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THESIS

SCREENOP: A COMPUTER ASSISTED MODEL
FOR ASW SCREEN DESIGN

by

William Joseph Mickler, Jr.

September, 1983

Thesis Advisor: A. F. Andrus

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SCREENOP:
A Computer Assisted Model for ASW Screen Design

by

William Joseph Mickler, Jr.
Lieutenant, United States Navy
B. S., United States Naval Academy, 1977

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1983

DU
NA
MONTEREY, CALIFORNIA 93943

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I. INTRODUCTION

A. PREFACE

The design of anti-submarine warfare (ASW) screens is a difficult problem of integrating acoustic, environmental and intelligence data to position screening units to most effectively protect the main body unit. Numerous tactical and acoustic publications contain procedures to design an ASW screen, but do not consider the complete ASW situation. Personal experience is used to incorporate enemy and screening units capabilities and environmental variances. The ASW problem is a dynamic tactical situation which requires constant monitoring and reassessment. Environmental predictions and sonar system performance as well as intelligence estimates further complicate the optimal placement of screening units in the ASW screen.

SCREENOP, a computer program designed to assist in the formation of optimal screen defenses, was developed by Daniel H. Wagner, Associates in April 1981 for the Chief of Naval Operations (OP961). The SCREENOP program assists in designing ASW screens which minimize the probability of a successful launch by a screen penetrator against protected units before being detected by the screen. The SCREENOP program is resident to the Naval Ocean Systems Center (NOSC), San Diego, California. As a result of this thesis, a conversion of the NOSC version of SCREENOP, selected modules of SCREEN (version 5.0), and program documentation are now available at the Naval Postgraduate School.

B. PURPOSE

The purpose of this thesis is threefold: First, to make available the SCREENOP model for research and analysis by students in the ASW Systems and Operations Research curriculums at the Naval Postgraduate School. Second, to provide a description of the computer program SCREENOP, the target motion and detection models, the optimization technique used in the program and a user's guide with an example to assist in the running of the program; and Third, to evaluate the SCREENOP program for ASW screen design.

C. BACKGROUND

SCREENOP utilizes selected data from files created by its predecessor, SCREEN, which was designed by Daniel H. Wagner, Associates to evaluation acoustic detection and localization of a protective screen. SCREEN was first developed in 1976 for the Chief of Naval Operations (OP961) and has evolved through several versions into a modularized version with six program parts. Three of the six modules of SCREEN, namely Acoustic, Target, and Sensor are utilized to create the input data files for SCREENOP. Not all the information contained in the SCREEN files is utilized by SCREENOP. Additional information can be found in the SCREEN User's Manual. [Ref. 1]

SCREENOP was interfaced with SCREEN to have SCREENOP recommend location of screen assets. SCREENOP utilized improvements to the motion models developed by Daniel H. Wagner, Associates. The first version of SCREENOP was created for OP961. In 1982 SCREENOP was transferred to NOSC, San Diego. The various segments of SCREENOP were combined under

a single executive program and interactive graphics were added. [Ref. 2] A third version of SCREENOP is resident to the Naval Postgraduate School and is written in the Fortran 77 programming language and the PLOT10 graphics software package.

The program is resident at the Naval Postgraduate School in two forms. The first utilizes a Digital Equipment Corporation VAX 11/780 computer in the Computer Science Laboratory, VMS Operating system, and TEKTRONIX 4014 graphics terminal, to provide a graphic display of the optimal screen. The second utilizes a VAX 11/780 computer in the Wargaming Laboratory, VMS operating system, and VT 100 terminal but currently has no graphics capability. The Acoustic, Sensor and Target modules of SCREEN are available for creating data files for SCREENOP.

D. PROGRAM OVERVIEW

SCREENOP is comprised of the following four major program sections:

1. Initial inputs,
2. Data preparation,
3. Optimal allocation,
4. Interactive screen formation.

The first section is an initial inputs section. In this section the gridwork of the operating area is defined; Environmental and contour data and sensor information are accessed from SCREEN files; and Target penetrator tactics are entered in the input section. The second section, data preparation section, is where the effort and degradation factors are computed. The third section is the optimal allocation section. It

allocates the computed effort which is assumed to be infinitely divisible. The fourth section is the screen formation section which interactively positions the screen units.

E. ORGANIZATION

The organization of the thesis is as follows:

Chapter two is a description of the program including the four major sections of SCREENOP. The discussion will not be a detailed description of the computer code and subroutines but rather a basic description of the program structure and input requirements.

Chapter three will provide a description of the target motion and the detection model used in SCREENOP. Additionally, it will provide a brief description of the optimization technique for effort allocation and sensor placement.

Chapter four will provide a user's guide with an example to describe how to access, to run, or to make changes to the program. It will also discuss file manipulations for SCREEN input files as well as effort and allocation files created by SCREENOP during program execution.

Chapter five will evaluate the results of the example provided in the user's guide and discuss the value of the program and possible applications in the ASW environment. It is not intended to be a validation and verification of the program, but rather it is intended to offer an explanation of the program results.

Finally, Chapter six will include conclusions, recommendations, and suggested improvements for SCREENOP.

II. PROGRAM DESCRIPTION

A. INITIAL INPUTS

The input section of SCREENOP consists of four subsections which describe the screen formation problem to the program. The four subsections are:

1. Gridwork parameters,
2. Environmental/contour parameters,
3. Sensor parameters,
4. Penetrator tactic parameters.

Three of the four subsections, namely, the environmental/contour data subsection, the sensor data subsection, and the penetrator tactics subsection interface with the computer program SCREEN.

1. Gridwork Parameters

This subsection solicits inputs about the battle group operating region in which the passive screen sensors and penetrator will operate.

The following inputs are required from the user to define a problem:

1. Number of rows,
2. Number or columns,
3. Scale factor,
4. Length of a cell side,
5. Row number of the battle group center,

6. Column number of the battle group center,

7. Battle group speed.

The first two inputs entered in the gridwork parameters subsection are the number of rows and columns of square cells which describe an operating area for the battle group. The maximum number of rows or columns is 15.

The model assumes that the battle group moves and the square gridwork which is fixed relative to the battle group moves along with it. The gridwork orientation is such that the battle group moves towards the direction of the top of the gridwork. SCREENOP numbers the user defined cells from left to right starting with the top row of cells. Figure 2.1 displays the numbering of a 5 x 5 cell as an example of cell numbering in SCREENOP.

In addition to the cells defined in the user defined gridwork, the SCREENOP program defines two imaginary cells -- the "success cell" and the "failure cell". The "success cell" is entered by the penetrator by launching a successful attack. The "failure cell" is entered by the penetrator if it launches an unsuccessful attack, or if it is unable to attack. The model assumes that the penetrator could be unable to launch an attack due to excessive navigation errors which causes it to move outside its limiting lines of approach.

The third gridwork input, the scale factor, accounts for computer storage requirements and model accuracy. The possible scale factors are 1, 2, or 3. Propagation loss data from a SCREEN data file is a major component of the data storage. SCREENOP was originally written to process propagation loss data in increments of one nautical

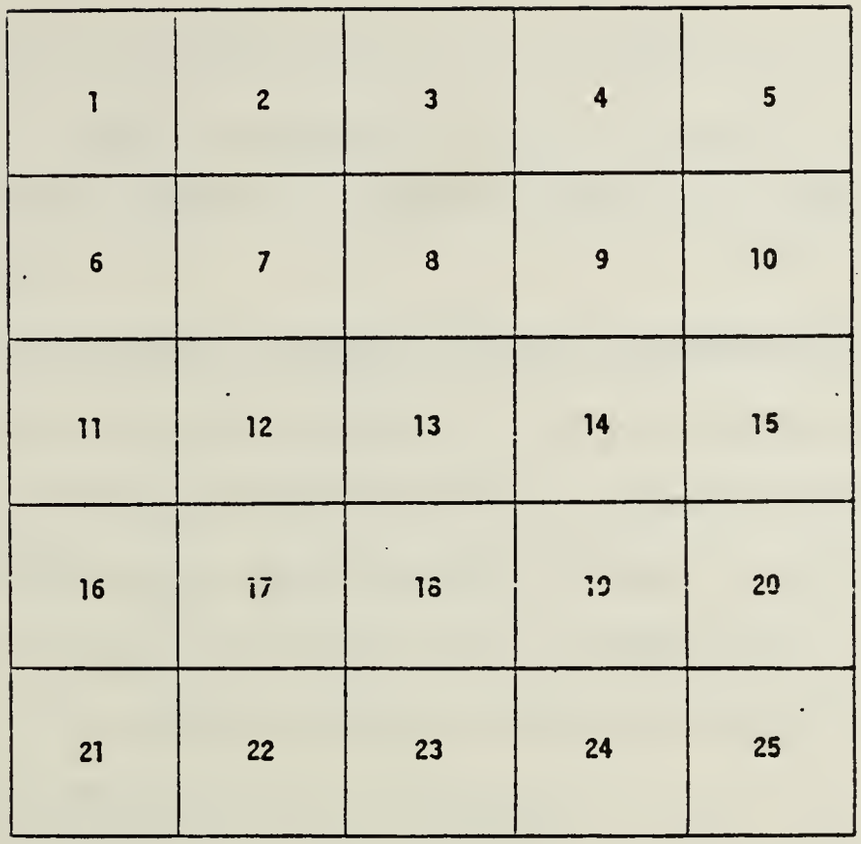

Figure 2.1 The Numbering of a 5 x 5 Gridwork.

mile to a distance of 120 nautical miles. Larger ranges are accomodated by inputting a scale factor of 2 or 3. A scale factor of 2 results in processing propagation loss data at 2 nautical miles. The scale factor is the smallest integer N such that 120N is greater than or equal to the maximum range of the propagation loss data. Equivalently, setting the scale factor to 3 processes propagation loss data at three mile increments to a maximum distance of 360 nautical miles.

The choice of a scale factor should be made on the basis of range of the propagation loss date and fineness of resolution in the modeling problem. By design, the cells in SCREENOP must have a length that is a multiple of 5 times the scale factor. Hence an increase in the scale the scale factor increases cell size. The increase in cell size diminishes the model's ability to amount for fine detail.

The fourth gridwork input is the length of the cell side. A maximum cell length is determined by the scale factor. In SCREENOP the maximum cell length is 60 nautical miles when a scale factor of three is used.

The location of the battle group center and the battle group speed are the next required inputs. A row and column number of the cell in the user defined gridwork describes the center of the battle group. Next, the battle group speed is entered in knots. After the above inputs are made, the user is given the option to change any of the grid parameters. The gridwork parameters subsection is now complete.

2. Environmental/Contour Parameters

Environmental and contour parameters are required after the gridwork parameters are entered. The environmental and contour data files are created and stored by the Acoustic module of SCREEN. The environmental file contains the propagation loss data and ambient noise levels. The contour file contains the directivity index of the sensor array. For ease of inputting the data, only the SCREEN file names for environmental and contour files are entered. This information as well as target source level information which will be input later will be used to implement the passive sonar equation. The scale factor input also determines which data points in the propagation loss data will be read. Given a scale factor of N, only points with the indices of the form 1+kN are read into SCREENOP. The environmental/contour subsection is now complete.

3. Sensor Parameters

The third of the four input subsections describe the screen sensors. A maximum of five sensor types can be described in SCREENOP. The sensor

data subsection of SCREENOP uses a file created by the sensor module of SCREEN and some additional user inputs. The following inputs from the SCREEN sensor data files are entered by inputting a sensor file name:

1. Number of sensor types,
2. Number of high value units,
3. Source levels of each high value unit,
4. Sensor course and speed,
5. Recognition differential,
6. Sensor self noise,
7. Standard deviation in signal excess of each sensor.

Besides the data provided from the sensor data file, additional required and optional sensor data is requested by SCREENOP. The number of sensors of each type is required for both stationary and moving sensors.

Stationary sensors are assumed by SCREENOP to be sonobuoy fields. Rectangular buoy fields, oriented at 0 or 90 degrees with respect to the battle group course are the only fields allowed. The number of rows and columns of the sonobuoy field and the spacing between rows and columns are required inputs for a sonobuoy sensor. A single buoy is described with a row and column input of one.

Non-stationary sensors move in one of two ways. These sensors either move with the battle group or sprint and drift. Sprint and drift times and speeds are optional inputs and are entered in hours and knots, respectively. Moving sensors also

require direct path and convergence zone upperbounds. The annular region about the sensor is divided further into annular subregions determined by the direct path and convergence zone upperbounds. An inportant assumption by SCREENOP is that the glimpses of the target in different subregions are independent. The sensor parameters subsection is now complete.

4. Penetrator Tactic Parameters

The penetrator tactics subsection of the input section of SCREENOP utilizes a target data file created by SCREEN to obtain penetrator source levels. A SCREEN target data file name is entered to provide this information. The following additional target information is required in the penetrator tactics subsection:

1. Discrete target motion time step,
2. Target scenario.

SCREENOP asks the user for a time step which will be used in the target motion model. The target motion model is a Markov chain which uses the time step as the time between transitions in the motion process. The choice of a time step should be made on the basis of modeling detail. A smaller time step requires more run time of the target motion calculations than a larger time step but captures more details of the target motion. The choice of a time step effects not only target motion calculations but also effort calculations.

The program now requires target scenario information referred to as penetrator tactic information. A basic penetrator tactic is

made up of the following three components:

1. Target initial distribution,
2. Penetrator motion model,
3. Attack probabilities.

Several basic tactics or a composite of basic tactics may be used to describe the problem scenario. The program asks for a measure of the likelihood of the use of that tactic.

The penetrator's location as it enters the gridwork is described by an initial probability distribution. The distribution describes the relative likelihood of the penetrator entering the gridwork from a particular cell. The distribution can be entered into SCREENOP by selecting one of two options. The first option allows for the user to input the initial probability on a cell by cell basis. The second option allows for the user to describe the probability distribution with a cosine distribution across the top row of cells. A cosine distribution has a density function which is proportional to the cosine function restricted to angles of a -90 to 90 degree range. The cosine distribution is described to SCREENOP by entering the mean and the distance from the mean to the edge of the distribution. Figure 2.2 is an example of a cosine distribution. The user is now given the option to change the parameters of the initial distribution.

The second part of the target scenario is the target motion. Motion assumptions consist of the following four parts:

1. Target speed,

2. Target tactic,

3. Target course and speed uncertainty,

4. Threshold probability.

Target speed is entered in knots.

Two types of penetrator tactics are available to describe the penetrator after it has entered the gridwork. The target motion is modeled as an intercept course strategy or as lead/lag strategies.

The intercept strategy is a constant course and speed tactic which minimizes the time required for a penetrator moving at a fixed speed to intercept the battle group. In the case where battle group speed is greater than target speed, the penetrator will only be able to intercept the battle group if the angle on the bow to the battle group is between -a and a where

$$a=\arcsin(\text{target speed}/\text{battle group speed}). \qquad \text{(EQN 2.1)}$$

If the angle on the bow to the battle group is not in the -a to a sector then the penetrator goes to the failure cell.

The lead/lag strategies describe a class of tactics in which the target leads or lags the battle group by a fixed angle. The lead/lag angle is defined as the difference between the absolute penetrator course and course which would cause the penetrator to head directly at the battle group. A pointing tactic describes the case where the angle between the penetrators course and the course required to cause the penetrator to head directly at the

battle group is zero. A pointing tactic is not the same as an intercept strategy unless the penetrator is directly ahead of the battle group. Lead/lag strategies are not normally constant course tactics. Constant lag or pointing tactics should not be used unless the penetrators speed is greater than the battle group speed or the penetrator possesses a long range weapon capability. Otherwise a penetrator following a constant lag or pointing tactic will eventually fall below any non-vertical line intersecting the location of the battlegroup. In certain

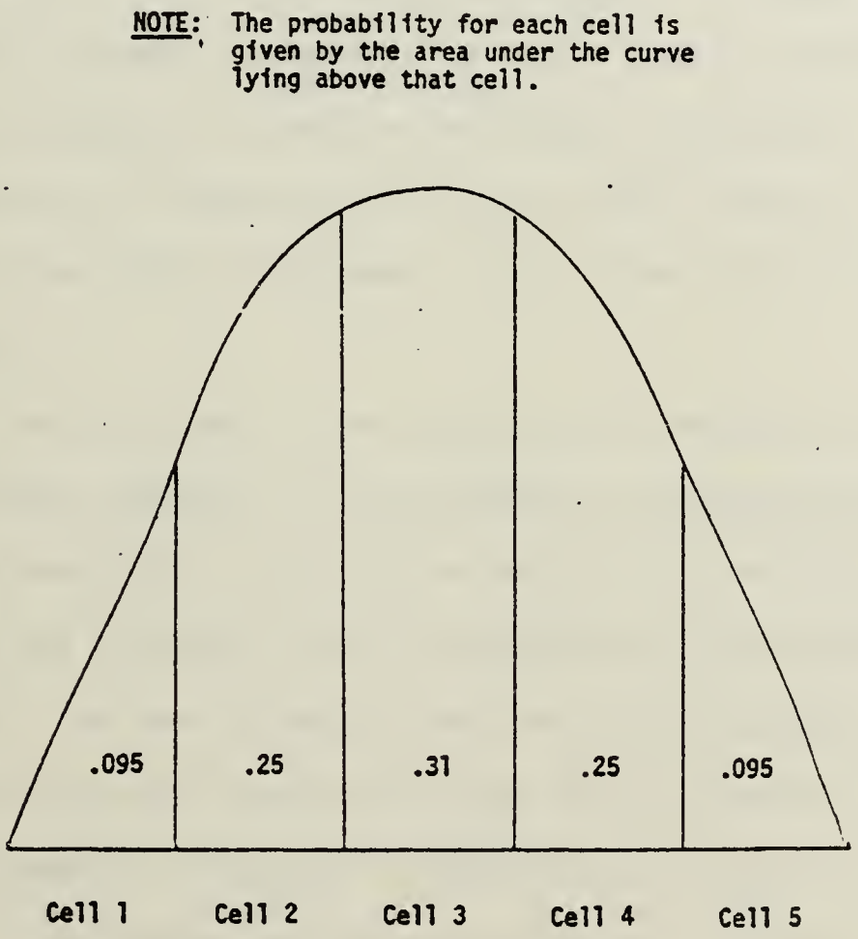

Figure 2.2 An Example of a Cosine Distribution

lead strategies even when the penetrators speed is less than the battle group speed, it is possible for the penetrator to fall below its limiting lines of approach.

The program is ready to transform the penetrator tactic described by the user into a time homogeneous Markov chain. The third part of target motion required for the transformation is the course and speed uncertainty. With a Markov chain model there is some small probability that the penetrator will take longer than some fixed time horizon to execute its maneuvers and either succeed or fail. The fourth target motion parameter is the threshold probability. SCREENOP requires the entry of a threshold probability which is used to determine when the program is allowed to complete the motion calculations. If the probability of a penetrator not having either failed or launched an attack is less than the threshold value, then the motion problem is truncated.

The third part of the target motion scenario is the attack probabilities component. The probabilities represent the likelihood that the penetrator will launch an attack from any point in the grid-work and the likelihood that that attack will suceed given that it is launched. For ease of description, the attack probabilities are entered for annular sectors about the battle group with right-left symmetry assumed. Figure 2.3 illustrates the attack probability sectors. The annular sectors are described in terms of a radius and angle from the battle group course. The entries are entered in increasing magnitude of the radii. The radius entered marks the outer edge of the annular sector. The inner edge of the annular

NOTE: The attack probabilities are assumed to be constant over annular sectors. Also, right-left symmetry is assumed.

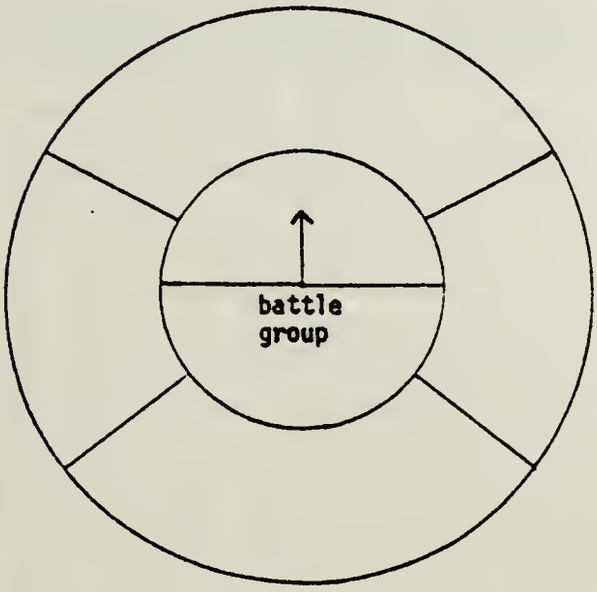

Figure 2.3 Describing the Attack Probabilities.

sector is determined by the preceeding radius. Only bearings between 0 and 180 degrees are entered since right-left symmetry is assumed. In the same way that radii were entered, angles are entered with the smallest first and increasing in size for a given radius.

The attack probabilities entered in the annuar fashion are now converted to individual cell attack probabilities. The converted cell probabilities are available for review by the user. Figure 2.4 displays the transfored cell probabilities. At this point the user is able to verify that motion described to the program is an accurate reflection of

ATTACK PROBABILITIES

TOP NUMBER IS PROB OF UNSUCCESSFUL ATTACK
BOTTOM NUMBER IS PROB OF SUCCESSFUL ATTACK

NM

						0.04 0.06	0.08 0.12	0.04 0.06						
					0.04 0.06	0.16 0.24	0.17 0.48	0.16 0.24	0.04 0.06					
					0.08 0.12	0.16 0.39	0.16 0.54	0.16 0.39	0.08 0.12					
					0.04 0.06	0.16 0.24	0.16 0.30	0.16 0.24	0.04 0.06					
						0.04 0.06	0.08 0.12	0.04 0.06						

NM

Figure 2.4 The Transformed Attack Probabilities.

the desired tactic. As a final check, sample penetrator tracks based on user inputs are displayed for the user. The user may alter any penetrator parameters. Figure 2.5 shows an example of the sample tracks. The SCREENOP program now has the necessary initial data to define the problem and to make effort computations.

B. DATA PREPARATION

The data preparation section calculates two quantities based on user inputs from the input section. The quantities are sensor effort arrays and degradation factors.

1. Sensor Effort

Effort is described by a local effort function, alpha, which measures the sensor's effort at a given point. Total sensor effort is then described as the sum of the effort over all points of the plane. This is actually the integral of the local effort function over the plane. The function alpha is evaluated for each type of sensor on a gridwork of points in the plane. This gridwork of points in the plane is a different gridwork defined by the user. The scale factor N, entered previously in the input section, determines the spacing of the points in the gridwork; that is, each point is N nautical miles apart. The computations for each sensor type are stored in separate arrays. The arrays are stored and used in the final section of SCREENOP. The effort allocations provided by the actual sensors will be compared with the theoretically optimal effort calculation.

Since the effort computations require a large amount of run time, the program allows for the storage of the effort arrays. This feature can save run time if a series of SCREENOP runs are being made.

in which only the penetrator tactic is being varied. There are three basic inputs to the effort calculation:

1. Passive sonar equation inputs,
2. Sensor data,
3. Penetrator speed.

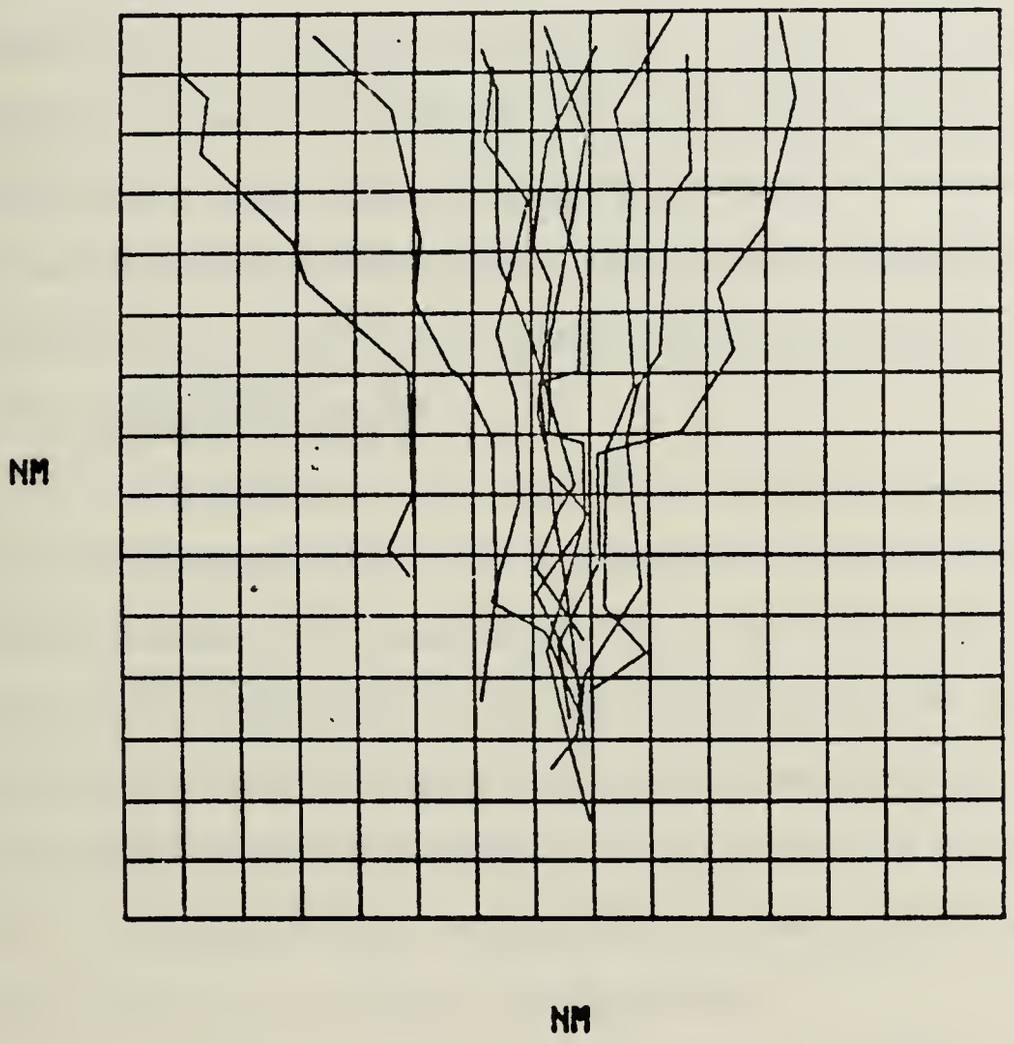

Figure 2.5 Graphic Display of Sample Target Tracks.

The first type of input involves any inputs to the passive sonar equation. These inputs can be information from the propagation loss curves as well as the target source level. The second type of input is the sensor type data. For example, the upper bounds on direct path and convergence zones

for moving sensors and the row, column and spacing information for sonobuoy fields is used to compute effort. The third type of input is the penetrator speed. In summary only environmental and sensor inputs effect the effort computation. The penetrator tactic has very little effect. Thus if SCREENOP will be used for several runs in which only the tactic is being varied, run time can be saved by doing the effort computations once, storing the results, and later retrieving these results. The user is asked the name of an old effort file which he might like to use. Next, the program displays the effort computation for each sensor and sensor type. Note that the effort displayed is actually effort reduced by a degradation factor which is described below.

2. Degradation Factor

The second quantity computed in the data preparation sections is the degradation factor. It is computed for each cell in the user defined gridwork. The degradation factor is a description of the effect of the battle group noise on the detectability in each cell. The degradation factor is defined as a ratio of sweep widths. The range of a degradation factor is between 0 and 1/A where A is the area of a cell. 0 indicates a total degradation of detectability due to battle group noise and 1/A indicates no degradation.

The degradation factor is used twice in SCREENOP. The first use of the degradation factor is in the calculation of detection probabilities. The detection probability for each cell is computed using the formula:

$$1 - (-WE) \qquad \text{(EQN 2.2)}$$

Where W is the degradation factor and E is the effort applied to that cell. The second use of the degradation factor in SCREENOP is in the final section. Here it is used when the sensor effort allocations and optimal effort allocations are compared. There is a difference in definition of "degraded effort" used in the optimal allocation. Note that the "degraded effort" not the actual effort is compared. For a sensor located in a cell with a degradation factor W, the degraded effort applied by that sensor to any cell is the actual effort applied times W. But in an optimal allocation of "infinitely" divisible effort, the degraded effort in any cell is the degradation factor of the cell times the actual effort in that cell. The effort and degradation factor calculations are now complete.

C. OPTIMAL ALLOCATION

SCREENOP has computed the amount of effort available from each of the sensor types. The total effort available for allocation is the sum of the effort of each sensor type. As previously stated, the effort for each sensor type is stored in a separate array and placed in a file named by the user. Assuming that effort is infinitely divisible, that is that sensors can be placed in such a way as to distribute the search effort in any distribution over the search area, SCREENOP finds an optimal allocation of effort. Placement of sensors is based on the optimal allocation of the available effort. The allocated effort is stored like the computed effort and is available for subsequent SCREENOP runs. The program asks the user is he desires to use an effort allocation file from a previous SCREENOP run.

The optimization technique requires an initial guess by the user of the placement of effort in the gridwork cells. The initial guess is an important user input because a "good" initial guess reduces the time for the program to converge to an optimal solution. An initial guess has three parts:

1. Cell number,
2. Initial cell effort,
3. Cell least effort.

The least cell effort is a lower bound and constrains the program to assign an amount of effort which is at least equal to the lower bound for that cell. Thus, SCREENOP can be forced to find an optimal allocation subject to minimum effort constraints input by the user.

SCREENOP utilizes the Convex-Simplex technique to find the optimal effort allocation. Because effort for a particular cell can only be moved to one other cell for each iteration, the redistribution of effort might require a substantial number of iterations of the technique to reach the optimal allocation. The user is asked for the number of iterations of effort allocations to be displayed.

In theory, the Complex-Simplex technique for determining the optimal allocation is guaranteed to converge, but not necessarily in a finite number of iterations [Ref. 3] SCREENOP provides an approximation of the optimal allocation. An upperbound on the probability of detection is used to determine that the approximation of the optimal allocation is reached. The upperbound, is comprised of the sum of the most recent iteration of the probability of detection and a term called the Washburn bound. This is an upperbound on the probability of detection of the

optimal allocation. The user decides how many iterations are required for a satisfactory result. Further information on the Washburn bound is found in Reference three and seven. Upon completion of the effort allocations, the program asks the user for a file name to store them. The optimal allocation is completed. Now, the sensors must be positioned. The next section describes the formation of a screen.

D. SCREEN FORMATION

This is the final section of SCREENOP and is used to aid the user in creating a screen formation. The optimal degraded effort allocation is used as a guide for the screen formation.

1. Initial Sensor Position

The user must now enter an initial guess for the sensor locations. SCREENOP now uses a rectangular coordinate system centered at the battle group with axes parallel to the sides of the gridwork of cells. A plus or minus X and Y coordinate can be entered. A plus X coordinate represents a position to the right of the battle group. A plus Y coordinate represents a position ahead of the battle group. Similarly, negative X and Y coordinates represent positions to the left of and behind the battle group, respectively. Figure 2.6 displays the coordinate system for sensor placement. SCREENOP then optimizes the position of the sensors so as to provide the optimal probability of detection. As previously stated in the optimal allocation subsection, a reasonable initial guess reduces the number of iterations required to obtain the optimal allocation.

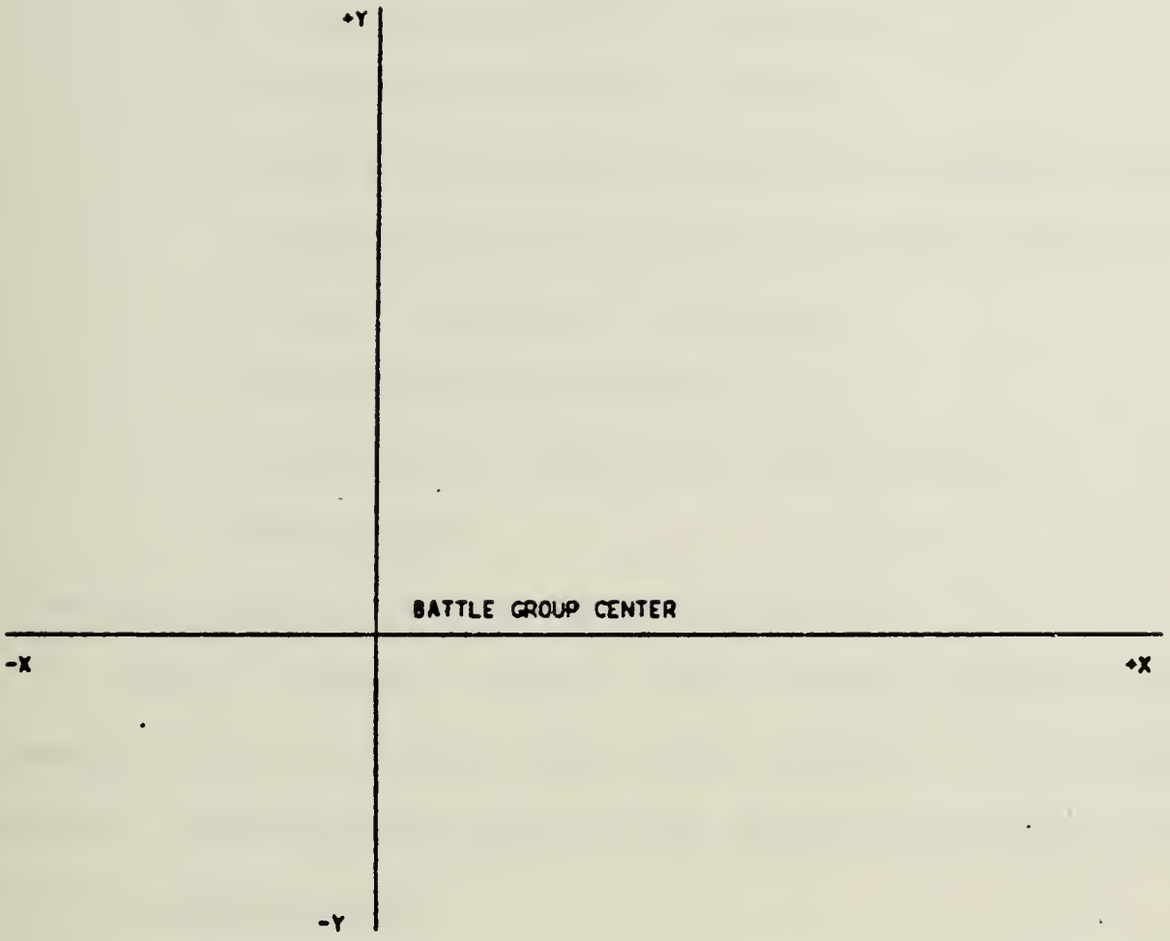

Figure 2.6 Sensor Placement Coordinate System.

2. Options

Upon entering the initial sensor placements, the user is presented with a menu of eleven program options. The following is a list of user options:

1. List of sensor locations,

2. Display sensor locations,
3. Display sensor locations and sample tracks,
4. Display optimal effort allocation,
5. Display sensor effort allocation,
6. Display sensor effort allocation and sample tracks,
7. Display sensor allocation minus optimal allocation,
8. Compute probability of detection,
9. Manually move some sensors,
10. Automatically compute new sensor locations,
11. End program.

A brief description of each option is found below.

Option 1 is used to obtain a list of sensor location coordinates. It returns the user's initial guess unless options 9 or 10 have been executed. The updated locations will be returned after either option 9 or 10 have been utilized.

Options 2 through 7 are graphic displays of the SCREENOP problem. Option 2 displays the sensor locations in the gridwork. Option 3 displays both the sensor locations as well as ten sample target tracks. The tracks are a graphic display of the target motion until the last time step at which a target can be in the grid is reached. Option 4 displays the optimal effort allocation. The optimal effort displayed is degraded effort. Option 5 displays the degraded sensor effort allocation. Like Option 3, Option 6 displays both sensor effort allocation as well as sample tracks. Option 7 displays the sensor effort allocation minus the optimal effort allocation. The sensor effort allocation is calculated using the current sensor locations

and the sensor effort arrays stored earlier in the program execution. These options allow the user to compare the optimal allocation, current sensor location, and the penetrator tactic.

Option 8 computes the probability of detection of the current sensor allocation and the probability of detection of the optimal allocation. It is important to note that the sensors probability of detection will be less than the probability of detection of the optimal allocation because effort is not infinitely divisible.

Option 9 provides the user with the capability to enter a new guess for sensor locations. That is, the sensors can be manually moved by the user. The optimization routine used in Option 10 can be exercised or Option 8 can then be exercised to calculate the probability of detection.

Option 10 automatically computes new sensor locations based on a guess by the user. It attempts to improve the current sensor location by comparing the sensor effort allocation with the optimal effort allocation. The program minimizes the sum of the squared differences of the optimal and sensor effort allocations for each cell. A major assumption of the SCREENOP program is that by matching sensor effort allocation to optimal allocation improves the probability of detection of the sensors. This does not always occur. After exercising Option 10, the user should exercise Option 8 to check the probability of detection. Option 10 is very sensitive to the initial position of the sensors. It should be exercised for several selections of the initial position.

Finally, Option 11 is used for an orderly termination of the program. Options 1 through 10 may be used any number of times before executing Option 11.

III. PROGRAM MODELS

A. DESCRIPTION

SCREENOP utilizes a Markov chain model for target motion and an exponential detection model for target detection. It uses a Convex-Simplex algoithm as an optimizing technique for optimal sensor placement. A general discussion of each model and the optimizing routine will be presented in this chapter to enhance the user's understanding of SCREENOP.

1. Target motion

The general form of the target motion model in SCREENOP is a time homogeneous Markov chain where both time and space are discrete quantities. A transition matrix P describes the probabilities of a target moving from a cell i at some time t to a cell j at the time t + 1. Thus the transition matrix describes the probability of a target being in any of the cells defined by the user in the gridwork input section or the success and failure cells defined by the SCREENOP program and moving to any other cell during some time step. The success and failure cells are trapping states in the Markov chain and cannot be searched. The description which follows will outline the procedures for generating the transition matrices from the target motion scenarios.

Recall that a target motion scenario consisted of an initial target distribution, a target motion strategy, and a set of attack probabilities. The initial distribution describes the penetrator's

location as it enters the gridwork as the relative likelihood of the penetrator making its initial appearance in each cell.

The second part of the target motion scenario, the penetrator motion model, describes the penetrators motion after it has entered the gridwork using the initial distribution. Two basis strategies available to describe the penetrator motion are the intercept strategy and the lead/lag strategy. The intercept strategy is a constant course and speed tactic which minimizes the intercept time to the battle group by the target. This strategy is specified by the absolute target speed and the battle group speed. The lead/lag strategies are a class of tactics in which the target leads or lags the battle group by a fixed angle. These strategies are specified by the absolute target speed, the battle group speed, and the lead or lag angle. A detailed discussion of the basic strategies can be found in Reference four.

The third part of the target motion scenarios is the attack probability section. The attack probabilities are a measure of the likelihood that a penetrator will launch an attack from any given point in the gridwork and the likelihood that such an attack will succeed given that it is launched. The annular sectors about the battle group of attack probabilities are converted to attack probabilities for each cell.

Given a gridwork and target motion strategy, the Markov transition probabilities can now be computed. But there is some small probability that the penetrator will take longer than some fixed time horizon to execute its maneuvers and either succeed or fail. If the

probability of a penetrator not having either launched an attack or failed is less than the threshold probability, then the program is allowed to truncate the problem.

The first step in the conversion of the motion assumptions to Markov transition probabilities is to cycle through the cells one at a time to compute the probability of transiting from the chosen cell to each other cell. The following information is used in this computation:

1. Target speed,
2. Battle group speed,
3. Time step,
4. Course and speed uncertainty.

Additionally, motion strategy provides mean course information on the penetrator. The mean course is not a constant; it depends on penetrator location. Because mean course is position dependent, it subdivides the cell into smaller subcells (each five nautical miles on a side). The center point of each cell and the mean course at the centerpoint is then computed. SCREENOP supposes the penetrators distribution is uniform on the subcell. The effects of the penetrator's motion are now examined. The center point of the cell is chosen as a representative point. A terminal position of the penetrator, which starts from the center point, follows the mean course, and moves at the penetrator speed for one timestep, is computed. SCREENOP then translates the entire subcell so that it is centered on the terminal position of the penetrator. This procedures accounts for the effect of average penetrator motion on a

subcell and does not reflect course and speed uncertainty. The consideration of course and speed uncertainty defines a region of uncertainty determined by target speed, battle group speed, time t, and course and speed uncertainty.

SCREENOP assumes the conditional distribution on target position at time t, given that the target was at some point of the subcell at time zero, is a uniform distribution. This assumption allows SCREENOP to compute the effect on the penetrator motion. At t time units later, the penetrator distribution is obtained by averaging a uniform density on the translated rectangle over all points in the subcell. This distribution shows what proportion of the subcell is moved into each cell of the user defined gridwork. By averaging these proportions over all subcells, the transition probabilities are computed. This computation only accounts for motion within the user defined gridwork.

The second step in the transition matrix procedure uses the attack probabilities entered by the user to modify the results computed in the first step to reflect transitions into the success and failure cells. The attack probabilities entered by the user are converted to successful and unsuccessful attack probabilities for each cell in the gridwork. These cell quantities are computed by averaging the corresponding section quantities over each cell. SCREENOP renormalizes the result from the first step to compute the entries of the transition matrix. A detailed account of this process can be found in Reference five.

2. Target Detection

The target detection model used in SCREENOP is an exponential detection function. Effort is assumed to be measured in swept area. The detection function uses the effort placed in cell i, Ei and the area of cell i, Ai to compute the probability of detecting a target in cell i. The probability of detecting a target in cell i is given by the following equation:

$$1-\exp(-Ei/Ai). \qquad \text{(FQN 3.1)}$$

The following is a description of the conversion of the sensor parameters from the SCREEN sensor data file and the user input section to sensor effort. This effort is an input to the detection model. For each point X in the plane, the joint probability that a target starting at X is detected in time t to t+ timestep and not detected before time t is calculated. The program calculates a finite sum to approximate the integral over the plane of the joint probability function. The finite sum of the integral is equal to the area swept out in the time increment. This area is the effort contributed by a sensor during that increment. Detection probabilities are calculated by the exponential detection function using the effort calculated by the above procedure.

The cumulative detection model used in SCREENOP is a standard Lambda-Sigma Jump Process model. Radiated noise is also modeled by a Lambda-Sigma Jump Process. SCREENOP assumes that each crossing of a direct path or convergence zone detection region implies an independent detection opportunity. The Lambda-Sigma Jump Process model assumes

that signal excess is a time dependent stochastic process instead of a random variable. The probability of detection during some interval (t+timestep)-t is the probability that the signal excess is greater than zero for some time in that interval. Detection occurs the first time that signal excess is greater than zero. In SCREENOP this probability is a finite sum which approximates an integral over the plane.

A Lambda-Sigma Jump Process is defined so that each sample path is a step function where the length of each step (i.e. the time between jumps) is distributed with mean lambda and the height of each step (i.e. the value of the process) is a normally distributed random variable with mean equal to zero and some specified lambda. The value of lambda is parameterized in SCREENOP and is set equal to one. 1/lambda is the mean time between glimpses in hours. Sigma, the standard devitation of fluctuations in signal excess, is input from the SCREEN sensor data file. The time increment used in this process is the same as the timestep for the Markov chain which the user inputs in the target parameter section. Background noise further complicates the detection problem by reducing the probability of detection. A degradation factor is computed using a ratio of sweepwidths. The effort for each cell is multiplied by the degradation factor for that cell. The degradation factor influences the optimal placement of the search effort. A more detailed discussion of degradation factors can be found in Reference six.

The target motion and detection models and the computation of effort have been sufficiently described. Now SCREENOP can maximize the probability of detection before a target can launch or the probability

that the target is forced into an unsuccessful attack. SCREENOP takes the total effort available from the screen assets and optimally distributes it in the gridwork cells to achieve the maximum probability of detection. It uses the results from the exponential detection function and the Markov chain motion model as inputs to the optimal allocation technique. It is important to restate the assumption that effort is infinitely divisible.

3. Optimal Effort Allocation Computation and Sensor Placement

Finding the optimal effort allocation is a non-linear programming problem. SCREENOP maximizes the probability of detection using the Convex-Simplex algorithm. A detailed formulation of the effort allocation problem can be found in Reference four. An algorithm is developed to produce a sequence of allocations which will converge to an optimal solution.

The following six steps of the algorithm produce a sequence of allocations which approach the optimal allocation:

1. Choose the cell in the allocation of effort with the most effort.
2. Find the cell which can increase the objective function (probability of detection) at the greatest rate by decreasing the amount of effort in the cell with the most effort.
3. Find the cell which if the effort were decreased and the maximum cell effort increased would improve the probability of detection most.

4a. Check to see if the rate of increase of the value of the objective function found in step 2 is equal to zero, and if the produce of the amount of effort and the rate of decrease of the objective function from step 3 is equal to zero. If both quantities are zero, the sequence has converged the optimal allocation is found; and the optimization process stops.

4b. If the sequence has not converged, check to see if the current allocation provides a probability of detection close enough to the optimal solution using the Washburn bound. If the probability of detection is acceptable, stop the optimization .

4c. Otherwise, go to step 5 .

5. Check to see which cell from steps 2 and 3 would increase the prcbability of detection most with all other cells unchanged except for the decrease in cell with the most effort.

6. Compute the probability of detection with the new allocation and go to step 1.

The sequence will not always converge in a finite number of steps. When this is the case, only an approximation to the optimal allocation can be computed. An upperbound on the difference of the probability of either detecting a penetrator before launch or forcing an unsuccessful approach or attack with optimal allocation and the latest of the sequence of allocations is calculated. The upperbound, referred to as the Washburn Bound, is used to determine when the latest allocation of effort is close enough to the optimal allocation.

A discussion of the Washburn Bound follows. The Washburn Bound is computed in three steps for every iteration of the optimization process. First, the difference of the rate of change of the objective function with respect to the cell with the maximum effort and the rate of change of the objective function with respect to the chosen cell is computed. Second, the product of the amount of effort in the chosen cell and the difference calculated in the first step is computed. Third, the sum of the products is computed over all grid cells. The Washburn Bound computed can be no smaller than zero but might be larger than one. Also, the Washburn Bound may oscillate from one iteration to the next before it eventually decreases monotonically. The Washburn Bound may not be valuable during the beginning iterations but becomes more useful as the algorithm approaches optimality. A detailed description can be found in Reference seven.

The optimal allocation of effort described above will be used for sensor placement. Since screen sensors do not possess the infinitely divisible property, sensors cannot be optimally placed. A major assumption in SCREENOP is that matching sensor effort as close as possible with the optimal effort will result in finding the best probability of detection of the target before it can launch its weapons. Given a placement of sensors, SCREENOP computes the search effort placed in each cell. The program attempts to position sensors so that the actual effort allocation more closely matches the optimal effort allocation. SCREENOP uses the sum of the squared differences over the cells between the actual and optimal effort allocation. The program does this for each sensor, one at a time, so as to lower the sum of the squared differences. A

binary search is conducted to find the minimum of squared differences in each direction of movement. The process continues until the positions cannot be improved. This process gives a local best match to the optimal allocation. For this reason also, an initial sensor guess is important.

B. VALUE

The target motion model and detection model used in SCREENOP are used in the search theory literature. Both models provide a reasonable description of the search problem and are sufficiently simple to understand and use. The ratio of the swept area to cell area, Ei/Ai, might also have been used to calculate the probability of detection. However, the exponential detection function accounts for inefficiencies in an operational search. Randomness in the target motion not accounted for in the swept area computation is allowed for in the exponential detection function. The exponential detection function provides a reasonable and conservative estimate of detection probability in an operational search.

The Convex-Simplex optimization routing provides a straight forward approach to solving the non-linear programming problem. In short, the models and techniques provide an adequate description of the ASW passive search problem. The user should now have a better understanding of the modelling in SCREENOP and is ready to run the program. A user's guide to the SCREENOP program will be presented in the next chapter.

IV. USERS GUIDE

A. ACCESSING THE PROGRAM

1. The System

Two forms of the program SCREENOP reside on the VAX 11/780 computers at the Naval Postgraduate School. A form of SCREENOP with Plot 10 graphics is located on the VAX 11/780 in the Computer Science Laboratory. It requires a TEKTRONIX 4014 terminal to run and utilizes the VMS operating system. A second form of SCREENOP without a graphics capability, is located on the VAX 11/780 in the Naval Postgraduate School Wargaming Laboratory. It can be run on the VT 100 terminal and uses the VMS operating system. Only the operation of the graphics version of SCREENOP will be described further.

2. Login Procedure

The TEKTRONIX 4014 terminal user energizes the terminal switch on the lower front side of the terminal (approximately at knee level). The login procedures begins as follows:

1. Enter a carriage return,
2. Enter the user name "Andrus",
3. Enter the user password "Andrus",
4. Wait for the system login message followed by a dollar sign "$" on a separate line,
5. Enter the command "run SCREENOP".

The execution of the program begins with an erasure of the screen and display of the SCREENOP heading.

3. Logoff and Break Procedure

The user may log off the system any time by entering the command "log" after receiving a dollar sign "$" prompt. SCREENOP provides for an orderly termination of the program with option 11 in the screen formation section. However, the user can interrupt program execution by depressing the control key (CTRL) and simultaneously depressing the letter Y. The SCREENOP program can be rerun by entering the "run SCREENOP" command.

4. File Operations

During a SCREENOP run the user is asked to name four SCREEN input data files and two input/output data files. A listing of all data files in the user directory may be obtained by entering the command "dir" after receiving a dollar sign prompt. Entering the name of an input data file name which does not exist will result in an error message. If a file already exists with the desired name for the input/output data files, the original file will be overwritten. To delete a file after a SCREENOP run is completed, enter the command "delete filename.data" where filename is the name of the file to be deleted. Other VMS system commands may be found in the VAX 11 System User's Guide.

5. Changing the Program

Several key quantities are parameterized in SCREENOP using a Fortran parameter statement. It is unlikely that a user will have the need to alter the parameter values, therefore specific procedures will

not be addressed. The user should consult the VAX 11 Fortran Reference Manual and User's Guide for a description of the procedures to edit, compile, and link programs prior to attempting any program changes.

6. Clearing the Screen

When the screen is filled it will continue to output information by overwriting the information already displayed. To avoid overwriting the screen, depress the reset page button on the upper left corner of the keyboard before the screen becomes filled.

7. Deleting Characters

To delete characters which may have been typed in error but not entered, depress the rubout key once for each character. The incorrect characters will remain on the screen. The user may then type in the correct entry. The correct characters will appear over-written on the incorrect characters. If unsure as to what charactures are actually typed onto the screen, the user should simultaneously depress the control and R keys. The user will be provided with the current version of the input characters. The characters can now be entered if correct or corrected using the rubout key.

The user should now possess the basic skills to run the SCREENOP program.

B. A SCREENOP EXAMPLE

The following example provides a sample run of the SCREENOP program. Althouth the results of this example will be discussed in the next chapter, the purpose in this chapter is to demonstrate the operation

of the SCREENOP program and not to provide a basis for a full scale analysis. During the execution of the program, graphic displays will be presented on the screen. The user must enter a carriage return to clear the screen and continue the program.

In this example, the user has two moving sensors and two sonobuoy fields to place in a screen against a penetrator utilizing an intercept target. Also, none of the sensors have a detection capability beyond 32 nautical miles. Table I shows the input from the SCREEN data files which describe the sensors, the target and the environmental conditions. Figures 4.1 through 4.5 illustrate the initial input section for the example. The user is asked to input the gridwork parameters. In the example, a 15 x 15 square grid of cells, with each cell measuring 10 nautical miles on a side, is defined. A scale factor of one indicates that the environmental conditions are described only within 120 nautical miles of the battle group. The initial position of the battle group center is located at the cell which is the third row from the bottom and the eigth column from the left in the gridwork. The battle group is moving at a speed of 10 knots toward the top of the gridwork. Figure 4.6 is a display of the initial grid. At this point, the user is given the option to change any of the gridwork parameters.

The environmental and contour parameters are entered next by inputting the file name of an environmental file and a sensor contour file. The user is provided with a message when the files have been read successfully.

TABLE I

Data From SCREEN Input Data Files

Ambient noise
60 dB

Propogation loss curve (range, dB pairs)
(1,63), (5,97), (7,101), (27,15), (30,92), (32,98)

Directivity index
30 dB

Sensor recognition differential
10 dB (moving), 9dB (stationary)

Target source level
130 dB

Battle group noise level
165 dB

Self noises
25 dB (moving), 0 dB (stationary)

Standard deviation in signal excess (sigma)
6 dB (moving), 3 dB (stationary)

The sensor parameters are entered by inputting the name of a sensor data file. The SCREENOP program describes the 2 types of sensors from the input file and asks for the number of each that are available for the search. The user indicates that 2 of each type sensor are available.

The user is queried for the direct path and convergence zone uppderbounds for the moving sensors. These entries must be 3 digit integer numbers. In the example, 27 nautical miles will be used for

```
          ::::::::::::
          :          :
          : SCREENOP :
          :          :
          ::::::::::::

                    INPUT SECTION
                    ----- -------

GRID PARAMETERS
---- ----------

ENTER THE FOLLOWING:

NUMBER OF ROWS OF CELLS (MAXIMUM ALLOWED IS  15):
15
NUMBER OF COLUMNS (MAXIMUM ALLOWED IS  15):
15
SCALE FACTOR (1,2, OR 3):
1
LENGTH(NM) OF A CELL SIDE (MUST BE MULTIPLE OF  5 AND
MAXIMUM ALLOWED IS  20):
10

ENTER LOCATION OF THE BATTLE GROUP CENTER
ROW NUMBER (FROM BOTTOM):
3
COLUMN NO. (FROM LEFT):
8
ENTER THE BATTLE GROUP SPEED (KTS):
10



DO YOU WANT TO CHANGE THE GRID PARAMETERS(Y/N)?
N


ENVIRONMENTAL/CONTOUR PARAMETERS
------------- ------- ----------

ENTER THE NAME OF THE ENVIRONMENTAL FILE:
EXEN

ENTER THE NAME OF THE SENSOR CONTOUR FILE:
EXCO

THE ENVIRONMENTAL AND CONTOUR FILES HAVE BEEN READ.
```

Figure 4.1 Grid and Environmental/ Contour Parameters.

```
SENSOR PARAMETERS
------ ----------

ENTER THE NAME OF THE SENSOR FILE:
EXSE

THE SENSOR FILE HAS BEEN READ.


ADDITIONAL SENSOR DATA:

SENSOR TYPE 1      SENSOR NAME: S1
------ ----        ------ ----
THIS IS A MOVING SENSOR.
ENTER THE FOLLOWING:
NUMBER OF AVAILABLE SENSORS OF THIS TYPE:
3
C2 UPPER BOUNDS(NM):
27,040
SPRINT AND DRIFT DATA
(IF SENSOR DOES NOT SPRINT AND DRIFT, ENTER 0
FOR THE SPRINT SPEED.)
SPRINT SPEED(KTS):
0

SENSOR TYPE 2      SENSOR NAME: S2
------ ----        ------ ----
THIS SENSOR IS A SONOBUOY FIELD.
ENTER THE FOLLOWING:
THE NUMBER OF AVAILABLE SENSORS OF THIS TYPE:
2
NUMBER OF ROWS IN THIS FIELD:
4
THE DISTANCE BETWEEN ROWS(NM):
10
THE NUMBER OF COLUMNS:
4
THE DISTANCE BETWEEN COLUMNS(NM):
5
```

Figure 4.2 Sensor Parameters.

```
TARGET PARAMETERS
------ ----------

ENTER THE NAME OF THE TARGET FILE:
EXTA

THE TARGET FILE HAS BEEN READ.


THE MAXIMUM NUMBER OF TARGET SCENARIOS IS  2.

TARGET MOTION IS MODELLED IN DISCRETE TIME.
ENTER THE TIME STEP(HRS):
1.

THERE ARE THREE PARTS TO EACH TARGET SCENARIO:
   1. INITIAL DISTRIBUTION.
   2. MOTION ASSUMPTIONS.
   3. ATTACK PROBABILITIES.


               SCENARIO NUMBER   1

ENTER THE FIRST SCENARIO WEIGHT (NON-ZERO):
1.

   xxxxx   INITIAL DISTRIBUTION   xxxxx

THIS DISTRIBUTION DESCRIBES THE TARGET LOCATION AS
THE TARGET ENTERS THE SCREENOP GRID.
THERE ARE TWO WAYS TO ENTER THIS DISTRIBUTION:
   1. ENTER PROBABILITIES CELL-BY-CELL.
   2. ASSUME THAT THE DISTRIBUTION HAS A
      COSINE DENSITY OVER THE TOP ROW OF CELLS.
ENTER YOUR CHOICE (1 OR 2):
2

ENTER THE MEAN OF THE COSINE DISTRIBUTION(NM):
0
ENTER THE DISTANCE FROM THE MEAN TO THE EDGE
OF THE COSINE DISTRIBUTION(NM):
60



DO YOU WANT TO CHANGE THE INITIAL PARAMETERS(Y/N)?
N
```

Figure 4.3 Target Parameters.

```
   *****   MOTION ASSUMPTIONS   *****

TARGET SPEED (KTS):
5

TWO TARGET TACTICS ARE AVAILABLE:
   1. INTERCEPT.
   2. LEAD/LAG.
ENTER 1 OR 2:
1


ENTER THE FOLLOWING:

COURSE UNCERTAINTY (DEG):
10
SPEED UNCERTAINTY (KTS):
2

WHEN THE TARGET MASS REMAINING IN THE SCREENOP
GRID FALLS BELOW A THRESHOLD VALUE, THE TARGET
IS FORCED INTO THE FAILURE CELL.
ENTER THIS THRESHOLD PROBABILITY:
.05

   *****   ATTACK PROBABILITIES   *****

ENTER REGIONS FOR ATTACKING IN TERMS OF RADIUS AND
ANGLE (CENTERED AT THE TASK GROUP).  DO THIS JUST FOR THE
RIGHT HALF-PLANE (WE WILL ASSUME SYMMETRY).  START FROM
THE CENTER AND WORK OUT IN R.  FOR AN ANNULAR REGION,
START FROM 0 DEG (SOA OF TASK GROUP) AND WORK AROUND
CLOCKWISE TO 180 DEG.


ENTER RADIUS (NM) (0 TO QUIT):
10
ENTER ANGLE (DEG):
90
ENTER PROBABILITY OF ATTACK:
.9
ENTER CONDITIONAL PROBABILITY OF SUCCESS:
.5
ENTER ANGLE (DEG):
180
ENTER PROBABILITY OF ATTACK:
.5
ENTER CONDITIONAL PROBABILITY OF SUCCESS:
.7

ENTER RADIUS (NM) (0 TO QUIT):
20
ENTER ANGLE (DEG):
180
ENTER PROBABILITY OF ATTACK:
.4
ENTER CONDITIONAL PROBABILITY OF SUCCESS:
.6

ENTER RADIUS (NM) (0 TO QUIT):
0


DO YOU WANT TO CHANGE THE ATTACK PARAMETERS(Y/N)?
N
```

Figure 4.4 Target Motion and Attack Probabilities.

```
FOR SCENARIO NO.   1, THE LAST TIME STEP AT WHICH
A TARGET CAN BE IN THE GRID IS  14

 DO YOU WANT TO CHANGE ANY TARGET PARAMETERS
FOR THIS SCENARIO(Y/N)?
N

                SCENARIO NUMBER   2

ENTER THE SCENARIO WEIGHT (ZERO IF NO
MORE SCENARIOS.):
0


                END OF INPUT SECTION
                --- -- ----- -------
```

Figure 4.5 Target Scenario Description.

The convergence zone upperbound. Each upperbound is entered with a leading zero. The entries are separated by commas. Although additional convergence zone upperbounds are not used in this example, SCREENOP is capable of accommodating them. The moving sensors in the example do not sprint and drift so a zero is entered for sprint speed. In the example, the two sonobuoy fields are 4x4 with 10 nautical mile spacing between rows and 5 nautical mile spacing between columns.

The target parameters are entered next. The file name of the screen data file with the target source level is entered. Next, a time step of 1 hour is entered. Only one target scenario will be used in the example so its weighting factor is one. The initial distribution will be described by a cosine distribution with mean equal to zero and distance from the mean to the edge of the distribution equal to 60 nautical miles. Figure 4.7 is a display of the initial target distribution in the gridwork of cells. The user is given the option to change the distribution parameters. The target is moving at 5 knots while employing an intercept tactic. The course and speed uncertainty of the target is 10 degrees and 2 knots, respectively. A threshold probability of .05 guarantees that the target will have at least a 95% chance to perform its mission before the pboblem is truncated. In the example the target may attack 40% of the time with a probability of success of .6 given that it is within 20 nautical miles of the battle group. When the target gets to within 10 nautical miles of the battle group, it is more likely to attack from the front

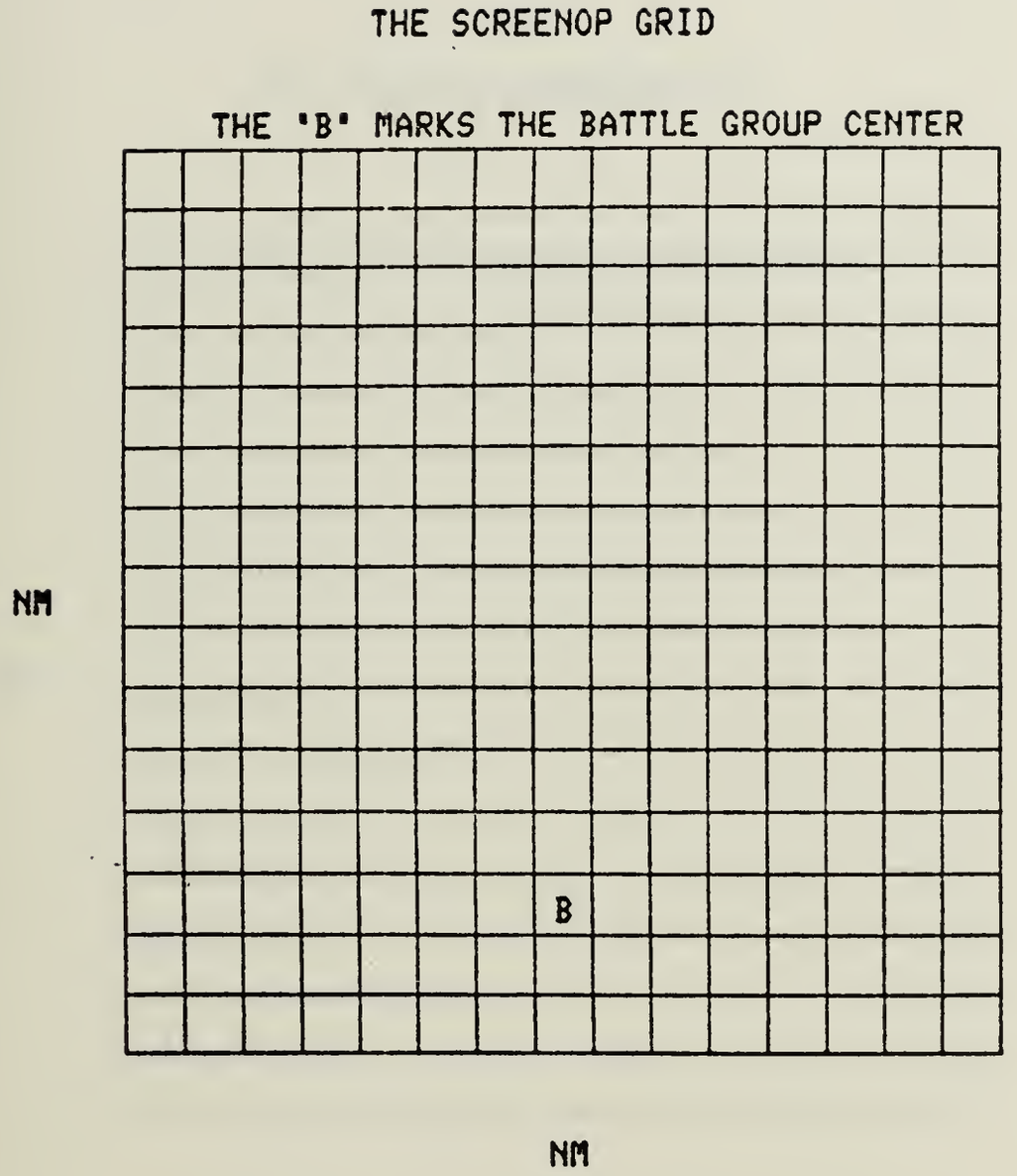

Figure 4.6 The SCREENOP Grid.

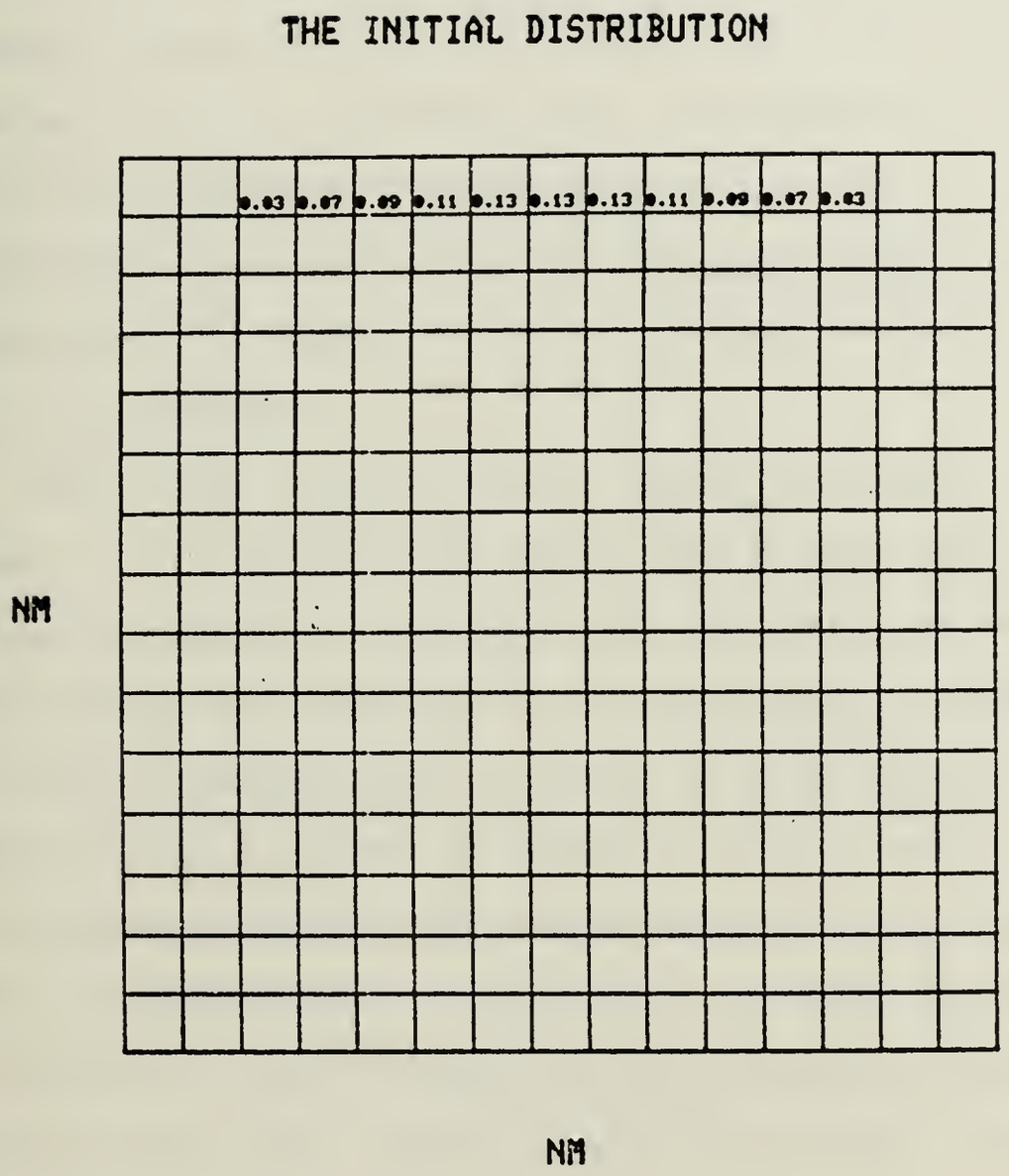

Figure 4.7 The Initial Target Distribution.

rather than the rear of the battle group. In fact, the probability of attack is .9 and the conditional probability of success is .8 when the target is within 90 degrees either side of the battle group heading and within 10 nautical miles of the center. When the target is beyond the 90 degrees of either side of the battle group heading and within ten nautical miles, the probability of attack is .5 and the probability of success given an attack is .7. The attack probabilities are converted for each cell and presented to user in a display shown in Figure 4.7. The user is given the option to change any attack parameters.

Next the user is provided with a display of 10 sample target tracks. (See Figure 4.9) the initial point of each track is obtained by chosing a random point from the initial target distribution. The final point of the sample track is reached when an attack is launched, when the target is forced outside of the limiting lines of approach by navigation errors, or when the problem is terminated because of time. After the target track display, the user is given the chance to change any of the target parameters for the scenario. A zero is entered for the next target scenario weight since only one target scenario is used in the example. The input section is complete for the example.

The program moves to the data preparation section. The user is asked if an old effort file is to be used. Since this is the first run of the program for the example, a negative response is entered. The user must now enter the name of the file for the effort computation

to be stored for later use. The effort computations will be displayed for each sensor. Figure 4.10 illustrates the effort computation for the example.

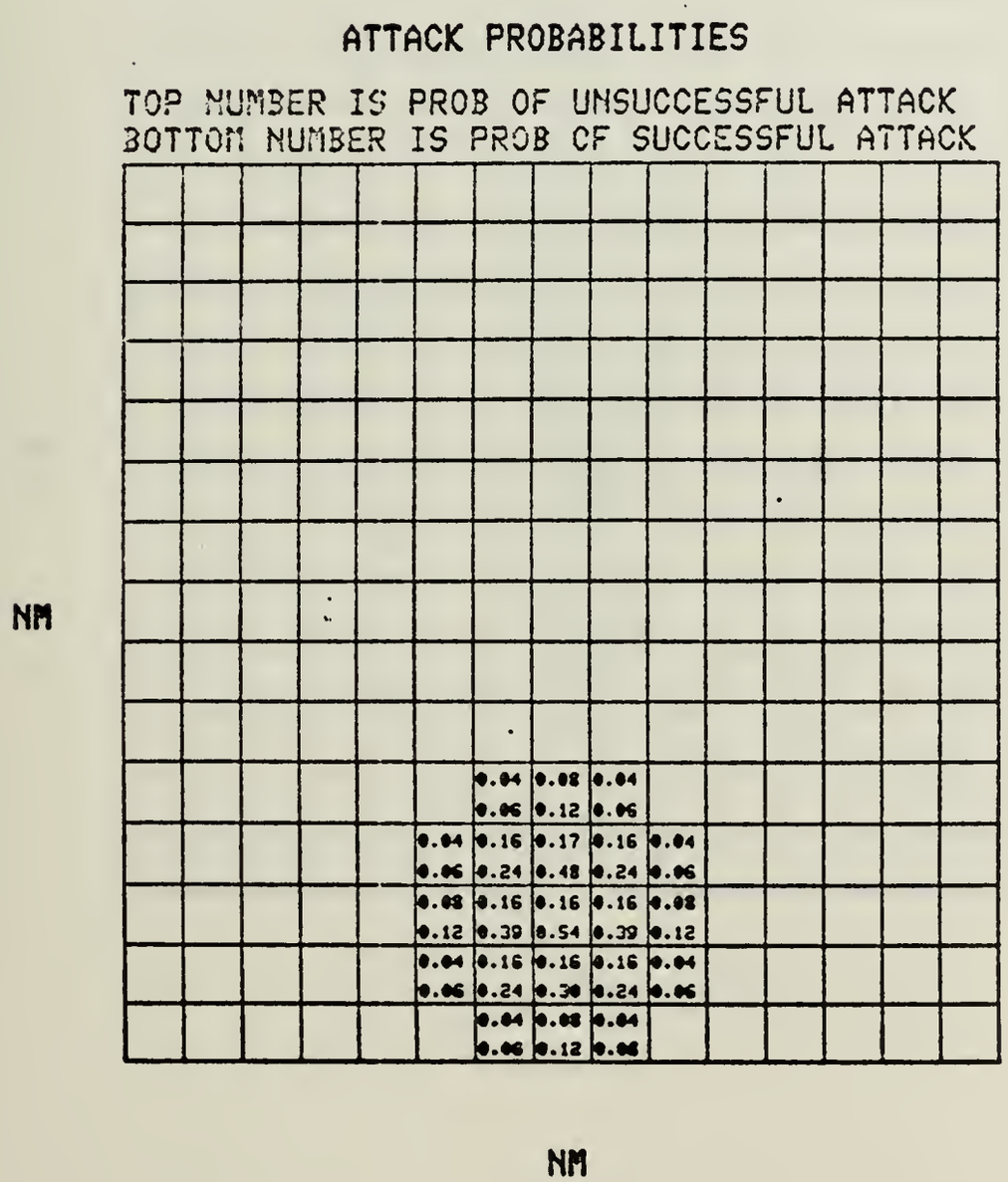

Figure 4.8 The Attack Probabilities.

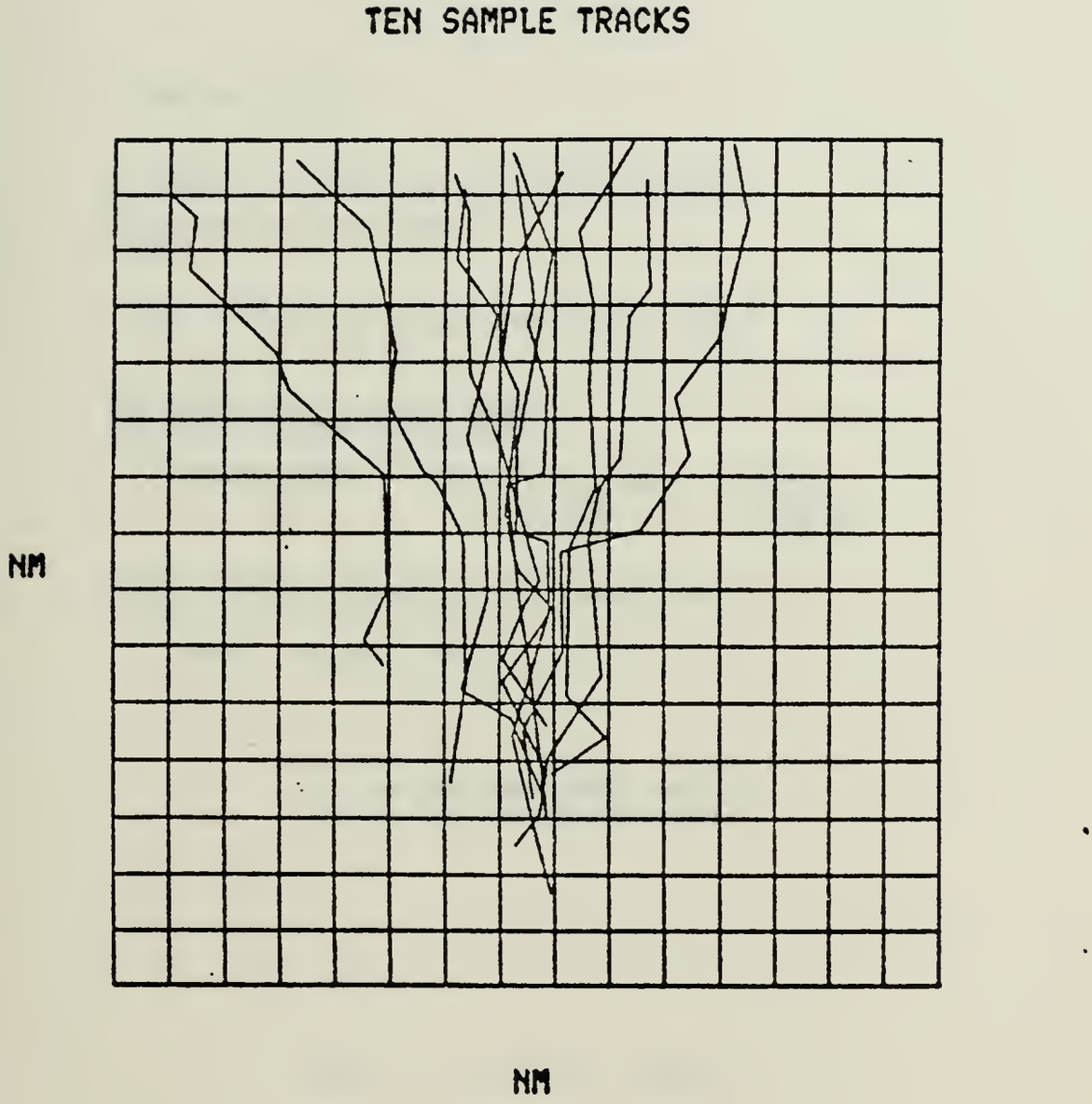

Figure 4.9 Ten Sample Target Tracks.

```
                    DATA PREPARATION SECTION
                    ---- ----------- -------

EFFORT COMPUTATION
------ -----------

DO YOU WANT TO REUSE AN OLD EFFORT FILE(Y/N)?
N
ENTER NAME OF EFFORT FILE
FILE1

*****   STANDBY FOR EFFORT COMPUTATION   *****

THE EFFORT FILE HAS BEEN STORED.
SUMMARY OF EFFORT COMPUTATIONS

     SENSOR NUMBER     EFFORT PER SENSOR     TOTAL
           1                 411.95           823.91
           2                 417.93           835.85

FIGURE OF MERIT AND SWEEP WIDTH COMPUTATIONS
------ -- ----- --- ----- ----- ------------

     *****   STANDBY   *****

                    END OF DATA PREPARATION SECTION
                    --- -- ---- ----------- -------
```

Figure 4.10 Effort Summary

The optimal allocation section of the program begins by querying the user as to whether an allocation file exists from a previous SCREENOP run. Again, for this example, a negative response is entered. The SCREENOP program will now attempt to optimally allocate the total amount of sensor effort, assuming that it is infinitely

divisible. The initial guess for the sensor effort placement will be directly in front of the battle group centered at the top of the grid. 1659 units of effort will be placed in call number 8 with no restriction placed on the minimal amount of effort which must be allocated to that cell. When the initial guesses for effort placement have been entered, the word "END" is entered. The user is asked to enter a carriage return to continue. The program begins to optimize the allocations in a series of iterations. In the example the probability of detection for that allocation and the Washburn Bound will be displayed every fifth iteration. After 25 iterations, the program has computed a probability of detection of 92%. The Washburn Bound indicates that no more than a 3% improvement in probability of detection can be made. Thus the maximum probability of detection which is possible for any allocation is 95%. The user is satisfied with the probability of detection after 25 iterations and moves on to the sensor placement section. Figure 4.11 is a display of the effort allocation after 25 iterations.

In the optimal screen formation section the user is asked for an initial guess of each sensor. (See Figure 4.12). The moving sensors are placed at (-5,40) and (5,40) from the battle group center. The sonobuoy fields are placed at (-15,40) and (15,40) from the battle group center. Next the program provides a list of the 11 options for the user. Figure 4.13 illustrates the options which were discussed in detail in Chapter 2.

The user will select option 4 to display the optimal allocation of the total effort of the sensors. (See Figure 4.14). The effort

displayed is effort that has been degraded by a factor of .01. Option 10 is selected next for a computation of optimized sensor location. SCREENOP optimally positions the moving sensor locations at (-8,34) and (6,36) and thesonobuoy fields at (-27,22) and (26,23). (See Figure 4.15). As shown in Figure 4.16, option 8 displays a probability of detection of .82 which is less than the .92 probability of detection determined by the optimal allocation. The assymetrical optimal sensor placement is due in part to the fact that the computed optimal allocation is sometimes only an approximation to the actual optimal allocation. Since effort is certainly not infinitely divisible, the probability of detection of .82 for the optimal placement of sensors is acceptable. Option 11 is exercised to terminate the program.

```
                OPTIMAL ALLOCATION SECTION
                ------- ---------- --------

DO YOU HAVE AN ALLOCATION FILE:
N

INITIALIZATION
--------------

Enter cell no., initial cell effort, lower cell effort bound triple
s
(Default values are 0.)
Enter 'END' to terminate list

   cell, initial effort, least effort:
8,1660,0
   cell, initial effort, least effort:
END
HIT RETURN TO CONTINUE

ALLOCATION WILL BE SHOWN EVERY K-TH ITERATION
ENTER K
5
AFTER   5 ITERATIONS
            PROBABILITY OF DETECTION =    0.88496
            WASHBURN BOUND =    0.61725
HIT RETURN TO CONTINUE

CONTINUE(Y/N)?
Y
AFTER  10 ITERATIONS
            PROBABILITY OF DETECTION =    0.88901
            WASHBURN BOUND =    0.48175
HIT RETURN TO CONTINUE

CONTINUE(Y/N)?
Y
AFTER  15 ITERATIONS
            PROBABILITY OF DETECTION =    0.91104
            WASHBURN BOUND =    0.10413
HIT RETURN TO CONTINUE

CONTINUE(Y/N)?
Y
AFTER  20 ITERATIONS
            PROBABILITY OF DETECTION =    0.91412
            WASHBURN BOUND =    0.04786
HIT RETURN TO CONTINUE

CONTINUE(Y/N)?
Y
AFTER  25 ITERATIONS
            PROBABILITY OF DETECTION =    0.91494
            WASHBURN BOUND =    0.02541
HIT RETURN TO CONTINUE

CONTINUE(Y/N)?
N

ENTER NAME OF ALLOCATION FILE:
FILE3
END OF OPTIMAL ALLOCATION COMPUTATION
--- -- ------- ---------- -----------
```

Figure 4.11 Optimal Allocation After 25 Iterations.

```
          OPTIMAL SCREEN FORMATION
          ------- ------ ---------

INITIAL USER GUESS FOR SCREEN

ENTER POSITION (X,Y) OF SENSOR  1 OF SENSOR TYPE  1:
-5,40
ENTER POSITION (X,Y) OF SENSOR  2 OF SENSOR TYPE  1:
5,40
ENTER POSITION (X,Y) OF SENSOR  1 OF SENSOR TYPE  2:
-15,40
ENTER POSITION (X,Y) OF SENSOR  2 OF SENSOR TYPE  2:
15,40
```

Figure 4.12 Initial Guess of Sensor Location.

```
                    OPTIONS
                    -------

    1. LIST SENSOR LOCATIONS.
    2. DISPLAY SENSOR LOCATIONS.
    3. DISPLAY SENSOR LOCATIONS AND SAMPLE TRACKS.
    4. DISPLAY OPTIMAL EFFORT ALLOCATION.
    5. DISPLAY SENSOR EFFORT ALLOCATION.
    6. DISPLAY SENSOR EFFORT ALLOCATION AND SAMPLE TRACKS.
    7. DISPLAY SENSOR ALLOCATION MINUS OPTIMAL ALLOCATION.
    8. COMPUTE PROBABILITY OF DETECTION.
    9. MANUALLY MOVE SOME SENSORS.
   10. AUTOMATICALLY COMPUTE NEW SENSOR LOCATIONS.
   11. END PROGRAM.
```

Figure 4.13 Program Options

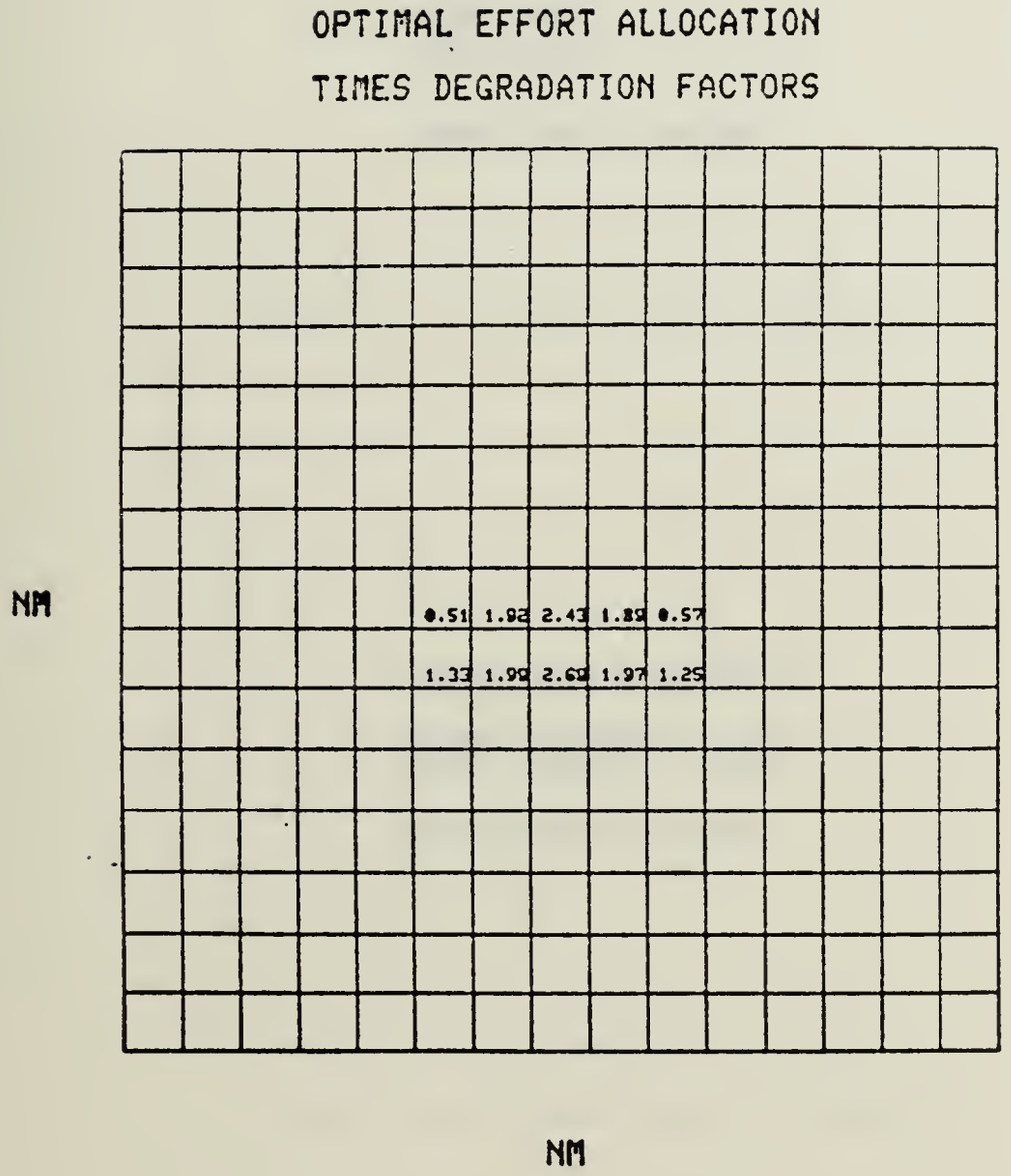

Figure 4.14 Optimal Allocation of the Sensor Effort.

```
COMPUTATION COMPLETE

SENSOR LOCATIONS
------ ---------

SENSOR TYPE  1
  -8.0  34.0
   6.0  36.0

SENSOR TYPE  2
 -27.0  22.0
  26.0  23.0

PRESS RETURN TO CONTINUE.
```

Figure 4.15 Optimal Sensor Locations

```
PROBABILITIES OF DETECTION
------------ -- ---------

OPTIMAL ALLOCATION:  0.824
SENSOR ALLOCATION:   0.852

PRESS RETURN TO CONTINUE.
```

Figure 4.16 Probabilities of Detection

V. RESULTS

The example presented in the user's guide in Chapter 4 is elementary in scope but provides some basis for discussing the SCREENOP program performance. The dynamic nature of the screening problem and the difficulty with the integration of the plethora of information which constitute the tactical and environmental situation cannot be overstated. Nonetheless, the ASW screen designer possesses an intuition influenced by previous experience. The results from the example serve to support a user's intuition that the moving sensors should be placed symmetrically approximately 35 nautical miles ahead of the battlegroup. The battlegroup noise is probably the factor which causes SCREENOP to place them away from the battle group. The sonobouy fields were placed further from the battle group than initially estimated by the user. Again, the battle group noise is the most likely reason for it. The acoustic environment is limited as described by a maximum range of 32 nautical miles in the propagation loss curve. This condition compounded with the maximum weapons range described by the attack probabilities at 20 nautical miles also serve to explain the sensor placement by the SCREENOP program.

This example does not provide a strong basis for determining the value of the model. The SCREENOP program has been used by Daniel H. Wagner, Associates to develop ASW screens in a tasking by the Commander, Third Fleet (COMTHIRDFLT). The results of the runs of the four scenarios proposed by COMTHIRDFLT showed that the user's initial guess of sensor placement was improved significantly [Ref. 8] .

Further analysis reveals that SCREENOP does produce some screens which are not realistic. The SCREENOP program may place sensors on top of each other. This is an unsatisfactory situation. In other cases, the optimal allocations have more effort in some cells than can be possibly attained by any placement of actual sensors.

Despite some of the unfavorable results, SCREENOP extends a user's intuition in most cases and does improve screen design and the probability of detection. Possible improvements to SCREENOP will be discussed in the next chapter.

VI. CONCLUSIONS AND RECOMMENDATIONS

The SCREENOP program as it exists in its current forms at the Naval Postgraduate School is a useful tool for ASW research. However, the user requires a strong technical background to understand the modeling that is used. It is not designed for the typical officer in the fleet. It is envisioned that SCREENOP could be further developed as a tactical decision aid for the ASW commander; but not without a substantial number of improvements. The following is a list of areas where SCREENOP could be improved not only for making it a tactical decision aid, but also for using it for further research:

1. Allow for an active sensor capability,
2. Account for interference between sensors,
3. Account for directionality of sensors,
4. Maintain a minimum spacing between sensors,
5. Allow for an arbitrary orientation for sonobuoy fields,
6. Limit the amount of effort that can be placed in a cell,
7. Replace the current optimization method with a more efficient one,
8. Improve the method for matching the optimal effort allocation,
9. Simplify the detection model,
10. Expand the target motion models to allow for a greater number of and more realistic target tactics,
11. Improve the graphics capabilities.

The current version of SCREENOP with the PLOT 10 graphics cannot be used for any classified research. It is recommended that the SCREENOP program in the Wargaming laboratory be enhanced with color graphics using the DI 3000 graphics software. This would provide a capability for further, more detailed research with the option of using classified but more realistic inputs.

Finally, some of the needed improvements might require a significant amount of restructuring and rethinking of the problem. But, others are more easily implemented. Follow on research by students in the Operation Research or ASW Systems curriculums would make SCREENOP an even more useful tool for designing ASW screens.

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3. Daniel H. Wagner, Associates Memorandum to the Chief of Naval Operations (OP-961C1), On Maximizing a Concave Function Subject to Linear Constraints, by T. L. Richardson, 22 May 1981 (Case 608.9)

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7. Washburn, A.R., "An Upper Bound Useful in Optimizing a Search for a Moving Target", Operations Research V. 29, No. 6, 1981, pp. 1227-1230.

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