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As an aspect of the operational decision aid program of the Office of Naval Research, an emission control decision aid was evaluated.

The evaluation was completed under laboratory conditions and involved use of the aid by Navy officers to develop emission control plans for a variety of task force situations.

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The results supported contentions favoring the value of the aid. There was a positive and statistically significant effect of aiding on emission control plan quality. When emission control plans developed with the use of the aid were compared with those developed without employing the aid, a 25 percent increase was suggested in the value of own task force remaining after a hostile air strike. It was suggested that the strength of the aid was largely due to the trade off evaluations that it provides. Interview information suggested that the participants in the study viewed the aid quite favorably, but that a number of "improvements" would produce a more useful tool.

EVALUATIONS OF OPERATIONAL DECISION AIDS

2. The Emissions Control Aid

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This work formed a part of the operational decision aid program of the Office of Naval Research.

SUMMARY

As an aspect of the operational decision aid program of the Office of Naval Research, the second in a series of decision aiding tools, an emission control, electronic warfare (EWAR) decision aid was evaluated. The evaluation objectively tested both the general and the specific utility of the aid.

Description of the EWAR Aid

The EWAR decision aid was developed by Decision Science Applications, Inc., and is representative of a class of decision aids which stress assessment of various contingencies and trade offs among conflicting alternatives. The version tested was not considered to be ready for use but had reached a sufficient developmental stage as to warrant some evaluation for effectiveness and utility.

Essentially, the EWAR aid evaluates candidate emission control plans in a hierarchical manner along a number of dimensions. Four classes of information are made available by the aid to its user: (1) radar order-of-battle, (2) surveillance effectiveness, (3) information denial, and (4) trade off analyses.

The first information class, the order-of-battle information, provides data of a basic nature such as the radar suite on each ship in the task force and the configuration of the task force. The second and third information classes provide data which make increasingly abstract assessments of potential emission plans from unique and somewhat divergent perspectives; the perspective of the former is that of surveillance effectiveness while that of the latter is information denial. The final class of information attempts a synthesis or a trade off between these divergent perspectives. It evaluates by making a variety of assessments of the interplay of the surveillance coverage and information denial aspects of candidate emission control plans.

One user oriented feature of the aid appears to be especially useful to the fleet user. This feature allows the user to assign a "value" to task force ships which represents his evaluation of the various ships' importance to a specific mission.

Method

Two study groups were established. One group received specific training in emission control planning and in the use of the aid. The second group received only training in the use of the aid. Participants in both

groups were military members of the faculty of the U. S. Naval Academy. Both groups developed EMCON plans with and without the use of the EWAR aid. Both "easy" and "hard" problems were involved. Four hypotheses were tested: (1) emission control plans produced using the decision aid will be superior to those plans produced without the aid, (2) emission control training will further enhance the quality of the plans, (3) the difficulty of the problems will not affect the quality of the emission control plans generated in the aided condition, and (4) there will be a high correlation between constructed problem difficulty and perceived problem difficulty.

Data pertinent to each of the four hypotheses were collected and compared on the basis of an internal criterion measure--fraction of task force remaining after a strike. The criterion measure was selected because it reflected the essential and divergent aspects of emission control planning and because it was operationally meaningful.

Each participant was also interviewed to obtain his perceptions of the various features of the aid and his opinions about how completely the aid achieved its goals.

Findings

The results support contentions favoring the value of the aid. There was a positive and statistically significant effect of aiding on emission control plan quality. The merit of the aid can be indicated in terms of the value of the task force remaining after a simulated air strike. The use of the aid led to approximately a 25 percent increase in this value.

A multiple regression analyses indicated that the strength of the aid was largely due to the various trade off evaluations that the aid provides. A structural equation analysis suggested that the trade off was: (1) achieved by a reciprocal activity between the surveillance effectiveness and information denial, and (2) most heavily a function of surveillance coverage.

A multiple attribute utility analysis suggested that, on the overall, the aid achieved its goals quite well.

Interview information produced evidence that the participants in the study believed the "second order" (e.g., trade off) information provided by the aid to be most useful while the more basic situational information was said to be least useful.

No statistically significant effects were noted of training or of problem difficulty on EMCON plan quality.

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I. INTRODUCTION

The Office of Naval Research has been involved for the past five years in a program aimed at developing technologies for operational decision aids to be used by task force level officers and their staffs. Within this program, the Applied Psychological Services has been concerned with the empirical evaluation of various aids as they reach a suitable developmental stage. This report presents the results of the second such evaluation undertaken by Applied Psychological Services.

The report is concerned with the Electronic Warfare (EWAR) decision aid under development by Decision Science Applications, Inc. (Noble, et al., 1978). The EWAR aid was designed to be used by electronic warfare officers to facilitate the development and appraisal of emission control (EMCON) plans.

The task of an electronic warfare officer, in terms of radar emissions, is twofold. The two aspects of EMCON planning which he must consider are, to some extent, diametrically opposed. The basic function of radar emitters is to provide surveillance coverage against possible enemy attacks, either surface or air. However, active radar emitters can give an enemy valuable information which can be used for locating, identifying, and targeting the ships of one's own task force. Therefore, two dimensions of EMCON planning must be simultaneously considered and traded off: (1) the need for surveillance coverage, and (2) information denial. Of course, the adequate balancing or weighting will vary with the task force, its mission, the configuration of the task force, and the number and type of possible enemy threats.

EWAR Decision Aid

The EWAR decision aid does not create EMCON plans but rather the aid provides assessments of EMCON plans developed by the user. The information yielded by the aid can be roughly classified into four groups: (1) order-of-battle, (2) surveillance effectiveness, (3) information denial, and (4) trade-off analyses. The EMCON plan a user wishes to assess is entered into the computer based aid by means of an interactive computer terminal. Once the EMCON plan is entered, it can be assessed by use of a variety of commands which call displays--either tables or graphs--containing information pertinent to some specific aspect of the plan. The displays are made available on cathode ray tubes of the terminals and a "hard copy" capability is also provided. In the present evaluation of the EWAR aid, only a subset of the possible displays was made available. Displays considered by the aid's developers to be not particularly useful within the context of a laboratory evaluation were not made available. Each display included in the evaluation of the EWAR aid is described below.

Order-of-Battle. Three order-of-battle displays are presented: (1) list of the task force ships and the value of each ship, (2) the position of each ship in the convoy, and (3) the type and status of each available radar on each ship. The ship/value presentation is illustrated in Exhibit 1. Under normal use of the aid, the user assigns the ship value as a function of the relative importance of each ship to the mission. However, for purposes of this study, the value was preassigned. The value assigned to a ship represents its normalized displacement in relation to a baseline ship which is assigned a value of 1. Also displayed are the ship index numbers, uniquely assigned by the aid to each ship in the data base.

The second order-of-battle display, showing the disposition of the task force, is illustrated in Exhibit 2. Each ship in the task force is redundantly represented by a pictorial symbol and an index number. The size of the pictorial representation of a ship type to some extent correlates with its value. At the top right corner of the display, two sets of tables relate the symbols to ship type, and the task force ships and index numbers to the appropriate symbols.

The final order-of-battle display (Exhibit 3) presents the EMCON plan under consideration (current plan). This is essentially a matrix of task force ships and radars. An "X" in a row-column interset indicates that the radar type (column) is aboard the indicated ship (row). If the "X" is solid, the radar is emitting and, if the "X" is broken, the radar is not emitting. Under each radar, the type is indicated: S = Surface, A = Air.

Surveillance Displays. The previously discussed order-of-battle displays organize and present basic information without transforming the data in any way. In most other displays, an algorithm is applied which abstracts and assesses various features of an EMCON plan. For example, the surveillance displays provide an assessment of a plan in terms of surveillance effectiveness.

Four displays supply information on various aspects of the surveillance coverage. The first, the surveillance range display, contains information on the maximum detection range for each radar type against several potential threats (Exhibit 4). Maximum range is estimated by an algorithm that considers the altitude of the threat, its radar cross section, and its velocity. Maximum detection

INDEX	SHIP	VALUE
1	KITTY HAWK	940.000
2	SPRUANCE	91.000
3	NASTY	1.000
4	TRUETT	48.000
5	CHICAGO	203.000
6	OKLAHOMA CITY	175.000
10	HOLT HE	48.000

Exhibit 1. The list of task force ships, their index numbers, and their values.

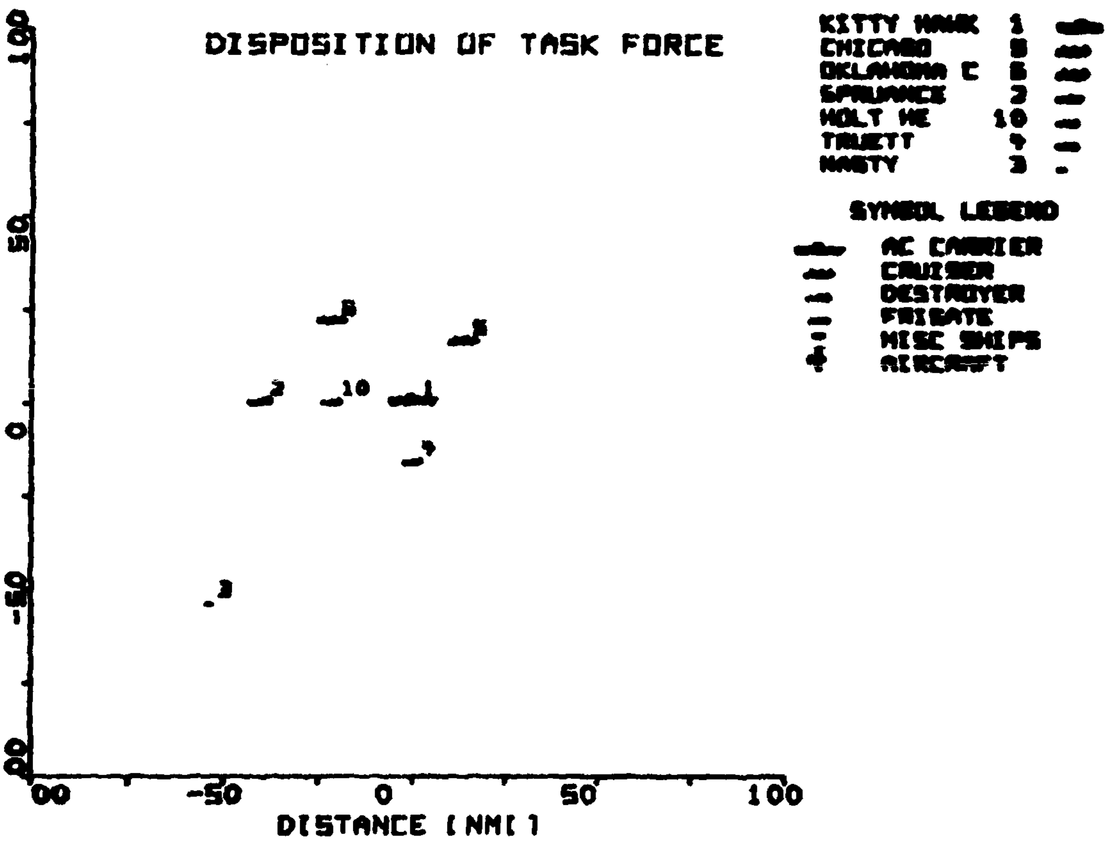


Exhibit 2. The disposition of the task force centered on the Kitty Hawk.*

*This Exhibit, as well as Exhibits 3 through 20, is a reduced, but exact, reproduction of the actual display.

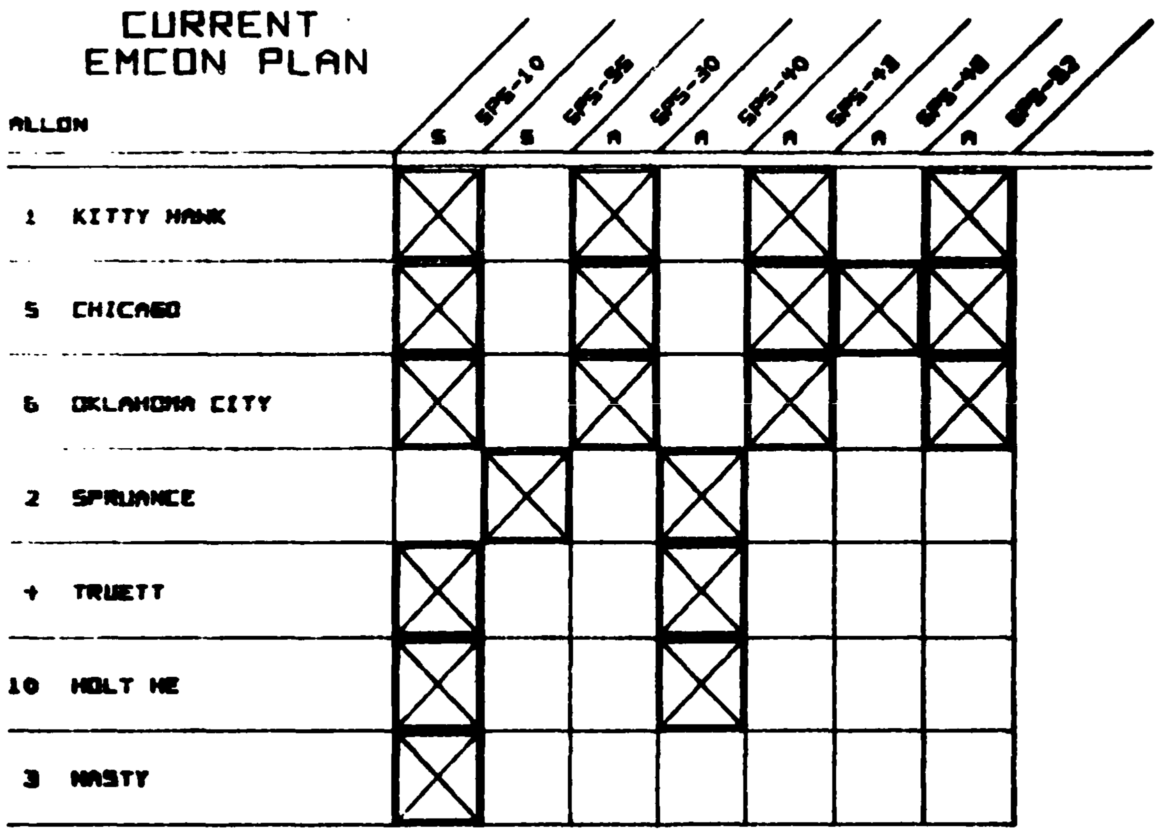


Exhibit 3. The EMCON plan display.*

*Because all radars are active in this example, no broken Xs are shown.

MAXIMUM DETECTION RANGE IN NMI

	STREAKER	SNEAKER
SPS-48	111.	25.
SPS-10	13.	13.
SPS-52	111.	25.
SPS-55	8.	8.
SPS-29	67.	23.
SPS-30	98.	24.
SPS-39	93.	24.
SPS-43	114.	26.
SPS-40	60.	23.
SPS-37	114.	26.

Exhibit 4. Maximum detection ranges for each radar type against two hypothetical threats, Streaker and Sneaker.

range for each radar type against a variety of threats is contained within the data base. However, for the purposes of the evaluation, two hypothetical threats were used: (1) Sneaker, which possesses the characteristics of a low, slow flying missile, and (2) Streaker, which has the characteristics of a high, fast flying missile. The maximum detection ranges in Exhibit 4 were obtained by averaging across the ship types (in the data base) which contain a specific radar type. This was necessary because the actual range varies with the height of the radar platform on a ship's superstructure.

The second surveillance range display, illustrated in Exhibit 5 for Sneaker and in Exhibit 6 for Streaker, presents the maximum detection range in pictorial form. Each ship in the task force is indicated by a symbol appropriate to its type and a unique index number. In both exhibits, no circles for the surface radars (SPS-10, SPS-55) are included because the potential threats are both aerial.

The third surveillance display makes use of the detection ranges to calculate detection probabilities and plots the probabilities cumulatively. The cumulative detection probabilities, as illustrated in Exhibit 7 for Sneaker and in Exhibit 8 for Streaker, are plotted for three detection contours with probabilities of: 0.30, 0.50, and 0.90.

The information contained in the final display goes beyond the detection probability and presents interception probability for the relevant threats. The interception probability (Exhibit 9) is given for the current EMCON plan and for a plan in which all the radars are active (ALL ON).

The mean interception probability is a single number reference--the surveillance score--which indicates the merit of an EMCON plan in terms of surveillance coverage across threat types. The highest mean interception probability or highest surveillance score that can be obtained for a given scenario is the plan in which all radars are emitting. This highest probability is indicated by the ALL ON plan in Exhibit 9. How much loss of surveillance coverage results from turning some radars off may be estimated by comparing the interception probabilities of the current plan with that of the ALL ON plan. The interception probability (Exhibit 9)

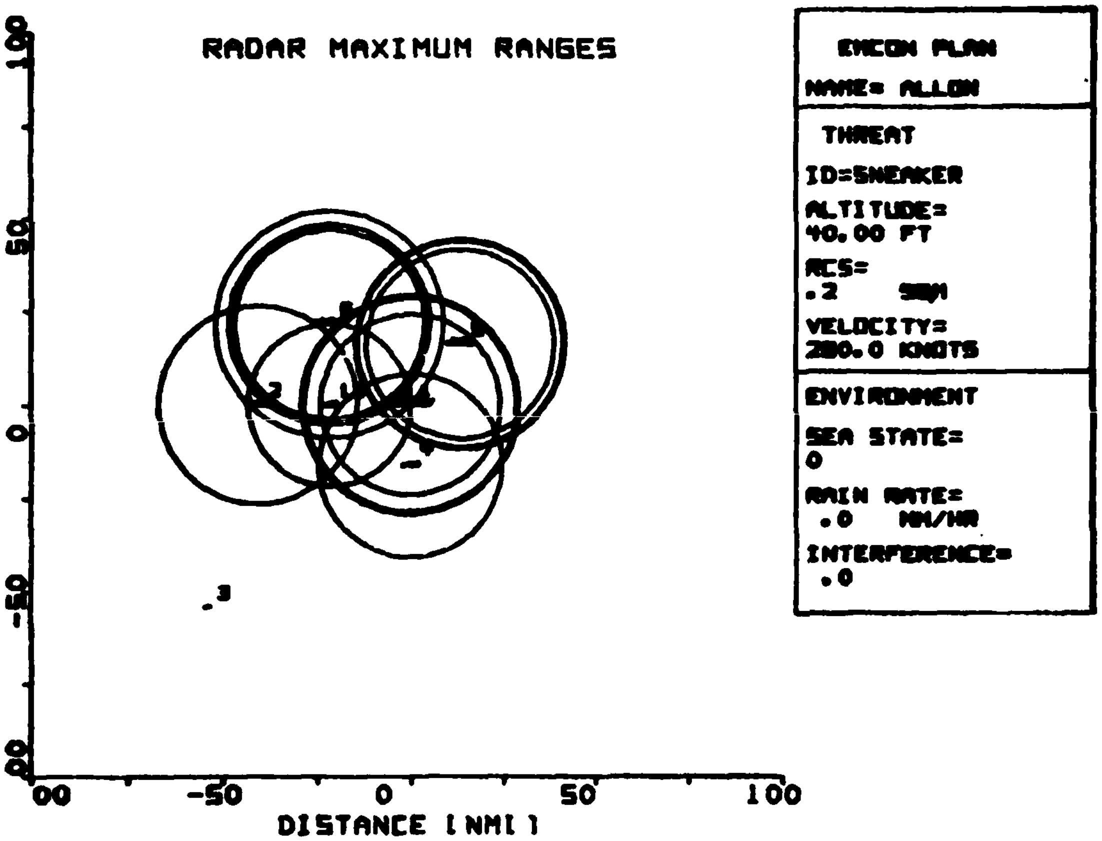


Exhibit 5. Maximum range circles for air search radars against Sneaker threat.

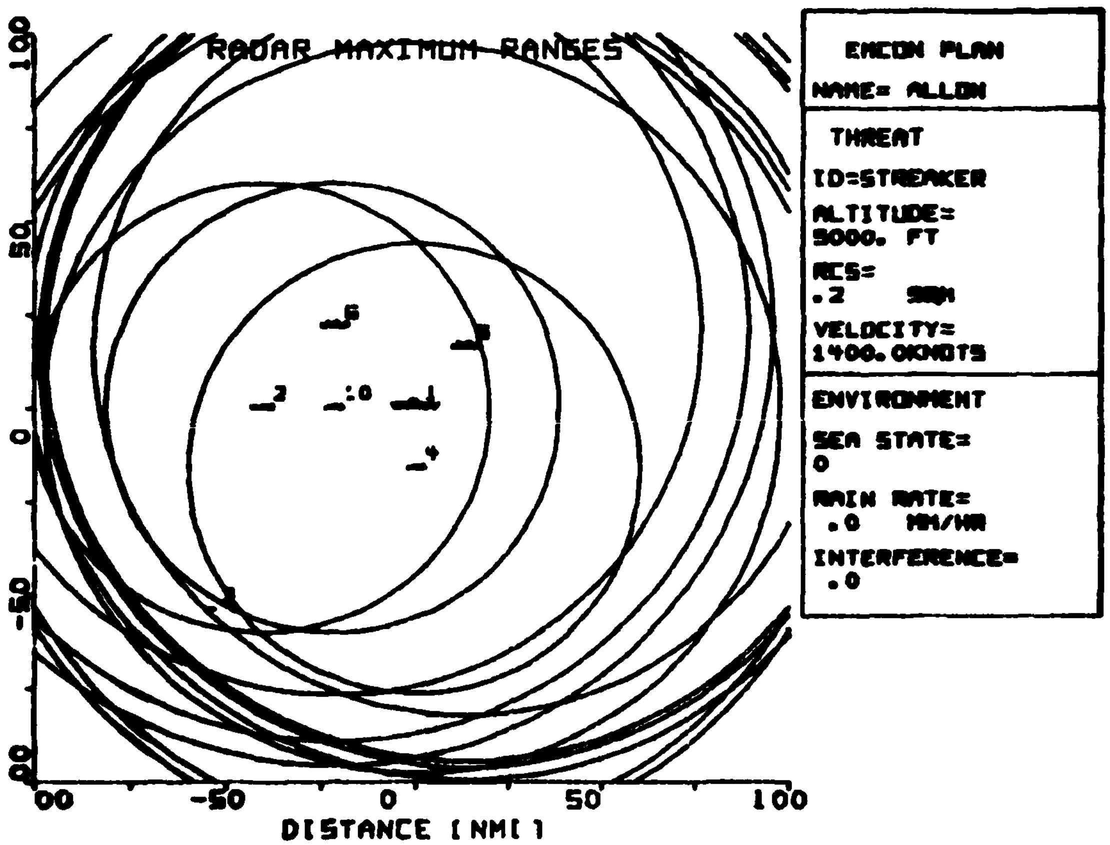


Exhibit 6. Maximum range circles for air search radars against Streaker threat.

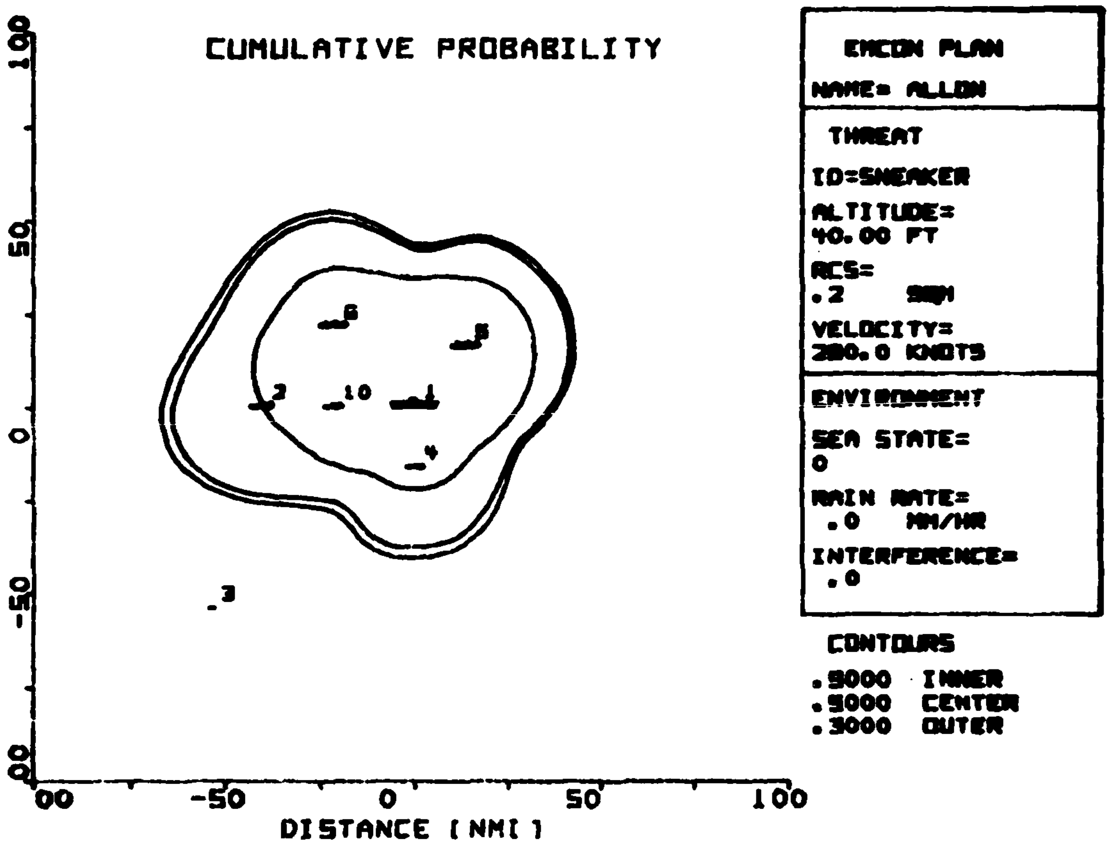


Exhibit 7. The cumulative probability of detection for the air search radars against Sneaker threat.

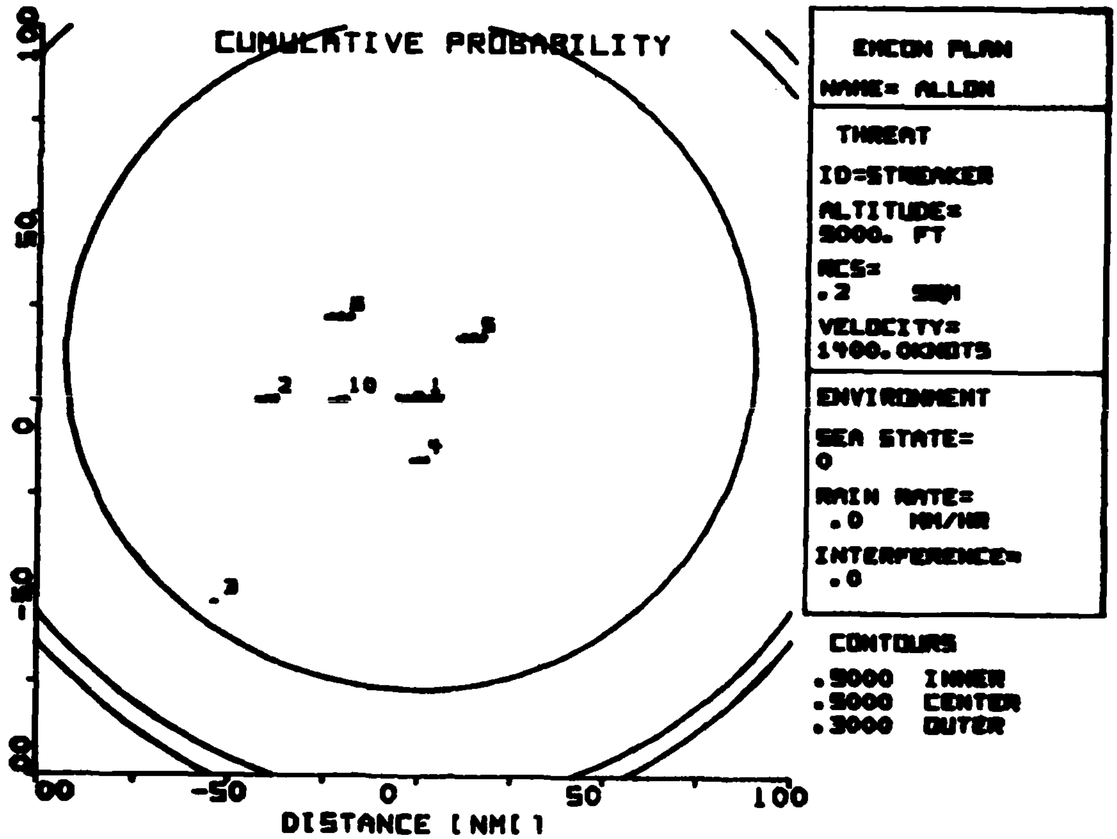


Exhibit 8. The cumulative probability of detection for the air search radars against Streaker threat.

EMCON PLAN =SPRUON

SURVEILLANCE SCORE----INTERCEPTION PROBABILITIES

THREAT NAME	INTERCEPTION PROBABILITY CURRENT PLAN	ALL ON	WEIGHT
SNEAKER	.29	.74	.50
STREAKER	.62	.62	.50
SCORE--MEAN	.45	.68	

Exhibit 9. The surveillance scores--the interception probabilities for both the current plan and the ALL ON plan.

(for an EMCON plan) against one threat type was a weighted mean of the individual interception probabilities for all task force ships. The weights were the ships' values.

Information Denial. One of the problems facing an EW officer in developing and assessing EMCON plans is ascertaining how much information is being given away. EWAR assumes that an enemy will possess some information regardless of whether or not any emissions are taking place. The aid assumes that the enemy knows the identity of the ships and the location of the task force. It also assumes that the enemy is actively monitoring the task force and that it has the equipment and capability of: (1) identifying the emissions of any particular type of radar, and (2) identifying the location of the emission. The information the enemy lacks, and that which an EW officer would want to deny, is the true identity of each target. That is, the true ship assignments are the only important information the enemy lacks and this information may be deduced from radar emissions with varying degrees of success.

The EWAR aid further assumes that the enemy will allocate weapons in proportion to each ship's perceived value and that, if the enemy can correctly identify each ship, it will target in proportion to the true value of the ship.

In denying information, the major consideration is how to reduce the probability that a target will be correctly identified. The effects of deactivating radars or sets of radars that uniquely identify a ship are to decrease the probability of correctly identifying the ship. This, in turn, could affect the perceived value of the task force's ships and therefore the allocation of threats to ships.

The EWAR decision aid attempts to help with the information denial aspects of EMCON planning by supplying displays that provide increasingly complex measures or assessments of information denial. Three of these displays were used in the EWAR evaluation. At the lowest level, the aid supplies details of the probability that a radar target will be identified as a particular ship. Exhibit 10 illustrates the assignment of

EMCON PLAN = ALL ON

BLIP		
KITTY HAWK	KITTY HAWK	.50
	OKLAHOMA CITY	.50
CHICAGO	CHICAGO	1.00
OKLAHOMA CITY	KITTY HAWK	.50
	OKLAHOMA CITY	.50
SPRUANCE	SPRUANCE	1.00
TRUETT	TRUETT	.50
	HOLT HE	.50
HOLT HE	TRUETT	.50
	HOLT HE	.50
NASTY	NASTY	1.00

Exhibit 10. The ships that a blip could be identified as and the probability of identification as that ship.

radar targets to ships. The first column contains the name of the actual ship producing the signature; the second column presents the ships for which it could be mistaken, and the third column presents the probability of the correct and the mistaken assignments. Accordingly, the Kitty Hawk could be identified as the Kitty Hawk or Oklahoma City with a probability of 0.50. The reason for this is that the target corresponding to the Kitty Hawk on the enemy's radar screen has four radar types associated with it (see Exhibit 3): SPS-10, SPS-30, SPS-43, and SPS-52. Because the Oklahoma City also has these same emitters, the Kitty Hawk could be misidentified by the enemy as the Oklahoma City.

On the other hand, the Chicago is uniquely identified because it possesses the only SPS-48 radar in the task force.

The second information denial display (Exhibit 11) combines the ship assignment probability with the value of the ship to produce an approximation of the perceived targeting value of the ship. The first column of Exhibit 11 presents the ships in the task force. The second column shows the value of each ship. The bars on the right indicate the true and perceived fractional values. The true value of the Kitty Hawk is 940 and constitutes about 62 percent of the total value of this task force. However, because the Kitty Hawk and the Oklahoma City cannot be distinguished from each other, the perceived value of the former is reduced and that of latter increased from the true values. This means that if targeting is proportional to perceived value, approximately 74 percent of the enemy weapons will be distributed equally between the Kitty Hawk and the Oklahoma City.

The final information denial display contains a set of single measures, one of which is intended as an information denial score. This display, (Exhibit 12), contains three scores: (1) a score for an EMCON plan with all emitters off, (2) a score for the current EMCON plan (the information denial score), and (3) a score for an EMCON plan with all emitters on. Each score represents the fractional reduction in the amount of task force damage when compared to the task force damage resulting from strikes by Sneaker and Streaker distributed in proportion to the true value of the ships.

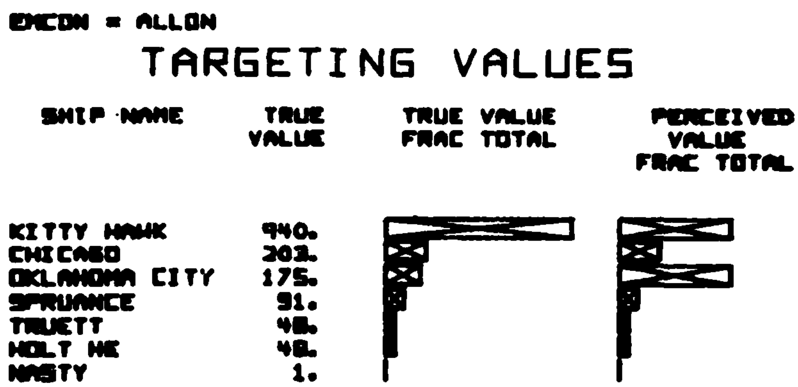


Exhibit 11. The perceived and the true value of the task force's ships.

EMCON PLAN = ALL ON INFORMATION DENIED	SCORE
ALL EMITTERS OFF	.42
CURRENT STATUS	.16
ALL EMITTERS ON	.16

Exhibit 12. Information denial score from current plan and for plans with "all emitters off" and "all emitters on."

In the Exhibit 12 example, an allocation of threats on the basis of the ALL ON plan and the current plan would represent a 16 percent reduction in expected task force damage. This would be due to the inability of the enemy to identify accurately the Kitty Hawk (Exhibit 10). Task force damage would be further reduced by eliminating any targeting information provided by the emitters. This could be accomplished by turning all emitters off. In the Exhibit 12 example, having all emitters off resulted in an information denial score of 42.

However, it is possible to produce an EMCON plan which would have a higher information denial score than the ALL OFF plan. This could be accomplished by manipulating the emitters so that the high value ship is misidentified as a low value ship and the intermediate value ships are misidentified as the high value ship. In this case, the expected damage to the task force would be lower than with an ALL OFF plan because the majority of the threats would be directed toward the intermediate value ships while few or none would be allocated to the high value ship.

Trade Off Analysis. Whereas the surveillance effectiveness and information denial displays may be employed to evaluate EMCON plans from unique and divergent perspectives, the trade off analysis attempts to present a synthesis of these divergent views. The first of the trade off displays combines data from two sources which were previously described. One source is the cumulative detection probability (a measure of surveillance effectiveness) and the second is the perceived value of the targets (a measure of information denial). These are combined into a trade off map as illustrated in Exhibit 13. The targeting value data are coded in two forms. One form relates to each ship's true value while the second relates to each ship's perceived value. At the location of each ship, the upper symbol (a heavy line or ship) represents the true value of the ship whereas the lower, light line represents the perceived value of the ship. Since it is logical that threats will be targeted in proportion to perceived value, the ships indexed by the 1 (the Kitty Hawk) and the 6 (Oklahoma City) are likely to receive the brunt of any attack. The fact that the perceived value line extends beyond the true value line for index number 6 means that the ship will be targeted with more

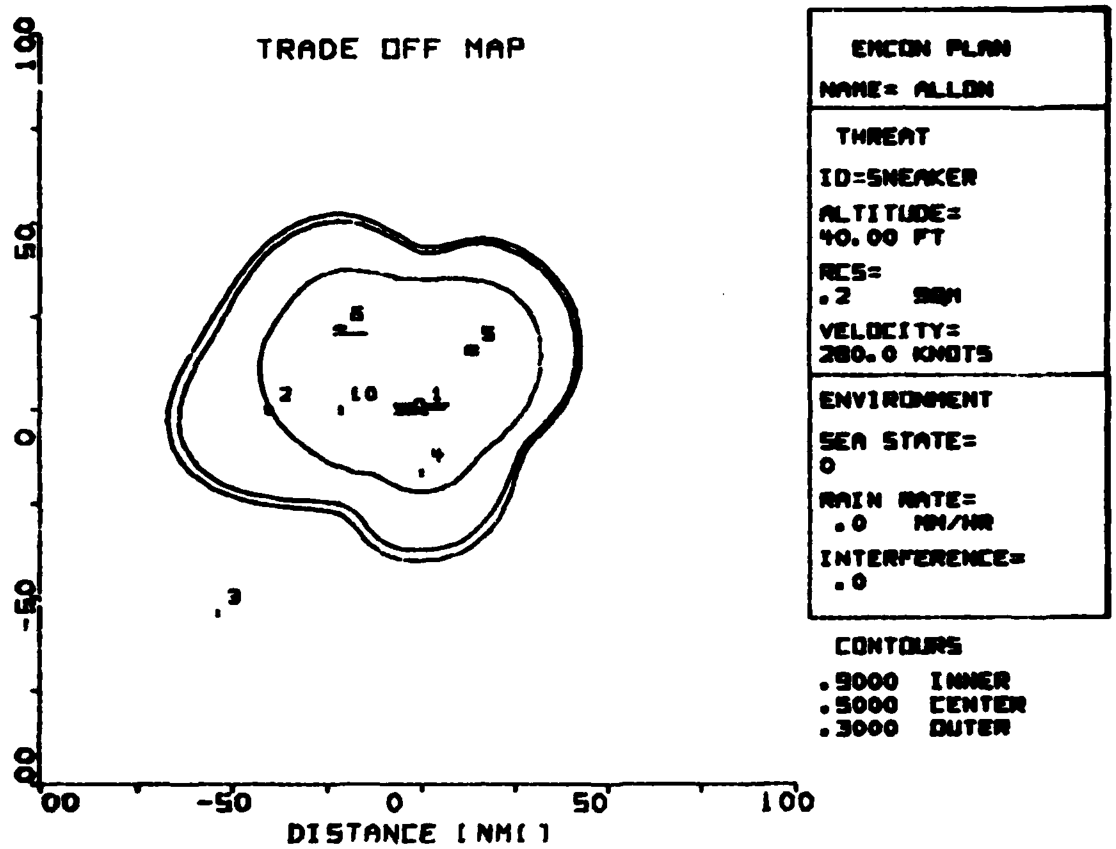


Exhibit 13. The trade off map for threat Sneaker combining several aspects of surveillance effectiveness and information denial.

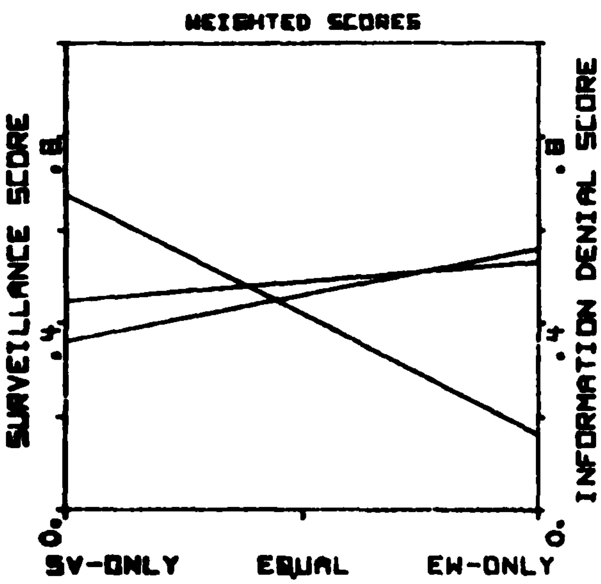
threats than its true value warrants. The reverse situation is indicated for the index number 1 ship. The cumulative detection probability contours are given so that an EW officer can see how well the heavily targeted ships are protected.

The second trade off display is also intended to allow joint evaluation of divergent aspects of surveillance effectiveness and information denial but it also acts as a bridge for comparisons with other candidate EMCON plans. The data presented in this display (see Exhibit 14) are the surveillance scores (the interception probabilities) and the information denial scores. On the left ordinate, the surveillance scores are plotted and on the right the information denial scores are plotted. On the abscissa, the weights that could be assigned to information denial are plotted. On the far right, the list of EMCON plans for which the scores have been plotted appears. The EMCON plans are ranked in terms of the information denial score (the EW). The lowest EW score is from plan ALL ON which also has the highest surveillance score. The data for this plan are plotted on the graph with the surveillance score of .68 and the information score of .16 and with a line connecting these two points. The scores for each other plan are plotted in a similar manner.

This display facilitates comparisons across plans. If the only important need of an EMCON plan is surveillance coverage, then the plan corresponding to the line intersecting the surveillance ordinate at the highest point should be chosen (ALL ON). If information denial is of paramount importance, then the plan represented by the line intersecting the information denial ordinate at the highest point should be chosen (INFO). If both the information denial and surveillance coverage aspects are equally important, then the plan corresponding to the highest line above the point at which both are given equal weight should be chosen (SPRUON).

The final display attempts to carry the ideas of surveillance effectiveness and information denial one step further and to test a plan. The test is based on a simulated strike against the task force in which threats are allocated in proportion to perceived value and the

COMBINED SURVEILLANCE AND EW INFORMATION SCORES



EMCON ALTERNATIVES	PURE SCORES SV.	PURE SCORES EW
INFO	.36	.56
SPRUON	.45	.53
ALLON	.88	.18

Exhibit 14. Trade off display combining surveillance and information denial scores from selected EMCON plans for purposes of comparison.

threats are destroyed according to the interception probabilities. This display, the trade off strike display, is presented in Exhibit 15.

The information supplied in the trade off strike display includes the fractional value of the task force remaining after the strike. This figure is to some extent intended as an overall measure of the goodness of an EMCON plan. Generally, the higher the fractional value remaining, the better the plan. Other information supplied concerns the effect of the strike on each ship: (1) the threat allocation, (2) the penetration probability, (3) the number of hits, (4) the fractional value of the ship remaining, (5) the initial ship value, and (6) the value remaining.

ATTACKER GUESSES SHIP IDENTITY

FRACTIONAL VALUE REMAINING =.593
STRIKE = STREAKER
EMCON PLAN = ALL ON

STRIKE = STREAKER
EMCON PLAN = ALL ON

THREAT	SHIP	ALLO-CATION	PEN PROB	# HITS	FRACTION REMAIN	SHIP INIT	VALUE REMAIN
STREAKER	KITTY HAWK	0.469		1.7	0.54	940.0	504.4
	SPRUANCE	--		--	1.	91.0	91.0
	NASTY	--		--	1.	1.0	1.0
	TRUETT	--		--	1.	48.0	48.0
	CHICAGO	0.469		0.4	0.77	203.0	156.5
	OKLAHOMA CITY	0.481		2.0	0.25	175.0	43.3
	HOLT HE	--		--	1.	48.0	48.0
TOTALS		--		4.1	--	1506.0	892.3

Exhibit 15. The trade off strike display.

II. EVALUATION PURPOSE AND SPECIFIC APPROACH

The purposes of the current evaluation included determining the usefulness, if any, of the EWAR aid in deriving EMCON plans. Specifically, the evaluation was designed to test four hypotheses:

(1) EMCON plans produced using the decision aid will be superior to plans produced without the aid

(2) EMCON plan training will further enhance the quality of the EMCON plans

(3) The difficulty of the scenario problems will not affect the quality of the EMCON plans generated in the aided condition

(4) There will be a high correlation between constructed problem difficulty and perceived problem difficulty.

The hypotheses and evaluative design were derived as the result of an interested parties meeting attended by members of the staffs of Applied Psychological Services, Decision Science Applications, Office of Naval Research, and the Department of Decision Sciences, University of Pennsylvania.

The first hypothesis was tested by using a within groups design in which each participant was required to develop EMCON plans both with and without the use of the EWAR aid.

The second hypothesis was tested by means of a between groups design in which one group received extensive training in EMCON planning while a second group received no training.

The third hypothesis was tested by employing problems which varied along a dimension of difficulty.

The final hypothesis was tested by comparing judgments made by participants about the difficulty of each scenario with the a priori difficulty of the problems.

In essence, a basic two-by-two-by-two split plot factorial design with block-treatment confounding was employed. The first factor was the between subjects (blocks) training factor, the second factor was the within subjects aiding factor, and the third factor was the within a within block difficulty factor. A representation of the basic design is presented in Exhibit 16.

Group	Training	Aid Levels	Difficulty
Experimental	Heuristics Included	Full Aid	Easy
			Hard
		No Aid	Easy
			Hard
Control	No Heuristics	Full Aid	Easy
			Hard
		No Aid	Easy
			Hard

Exhibit 16. Design for the EWAR decision aid evaluation.

Independent Variables

Training

The training was concerned with: (1) the broad aspects of EMCON planning, (2) a set of manual methodologies for evaluating plans, and (3) information denial rules (Exhibit 17) and their applications. To assess the effects of the training, two groups of subjects were used. One may be considered to represent an experimental group and the second group may be considered to represent a control group. Because of the impossibility of separating the training in manual EMCON planning from the training in the information denial guidelines, these two aspects were combined in the training received by the experimental group.

The manual techniques included in the training could be used to estimate, with the use of a hand calculator, most of the indices supplied by the aid, e.g., the surveillance circles, cumulative probabilities, information denial details, trade offs, and the like.

The information denial guidelines were six rules which could be applied to a task force to minimize information given away. The guidelines were statements of what emitters should be activated or deactivated in order to maximize information denial. The first three suggested how to deny targeting information while the last three suggested means whereby a high value ship could be "hidden." Application of the guidelines to a scenario resulted in an EMCON plan which maximally denied information to an enemy.

Aid Levels

The main test of the effectiveness of the EWAR decision aid involved comparing EMCON plans developed with the aid with plans developed manually. Therefore, there were two aid levels: (1) a full aid condition and (2) a no aid condition. Each participant was exposed to both the full aid and the no aid conditions. In the full aid condition, all of the displays and aid generated information, described previously, were available to the subjects. In the no aid condition, only a very restricted set of information was made available. However, additional information could be generated through hand computational methods, at the option of the individual participant. The information made available in the no aid condition included radar order-of-battle information and the surveillance range information. The information supplied in the no aid condition was chosen to reflect the type of information an EW officer would be likely to have immediately available under normal operating conditions.

Information Denial Guidelines

1. Avoid turning on a unique radar or a unique group of radars.

2. Turn on all radars common to all ships.

3. Look for radar groups; turn such radars off or on as a group.

4. Turn off all radars in the task force that are not aboard a ship to be "hidden."

5. Turn off all radars aboard any ship to be hidden, except for those radars which are common to all ships.

6. Turn on a radar or radars aboard an intermediate value ship where such an action would result in an intermediate value ship being identified as a high value ship and the high value ship being identified as a low value ship.

Exhibit 17. The information denial guidelines used in the training of the experimental group.

Difficulty

It was assumed that the difficulty of developing an EMCON plan would be a function of a number of variables. Difficulty was assumed to be positively related to three factors: (1) the amount of information processing inherent in a problem, (2) threat heterogeneity, and (3) number of ships in the task force.

The magnitude of the information processing in developing an EMCON plan relates strongly to two considerations: (1) differences in the radars across ships, and (2) differences in ships across radars. Each of these is related to cues that could be used to identify ships. As the number of such cues increases, so would the magnitude of the information processing load. Accordingly, information load may be viewed as a measure of the difficulty of formulating an EMCON plan for a given situation. To facilitate the assessment of the information processing load, a complication score was obtained for each problem included within the present evaluation. The complication score was the product of the sum of the differences of the radars across ships and the sum of the differences in ships across radars.

The complication score was used along with the other two factors to produce a difficulty score for each problem. The number of different potential threats was expected to increase difficulty because an EMCON plan suited for one threat type might be inadequate against another threat type.

It was also assumed that the number of ships to be protected affects the difficulty of a problem. These three factors: complication score, heterogeneity of threats, and number of ships, were weighted and summed to produce a measure of difficulty for each problem:

$$\text{Difficulty scores} = CS + w_1 T + w_2 S$$

where CS = complication score
T = number of different threats
S = number of ships in the task force
$w_1 = 50$
$w_2 = 20$

The weights, w_1 and w_2, were incorporated to make the variance of the final two factors approximate the variance of the first factor.

To assess the effects of difficulty on EMCON planning, problems were chosen so that half of the problems had relatively low difficulty scores and half had relatively high difficulty scores.

Dependent Variables

Quantitative

The major dependent measure was based on the EMCON plan each participant developed as his best solution for each problem. The measure of the goodness of each of the participants' chosen plans was the fractional value of the task force remaining after a strike when the task force used the plan. This measure was produced by the aid and was available to the participants in the aided condition. The measure assesses three different aspects of an EMCON plan--the information denial, the surveillance effectiveness, and the trade off between them.

Criterion

The dependent measure, fractional value remaining, could be compared both between and within conditions. However, it was also thought that each of the participants' EMCON plans should be compared with a criterion representing the best possible plan. To develop the criterion for each problem, the EMCON plan in which the fractional value remaining was highest was constructed and the fractional value of the task force remaining under each of these plans was used as a measure for evaluating the goodness of the experimental subjects' derived plans. Difference scores were developed and were used to estimate how closely the participants' plans approximated the best possible plans and how they varied with the independent variables.

Difficulty and Confidence Ratings

In addition, the participants were asked to rate each problem on two dimensions. They were first asked to indicate how confident they were in each solution and, second, how difficult it was to arrive at the solution. Magnitude estimation techniques were used to obtain both judgments. The difficulty judgments were used to analyze the relationship between perceived difficulty and the a priori difficulty scores which were calculated as described above. In addition, there was also interest in the relationship between perceived difficulty and confidence.

Percentage Correct

An EMCON plan could be thought of as a set of independent statements about the status of each of the radar emitters in the task force. Using this conceptualization, another way to compare the criterion plans with the plans of the participants becomes obvious. Participants' plans could be graded on how many emitters that should be on, according to the criterion plan, were actually on, and how many emitters that should be off, were off. A percentage correct score could then be derived. In addition, the data could be assessed to determine how the distributions of false positives and negatives vary across and within conditions and how they may relate to each other.

Qualitative

After each participant completed the last of the test scenario problems, he was interviewed on a variety of topics. Generally, three types of information were solicited: (1) categorical ratings and rank orderings of the usefulness of the aid, (2) descriptions of strategies and heuristics used to develop and evaluate EMCON plans, and (3) estimates of the relationship between the aid and its goals. The data on how closely the EWAR aid approximated its goals provided the basis for a multiple attribute utility analysis. To obtain the goals and their weights as required for the analysis, Decision Science Applications supplied seven goals, or general objectives of the EWAR aid. They ranked these goals from most important to least important and weighted them as to their importance by distributing 100 points among them. The goals, ranked and weighted, are presented in Exhibit 18. The full interview content is presented in Appendix A.

Goal		Weight
G1.	To facilitate the formation of hypotheses about how best to improve a current plan	10
G2.	To produce better EMCON plans	20
G3.	To help quantify the surveillance and information consequences of a plan	15
G4.	To make it practical to examine a larger set of alternative plans	10
G5.	To understand how different factors (threats, radars, etc.) contribute to EMCON planning	15
G6.	To improve planner confidence in the quality of his EMCON plans	15
G7.	To facilitate comparison of alternative plans	15

Exhibit 18. Goals of EWAR decision aid and their weights.

Subjects, Methods, and Procedures

Subjects

The participants were 16 members of the faculty of the United States Naval Academy who volunteered to participate in the EWAR evaluation. Thirteen were Naval officers and three were Marine officers. Of the Naval officers, five were Lieutenants; six were Lieutenant Commanders; one was a Commander, and one was a Captain. The Marine officers were all Captains. The average time in the service of the total group was about 12 years.

Apparatus

The evaluation was conducted at the facilities of the Decision Aiding Systems Laboratory, Department of Decision Science, Wharton School, University of Pennsylvania. The EWAR data acquision program operated on line with a DEC-10 computer (located in the Wharton computer facility) in a time sharing mode during the aided condition. In addition, the DEC-10 operated a variety of peripheral equipments in the laboratory proper.

The arrangement of the evaluation equipment and the general organization of the laboratory room are presented schematically in Figure 1. The laboratory room was partitioned into two areas--an experimental area and a support area. The experimental area was in turn divided into two areas, area "A" and area "B", each of which was designed for the use of one participant. At one end of the experimental section, two stations, which were separated by a partition, were constructed to be used by the participants in the aided condition. These sections will be called EWAR stations. Two additional sections, used by the participants in the no aid condition--the manual stations--were arranged at the other end of the room.

At each EWAR station, there was a Concept 100 terminal and a Tektronix 4013 display. Commands were entered through the Concept 100 keyboard and alphanumeric displays were presented on its cathode ray tube. Graphic displays were presented on the Tektronix 4013. Two devices, capable of producing hard copies, were shared by the participants. One, the Tektronix 4010, was situated in front of the partition separating EWAR station "A" from station "B." It produced, on participant request, a copy of any of the graphics displayed on the Tektronix 4013. The other, a DEC-Writer, produced on demand hard copies of the alphanumeric displays presented on the Concept 100. The DEC-Writer was located adjacent to the Tektronix 4010 copying machine.

The manual stations consisted of a table and chair for each participant along with any necessary materials, such as a hand calculator, scratch paper, pencils, and overlays representing maximum radar range circles.

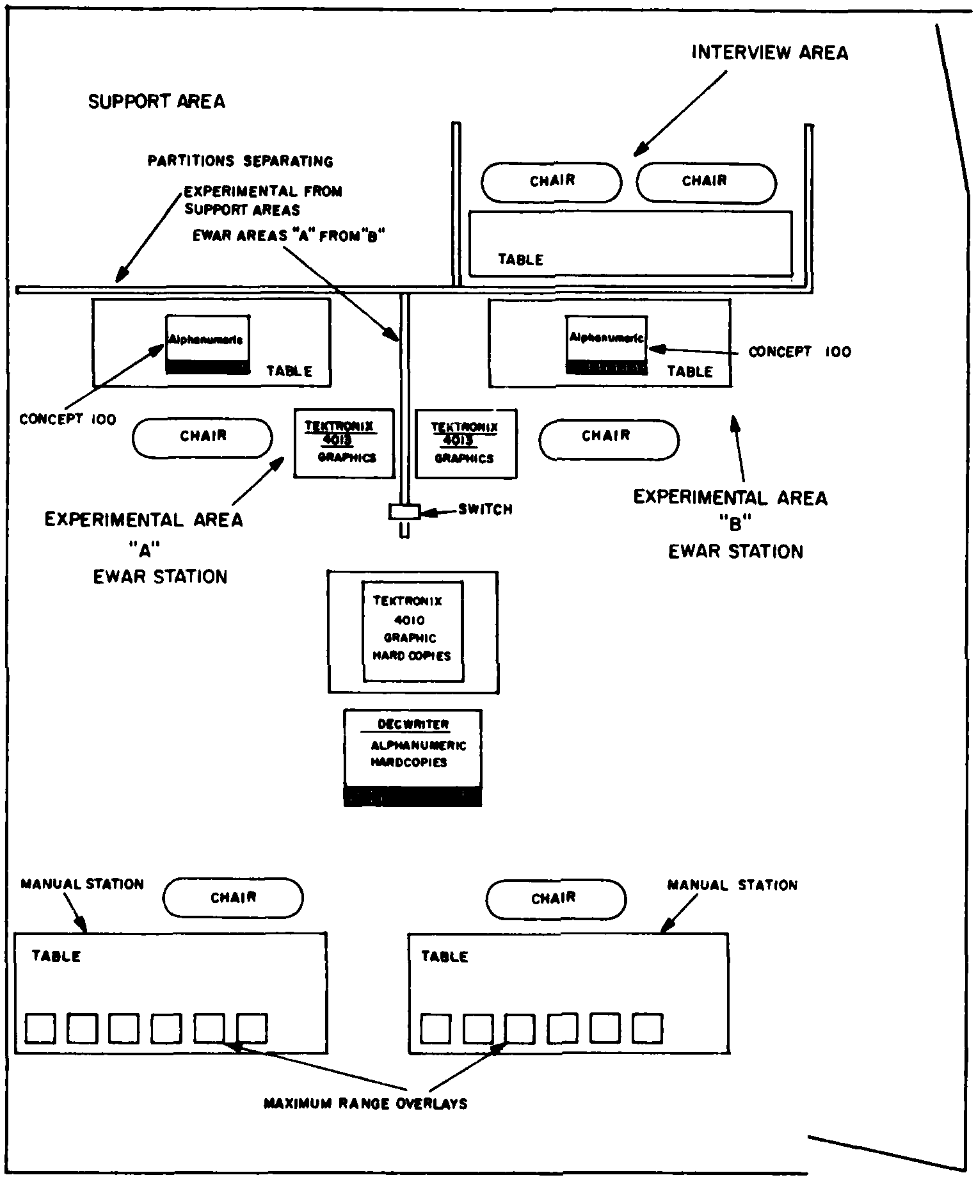


Figure 1. Schematic of equipment arrangement for the EWAR evaluation.

The overlays provided a convenient technique for hand production and visualization of maximum range circles. Such production may have been time consuming with a hand drawing compass.

Group Assignments and Prerequisite Training

The participants were divided into two groups: an experimental and a control group. Eight persons were assigned randomly to each group.

The experimental group was given one and half days of prerequisite training at the Naval Academy. The first one and a quarter days of this training were devoted to training the experimental group in: (1) the problems of emission control, (2) the manual development and testing of EMCON plans, and (3) the applications of the information denial guidelines. The training was conducted using an audio-visual-lecture technique and strictly followed lesson plans jointly developed by Decision Science Applications and Applied Psychological Services. Within the lesson plans, there was considerable emphasis on practice exercises within three typical scenario problems, and on the development and evaluation of a number of EMCON plans for each problem.

The last one quarter day of training was devoted to the EWAR decision aid and, for this period, the experimental and the control groups were both present. Before the control group was permitted into the classroom, the experimental group was advised about the necessity for keeping the contents of the earlier training secret and the group was asked to refrain from discussing the content with the members of the control group. In addition, the experimental group was advised not to ask any questions which woula relate their training to the EWAR aid's displays.

The information about the EWAR discussed in the joint briefing consisted of a full description and interpretation of the displays made available by the aid. It was made clear to the participants that the purpose of the briefing was to provide familiarization with the aid and that additional training on how to use the aid would ultimately be given at the University of Pennsylvania when they arrived to participate in the actual evaluation.

Problems

Decision Science Applications created 15 EMCON problems, three of which were used during the training at the Academy. From the remaining 12, eight were used in testing and two were used as practice problems. The eight test problems were selected on the basis of their difficulty scores (described earlier) and classified as either "easy" or "hard." The four assigned to the "easy" category had a mean difficulty rating of 216 with a range of 160 to 242. The four categorized as "hard" had a mean difficulty rating of 379 and a range of 320 to 409.

Problem Presentation Sequence

The sequence of problem presentation for each participant in the experimental group is shown in Figure 2. The same sequence was followed for the control group. Each participant was required to work through eight problems--four aided, four unaided--four of which were "easy" and four of which were "hard." Each participant was exposed to the aid levels in a double rotated ABBA sequence in order to distribute the more pervasive sequential effects evenly across aid levels. Across the ABBA distribution, problem difficulty was alternated.

The ordering, shown in Figure 2, was produced by first randomly assigning symbols E_1, E_2, E_3, E_4, and H_1, H_2, H_3, H_4, to the "easy" and to the "hard" problems, respectively. These problems were then ordered, E_1, H_1, . . ., E_4, H_4, to produce a sequence of successively alternating "easy" and "hard" problems to be used as the basic ordering of problems for the evaluation.

This order was received by the first participant, (S_1, in Figure 2) starting with the aided condition and by the third subject, S_3, starting with the unaided condition. Both S_2 and S_4 received this sequence in reverse order but each problem was aided or unaided in the same manner as for S_1 and S_3, respectively. The same sequence was split and reversed from the middle for S_5 and S_7 and the split and reversed sequence were completely reversed for S_6 and S_8. S_5 and S_6 began with an aided condition and S_7 and S_8 began with an unaided condition. This presentation sequence allocated each problem equally often to both the aided and the unaided conditions. The design did not fully control for serial effects but to do this completely would require an unwarranted increase in the number of subjects. However, the design controlled for order and sequence of presentation so that a rather detailed analysis of any learning effects was possible.

Each subject in the control group received the same problems in the same order as the same numbered subject in the experimental group.

Data Collection

Each participant was allocated between one and a half and two hours for each problem. The time allocation for each problem depended on the problem's rated difficulty. At the end of the allocated time, or when a participant indicated that he had decided on a best EMCON plan for the problem, he was asked to supply three sets of information: (1) the best EMCON plan, (2) a difficulty rating for the problem, and (3) a confidence rating.

The EMCON plan was recorded by simply listing the ships in the task force that had activated radar emitters and by marking the box corresponding to the radars emitting on each ship. With this information, Sequential Presentation of Aid and Difficulty Levels

Subjects								
	A	B	B	A	A	B	B	A
S_1	E_1	H_1	E_2	H_2	E_3	H_3	E_4	H_4
S_2	H_4	E_4	H_3	E_3	H_2	E_2	H_1	E_1
	B	A	A	B	B	A	A	B
S_3	E_1	H_1	E_2	H_2	E_3	H_3	E_4	H_4
S_4	H_4	E_4	H_3	E_3	H_2	E_2	H_1	E_1
	A	B	B	A	A	B	B	A
S_5	E_3	H_3	E_4	H_4	E_1	H_1	E_2	H_2
S_6	H_2	E_2	H_1	E_1	H_4	E_4	H_3	E_3
	B	A	A	B	B	A	A	B
S_7	E_3	H_3	E_4	H_4	E_1	H_1	E_2	H_2
S_8	H_2	E_2	H_1	E_1	H_4	E_4	H_3	E_3

A: Aided
B: Unaided
H: Hard problems
E: Easy problems

Figure 2. Schedule of four easy (E) and four hard (H) problems distributed across counterbalanced ABBA sequences for the experimental group.

the rest of the EMCON plan was directly deduced and the relevant value of each dependent measure could be generated. Each participant in the evaluation was exposed to two practice problems.

Procedure--Specific Practice and Testing

Each participant was allocated a total of 16 hours. The time was distributed over two successive days of eight hours each. The first three hours were devoted to tutoring the participant in the use of the EWAR decision aid and the other 13 hours were devoted to the actual evaluation of the aid. The participants were scheduled for the evaluation in pairs. Both members of a pair were assigned to the same group, either experimental or control. This procedure was instituted so that the members of the experimental group could receive a review of the use of the information denial guidelines which formed a part of their earlier training.

When the participants arrived at the laboratory, the purpose of the evaluation was rearticulated, and the importance and possible contributions that their time and effort would make to the project was stressed. Following this, the schedule for the next two days was outlined. Then, the practice session began and the participants and the evaluator worked together.

To facilitate interaction with the EWAR aid, each participant was given a list of the commands with which he could modify, save, or retrieve EMCON plans, as well as call up desired displays. (These commands are presented in Appendix B.) Then, the evaluator acted as the system operator and, in conjunction with the participant, worked through the first practice problem calling up the various displays in the order in which they were listed in the handout while the participant watched. The content of each display was described and any questions were answered. Next, the evaluator used the operational commands to modify the EMCON plan. The participant was queried as to how the radar emission configuration should be altered. If the participant was a member of the experimental (trained) group, the evaluator suggested that individual radars should be turned on or off to satisfy the information denial guidelines. However, if the participant was from the control group, then the choice was left to the participant and the evaluator made no suggestions. After modifying the EMCON plan, the displays were again called and the resultant changes were indicated and explained. There was no attempt made to fully develop the best EMCON plan for this practice problem. The intent was to familiarize the participant with the use of the EWAR aid.

Then, the second practice problem was worked through. This time, the participant acted as the system operator. Before starting, the fact was explained that this problem would be used as the modulus for the difficulty and confidence ratings of the test problems. A clear and concise statement concerning the magnitude estimation technique was made. Both difficulty (how difficult it was to arrive at a preferred EMCON plan) and confidence (how confident the participant was in the plan) were assigned the same modulus value of 100. Therefore, if the first test problem was twice as difficult as the second practice problem, then the participant would assign a difficulty rating of 200 to that test problem. In a similar vein, if the participant was half as confident in the EMCON plan for the first test problem as he was for the second practice problem, he would be expected to assign a confidence rating of 50 to the first test problem.

Data recording sheets were also distributed and explained at this point.

Once he understood how to record the best plans and the ratings, the participant was allowed to use the aid to work through the second practice problem. The evaluator remained present and helped, as required, with the mechanics of the peripheral hardware and the command structure. Again, as with the first practice problem, the evaluator attempted, if necessary, to help a participant in the experimental group in the applications of the information denial guidelines. This assistance was not given to the control subjects.

About 20 minutes before the expiration of the allocated time for the problem, the participant was told that the allocated time had just about expired and that he should try to make a decision. When the time expired, or when the participant indicated that he had made a decision, the evaluator assured that the plan was properly recorded. At this time, the significance of the moduli and how to use them were reiterated.

After the participant completed the second practice problem, he was allowed to start immediately on his first test problem. Each participant was assigned a subject number associated with the preestablished ordering of the problems and sequence of aid levels.

While the participant worked through the problems, the evaluator waited in the support area and remained prepared to intervene if any problem arose.

As a participant finished each problem, the evaluator ascertained that he had properly completed the data sheet. Then, the handout for the next problem was given to him and, after being told whether or not to use the aid, the participant was allowed to begin work on the problem.

Post Data Collection Interview

After completing all eight problems, each participant was individually interviewed. The interview was conducted by the evaluator in the interview area and consumed about one hour.

III. RESULTS

The EWAR aid evaluation was designed to provide both quantitative and qualitative information about the EWAR aid when it is used in a laboratory situation. The obtained best EMCON plans of each participant were first subjected to a set of analyses to determine the effects of each of the independent variables (use of aid, training, and problem difficulty) on the plans produced.

Fraction of Own Force Remaining

A fractional value of the task force remaining (FRAC) score was derived for each best participant plan by taking the mean (as computed by the aid) of the fractional value remaining after two strikes against the task force--one by Sneaker and the other by Streaker. The FRAC score represented a trade off between surveillance coverage and information denial. Indeed, to obtain the highest possible FRAC score, it was necessary to consider both surveillance protection and information denial. This suggests that the FRAC score was a quite adequate measure of the overall quality of an EMCON plan. Moreover, this score is essentially a "payoff" score and may be considered to reflect directly overall plan effectiveness.

The distribution of the FRAC scores was examined through a two (training-no training) by two (aided-unaided) by two ("easy"-"hard") analysis of variance. Within each training by aid level by difficulty cell, each subject was observed twice. The data used in this variance analysis and all those reported herein were the mean of the two observations. The results of the variance analysis are summarized in Table 1. The variance produced by the aid levels was statistically significant. No statistically significant variance could be attributed to the other main effects. The mean FRAC scores expressed in standard deviates for each condition were:

Training Levels	Mean
Experimental	-.07
Control	.07
Aid Levels	
Aided	1.44
Unaided	-1.44
Difficulty Levels	
"Easy"	-.36
"Hard"	.36

The mean FRAC scores were not affected by the training or by the problem difficulty but they were clearly influenced by the use of the aid.

Table 1

Variance Analysis Summary for the FRAC Scores

Source	Sum of Squares	d.f.	Mean Square	F
Between Groups	6.554	15		
Training (T)	0.009	1	0.009	0.019
Subjects Within Groups	6.545	14	0.468	
Within Conditions	21.010	48		
Aid Use (A)	3.530	1	3.530	14.010*
T x A	0.044	1	0.044	0.175
A x Subjects Within Groups	3.530	14	0.252	
Difficulty (D)	0.224	1	0.224	0.424
T x D	0.132	1	0.132	0.250
D x Subjects Within Groups	7.394	14	0.528	
A x D	0.274	1	0.274	0.665
T x A x D	0.454	1	0.454	1.100
A x D x Subjects Within Groups	5.768	14	0.412	
Total	27.56	63		

*p = < .01

Moreover, the variance accounted for by all the independent variables was about the same as the variance accounted for by the aid levels alone. It appears that for the proportion of the variance accounted for, that proportion can be understood to be largely a function of only the aid levels.

Comparison With Criterion Scores

To examine more fully the best EMCON plans of the participants in the EWAR evaluation, the participants' FRAC scores were compared with a criterion score.

The criterion fraction (CFRAC) scores were calculated by generating the best EMCON plan for each problem. The best EMCON plan was, by definition, the one associated with the highest fractional value remaining, averaged across both threat types.

The relationship between the criterion and the participants' EMCON plans was studied by analyzing the difference (DFRAC) between the CFRAC and FRAC scores. The obtained DFRAC scores varied from zero, where the FRAC and DFRAC were equal, to 3.62.

The DFRAC scores were subjected to a two-by-two-by-two analysis of variance. The results are summarized in Table 2. Again, a statistically significant effect was attributed to the manipulation of the aid levels. The mean difference value in standard score form for each condition was:

Training Levels	Mean
Experimental	-.42
Control	.34
Aid Levels	
Aided	-1.46
Unaided	1.61
Difficulty Levels	
"Easy"	-.09
"Hard"	.02

Only negligible variance was attributable to the manipulation of the training or to the problem difficulty. In the aided condition, the DFRAC scores tended to be relatively low, with a mean of -1.46, and in the manual condition they tended to be relatively high, with a mean of 1.61. Again, of the variance accounted for, was mostly a function of aid levels.

Table 2

Variance Analysis Summary for the DFRAC Scores

Source	Sum of Squares	d.f.	Mean Square	F
Between Groups	3.929	15		
Training (T)	0.627	1	0.627	2.658
Subjects Within Groups	3.302	14	0.236	
Within Conditions	25.208	48		
Aid Use (A)	8.960	1	8.960	56.837*
T x A	0.674	1	0.674	2.858
A x Subjects Within Groups	2.207	14	0.158	
Difficulty (D)	0.018	1	0.018	0.028
T x D	0.014	1	0.014	0.021
D x Subjects Within Groups	9.170	14	0.655	
A x D	0.007	1	0.007	0.029
T x A x D	0.815	1	0.815	3.448
A x D x Subjects Within Groups	3.309	14	0.236	
Total	29.137	63		

*p = < 0.01

It appears that the quality of the EMCON plans, measured in terms of either FRAC or DFRAC scores, was directly related to whether or not the participants used the EWAR aid. The other independent variables manipulated had no systematic effects on either measure.

Percentage Correct

An EMCON plan may be considered as a set of statements about the status of emitters. Within this logic, a criterion EMCON plan could be considered to be a statement of the status of the emitters for a best plan. Such a logic considers the status of each emitter as a true-false item and allows direct scoring of each participant's best plan for each problem.

Taking the proportion of the total number of emitters correctly set against the total number of emitters in the task force gave a percentage correct (PERCOR) measure of the correspondence between the criterion plans and the participants' plans. Over all conditions, the mean PERCOR, score was 76.80 with a standard deviation of 20.04. These scores suggest that about 70 percent of the time there was a 55 to 95 percent correspondence between the criterion and participant generated EMCON plans.

However, it was possible to partition the PERCOR score into two parts: (1) the percentage of the radars correctly turned on (PERON), and (2) the percentage of the radar emitters correctly turned off (PEROFF). The mean PERON score, 66.71, was substantially lower than the mean PERCOR score, whereas the mean PEROFF score, 91.05 was considerably higher.

The *t*-test was used to examine the difference between the PERON and PEROFF scores. A statistically significant difference was observed. This finding suggests, in one sense, a tendency on the part of the participants to underemphasize surveillance in their EMCON planning.

The effects of the manipulation of the independent variables on the PERCOR scores were also examined by means of a two-by-two-by-two analysis of variance. The results of the variance analysis are summarized in Table 3. The results indicated that the aid level manipulation contributed significantly to the PERCOR. In addition, as was indicated previously for other measures, the manipulation of training and of problem difficulty did not produce any statistically significant effects on the PERCOR scores. The mean PERCOR scores, across and within conditions, were:

Training Levels	Mean
Experimental	76.78
Control	76.82

Table 3

Variance Analysis Summary for the PERCOR Scores

Source	Sum of Squares	d.f.	Mean Square	F
Between Groups	2,579.938	15		
Training (T)	0.063	1	0.063	.0003
Subjects Within Groups	2,579.875	14	184.277	
Within Conditions	9,692.000	48		
Aid Use (A)	1,640.250	1	1,640.250	8.5920*
T x A	0.025	1	0.025	.0001
A x Subjects Within Groups	2,672.725	14	190.909	
Difficulty (D)	80.999	1	80.999	.6029
T x D	225.000	1	225.000	1.675
D x Subjects Within Groups	1,881.000	14	134.357	
A x D	1.687	1	1.687	.0076
T x A x D	85.913	1	85.913	.3874
A x D x Subjects Within Groups	3,104.400	14	221.743	
Total	12,271.937	63		

*p = < .05

Aiding Levels	Mean
Aid	81.86
Manual	71.74
Difficulty Levels	
"Easy"	75.57
"Hard"	78.03

One partitioned component of the PERCOR was the percentage of the radars that was properly turned on (PERON). These scores were similarly subjected to a two-by-two-by-two analysis of variance. The variance summary is shown in Table 4. Only the aid levels variable was statistically significant. The probability of turning on the correct radar emitters increased in the aided condition and decreased in the manual condition. This seems to suggest that the aid facilitated an increase in the rate of turning on correct emitters.

There was also a tendency toward a statistically significant interaction between training and problem difficulty level. This tendency is plotted in Figure 3. The PERON score did not tend to vary across "easy"-"hard" problems for the trained (experimental group) subjects but, for the nontrained (control group) subjects, the scores tended to increase markedly between "easy" and "hard." Evidently, the training differentially affected the tendency to activate emitters for the control as compared with the experimental group. Here, we note that information denial was emphasized during the training. The obtained means were:

Training Levels	Mean
Experimental	67.17
Control	66.25
Aiding Levels	
Aid	72.73
Manual	60.69
Difficulty Levels	
"Easy"	64.67
"Hard"	68.75

The final partition of the PERCOR, the PEROFF, was also evaluated by a two-by-two-by-two analysis of variance. The results are summarized in Table 5. The only statistically significant main effect was aid levels; neither training nor difficulty, nor their interactions systematically affected the PEROFF. The means were:

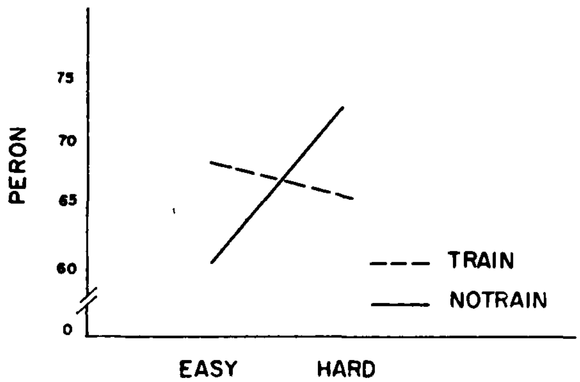


Figure 3. The interaction between training and difficulty in the PERON scores.

Table 4

Variance Analysis Summary for the PERON Scores

Source	Sum of Squares	d.f.	Mean Squares	F
Between Groups	4,221.484	15		
Training (T)	31.629	1	31.629	0.11
Subjects Within Groups	4,189.845	14	299.275	
Within Conditions	20,912.250	48		
Aid Use (A)	2,292.014	1	2,292.014	5.75*
T x A	107.643	1	107.643	0.27
A x Subjects Within Groups	5,578.093	14	398.435	
Difficulty (D)	260.014	1	260.014	1.30
T x D	984.391	1	984.391	4.94
D x Subjects Within Groups	2,789.343	14	199.239	
A x D	13.143	1	13.143	0.02
T x A x D	228.760	1	228.760	0.37
A x D x Subjects Within Groups	8,656.845	14	618.346	
Total	25,133.734	63		

*p= < 0.05

Table 5

Variance Analysis Summary for the PEROFF Scores

Source	Sum of Squares	d.f.	Mean Square	F
Between Groups	2,795.938	15		
Training (T)	10.568	1	10.568	0.053
Subjects Within Groups	2,785.370	14	198.955	
Within Conditions	6,707.000	48		
Aid Use (A)	742.568	1	742.568	4.960*
T x A	52.550	1	52.550	0.351
A x Subjects Within Groups	2,095.880	14	149.706	
Difficulty (D)	232.568	1	232.568	1.866
T x D	33.053	1	33.053	0.265
D x Subjects Within Groups	1,745.380	14	124.670	
A x D	52.553	1	52.553	0.429
T x A x D	60.078	1	60.078	0.491
A x D x Subjects Within Groups	1,712.370	14	122.312	
Total	9,502.938	63		

*p = <0.05

Training Levels	Mean
Experimental	90.58
Control	91.52
Aiding Levels	
Aided	94.38
Manual	87.72
Difficulty Levels	
"Easy"	89.25
"Hard"	92.89

The analysis of the relationship of activated and deactivated emitters between the plans obtained from the participants and those of the criterion plans indicated that participants more frequently errored in the direction of leaving radars off that should be on. They might be described as having decision rules or rule governed behavior that was very conservative. Not turning on radars could of course be considered an extension of denying information to an enemy. Perhaps the participants were operating on the conjecture that the best way to avoid giving away information about task force composition was to be very conservative.

There was a substantial difference between a conservative plan and the best possible plan. The aid does not appear to address this difference. Perhaps the aid should allow an interactive conversation between the aid and a user which would attempt to at least enlighten an individual about the possible benefits of being less conservative.

Summary of Variance Analyses

The quality of the EMCON plans developed by the participants was evaluated by studying the variance of a number of measures. The FRAC score was used to evaluate the plans among themselves and the DFRAC and PERCOR scores (including the PERON and PEROFF scores) were employed to evaluate the plans in regard to a criterion. Consistently, it was shown that use or non-use of the EWAR aid in solving an EMCON problem had statistically significant effects on the scores. In FRAC alone, there was about 25 percent increase when the aid was used. Statistically significant differences due to training or to problem difficulty level were not evident. These latter indications may be an artifact of the scoring methods employed--especially for the PERCOR, PERON, and PEROFF scores. There was almost an infinite number of different possible EMCON plans that potentially could be developed for each problem.

Assessing these in terms of a set of binary measures is similar to scoring a musical composition against a set of binary criteria. It seems that development of a symphony was asked and that the symphony was graded on specific criteria. The general goal allowed for a great deal of artistic variability between answers and the variance across the specific measures (PERCOR, PERON, PEROFF) may simply not have reflected this artistic latitude. Such a situation might have been avoided if the participants were asked to "select the best EMCON plan from the alternate plans A, B, C, and D" as opposed to "develop a best EMCON plan" from the almost infinite number of plans.

Policy Capturing

During the data acquisition, each participant was required to produce the EMCON plan he thought was best for eight problem situations. It may be assumed that when a participant made a decision, it was based on some selected set of values, each being assigned a unique importance or weight. Knowing what sets of EWAR provided data were emphasized by the participants would allow insights into the general nature of EMCON decision making and into the issues of the relevance of the data supplied by EWAR.

In order to ascertain the relationships between the derived plans and the associated available information, a set of multiple regression analyses was completed. In these analyses, the participant plans constituted the dependent variable, measured in terms of the percentage of correct emitters (PERCOR), which was regressed against eight independent variables. Each independent variable was a single reference number designed either to summarize the data about a plan or to represent an index of an important aspect of available data.

The eight independent variables were:

surveillance score (SURV)
probability of identifying high value ship (PID)*
perceived value of high value ship (PERVAL)*
information denial score (INFO)
trade off score (TRADE)
fraction of task force remaining (FRACTF)
fraction of high value ship remaining (FRACHVS)
number of hits across both threat types (HITS)*

All of these data were given directly or indirectly by the EWAR aid. Two threat types (SNEAKER and STREAKER) were assumed and, where an asterisk is indicated in the above list, the reciprocal of the actual value was employed in the analysis.

The multiple regression analyses were performed on the overall data collasped across conditions and on the data fragmented by aid levels, training levels, and difficulty levels.

Overall Analysis

The first multiple regression analysis was based on the data collapsed across training, aiding, and difficulty. The results are shown in Table 6.

Three variables entered the multiple regression equation--the TRADE, the FRACTF, and FRACHVS. Collectively, they accounted for about 44 percent of the total variance.

TRADE was the first variable which entered the equation and it yielded an R of .61, accounting for 37 percent of the total variance, or about 84 percent of the predictable variance. Each of the other variables as they were entered accounted for a lesser amount of the variance. With the entry of FRACTF, the R increased to .65, accounting for an additional five percent of the variance. However, the entry of FRACHVS had only a negligible effect on total predictability.

It appears that the participants based their decisions primarily on increasingly high TRADE scores. The increasing absolute value of the TRADE scores was evidence of a more finely tuned balance between the surveillance coverage and information denial. After arriving at a finely balanced plan, the results suggest that minor adjustments may have been made to obtain higher FRACTF scores. The adjustments may have also resulted in some minor decreases in the FRACHVS. The participants evidently thought that the most important aspect of EMCON planning was appropriately balancing the divergent needs of the task force and that this should be done in such a way as to produce an expectation that a high fractional value of the task force will be remaining.

Aid Levels

The next multiple regression analyses were those differentiated on the basis of the aid levels. The results of these analyses are shown in Table 7. The upper half of Table 7 contains the data from the aided conditions and the lower half the data from the unaided conditions. There were virtually no differences in the variables entering the equation and in the variance accounted for between the aided condition and the overall data.

Table 6

Results of Overall Multiple Regression Analysis

Order of Variables Entering Equation	Multiple R	R^2	R^2 Change	Weight	Constant
TRADE	.6103	.3724	.3724	.3662	
FRACTF	.6520	.4251	.0526	.5242	
FRACHVS	.6500	.4350	.0099	.2289	
					-.0001

Table 7

Results of the Separate Multiple Regression Analyses of the Aided and the Unaided Conditions

Order of Variables Entering Equation	Multiple R	R^2	R^2 Change	B Weight	Constant
		Aided			
TRADE	.6020	.3625	.3625	.5283	
FRACTF	.6358	.4242	.0418	.6422	
FRACHVS	.6532	.4262	.0225	.4153	
					.0765
		Unaided			
FRACTF	.5890	.3469	.3469	.3564	
TRADE	.6181	.3820	.0351	.2630	
					-.1268

This was not the case in the unaided condition. For the unaided condition, the FRACTF variable was the first to enter the equation. Its entry was associated with an R of .59, accounting for about 35 percent of the variance. The only other variable entering the equation was TRADE which caused the R to increase to .62--a four percent increase in predictable variance.

These data suggest that EMCON planning was based on a different logic when the participants were in the aided and in the unaided conditions. EMCON planning was very strongly influenced by the FRACTF scores in the unaided condition, and not by the TRADE scores, as was observed in the aided condition. Balancing the components of the TRADE scores might have required some very fine assessments of the problems. If this is true, then it is possible that the aid might have facilitated these assessments, allowing for the distribution of the EMCON plans to be clearly related to the distribution of the TRADE scores. This, of course, suggests that these types of fine assessments were more difficult without the EWAR aid. What the participants seemed to have done in the manual condition was to select plans intended to maintain the integrity of the task force without being able to develop a high quality, well balanced plan.

Training

The next regression analyses were related to the training levels. The results of these are presented in Table 8. The data from the experimental group are presented at the top of the table and the control group's data are presented at the bottom. Two differences are apparent from a comparison of the two groups: (1) completely different variables were entered into the respective regressions equations, and (2) substantial differences existed in the amount of variance accounted for.

Two variables entered into the equation as a result of the regression analysis of the experimental group's data. The first was FRACTF which was associated with an R of .49 and accounted for 24 percent of the variance. When PID was also entered, the R increased to .52 representing a three percent increase in total predictability. The total variance accounted for, 27 percent, was the lowest observed in any of the current regression analyses.

The results of the regression analysis of the control group's data were very different. As with the aided and overall analyses, the TRADE variable entered first and accounted for 62 percent of the variance, the largest observed in any of the current regression analyses. The total variance accounted for, with the HITS and PERVAL entered, was 65 percent.

Table 8

Results of the Regression Analyses of the Training Levels (Experimental and Control Groups)

Experimental

Order of Variables Entering Equation	Multiple R	R^2	R^2 Change	B Weight	Constant
FRACTF	.4868	.2369	.2369	.4787	
PID	.5168	.2672	.0302	.1731	
					-.0050

Control

Order of Variables Entering Equation	Multiple R	R^2	R^2 Change	B Weight	Constant
TRADE	.7882	.6212	.6212	.6806	
HITS	.8023	.6438	.0225	4.5508	
PERVAL	.8062	.6500	.0063	.1309	
					-.9776

The differences between groups seem to suggest that the training in EMCON planning and in the use of the information denial guidelines affected the use of information. The experimental group's training was intended to give them technologies and algorithms which would enable them to generate rather close approximations of the information that was provided by the EWAR aid. They were trained in estimating the surveillance coverage, in most of the information denial aspects, and on trade offs. During the training, the participants negatively criticized, on the basis of incompleteness and lack of realism, some aspects of the trade off algorithm contained in the aid. This feeling tone may have negatively biased them against the TRADE score.

Apparently, because the control group was not exposed to the training, its members were not biased against the algorithm and the resultant TRADE score. When the members of the control group started using the EWAR aid, they proved to be surprisingly sensitive to these scores.

Difficulty

The final regression analyses were concerned with the difficulty levels. The results of these analyses are presented in Table 9.

The total variance accounted for varied between difficulty levels--43 percent for the "hard" problems and 52 percent for the "easy" problems. For the "easy" problems, the initial entry, TRADE, produced a R of .71 and accounted for 50 percent of the variance. For the "hard" problems, the initial entry, FRACTF, was associated with a R of .64 and represented 41 percent of the variance. For both problem difficulty levels, FRACTF and TRADE entered the regression equations, but in a different order. It appears that, across difficulty levels, the quality of the participants' selected plans was related to the trade off analyses but the TRADE score was differentially emphasized as a function of problem difficulty. TRADE scores were more heavily emphasized when "easy" problems were involved and the FRACTF was more heavily emphasized in the thinking of the participants when "hard" problems were involved.

Discussion of Regression Results

Consistently, the regression results indicated that the participants employed "second order" information in deriving EMCON plans. By "second order" information we mean derived or aid generated information as opposed to the basic surveillance and information denial information which are a direct function of emitters activated or deactivated. While different sets of information may have been more or less emphasized across conditions (as was to be anticipated), in no case did the participants revert to raw emitter status as a decision basis. Such a finding supports the need for and utility of some type of decision aiding in the EMCON context and of the EWAR aid.

Table 9

Results of the Regression Analyses of Difficulty Levels

"Easy"

Order of Variables Entering Equation	Multiple R	R^2	R^2 Change	B Weight	Constant
TRADE	.7080	.5012	.5012	.6767	
FRACHVS	.7154	.5118	.0106	.2878	
FRACTF	.7226	.5222	.0104	.2352	
					.0156

"Hard"

Order of Variables Entering Equation	Multiple R	R^2	R^2 Change	B Weight	Constant
FRACTF	.6439	.4146	.4146	.5422	
TRADE	.6526	.4259	.0113	.1444	
					-.0085

Linear Structural Equation Model

The regression analyses suggested that the variables most clearly associated with EMCON plan quality were "second order" functions such as TRADE scores.

The suggestion, however, says no more than that a trade off was made. While pragmatic, it does not yield an appreciation of what psychological acceptances or rejections were involved. To develop fuller insight into the nature of the trade offs, a structural equation trade off or "causal" model was developed. This model utilized as basic a set of assumptions as possible, while incorporating what appeared to be the major determinants of an EMCON trade off. The model, which is described in detail in Appendix C, considered five variables: trade score, surveillance score, information denial score, need for protection, and need for security.

The data from the aided conditions were employed to calculate structural coefficients by the least squares technique. The Statistical Package for the Social Sciences (SPSS) program (Nie, Hall, et al., 1975) was employed to this end. Appendix C contains calculational details.

The path coefficients, so derived, may be interpreted in terms of causality, i.e., a change of one unit in variable *x* causes a change in *y* units in variable *z*. The coefficients for surveillance score and information denial score on trade score were respectively .79 and .25. This suggests positive causal relationships for the two variables (surveillance and information denial) with the major consideration being surveillance coverage.

There was also a low reciprocal relationship (-20) between surveillance and information denial. This result represents a cognitive processing of the maximizing tendencies set into effect by the need for protection and the need for security.

Discussion of Structural Model

The findings suggest that the composition of the EWAR aid is such as to support the psychological (latent) and logical needs for developing an effective EMCON plan. It is not known whether or not such a model was implicit in the thinking of the aid's developers. Nevertheless, it seems that the aid's composition is such as to support the processes employed by our sample to develop their plans. To this extent, the EWAR aid may be held to provide direct support to the cognitive and psychological needs in EMCON planning. It goes without saying that a causative model should be implicit in the thinking of the developer of any decision aid. Moreover, it is quite possible that such a model should be made explicit before any decision aid is developed.

A preconceived model would tend to minimize the proliferation of aids and aid features which contain a wide variety of information of marginal value to the user. In such a case, the test of the aid might be based on the extent of causality indicated by the model.

Confidence, Difficulty, and Learning

When he completed each problem, each participant was required to make a judgment about the difficulty of the problem and his confidence in his decision. The relationship between these two ratings was examined. The relationship, as indicated by the Pearson product-moment correlation, was slightly negative ($r = -.18$). Confidence seems to have been only slightly affected by the perceived problem difficulty. The relationship varied with training. The correlation was more negative for the experimental group ($r = -.33$) than for the control group ($r = -.16$).

The relationship between the perceived and a priori difficulty ratings was also evaluated. The results indicated virtually no relationship ($r = .15$). In addition, a breakdown by groups revealed only minor influences: $r = .12$ and .18 for the experimental and the control groups, respectively.

Learning

The FRAC data were analyzed for a learning effect by a linear regression analysis. For each participant, the FRAC scores were organized in the serial order in which the associated problems were presented during the testing. These data were analyzed for any systematic variablity across the ordinal positions. The analysis indicated that a negligible, non-significant effect was apparent, $r = -.05$. That is, there was no apparent learning effect.

Multiattribute Utility Analyses

The multiattribute utility analytic technique is devised to allow quantification of the utility of a process or product when multiple goals and multiple attributes are involved, as in the case of the EWAR aid.

The participants rated the seven EWAR aid goals, shown in Exhibit 18, on how closely each was attained by the aid. To this end, they distributed 100 points across the goals. These ratings were used in combination with a set of weights, selected to reflect the importance of each goal, to obtain estimates of how well the EWAR aid achieved its purposes or goals in relation to their importance.

The utilities were obtained by the formula:

$$GU_i = \sum_{i=1}^{n} A_i w_i$$

where GU_i indicates the perceived utility of goal i, and A_i and w_i are the participants' achievement ratings and the developer's weights of the importance of goal i, respectively. The utilities are presented in Table 10. In Table 10, the first four rows of data under each goal contain the optimum utility, the overall utility, the utility from the experimental group, and the utility from the control group, respectively. The next three and the last three rows, respectively, contain the percentage of each goal's attainment and the mean ratings based on the overall data, and the experimental and the control groups' individual data.

The optimum utilities represent criteria against which the perceived utilities may be judged. The optimum utility measures rest on the assumption that goals should be achieved in proportion to their importance. Overachieving a goal represents an uneconomical allocation of resources and underachievement represents a deficiency. If each goal was perceived to be achieved at an optimum level, then the ratings of achievement would be equal to the weights of importance. Therefore, the optimum was produced using the goal utility formula but with A_i equal to w_i.

The first utility to be examined was based on the combined data of the experimental and the control groups (overall row in Table 10). Goal G_1 was one of the less important goals of the EWAR aid. It possessed a weight of 10 and had an overall perceived utility of 810. A comparison of this value with the optimum utility of 800 indicates that the aid achieved its goal of facilitating the formation of hypotheses about how best to improve a plan at about the optimum level. Goal G_2 was the most important goal of the EWAR aid. Goal G_2 possessed a weight of 20. The overall perceived utility was 2640 which represents an underachievement of 17 percent when compared with the optimum of 3200. An 83 percent goal attainment represents reasonable, but not full, success relative to the aid's most important goal--producing better EMCON plans.

The third goal, G_3, was moderately important. It possessed a weight of 15 and obtained an overall utility rating of 1275. Comparing this to the optimum, 1800, suggests that this goal was less well realized than the two previously described goals. The goal of helping to quantify the surveillance and information consequences of a plan had a 71 percent attainment. This was the lowest attainment percentage of any of the goals.

Goal G_4, to make it practical to examine a larger set of alternative plans, also possessed a lesser importance weight (10). The perceived utility, 1470, was 184 percent of the optimum utility of 800. This suggests considerable overachievement. Certainly, the hard copy features of the

Table 10

Optimum and Attained Utility of EWAR Aid Relative to Seven Goals

	G_1	G_2	G_3	G_4	G_5	G_6	G_7	Total
Optimum	800	3200	1800	800	1800	1800	1800	12,000
Overall	810	2640	1275	1470	1305	1680	2340	11,523
Experimental	1000	2420	1335	1290	1500	1770	2145	11,465
Control	620	2860	1215	1650	1110	1590	2535	11,580

Percentage of Each Goal's Attainment

	G_1	G_2	G_3	G_4	G_5	G_6	G_7
Overall	101	83	71	184	73	93	130
Experimental	125	76	74	161	83	98	119
Control	78	89	68	206	62	88	140

Mean Rating Assigned to Each Goal in Relation to How Closely It Was Approximated by the EWAR

	G_1	G_2	G_3	G_4	G_5	G_6	G_7	Total
Overall	10.12	16.50	10.63	18.38	10.87	14.00	19.50	100
Experimental	12.15	15.13	11.12	16.13	12.50	14.75	17.88	100
Control	7.75	17.87	10.13	20.63	9.25	13.25	21.12	100

EWAR aid facilitated the consolidation of data which could be used for comparative purposes. In addition, the TRADE, SCORE display may have contributed to the very high utility of G_4. The TRADE, SCORE was specifically designed to assist in making comparisons across plans. Presumably, it allowed the choice of finely balanced plans.

The fifth goal, G_5 (to understand how different factors contribute to EMCON planning), was moderately important. It possessed a weight of 15. The perceived utility of the EWAR relative to this goal was 1305. This value is somewhat lower than the optimum value of 1800. The 73 percent attainment level was about as low as that observed for G_3. That the goal of understanding how different factors (threats, radars, etc.) contribute to EMCON planning was only moderately achieved may signify a need for a more direct means of assessing the effects of changing physical factors. This may be relevant to the low relative rating of G_3. A prior report (Siegel & Madden, 1980) suggested that feedback functions within an aid act to sensitize users to relevant physical factors in the situation under consideration. The EWAR aid seems to lack any simple, direct feedback mechanism relative to physical features.

The sixth goal, G_6, of the EWAR aid, was to improve confidence in the quality of the user's EMCON plans. This goal received an overall utility of 1680 against an optimum utility of 1800. Accordingly, this goal had a 93 percent attainment level which compares favorably with the level attained by G_1. G_1 was the only other goal for which the attainment approximated the optimum.

The final goal, G_7, was also of moderate importance and was overachieved. Its overall utility was 2340. This value represents an attainment of 130 percent of the optimum. The goal, to facilitate the comparison of alternative plans, to some extent was not mutually exclusive from G_4. Goal G_7's overachievement may be related to the same factors described in relation to overachievement of G_4.

Comparing the utilities across groups indicated some variability although the individual group distributions across goals tended to be similar to the overall distribution. Generally, the experimental (trained) group rated four of the goals (G_1, G_3, G_5, and G_6) higher than the control (untrained) group. The largest difference was observed for goal G_1. The experimental group rated G_1 (to facilitate hypotheses about how best to improve a current plan) as being overachieved by 25 percent, while the control rated G_1 as being 22 percent underachieved. This result may be due to the training which stressed formulating hypotheses about improving plans in two ways: (1) in the general discussion of manual planning, and (2) in the description of the information denial rules.

Other differences in the perceived utility between groups related to the overattained goals, G_4 and G_7. In both cases, the experimental group's ratings, although above the optimum, were considerably below the control group's. This result may also be related to training and be an expression of the fact that the experimental group may have appreciated more subtle aspects of the aid as compared with the more obvious comparison facilitations.

Summary of the Utility Analysis

The goals of the EWAR decision aid were reasonably well attained. The aid apparently lent itself rather well to supporting hypothesis generation and to confidence assurance. It was also perceived to be somewhat successful relative to the goal of producing better EMCON plans. However, there was apparently some inability on the part of the aid to make the effects of physical factors evident and surveillance and information consequences clear. The aid overachieved the goals which were concerned with the comparison of plans. Further emphasis on features relating to the plan comparison goals during future development of the aid, does not seem warranted.

We note that some features of the EWAR aid were not included in the current test. It is not believed that the inclusion of these features would affect the utility scores to any marked degree. However, the possibility of such an effect can not be ruled out.

Postevaluation Interview

At the conclusion of the data acquisition, the participants were interviewed about their personal reactions to the EWAR aid, its value, and how it might be improved. The interview was semiformal in nature. The full details of the interview content are presented as Appendix A to this report.

Usefulness Ratings

At the opening of the postevaluation interview, each participant was asked to rate the usefulness of each of the various EWAR displays. Each display was rated by way of a five category rating scale which was calibrated as: (1) minimally useful, (2) somewhat useful, (3) moderately useful, (4) considerably useful, (5) extremely useful.

The mean usefulness ratings for each display are shown in Table 11. In Table 11, the displays are organized by type across the top of the table. In addition, the data are collapsed across the groups in the top row (overall) and they are differentiated on the basis of training in the second and third rows.

Table 11

Usefulness Ratings of the EWAR Displays

	Display	Surveillance			Information Denial			Trade Off		
	EMCON	MAX	CUM	SCORE	DETAILS	TARGET	SCORE	MAP	SCORE	STRIKE
Overall	4.06	2.06	3.50	3.06	1.88	3.31	3.07	2.56	4.07	4.82
Experimental	4.50	1.75	3.25	3.25	1.75	3.12	3.00	3.12	4.25	5.00
Control	3.62	2.37	2.88	2.88	2.00	3.50	3.13	2.00	3.88	4.63

Usefulness Ratings of Each of the Four Different Types of Displays

	EMCON	Surveillance	Information Denial	Trade Off
Overall	4.06	3.13	3.25	4.82
Experimental	4.50	3.00	3.12	4.88
Control	3.62	3.25	3.38	4.75

Collapsed across groups, the highest ratings were obtained for two of the trade off displays and the EMCON display. The TRADE, STRIKE, the TRADE, SCORE, and the DIS EMCON displays were assigned mean usefulness ratings of 4.82, 4.07, and 4.06 (considerably useful), respectively. That the TRADE, STRIKE and the TRADE, SCORES were rated highest is concordant with the results of the policy capturing analysis. As previously reported, the TRADE, SCORE along with two components of the TRADE, STRIKE--the FRACTF and the FRACHVS--rather consistently entered the multiple regression equations and in various combinations accounted for most of the predictable variance. The congruence between the results of the policy capturing and usefulness ratings reinforces the contentions concerning the emphasis on these displays by the participants.

The high ratings observed for the EMCON plan display seems to reflect its singular nature. The display provided no additional information but it organized the important ship by radar type data in a very logical way. It may be that this served an important function, helping to generate hypotheses as to what radars should be turned on and off. The utility of displays which serve an information organizational purpose within a decision aid was previously recognized (Siegel & Madden, 1980) and the present finding reinforces this prior conclusion.

The lowest rating, 1.88 (minimally useful), was observed for the INFO, DETAILS display, while the SURV, MAX and TRADE, MAP were rated only slightly higher with ratings of 2.06 and 2.56 (somewhat useful), respectively.

Considering only the surveillance coverage and information denial groupings, within each group each of the displays may be conceived as presenting increasingly abstract or "second order" assessments along the relevant dimensions. The least abstract of these were the SURV, MAX and INFO, DETAILS along the surveillance and information denial dimensions, respectively. From the relatively low ratings given these two displays, one may infer that the participants did not find the relatively fundamental displays to possess high value. However, the usefulness of the surveillance coverage and information denial displays were nonmonotonic functions of the order or level of abstraction of the data presented in the display. The most useful were the intermediately complex SURV, CUM and INFO, TARGETS displays. Of intermediate usefulness were the most abstract, the SURV and INFO scores.

A relatively low rating was given to the TRADE, MAP display, a display which can not be considered to represent a low level of abstraction. However, the low rating of the TRADE, MAP display probably was a special case. According to the statements made by several of the participants, this display was not used because it was redundant, i.e., it represented a restatement of the data from the SURV, CUM and INFO, TARGET displays.

Generally, there was a tendency for the experimental group to rate the DIS, EMCON and the trade off displays somewhat higher than the control group. The reverse was true for the surveillance and information displays where the control group tended to assign ratings which were higher than those of the experimental group. However, comparing the distributions of the ratings across displays indicates considerable similarity both between groups and with the distribution of the overall ratings.

Generally, the preference was for displays at some level of complexity; i.e., displays which presented "second order" or processed information.

Display Groups

In addition to the ratings of the individual displays, the participants rated the usefulness of each of the four general display groups. These ratings, shown in the lower half of Table 11, largely concur with the individual display ratings. The trade off group (a "second order" group) was rated highest. This preference was followed by the display EMCON group, while the information and surveillance groups were about tied for the lowest positions. The trained subjects rated the first two (trade off and EMCON groups) higher than the untrained and the reverse held true for the latter two (information and surveillance groups). Since the displays in the information and the surveillance groups were based on lower order information than the displays in the trade off group, it may be that the training sensitized the participants to the utility of the higher order information.

Rank Ordering

The participants were also asked to rank order the displays within each group and the groups in general. These rankings were obtained because it was thought that, if the ratings were inconclusive, then at least the rankings would show gross ordinal measures of usefulness. As indicated above, the rating data were far from inconclusive. Accordingly, the rankings are somewhat redundant.

The results of the ranking, shown in Table 12, indicate considerable consistency with the prior data. At the top of the table, the rank order of the surveillance displays is shown for the overall data and differentiated on the basis of training. Very consistently, the CUM display was ranked number 1 with SCORE display ranked number 2 and MAX ranked 3. The same consistency with the prior data was observed in the information displays. The TARGET, the SCORE, and the DETAILS were ranked 1, 2, and 3 respectively. Again with the trade off analyses, the STRIKE, the SCORE, and the MAP displays were consistently ranked 1, 2, and 3.

Table 12

Mean Rank Order of the EWAR Displays According to their Usefulness

		Overall	Experimental	Control
Surveillance	MAX	3	3	3
	CUM	1	1	1
	SCORE	2	2	2
Information	DETAILS	3	3	3
	TARGET	1	1	1
	SCORE	2	2	2
Trade Off	MAP	3	3	3
	SCORE	2	2	2
	STRIKE	1	1	1

Mean Rank Order of the Four Display Categories

	Overall	Experimental	Control
Display, EMCON	2	2	4
Surveillance	3	3	3
Information	4	4	2
Trade Off	1	1	1

The ranking of the displays by category showed less agreement with the prior data based on ratings. Although the trade off display group was again always ranked number 1, the ranking obtained from the pooled data assigned rank 2 to the EMCON display, rank 3 to the surveillance group, and rank 4 to the information group. This same ordering was also observed for the experimental data. However, the control group's data were different. The number 2 rank was assigned to the information group; the 3 rank was assigned to the surveillance group, and the lowest rank was assigned to EMCON.

Other Opinions

Each participant was asked a number of open ended questions in the course of the interview. The open ended questions were grouped into four general areas: (1) the usefulness and advantages/disadvantages of the aid, (2) the sufficiency/insufficiency of the information provided, (3) personal strategies and heuristics used by the participants in producing an EMCON solution, and (4) the assumptions on which the EWAR aid rested.

The participants generally found the aid to be very useful and about 60 percent indicated that the aid was more useful for some problems than for others. The reasons suggest that "the simple problems did not require computer treatment," and that "the aid was slower for some problems." Implied by the "simple" problems were the easy problems with "few ships and few radars." This opinion, however, was not universal and some participants thought the aid to be equally useful across all of the problems.

When asked to compare the plans developed with the aid against those developed manually, plans developed with the help of the EWAR aid were said to be superior. About 67 percent of the responses indicated that the use of the aid resulted in better EMCON plans. Most of the participants said that using the aid allowed for more "finesse" in planning, producing "better," more "sophisticated" plans and with an increased "confidence." Those participants who thought that there was little difference between plans developed with or without the use of the EWAR aid indicated that they had learned so much using the aid that they could now produce plans of equal quality without it. These participants stated that "after getting a feel for the trade offs between information denial and surveillance, the marginal value of using the aid was small" and that "after working with the aid you get basic insights and with minor corrections you get the same results with or without the aid." Furthermore, they said that they "took advantage of what was learned with the aid to apply strategies." Such findings support the utility of the aid as a training device.

When asked if one technique was better than the other, 77 percent affirmed that the aid represented a better technique. The reasons given were the possibility of "comparing numerous things simultaneously," "increasing flexibility" and the "number of plans that could be compared."

Those who denied the superiority of EMCON plans produced with the assistance of the EWAR aid based their arguments on the large amount of transfer from aided to nonaided development and suggested that under those conditions "neither technique was better."

Most of the participants said that the differences between techniques were quantitative rather than qualitative in nature. That is, the aid "does more at once," giving a "more exact idea of probabilities and exact coverage." The major differences centered on the "ability to do more quantitative analyses." Put another way, "gross assumptions were made manually" which were "not constrained" as they were when using the aid. Other important differences had to do with the graphics--"ability to get a visual representation of the plan."

All of the participants said that the aid increased their confidence in the plans they developed and all also trusted information claculated by the aid more than that which they calculated themselves.

Other questions concerned the use of the EWAR aid under live and real combat conditions. Ninety four percent of the participants answered that they would feel comfortable using the aid in such conditions. This primarily meant that the aid's information would represent another set of information that must be considered by an EW officer. Some also indicated that the aid would facilitate planning because it was "better than nothing," that they would "feel better with numbers," and the aid would probably "help make a better decision." On the other hand, some respondents thought that the aid needed "major modifications" because it was "much too slow" and "tried to do too much."

Sufficiency of Information Provided

The second major area about which detailed information was developed during the interview concerned the adequacy of the displays, the sufficiency of the data made available, and the mechanics of the command structure. About 69 percent of the participants thought that one or more of the graphic displays was confusing. One display that generally was thought to be confusing was the SURV, CIRCLES, especially when the threat was Streaker.

The participants also provided information about features that were thought to be needed. One change which was suggested several times emphasized that the aid "should provide optimum plans" or that the "computer make reasonable suggestions as to what to try." It was generally thought that a lot of time was wasted getting into a position from which good plans could be developed and that the aid should supply "some starting points."

The other two items most criticized were mechanical features of the aid. One concerned the necessity of saving scores for future use by the trade off analysis. The participants were somewhat vexed by the time consumed by the requirements to save scores and indicated that "every time the plan is changed, the scores should be automatically saved." The other criticism in this area was concerned with the difficulty of the command structure and the "inadequacy of the error messages." A complete "restructuring" of the command and rethinking of the error messages were generally thought to be needed.

Other improvements which were less consistently suggested included: (1) a comparison table for the TRADE, STRIKE, (2) concurrent presentation of INFO and SURV SCORES, (3) presentation of threat vectors on the SURV, CIR and CUM displays and TRADE, MAP displays, (4) combination of INFO, DETAILS and TARGETS so that there would be real numbers on the latter, (5) presentation of the differential effects of adding one or more radars (a sensitivity function). Each of these, as for the modification of the structure of the command sequence/language, would add user convenience. Such convenience features seem to be important to the users of decision aids.

The participants were also asked if any of the EWAR aid's displays were not necessary. Two displays were mentioned about 50 percent of the time, the INFO, DETAILS and TRADE, MAP. The former was mentioned because the information it presented was adequately handled at a higher level by the INFO, TARGET display and the latter because it was redundant, had "no function," and was "difficult to read." If one remembers that these displays were consistently given the lowest usefulness ratings, then their mention here should not be surprising.

Strategies and Heuristics

The third general area of inquiry concerned the strategies and heuristics used by the participants.

The first topic in this area was concerned with the information denial guidelines. These were provided only to the experimental group. The participants from this group were asked how useful the rules were in developing and evaluating EMCON plans and how much influence they had on plan development. To both of these questions, the participants most frequently answered "moderately useful and influential." In addition, they indicated that the rules made only a moderate contribution to their overall EMCON planning. The reasons given were related to the "common sense" nature of the rules; most indicated that the "concept is good for teaching purposes, but it is intuitive."

When all the participants from both groups were asked what strategies or heuristics they used to derive their best plan, the answers were the same. Regardless of the group, the participants overwhelmingly started a problem by hiding the high value ship. They did this by essentially applying the information denial rules. That is, even the control group participants, listed steps which to all intents and purposes were statements of the rules. The responses indicated that once the insight was developed that the radars on the high value ship should be deactivated, the rest of the problem became a game in which the goal was to maximize the fractional value remaining along with the surveillance and information scores.

The participants were also questioned about any differences in their approaches to EMCON plan development as opposed to plan evaluation. The displays most often used for plan development were the SURV, CUM display (indicated by about 40 percent of the participants to be important) and the TRADE, SCORES (indicated by 30 percent as important). Also mentioned about 10 percent of the time, were the EMCON plan display, the INFO, TARGET, and the SURV, CIRCLES. One display, the TRADE, STRIKE, predominated in plan evaluation.

These data suggest that the importance of the TRADE, SCORE and TRADE, STRIKE were derived from different sources. The TRADE, SCORE apparently was important because it helped generate hypotheses and the TRADE, STRIKE was important because it helped test the hypothesis.

When questioned about the strategies used to develop plans in the unaided condition, the responses centered on a "carry over" technique. The participants indicated that they learned some fundamental principles from the aid and by the end of the testing were developing EMCON plans manually by directly applying those principles. This finding again suggests the utility of the EWAR aid as a training device.

Generally, the participants indicated that manually developed plans were not quite equal to those developed with the aid. According to the participants, the fundamental operation, maximizing information denial, could be easily performed without the aid. This, of course, was only one part of plan development. The remainder, ensuring adequate surveillance coverage, demanded more sophisticated thinking and it was in this area that the "marginal utility of the aid as an operational tool" was apparent.

When the participants in the experimental group were asked if they used the manual techniques and methodologies presented during the training, they generally responded in the negative. This held in spite of the fact that 100 percent said that the manual methodologies were adequate and sufficient to the task. The techniques which were presented were held to be too cumbersome to use and it was said that "once you had some experience with the aid (usually as the result of working on the practice problems before the start of testing), they were not needed."

Assumptions of EWAR Aid

The fourth and final general area of inquiry was related to several of the assumptions on which parts of the EWAR aid were based. The first and less important of the assumptions was concerned with how threats were tracked and defenses targeted. There was a tendency to indicate that the targeting and tracking assumptions were somewhat unreasonable. The participants seemed to think that the aid underestimates the number of threats that will be destroyed.

The second, and somewhat more important assumption, was concerned with the targeting of threats in proportion to the perceived value of targets. While the responses indicated that the participants agreed to a considerable extent that the enemy would probably target by perceived value, there was a 50-50 split as to whether or not the enemy would derive perceived value in a manner analogous to that employed by the aid. Half of the participants thought that an enemy will have other sources of targeting information beyond those suggested by the aid. This suggests the need for revision of some of the aid's algorithms and for realistic algorithms in any decision aid.

When probed further on the reasons for the dramatic shift in the comfort level, the responses seemed to be related to "confidence." They were then asked; "what if the second plan, which resulted in substantial reductions in surveillance coverage, was carefully analyzed by the EWAR aid and the analysis indicated that the plan reduced expected damage below the level to be anticipated with all the emitters on?" Given this, the comfort level rose to the "moderate" level.

Summary of Opinions

It appears that the participants thought that the EWAR aid could be of value to fleet operations. There was, indeed, a good deal of discussion about the appropriate use, if any, of the EWAR decision aid. The major negative evaluation of the aid, and that which suggests its inappropriateness, was concerned with the kind of targeting information which may actually be available to an enemy. Many participants indicated that watching the activities of the task force or listening to their communications would be enough to allow inferences about the location(s) of the high valued ship(s).

Most positive assessments visualized the aid as having a multitude of uses. The first purpose, and the one most consistently stated, was to use the aid during the training of all EW officers and task force commanders. The second potential use was as a tactical planning device which would be used to develop contingency plans to be used in fleet operations. The third stated potential was as a decision aid under normal fleet operations. To meet the final purpose, a number of improvements were considered to be necessary. The most important improvement is the implementation of a system that automatically suggests the one or two best plans. This would, of course, be especially useful in rapidly changing situations.

One variant on this theme was the suggestion that "devious" plans which hide important ships may not be appropriate in all situations. Several participants thought that plans which depend on high levels of information denial might be usefully employed to get an intact task force into the area where a mission is to be conducted. Once the task force is safely into the area of operation, the need to hide was said to be over and all the emitters might be turned on. This suggestion seems to be a reflection of the participants' disbelief that the enemy's sources of information would be limited.

Implications for Aid Development

The present work has suggested a number of implications for operational decision aid development and design.

From the point of view of aid development, the most primary implication seems to rest on the suggestion that aid developers conceive a causal model within the specific decision(s) they are aiding. Such a model should be made explicit before actual aid design takes place. A causal model development phase within the aid development cycle would be analogous to the conceptual phase of the equipment development cycle. It is believed that resting aid design on such a model would avoid the proliferation of aid features and displays which add little, if anything, to the utility of the aid. At the least, the aid developer must possess some implicit model before he proceeds with his detailed design and development. The current suggestion would make the implicit model explicit. We do not advocate modeling the actual mental processes. Rather, we advocate providing the required results of the mental processes in the form which is logical to the user. Our contention is that the result of this approach to aid conceptualization will be aids which are more cost/effective and which are more valuable from the user's point of view.

One area in which the EWAR aid was said to require improvement was in making the effects of variability in physical factors apparent and in quantifying surveillance and information denial. The appropriate means for rectifying the shortfall is not at all obvious. Certainly any decision aid could take a number of approaches, either at molecular or molar levels, each of which derives from a different application of the feedback concept. Accordingly, in the context of the EWAR aid and at a molecular level, one could extract a sensitivity function that allows examination of a plan in regard to variations in the number, direction, or type of threats, or the destruction of threats in regard to variability in the number and type of radars activated, etc. On the other hand, from the point of view of information denial, a feedback function could be derived to analyze the effects of progressive changes in information denial on the fractional value of the task force remaining, or some other appropriate measure. At a more molar level and again in the context of the EWAR aid, the feedback could be textual in nature and a result of a critical analysis of the trade off aspects of an EMCON plan--pointing out its weaknesses, how it might be improved and to what end. Regardless of how feedback is achieved in any operational aid, it should not only allow for insight into the effects of certain decisions or contingencies, but it should also make clear the reasons for the effects of certain decisions or contingencies.

Another implication is the requirement for aids which are convenient to use. The command structure/language as well as some of the displays in the EWAR aid were negatively appraised by some of the participants in the current work. User convenience features such as menuing, error statements, prompting, and guided use are well within the current state-of-the-art and should constitute an essential ingredient during aid design. The interface between the user and the aid, while possibly of little interest to aid developers, represents a major consideration to the user. Time lost and the frustration involved when the user attempts to make the aid do what he wants it to do represent particularly annoying user problems and negatively impact aid acceptance and use.

The needs for basing the aid's algorithms on realistic considerations and for complete algorithmic consideration of all important impacting variables was made apparent on the basis of the criticisms of the EWAR aid that: (1) an enemy would base targeting information on information other than, or in addition to, perceived value as derived by the aid, and (2) the fraction of task force remaining algorithm in the EWAR aid may not be fully comprehensive. Such perceived gaps tend to cause the user to lose confidence in a total aid when only one or two, possibly minor, algorithmic inadequacies are in evidence.

The greater acceptance of "second order" (processed) information as compared with more primary (unprocessed) information speaks to a primary feature of computer driven aids. The user wants the aid to assist him in the more sophisticated, complex aspects of the solution process. He thinks, if necessary, he can easily perform the less complex operations himself. Accordingly, any aid must first unburden the user from complex information processing. Then, and only then, should the aid become involved with the more routine information processing.

Another implication is related to the suggestion that the EWAR aid provide a best EMCON plan (or two plans--one for surveillance coverage and one for information denial.) The participants indicated that such a feature would at least provide a point of departure. Evidently, the users wanted the aid to save them as much time as possible. We note here that the participants devoted less time to achieving problem solutions in the unaided condition as compared with the aided mode. However, time saving was not the only consideration involved. Here, again, the use of the power of the high speed computer system seemed, to the participants, to not have been fully taken advantage of.

This expressed need is not in conflict with the prior study (Siegel & Madden, 1980) which reported a number of reservations about an "expected utility" function which was designed to give a "best" solution to a strike timing problem. We believe that the participants in the prior study considered the basic expected utility calculation, which was simply the weighted sum of lost and destroyed units, to represent basic information whose derivation through computer processing was nice, but not necessary. On the other hand, the EMCON plans suggested by the participants in the present study were non-trivial in derivation time and calculational complexity.

One feature of the EWAR aid which seems to have proven its merit was the hard copy capability of the system. This feature allowed participants to collect quantities of information from a variety of displays and a number of EMCON plans for comparison. This situation can be compared with the observations from our prior aid evaluation (Siegel & Madden, 1980) in which the participants spent much time making hand copies of relevant information and reported some inability to make comparisons across displays. It would appear that hard copy capability may be a necessary component of any aiding system.

Some of the difficulty associated with the introduction of any operational decision aid rests on user apprehension about aid use, aid accuracy, and aid thoroughness. It seems that a focused user's manual should be made available with any operational decisions aid. If users have such a manual available before they use an aid, procedural problems would be lessened and questions about the aid's logic would be answered before they become a matter of user concern.

IV. DISCUSSION AND CONCLUSIONS

The major purpose of the present work was to provide an evaluation of the EWAR operational decision aid. The aid was designed to provide assistance in the derivation of effective radar emission plans by task forces. As such, the aid possesses a wide variety of features which integrate information of various types and present the results of the integration in forms which can be used to provide at least a partial basis for EMCON planning.

Discussion

The evaluation produced evidence from a number of sources that suggests that the EWAR decision aid possesses utility. This was apparent from the variance analyses, the perceived utility analyses, and from the participants' judgments and opinions. In addition, the multiple regression analyses and the usefulness ratings suggested that the major sources of utility were based on the trade off analyses the aid allowed and on the information cascading provided by the aid.

The analyses of variance consistently indicated the aid level factor to have statistically significant effects. This held for the fraction of own task force remaining after a strike (FRAC), the difference between the fraction remaining and the optimum (DFRAC), the total percentage of radars correctly activated and deactivated (PERCOR), the percentage of radars correctly activated (PERON), and the percentage correctly deactivated (PEROFF). The FRAC and DFRAC analyses were particularly important because they reinforce the finding that the aid helped the participants to select plans that were superior on a measure very much dependent on making difficult trade offs. The other scores were used to examine the correspondence of the participants' and "optimum" criterion plans. Using the aid significantly increased the probability that the emitters' status would be correctly set. Clearly, the use of the EWAR significantly increased the quality of the EMCON plans whether they were measured by the FRAC scores or in relation to some criteria, such as the CFRAC or PERCOR, etc.

The multiattribute utility analysis and the opinions and judgments of the participants seemed to reinforce the notion that the aid was generally a useful tool. Across seven goals of the EWAR aid, the multiattribute utility analysis suggested about 96 percent goal attainment. In fact, some of the goals were possibly overattained. This overattainment may be a reflection of an inappropriate allocation of resources or it may reflect a failure on the part of the developers to understand the importance of comparing alternative plans. With a large set of plans, such comparisons could become quite tedious. It may be that the pertinent goals of the aid were rated highly because the participants implicitly understood how oppressive manual comparison could be.

The data from the regression analyses and from the usefulness ratings were complementary and also indicated that the most important function of the EWAR aid was to provide a method for making trade offs between surveillance coverage and information denial. There were, of course, some problems inherent in the aid which were uncovered by the evaluation. Several different sets of data suggested that the aid did not adequately sensitize the participants to a variety of important elements. This was indicated by the differences between the PERON and PEROFF scores, and by the underachievement by the aid of two of its goals. The underattained goals were: (1) to help quantify the surveillance and information consequences of a plan, and (2) to understand how different physical factors contribute to EMCON planning.

There was also some participant disbelief of the information denial analysis logic. Most participants were unsure as to what kind of information an enemy might have and how they might use it for targeting purposes. It seems that this problem would need to be resolved before the EWAR aid could be given attention for possible fleet use.

<u>Original Hypotheses</u>

The evaluation was designed to test four hypotheses. The first hypothesis, EMCON plan training will enhance plan quality, is not accepted. The training failed to show any effects in the most important variance analyses. Although there was evidence that training may have had some effects on method of approach to EMCON planning, these effects were not influential on plan quality as measured. The training served a purpose other than tutoring the participants in EMCON planning. It was also intended to teach a set of specific information denial rules. It was expected that the use of the information denial rules would enhance plan quality. This was not observed. Knowing the rules did not give the experimental subjects any detectable advantage in EMCON planning. In fact, the control subjects deduced the rules from the use of the aid. Therefore, neither of the two primary elements embedded in the training exerted important effects on plan quality, as measured.

The second hypothesis, superior EMCON plans will be produced when the aid is employed, may be accepted. The results of each of the variance analyses lend credence to the acceptance.

The third hypothesis, the problem difficulty will not affect the quality of the EMCON plans developed with the aid, is also supported. However, this support must be qualified because difficulty manipulation similarly did not exert any effects on manually developed plans. Perhaps, difficulty did not interact with aid levels because manual problem solution turned out to be an application of knowledge learned when using the aid. The transfer from the aid was mostly in terms of information denial.

A major component of the a priori difficulty score--the complication component--was a measure of the amount of information processing which would be required to produce a basic information denial plan for a problem. This aspect of the planning was highly transferable from the aided to the unaided conditions. Therefore, the difficulty effect was mitigated across conditions. This reasoning also may provide a rationale for the failure to confirm the final hypothesis, a high correlation will be noted between the a priori problem difficulty and perceived problem difficulty.

Conclusions

The evaluation results presented, described, and discussed throughout this report tend to support the following conclusions:

1. The EWAR decision aid, developed by Decision Science Applications, possesses considerable merit and potential for fleet use both as a training aid and as an operational support instrument.

2. Before any additional implementation is considered, modification and elaboration of certain of the aid's algorithms seems indicated.

3. Similarly, some modification of the EWAR aid's displays is indicated along with improvement of other user oriented features.

4. Application of the EWAR aid could result in about a 25 percent increase in the fraction of a task force remaining after a strike against the task force. This result seems to be fundamentally a function of the facilitation of trade off considerations provided by the aid.

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APPENDIX A

POST EXPERIMENTAL INTERVIEW FORM

EWAR Decision Aid Debriefing Form

Subject Name ______________________________ Date ____________

Subject I.D. ______________________________

Treatment Condition ________________________

The first set of questions concerns the use of the EWAR aid in EMCON plan development.

1. Would you say that the EWAR aid: (a) was more useful in developing and evaluating EMCON plans for some problems than for others, or (b) was it equally useful for all problems?

a or b: _____ Why so? ____

____

2. With this usefulness rating scale (show card with scale) rate how useful the following information was in the development of the EMCON plans.

	Rating				
a) EMCON plan display	1	2	3	4	5
b) Surveillance effectiveness analysis (general)	1	2	3	4	5
Maximum range circles	1	2	3	4	5
Cumulative detection probabilities	1	2	3	4	5
Penetration probabilities (surveillance score)	1	2	3	4	5
c) Information denial analysis (general)	1	2	3	4	5
Ship-to-blip assignment (INFO, WHO)	1	2	3	4	5
Blip-to-ship assignment (INFO, WHERE)	1	2	3	4	5
Probability that each blip is being emitted by each ship (INFO, DETAILS)	1	2	3	4	5
Probability of correctly identifying each ship (INFO, SUMMARY)	1	2	3	4	5
Comparison of perceived to true value (INFO, TARGET)	1	2	3	4	5
Information denial score (INFO, SCORE)	1	2	3	4	5
d) Trade-off analyses (General)	1	2	3	4	5
The cumulative probability-of-detection and perceived value lines (TRADE, MAP, THR -)	1	2	3	4	5

	Rating				
d) continued					
Plot of surveillance and information denial scores (TRADE, SCORES)	1	2	3	4	5
Strike outcome scores (TRADE, STRIKE)	1	2	3	4	5

3. I would like you to rank order the following set or sets of information according to their usefulness--from most to least useful.

a) First rank order the general categories of information that were available.

	Rank
EMCON plan displays	____
Surveillance effectiveness analysis	____
Information denial analysis	____
Trade-off analysis	____

b) Rank order the surveillance effectiveness information.

Maximum range circles	____
Cumulation detection probabilies	____
Penetration probabilities (SURV, SCORE)	____

c) Rank order the information denial displays.

Probability that each blip is being emitted by each radar (INFO, DETAILS)	____
Comparison of perceived to true value (INFO, TARGET)	____
Information denial score (INFO, SCORE)	____

Rank

d) Rank order the trade-off information.

Cumulative probability-of-detection and perceived value lines (TRADE, MAP, THR -) _____

Plot of surveillance and information denial scores (TRADE, SCORES) _____

Strike outcome scores (TRADE, STRIKE) _____

e) Of all the displays listed in b, c, and d above, what were the five most useful displays?

1 _____

2 _____

3 _____

4 _____

5 _____

4. Was there anything confusing about the tables or graphs? __________

____

Which tables? (Show cards with an example each table.) __________

How so? ____

____

Which Graphs? (Show cards with an example of each graph.) ________

How so? ____

____

5. What additional information do you think should be provided by the aid? Is there any additional information that you think would be important to provide in such an aid? ______________________________

____

Tables: ____

____

Graphs: ____

____

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6. What information provided or made available by the aid do you think should be deleted? ______________________________

____

Tables: ______________________________

____

Graphs: ______________________________

____

7. In developing and evaluating EMCON plans, how useful did you find the information denial rules? ______________________________

____

	Low				High
Rate them on this usefulness scale.	1	2	3	4	5
Rate them on this influence scale.	1	2	3	4	5

8. Do you think that the information denial rules made an important contribution to your overall EMCON plan development and evaluation? ______

____

	Low				High
Rate them on this contribution scale.	1	2	3	4	5

How so? ______________________________

____

9. When using the aid, what strategies or heuristics did you use to approaching EMCON plan development and evaluating? ______________

____

____

____

10. Again, when using the aid, what were the differences in your approach to plan development as opposed to plan evaluating? ______________

____

____

____

Were there some sets of information or displays you used for one and not for the other? ______________________________

____

____

11-14. The next few questions concern how you developed and evaluated EMCON plans without the aid.

11. When you could not use the aid, did you use the methods supplied during the training for estimating surveillance effectiveness and information denial?

Yes or No: __________

If not, what methods did you use? ______________________________

____

12. Did you feel that these methods were sufficient to the task?

Yes or No: __________

How so? ____

____

13. When you were not using the aid, what strategies or heuristics did you use in the EMCON plan development and evaluation? ______________

____

____

14. What were the differences between your techniques for developing EMCON plans as opposed to evaluating plans when not using the aid? __________

____

How so? ____

____

Was there some information that you used for developing EMCON plans that you did not use in evaluating plans?

Yes or No: __________

What? ____

____

Why? ____

____

15-20. Now I would like to question you about what you perceived to be the important differences between developing and evaluating EMCON plans with and without the aid.

15. In a general way, do you feel that the EMCON plans you developed with the aid were any different from the plans you developed without the use of the aid?

Yes or No: __________

15. continued

How so? ______________________________

____

Was one technique better than the other?

Yes or No: ________

How so? ______________________________

____

Qualitatively or quantitatively different? ______________

____

16. What was the largest difference in developing an ENCON plan with or without the aid? ______________________________

____

____

17. How much trust did you have in the information you calculated yourself as opposed to the information supplied by the aid?

Trusted own most: ______
Trusted both equally: ______
Trusted aid's most: ______

Why? ______________________________

____

____

18. Do you think the use of the aid helped you to have any more confidence in the plans you developed then you had when you did not use the aid?

Yes or No: ________

How so? ______________________________

____

____

19. Would you feel "comfortable" in using EWAR or some variant of it under live and real combat conditions?

Yes or No: ________

Why? ______________________________

____

____

20. In a live combat situation would you be surprised if the actual damage done to the task force was far worse than that predicted by the EWAR?

Yes or No: __________

Why? ______________________________

____

____

21. The aid assumes that if a threat is detected, after an initial period of 90-seconds during which time the threat is being tracked and the defenses targeted, that during each successive 120-second period half the threats will be destroyed. To what degree, do you think that this is a reasonable and valid assumption?

	Low				High
Reasonable degree:	1	2	3	4	5

How so? ______________________________

____

	Low				High
Valid degree:	1	2	3	4	5

How so? ______________________________

____

What, if any, assumptions do you think would be more valid or reasonable?

Valid: ______________________________

____

Reasonable: ______________________________

____

22. Other assumptions incorporated into the aid are that the enemy will target, in accordance with the perceived value of targets and that he will distribute his fire power among the targets in order to optimize destruction in accordance with the perceived value of the blips.

a) To what extent do you think that the enemy targets by perceived value?

	Low				High
Extent:	1	2	3	4	5

Why? ______________________________

____

b) To what extent do you think that the enemy distributes its fire power so as to optimize damage in accordance with the perceived value?

	Low				High
Extent:	1	2	3	4	5

22. b) continued

Why? ______________________________

____

If not, on what basis do you think the enemy distributes its fire power among targets? ______________________________

____

c) Do you think the enemy derives the perceived value of targets in a manner analogous to that used by the aid?

Yes or No: __________

Why? ______________________________

____

If no, on what basis do you think the enemy evaluates the value of targets? ______________________________

____

d) Suppose you were in a real combat situation and had an EMCON plan tailor made for the task force and the mission. The plan was developed so that the value of various ships will be misperceived; i.e., a high value ship should be perceived to be a ship of a lower value. This was done under the assumption that the enemy would allocate its fire power in relation to perceived value resulting in more fire power being allocated to an intermediate value ship then to a higher value ship. You are aboard the intermediate value ship. What would be your reaction? ______________________________

____

How comfortable would you feel using the plan if it resulted in a reduction in surveillance coverage of the task force from what would be obtained with an ALL-ON EMCON plan in which the true value of the ships was approximated by the perceived value?

Low				High
1	2	3	4	5

Why? ______________________________

____

How comfortable would you feel using the plan if it resulted in a substantial reduction in surveillance coverage from that afforded by the ALL-ON plan?

Low				High
1	2	3	4	5

Why? ______________________________

____

22. d) continued

Again, consider a plan which altered perceived value but resulted in a substantial reduction in surveillance coverage from that afforded by an ALL-ON EMCON plan. How comfortable would you feel using this plan if a careful analyses indicated that it reduced the expected damage to the task force below the level expected with the ALL-ON plan?

Low 1	2	3	4	High 5

Why? ______________________________

____

If you would feel comfortable, would you use the plan in a real combat situation?

Yes or No: __________

Why? ______________________________

____

Under what conditions would you use the plan? ______________

____

23. The information score, supplied by EWAR is intended as a pure measure of information denial. In a live combat situation, how much confidence would you have that the information score accurately represented the actual information denied to the enemy?

Low 1	2	3	4	High 5

Why? ______________________________

____

____

To what degree would you be willing to use that information denial score as the basis for making an inportant EWAR decision?

Low 1	2	3	4	High 5

Why? ______________________________

____

____

24. The surveillance score is based on interception probabilities averaged over various threats. The score is intended to be a measure of pure surveillance effectiveness. How much confidence would you have under live combat conditions that the interception probabilities are valid?

Low				High
1	2	3	4	5

Why? ____

____

____

25. Do you have any other comments? ______________________

____

____

____

26. (Show list of goals.) Read these goals. I would like you to take 100 points and distribute them among the goals in proportion to how closely each goal was achieved by the EWAR decision aid. That is if in your estimation the EWAR aid achieved, say, goal 3 to a greater extent than the other goals than distribute proportionally more points to it. For example, a 20/40/15/10/5/5/5/ distribution would indicate that the second goal was achieved to twice the extent of the first; that the first was achieved somewhat more than the third and twice as much as the fourth; that the fifth, sixth, and seventh were the least achieved.

Goals of the EWAR decision aid.

1. To facilitate the formation of hypotheses about how best to improve a current plan

2. To produce better EMCON plans

3. To help quantify the surveillance and information consequences of a plan

4. To make it practical to examine a larger set of alternative plans

5. To understand how different factors (threats, radars, etc.) contribute to EMCON planning

6. To improve planner confidence in the quality of his EMCON plans

7. To facilitate comparison of alternative plans

27. (Show displays by goals Table.) I would like you to partition 100 points for each display across four general goals in relation to how much the display contributed to each goal. If a particular display was more important in terms of one goal than partition proportionally more of the 100 points to it. If the display effectively contributes equally to each goal than partition the 100 points equally.

	Understanding Physical Factors	Quantifying Information or Surveillance Consequence	Generating Hypotheses	Comparing Alternative Plans
SURVEILLANCE DISPLAYS Maximum Range Circle Map Cumulative Detection Probability Map Surveillance Score--Penetration Probability				
INFORMATION DISPLAYS Probability that a Blip Corresponds to a Given Ship Bar Lengths Showing True Ship Value and Perceived Ship Value Information Score				
TRADE OFF DISPLAYS Strike Simulation Outcome Surveillance and Information Score Summary Graph Detection Probability Contour-Perceived Ship Value Map				

APPENDIX B

LIST OF THE EWAR COMMANDS AND DISPLAYS

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EWAR Decision Aid Commands and Displays

Command	Description of Display
Order-of-Battle	
DIS, EMCON	Task force search radar order-of-battle and which radars are on/off for an EMCON plan
Surveillance	
SURV, CIR, THR = Threat Name	Plots maximum detection range circles for each emitting search radar for the specified threat
SURV, CUM, THR = Threat Name	Plots cumulative probability-of-detection contours for the specified threat
SURV, SCORE	Displays surveillance scores for each threat system and for an average system
Information Denial	
INFO, DETAILS	Lists probabilities that each blip is being emitted by each task force ship
INFO, DETAILS, SHIP = Ship Name	Lists probabilities that each blip is being emitted by the specified ship
INFO, TARGET	Compares "actual" ship values with "perceived" blip values
INFO, SCORE	Shows the information denial score for the EMCON plan being evaluated and for the ALL RADARS ON and ALL RADARS OFF reference plans

Command	Description of Display
Trade Off Commands	
TRADE, MAP, THR = Threat Name	Plots cumulative probability-of detection contours for the specified threat and draws blip "perceived" value lines below ship symbols
TRADE, SCORES	Plots surveillance and information denial scores which have been "saved" (Command is SAVE, SCORES for a given EMCON plan)
TRADE, STRIKE, Strike Name	Displays results of a simulated "trade off" strike (enemy must infer blip identities based upon radar emission data)

Operational Commands	Effect
ON, RAD=Radar Name, SHIP=Ship Name	Turns on the specified radar on the specified ship
ON, RAD=ALL, SHIP=Ship Name	Turns on all radars on the specified ship
ON, RAD=Radar Name, SHIP=ALL	Turns on specified radar on all ships
ON, RAD=ALL, SHIP=ALL	Turns on all radars
OFF, RAD=Radar Name, SHIP=Ship Name	Turns off the specified radar on the specified ship
OFF, RAD=ALL, SHIP=Ship Name	Turns off all radars on the specified ship
OFF, RAD=Radar Name, SHIP=ALL	Turns off specified radar on all ships
OFF, RAD=ALL, SHIP=ALL	Turns off all radars
ON (or OFF), RAD=First Radar Name/Second Radar Name/Third Radar Name, SHIP=Ship Name	Turns on (or off) more than one radar aboard the specified ship
ON (or Off), RAD=Radar Name, SHIP=First Ship Name/Second Ship Name/Third Ship Name	Turns on (or off) the specified radar aboard more than one ship
SAVE, SCORES	Saves Information and Surveillance scores
SAVE, EMCON Plan Name	Saves specified EMCON plan
GET, EMCON Plan Name	Sets all task force radars as specified by the EMCON plan named

APPENDIX C

DISCUSSION OF STRUCTURAL EQUATION MODEL

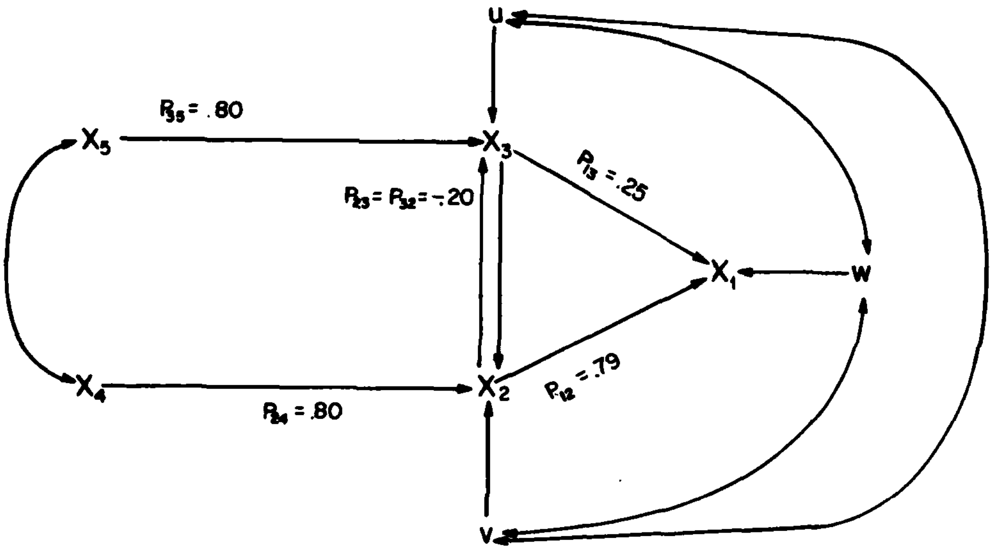
The structural model is illustrated as a path diagram in Figure C-1. Straight lines in the model indicate a causal relationship. The direction of the causality is indicated by the direction of the arrows on the straight lines. The bent lines containing bidirectional arrows indicate relationships between exogenous and disturbance terms. The model contains two exogenous variables and three endogenous variables.

The exogenous variables are not the concern of the model and are conceptually distant, but necessary, components. The first exogenous variable, X_4, represents the need to protect the task force and it was assumed that the effect of this need was to maximize surveillance coverage. The second exogenous variable, X_5, represents a need for security and it was assumed that this need resulted in a maximization of information denial. Both exogenous variables are conceived as latent variables which can not be measured directly and must be estimated. The premise behind these variables is that they represent two divergent responses to a state of primary motivation. This primary motivational state, which is not incorporated within the model, is assumed to be a function of a number of factors, such as the mission of the task force, the psychological make-up of the task force commander, relevant intelligence, and so forth.

Each exogenous variable has a direct effect on one endogenous variable. The "protection need," X_4, has a direct causal effect on X_2, the measure of surveillance coverage (the surveillance score) forcing it toward a maximum value. The "security need," X_5, has a direct causal effect on X_3, the measure of information denial, forcing it toward its maximum.

Obviously, maximum values of the X_2 and X_3 variables can not lead directly to the balance the trade off requires. Therefore, some other causal linkage must be assumed which will modify these maximizing tendencies. Certainly, direct linkages could be assumed between X_4 and X_3, and X_5 and X_2, representing a spread of the effect of the needs. However, the frequent use of the SAVE, SCORES command (in what might be called a change-and-test strategy), led to the supposition that the causal linkage was between X_2 (surveillance score) and X3 (information denial score), each having a negative effect on the other. This follows from the use of the SAVE, SCORES command, which resulted in the presentation of the surveillance and information denial scores; that is, the command led to the presentation of X_2 and X_3. Presumably, after seeing the surveillance and the information denial scores, the scores were assessed in terms of their effects on the trade off scores and strikes. Apparently, the plan chosen by a participant was the one among the alternative plans being considered, which had the highest trade score, i.e., the best balanced plan.

The causal linkage between X_2 and X_3 represents the point in the model where reciprocating activities resulted in a modification of each. The paths of each, the effect of X_2 and X_3 and that of X_3 and X_2, are represented



ENDOGENOUS VARIABLES
- X_1 = TRADE SCORE
- X_2 = SURVEILLANCE SCORE
- X_3 = INFORMATION DENIAL SCORE

EXOGENOUS VARIABLES
- X_4 = NEED FOR PROTECTION
- X_5 = NEED FOR SECURITY

DISTURBANCES
- u
- v
- w

STRUCTURAL EQUATIONS

$$X_3 = P_{35} X_5 + P_{32} X_2 + u'$$

$$X_2 = P_{24} X_4 + P_{23} X_3 + v'$$

$$X_1 = P_{13} X_3 + P_{12} X_2 + w'$$

Figure C-1. The trade off structural equation model.

in Figure C-1 by the double lines between them. Each arrow represents an effect in the opposite direction. It is further assumed that X_2 and X_3 both affected X_1, the measure of the achieved balance, the trade score.

The model attempts to account for the variability in each of the endogenous variables X_1, X_2, and X_3, as functions of causal relationships. However, total variance can never be completely accounted for by a model. The relationships are therefore assumed to be attenuated by disturbance terms. The disturbances shown in Figure C-1 (u, v, and w) represent other correlated sources of variability in the endogenous variables not specified in the model (Duncan, 1975).

The model which is nonrecursive and fully identified may be represented by three structural equations:

$$X_3 = p_{35}X_5 + p_{32}X_2 + u'$$

$$X_2 = p_{24}X_4 + p_{23}X_3 + v'$$

$$X_1 = p_{13}X_3 + p_{12}X_2 + w'$$

where the p's are the structural or path coefficients and where because of the correlation in the distrubance terms:

$$u' = p_{3u}u + p_{32}p_{2v}v$$

$$v' = p_{2v}v + p_{23}p_{3u}u$$

$$w' = p_{1w}w + p_{13}u' + p_{12}v'$$

In structural equation models, a simplifying assumption is that the path coefficients for the direct effect of the disturbances equals one (Duncan, 1975). Therefore, the disturbances terms can be rewritten:

$$u' = u + p_{2v}v$$

$$v' = pv + p_{3u}u$$

$$w' = w + p_{13}u' + p_{12}v'.$$

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