of operational time compressed into 50 minutes of real time. Detailed intelligence and instructions were provided to all participants, and research assistants interacted with the computer system so that the commander was not required to learn simulation language or procedures. In order to standardize the scenario for the purpose of comparing the performance of different commanders, enemy actions were entirely preprogrammed for all simulation runs.

Simulation Facility

The RESA facility contains several command centers, each of which can be programmed to view events from the perspective of a major organizational component of the battle force. Command center work stations were set up to simulate standard navy tactical displays. Each consisted of a geographic display (GEO-Plot) that presented game objects in standard navy tactical symbology and automatic status boards that presented various alphanumeric data, including weapon, track and sensor data.

Participants

Each experiment employed between 12 and 32 experienced, active duty naval officer volunteers from the San Diego area for a half-day session, consisting of three to five simulation runs.

Data Collection

The RESA software automatically recorded engagement, orders and position information each minute. These data were coded and stored on magnetic tape and disks at the conclusion of each run. In addition, participants made verbal reports and were encouraged to think aloud in order to reveal cognitive factors influencing their decisions. Their comments and verbal communications were recorded on audio tape for subsequent protocol analysis. All relevant measures of effectiveness and performance were recorded and analyzed, including:

- Interceptor launch decisions.
- Communications and information use.
- Individual characteristics of experience and training.

Experiment 1

The first experiment required participants to make a single decision to launch all of their interceptors, once they felt they had determined the location of the incoming raid. The timing of their launch decision and the intercept vector assigned to the F14D's were the performance measures of major concern. Complete and accurate tactical information was available to the participants throughout the entire experiment on simulated data links.

Experiment 2

A more complex scenario with increased decision options was employed in the second and following experiments. The commander was given a range of tactical options, including the opportunity to launch fighters and to control them at will. A tactical communication degradation condition was introduced in which the tactical data link and voice communications circuits among the commander's ships and aircraft were interrupted at prescribed intervals. These interruptions were designed to simulate communications link breakdown due to extensive jamming, equipment failure, unusual atmospheric conditions, or superimposed requirements for electronic silence. During periods of full communications, tactical voice and digital data were continuously (100%) available to the participants. During periods of degraded communications, tactical data were interrupted 50% of the time. Also, a parallel, record communication network was introduced with variable time delays of 3–5 minutes. Other scenario features remained constant to facilitate comparison with the earlier experiments.

Experiment 3

The third experiment employed a greater range of tactical communication interruption conditions. One third of the trials were conducted under entirely continuous (100%) communications conditions; one third of the trials used a 33% interruption schedule; and one third of the trials had a 67% interrupt schedule. In addition, false tactical information was introduced to increase the participants' uncertainty regarding the location of the main portion of the raid. The remaining scenario features were the same as used in Experiments 1 and 2.

Experiment 4

The fourth experiment examined two air defense commanders as they jointly defended the battle force against an attack of enemy bombers. The participants were experienced early warning and tactical air control officers (E2C aircraft) from the Naval Air Station, Miramar, CA. Tactical data and voice communications were available full-time (100%) in half of the simulations and part-time (50%) in the remainder. In addition, two tactical situations were presented. In the simpler, balanced raid situation, enemy force arrival was uniformly distributed across the defense sectors. In the more complex, unbalanced raid situation, the larger portion (60%) of the raid arrived within one E2C's sector of responsibility, and the smaller (40%) portion of the raidwithin the other E2C's sector. Besides increasing the participants' uncertainty about the tactical situation, the complex, unbalanced situation created an opportunity for each participant to exchange information and to share assets to optimize their defense. Two forms of communication interruption were presented: (1) between the two E2C commanders and (2) between each commander and their common superior (AW), played by a researcher.

Results

Interceptor Launch Decisions

The decision to launch interceptors to engage the incoming Orange bombers is one of the most significant command actions in response to the tactical situation in these scenarios. It is a complex decision that involves multiple launches at different times, as determined by the commander's interpretation of the tactical situation. The decision to launch interceptors is a critical determinant of the range at which threats can be effectively engaged and the number of enemy aircraft that can be destroyed. Therefore, the time and rate of interceptor launches are two of the measures of greatest concern to this research program.

Experiment 1

In the first experiment, participants typically delayed their launch decision beyond the optimum time needed to make the most effective and complete intercepts. These initial observations raised questions about the C^3 organizational and information processing factors that contribute to the delay and what difference it makes to combat system effectiveness. Experiments 2 through 4 verified these basic findings and also measured the effects of communications degradation on air battle outcome.

Experiments 2 and 3

The tactical communications interruptions of Experiments 2 and 3 produced measurable reductions in launch rates (Figure 1). Compared to full communications, interrupted tactical data flow resulted in significantly delayed launches during the initial 30 minutes. This effect was especially pronounced in the 67% and 33% conditions. These launch delays were correlated with other measures of effectiveness and performance [1, 2]. In addition, not all aircraft were launched, regardless of communications condition, partially due to inadequate time remaining to intercept the raid (shown in the Figure at 55 minutes). The tactical information time delay of Experiment 2 and the use of false tactical information in Experiment 3 did not significantly impact performance under these conditions.

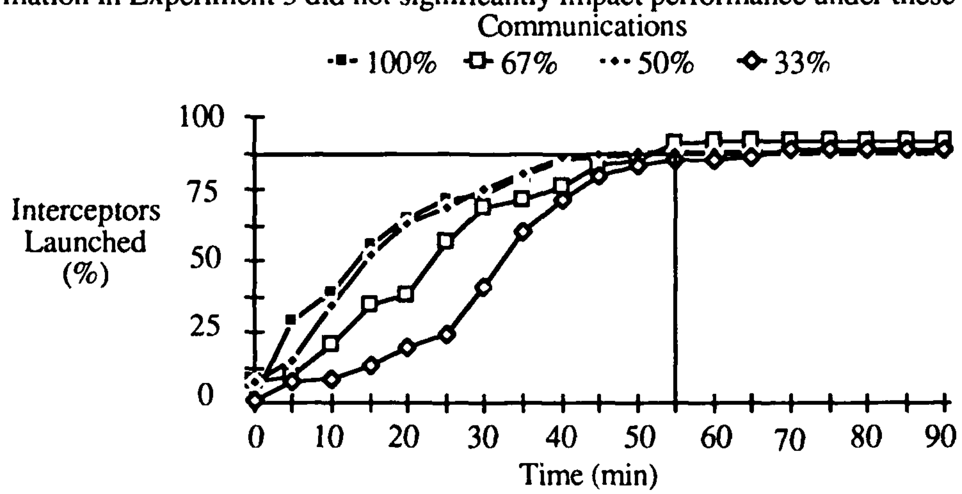

Figure 1. Cumulative interceptor launches, Experiments 2 and 3.

Experiment 4

Figures 2 through 4 show averaged, cumulative interceptor launches over the course of the battle simulation in Experiment 4. Figure 2 shows the simple tactic (balanced enemy force distribution) with full communications; Figure 3 shows the complex tactic (unbalanced enemy force distribution) with communications interruption between participants (E2C–E2C); and Figure 4 shows the complex tactic with communications interruption between the participants and their common superior (E2–AW). Each figure has been labeled to indicate the latest possible time of launch to successfully intercept the incoming enemy force.

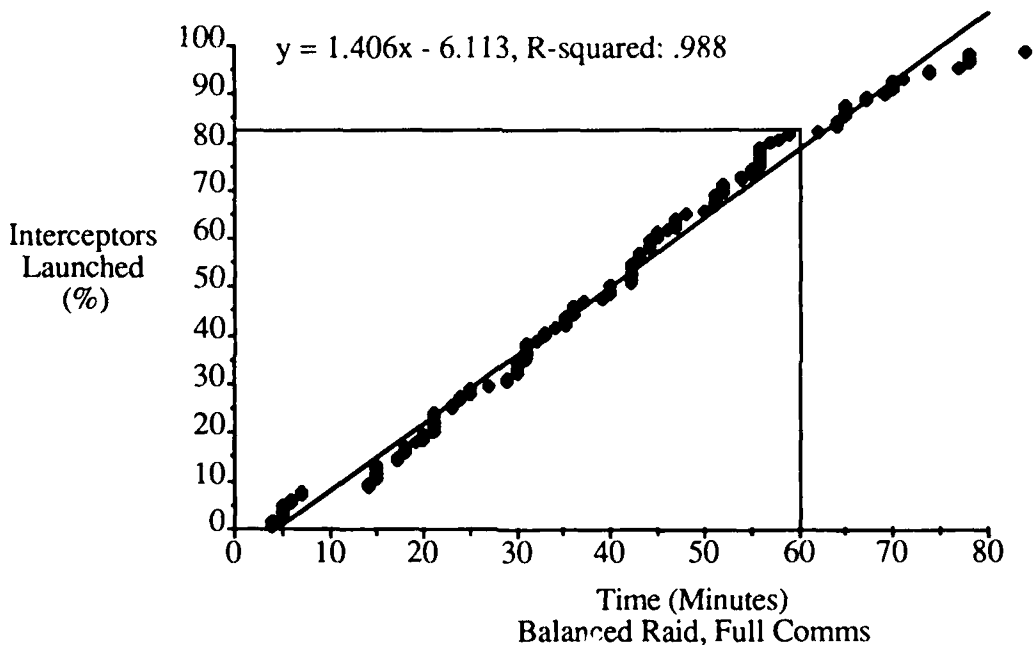

Figure 2. Cumulative interceptor launches: Simple tactic, no communications interruption.

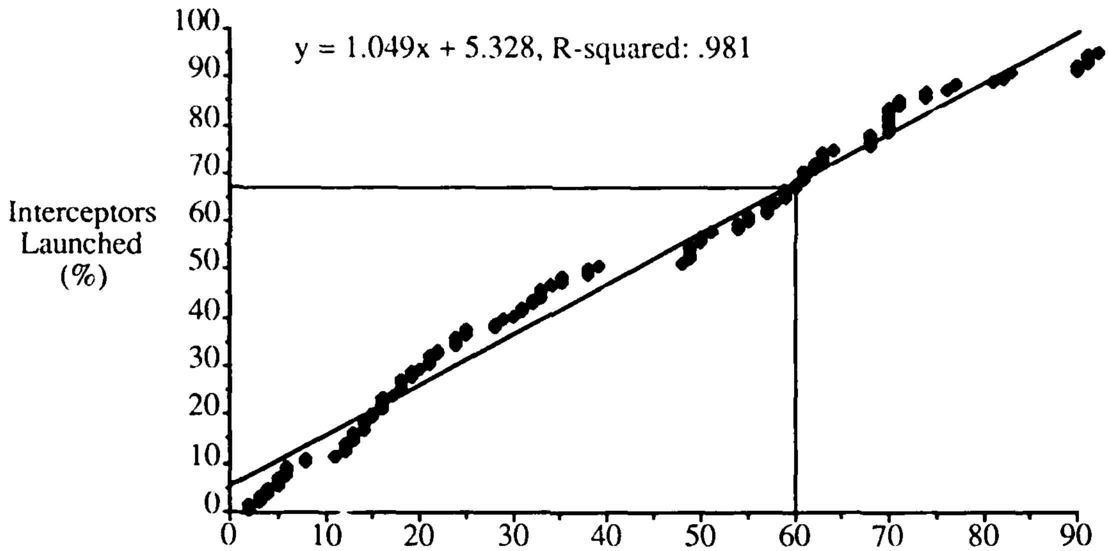

Figure 3. Cumulative interceptor launches: C‿mplex tactic, E2C–E2C communications interruption.

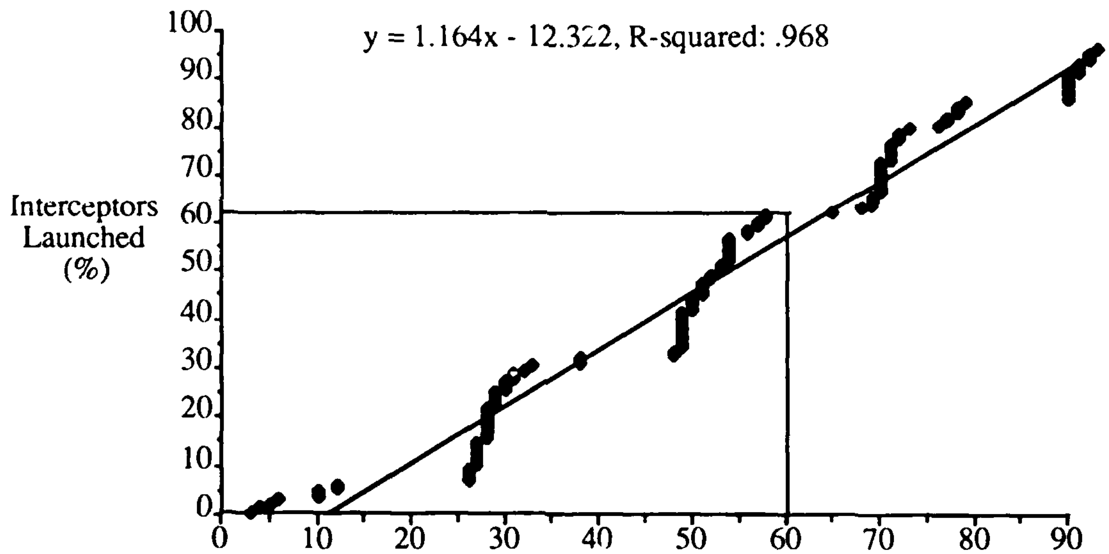

Figure 4. Cumulative interceptor launches: Complex tactic, E2–AW communications interruption.

Note the marked reduction in percentage of interceptors launched by time 60 from the simple, tactic, full communications condition (Mean = 83%), to the complex tactic, E2C–E2C interruption condition (Mean = 67%), to the complex tactic, E2C–AW communications interruption condition (Mean = 62%). The evidence indicates that the effect of information degradation is compounded by the complexity and uncertainty of the tactical situation.

Communications and Information Use

To analyze the commander's information requirements and cognitive processes, extensive verbal protocol analyses were conducted on audio tape recordings of the commander's comments and communications in all of the experiments. An example of the findings is shown in Figure 5.

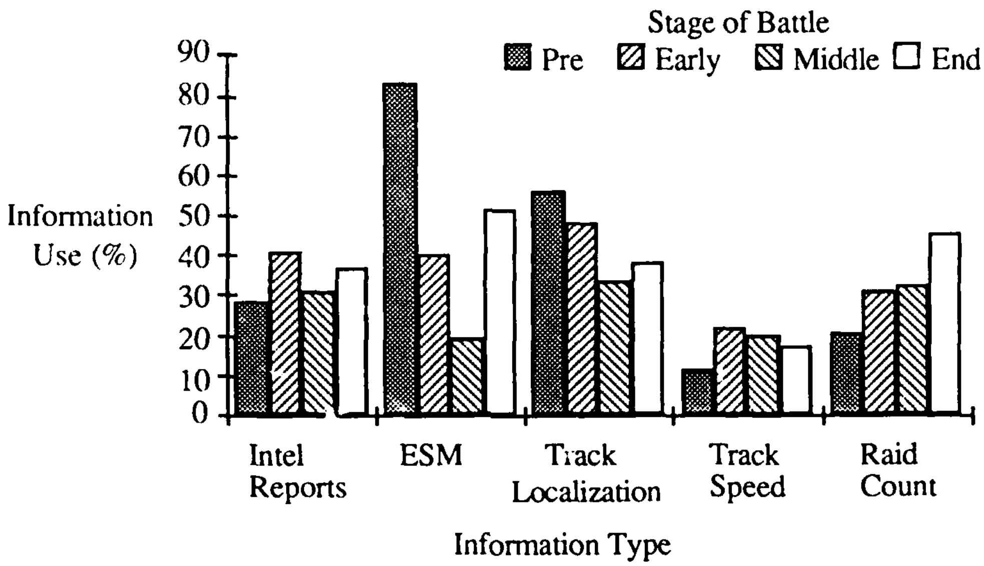

Figure 5. Information use profile during the air defense battle.

This figure shows the commanders' reliance on ESM information during the early stages of the battle, as well as the decreasing interest in location information (track location) and the increasing interest in raid count during the later stages of the battle. Other results of the protocol analyses describe changes in communication rates (messages per minute) during the course of battle.

Cognitive Network Analysis

A related part of this research program used network scaling techniques to investigate commanders' cognitive structures. Previous research has shown that cognitive structures exert a significant influence on decision making performance, and that experts and novices often differ noticeably in cognitive structure [3]. In the present context, cognitive networks can contribute to an improved understanding of how tactical informatin is organized in the decisison maker's mind.

The cognitive structures reported here are networks in which individual information elements are depicted as nodes, and the relationships among those elements are depicted as links connecting the nodes. A link is placed between two nodes if the resulting distance forms the shortest possible path between them. Link length is determined by weights that reflect the strength of the relationship between the elements. These weights, obtained through participants' ratings of element similarity, provide a direct measure of psychological distance between elements. Elements rated as highly similar are assigned a correspondingly small psychological distance value, and vice versa. Networks of tactical information elements based on psychological distance data can convey the cognitive organization of information which is used in tactical decision making.

A rating task was employed to collect similarity values among a set of ten tactical information elements that were closely related to air defense activities. Participants' similarity judgments were obtained for all pair-wise combinations of these elements. The similarities rating task was performed by each participant both before and after the air defense simulation exercises described above as part of Experiments 3 and 4.

Empirically-Derived Cognitive Networks

The cognitive network based on the averaged similarity ratings for all participants in Experiment 3 [2] is shown in Figure 6. Target Identification is the most central element in the network, being linked to more elements (5) than any other element. Note that link lengths, which reflect degree of element relatedness, do not differ greatly from each other. In part, this is a consequence of data averaging; however, it also indicates that the concepts linked directly to each other were judged as roughly similar in importance. Elements judged less similar to each other are separated by more than one link. Five intervening links separate the two pairs of elements that are least related to each other, Interceptor Launch - Emissions Control and Fuel/Weapons Replenishment - Emissions Control.

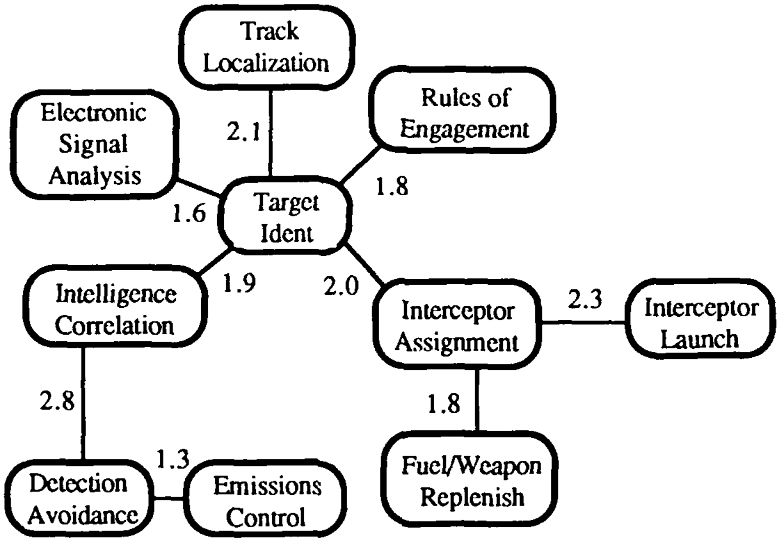

Figure 6. Information element network for Experiment 3.

The corresponding network obtained from Experiment 4 participants [4] is displayed in Figure 7. Once again, Target Identification is the most central element in the network, and is linked directly to the same five elements as in the Experiment 3 network. As before, note that the link lengths do not differ greatly from each other. Overall then, networks in Experiments 3 and 4 are remarkably similar in configuration and link length, in spite of the fact that the participants in the two experiments possessed different operational backgrounds and levels of experience.

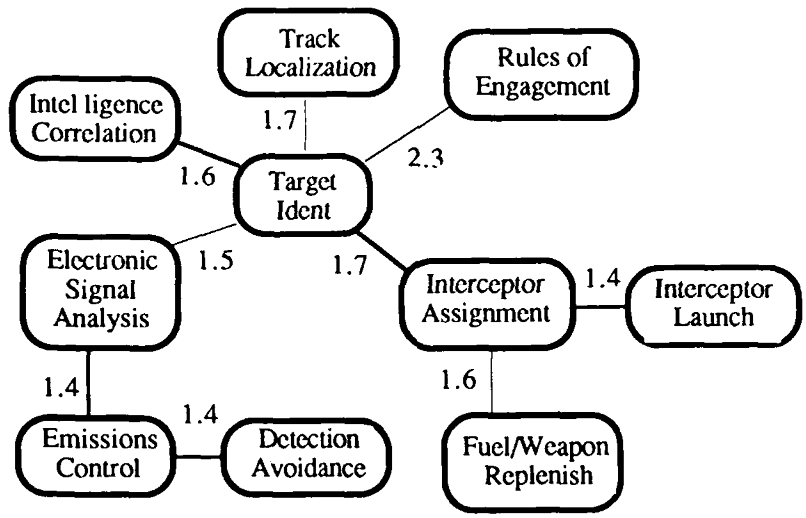

Figure 7. Information element network for Experiment 4.

Table 1 shows the results of a quantitative analysis of the degree of similarity of these networks. The **Centrality** of each network can be is represented as the median of the distances from the t..ctical information elements to the central element (Target Identification). The rank order correlation between the Centrality distances of the two networks is significant (Kendall's tau = .592, $p < .05$), supporting a conclusion that the two groups of officers possess highly similar cognitive structures for these information elements.

Table 1

Comparison of Information Networks: Experiments 3 and 4

Tactical Information Element	Difference Between Expts	Distance to Central Element Expt 3	Distance to Central Element Expt 4
Target Identification	0	0	0
Track Localization	0.4	2.1	1.7
Electronic Signal Analysis	0.1	1.6	1.5
Intelligence Correlation	0.3	1.9	1.6
Detection Avoidance	0.4	4.7	4.3
Rules of Engagement	0.5	1.8	2.3
Emission Control	3.1	6.0	2.9
CAP Assignment	0.3	2.0	1.7
Intercept Launch	1.2	4.3	3.1
Fuel/Wpn Replenishment	0.5	3.8	3.3

Median	0.4	2.1	2.3

The cognitive network analyses will be continued in future research to aid in understanding the effects of information organization for battle force commanders and their staffs. As part of this effort, we will also examine officers with a wider range of battle group experience and include control groups of individuals with no naval warfare training or experience.

Discussion

The purpose of this series of man-in-the-loop studies is to analyze the organizational structure and information requirements of the battle force. Reliable estimates of information requirements in combat can form a solid basis for C^3 system design guidelines. The types and patterns of communications among key personnel and tactical information flow to the battle commander were focused on in these studies. To achieve this we have assessed information use and decision making by personnel in command positions and relating it to the effectiveness of the total combat system. Experienced naval officers were examined under various tactical, information loading, and information degradation conditions during repeated simulation exercises of a prolonged air battle. Results showed that interruption of tactical communications introduced significant delays in critical interceptor launch decisions and reduced the effectiveness of tactical air control.

Most officers were unaware of the extent of the system performance deficit caused by the information degradation and, as a result, failed to compensate for it. They consistently delayed critical decisions (e.g., interceptor launches) until the threat was visible on radar. This conservative behavior persisted even after the officers had performed multiple simulation runs with similar outcomes. Furthermore, this conservatism was exacerbated by tactical situation complexity. Most participants concentrated their attention on a single geographical display, regardless of its currency, and neglected information from other sources. Most did not obtain maximum benefit from multiple sensors and tended to disregard contradictory information. Shifts in the use of tactical information were noted as a function of the stage of battle—from long range detection to final, close-in encounters. An individual-difference classification system was proposed along two dimensions: (1) extent of information used and (2) conservatism in response to tactical information.

Quantitative scaling techniques show promise for improving understanding of the cognitive organization basis of command decision making. Cognitive network structures, through their link patterns and link lengths, can explicitly depict the inter-relationship of tactical information elements and concepts. The role of experience in determining the organization of cognitive structure and information processing characteristics relevant to air defense merits further attention.

Conclusions and Recommendations

This experimental series represents an effort to gather empirical data about command decision making empirically, in a realistic, complex environment. Traditionally, system measures have been used to examine the outcome of warfare simulations without the measured contribution of the decision makers. Although this experiment demonstrated some notable and consistent effects of communications degradation, it also suggested several areas to be explored in future research. These areas, which directly extend the findings of this experiment, include:

- Design and/or test of decision aids for the anti-air warfare commander. Decisions such as those involved in interceptor launches can be aided by appropriate decision support tools. Existing aids can be evaluated and new concepts developed and tested in the RESA simulation with the commander in the loop.

- Expand investigations of the role of the decision maker to include planning functions. The influence of preplanning for air defense is of recognized importance, particularly to prepare for periods of communications interruption and/or unexpected tactical situations.

- Examine various distributions of duties and command structures. Each command organization calls for an appropriate communication architecture. The resulting distributions of function and their communications networks are likely to have differing force multiplier effects. The extent of the effects may be assessed through continued man-in-the-loop simulation research as represented by these experiments.

- Examine the impact of off-board information on effectiveness. The influence of such non-organic information depends partly on how well it can be transmitted through the command organization to reach the proper commanders in a timely fashion.

- Determine whether these effects can be generalized to other warfare areas. The findings concerning command decision making are intended to reveal potential improvements that can be used to enhance C^3 systems in all warfare areas.

- The cognitive network structures of tactical decision makers should be more thoroughly studied. Determining how they differ as a function of experience would be especially valuable. Such information could be used in developing training programs that encourage the development of cognitive structures associated with expert decision making performance.

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