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THE ANALYSIS OF TACTICS

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13 ABSTRACT

A methodology for analyzing ASW tactics is described. The ASW attack submarine is viewed as a component of an adaptive system, and a cybernetic model has been developed to describe its behavior in the tactical environment. The system has been partitioned into three interacting levels: tactical, operational and strategic. Tactical level behavior is represented in the model. Time series data have been collected aboard target and attacking submarines during exercises, and computer programs have been developed to answer the following questions from the data:

1. How does system behavior change in time? A program has been developed to display the values assumed by own-ship and target submarine variables in time. This is a graphic print-out and can be used to locate specified events, such as detections.

2. What behavior patterns does the system exhibit? Given an event of interest, the second program is designed to search the data forward and backward in time to identify specific behavioral patterns preceeding and following an event. In this way it is possible to identify the systems states which most frequently lead to events. It tabulates the responses made by the submarine commander to disturbances from his environment.

3. What functional relations or transformations can be derived from behavioral patterns prior to and following events? This program tabulates the interactions between own-ship and target across runs. A table is developed showing the state of the system following a disturbance from the environment and a consequent reaction from own-ship.

Although utilization of the method has been limited to a small data sample, the methodology provides a capability for analyzing time-series data collected at sea by interacting units in an ASW encounter. Further development is dependent upon the accumulation of continuous data under a wide range of conditions.

This report consists of an unclassified section describing the methodology, and a classified appendix illustrating the method with submarine exercise data.

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Strategy						

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I. INTRODUCTION

> "If, instead of sending the observation of able seamen to able mathematicians on land, the land would send able mathematicians to sea..."
>
> Sir Isaac Newton

This report summarizes the final phase of a study of the ASW Submarine Attack System (Howland, 1966). It is part of a long-range program for the development of methods for modeling the behavior of complex man-machine systems.

As a point of departure, a study of the submarine vs. submarine approach problem was conducted. This study focused on the development of a procedure for estimating range from bearing-only information (Colson, Edmonds & Mclean, 1967) and the development of a procedure for detecting target zigs (Edmonds, 1967). The zig detection problem was selected for study because of the difficulties encountered by fire control computer systems when target zigs were not detected. In addition, computer programs were developed to plot combined tracks from time series data. The geometric models, however, did not represent what we believed to be the essence of the tactical problem: the adaptive behavior of the submarine commander acquiring and processing the information required for successful task and mission accomplishment.

Our objective has been to develop a model to describe the time-varying behavior of an attack submarine adapting to information from its environment. The model which has been developed describes system behavior in terms of changes in system state vectors in time. These changes, summarized as transformations, or functions, relate the tactical behavior of the attacker and target in a range of ocean environments.

The two classical approaches to the development of functions are the deductive method of the mathematician, based on axioms and postulates, and the inductive method of the experimental scientist, based on observation and measurement. The inductive method, as Dantzig (1930, p. 68) has pointed out, "... is forever banned from rigorous mathematics." Nevertheless, this is the method we have chosen to ensure that our models were truly representative of the system for which predictions are being made. This is an important consideration because a major difficulty in the application of the cost-effective methods to system management has been poor prediction. One reason for this may be that the models used for analysis have not been sufficiently descriptive of the systems they were representing. As a result, systems have not always met performance and economic requirements when put in service.

We have developed a procedure for analyzing time series data which is free of the assumptions and constraints imposed by most of the classic mathematical methods.

A set of computer programs, developed for the analysis of health system data (Howland, 1970), has been modified to accept ASW System performance data. There are three basic programs. The first is designed to display the concomitant variation of selected system variables in time. The second can be used to identify system states prior to, during, and following selected events, such as a detection. The third can be used to tabulate patterns found in the data, showing how the system adapts to disturbances impinging on it from the environment. Fictional data have been used to illustrate the method in the body of the report. Actual data and computer printouts have been included in classified appendices.

II. A METHOD FOR THE ANALYSIS OF TACTICS

> "Tactics: The science and art of disposing and maneuvering troups or ships in action..."
>
> N. Webster

A. BACKGROUND

Increases in weapon capability and costs, coupled with decreasing resources and uncertain mission requirements, combine to increase the importance of developing strategic, operational, and tactical planning models. In the last analysis, strategy depends on operations and tactics. If strategic plans are to be realistic, they must be based on valid estimates of the capabilities and limitations of tactical force units. These capabilities and limitations, often expressed as probabilities of task accomplishment, provide guidance in determining the size and composition of forces needed to insure mission accomplishment. For example, information on the probability of target detection as a function of range provides a basis for determining the number of submarines to be assigned to a submarine barrier of given area.

Plans for the development and employment of weapon systems, such as the nuclear attack submarine, should be based on a consideration of the combined impact of technology, costs, and future mission requirements (Smith, 1966). Both long-range and immediate operational planning for submarine forces depend in part on estimates of the tactical capabilities and limitations of existing and future submarines. Because of the costs and time lags of trial and error system development, planners should be aware of the tactical capabilities and limitations of present and proposed force units before they are built and employed. This information can best be generated by system models. The fact that planning difficulties have been encountered when plans have been based on model-generated information in the past should result in increasing, not decreasing, emphasis on model development. The current "fly before you buy" policies do not alter the requirements for good models. They may, in fact, be viewed as an adaptive way of coping with the planning problems resulting from the use of nonrepresentative models.

Since military planning is based on the tactical capability of weapon systems, modeling should begin at the tactical level. Submarine exercises, conducted to generate information for determining force capabilities, are an example of modeling at this level. More abstract models, however, must be built to represent unbuilt systems. Because of the need for information about the behavior of such systems, models must be developed to represent the behavior of individual submarines so that: (1) the effectiveness of various tactical policies can be assessed, and (2) the influence of submarine and crew characteristics can be determined for the design and operation not only of future systems, but also of existing but unmeasurable systems such as those of potential enemies.

There are probably as many ways of modeling any given system as there are modelers. For this reason, the choice of a model should be based on the utility of the information it will provide and the feasibility of building and exercising it. Statistical models, of systems effectiveness, can be used to predict the probability of occurrence of empirical events, given a large number of trials under similar conditions. However, they offer relatively little information about the factors influencing the occurrence of a single event. In a weapon system, for example, many different component configurations could result in the same event frequency. If one is interested in the contribution of system components such as crews, sensors, weapons, and platforms to overall system performance in various operational environments, models containing terms to represent these components and the environment must be used. The data generated by such models can then be used to conduct experimental comparisons between component mixes. The results will be useful to the extent that the model truly represents the real world.

Having determined the kind of information the model must provide, the level of abstraction it will represent must be chosen. The choice depends on a number of factors such as understanding of the phenomena and the cost of building and exercising the model. The better one understands a system, the more abstractly it can be modeled. Several levels of abstraction for tactical models are shown in Fig. 1. It must be remembered that, regardless of the level of abstraction of the model, its function is the same; i.e., to provide the data required for analysis.

At the lowest, least abstract level, submarines operating in the ocean environment generate information representing target and attacker behavior. The major departures from realism are those imposed by safety requirements. A man-computer training device such as the submarine Attack Teacher might represent the next level of abstraction. A high level of realism is provided for certain aspects of the system, such as the physical arrangement of the attack center. Others, such as the ocean environment, and the target, are represented symbolically by computers. At the next level of abstraction, we might find man interacting with a computer-driven graphic display. The physical realism of the Attack

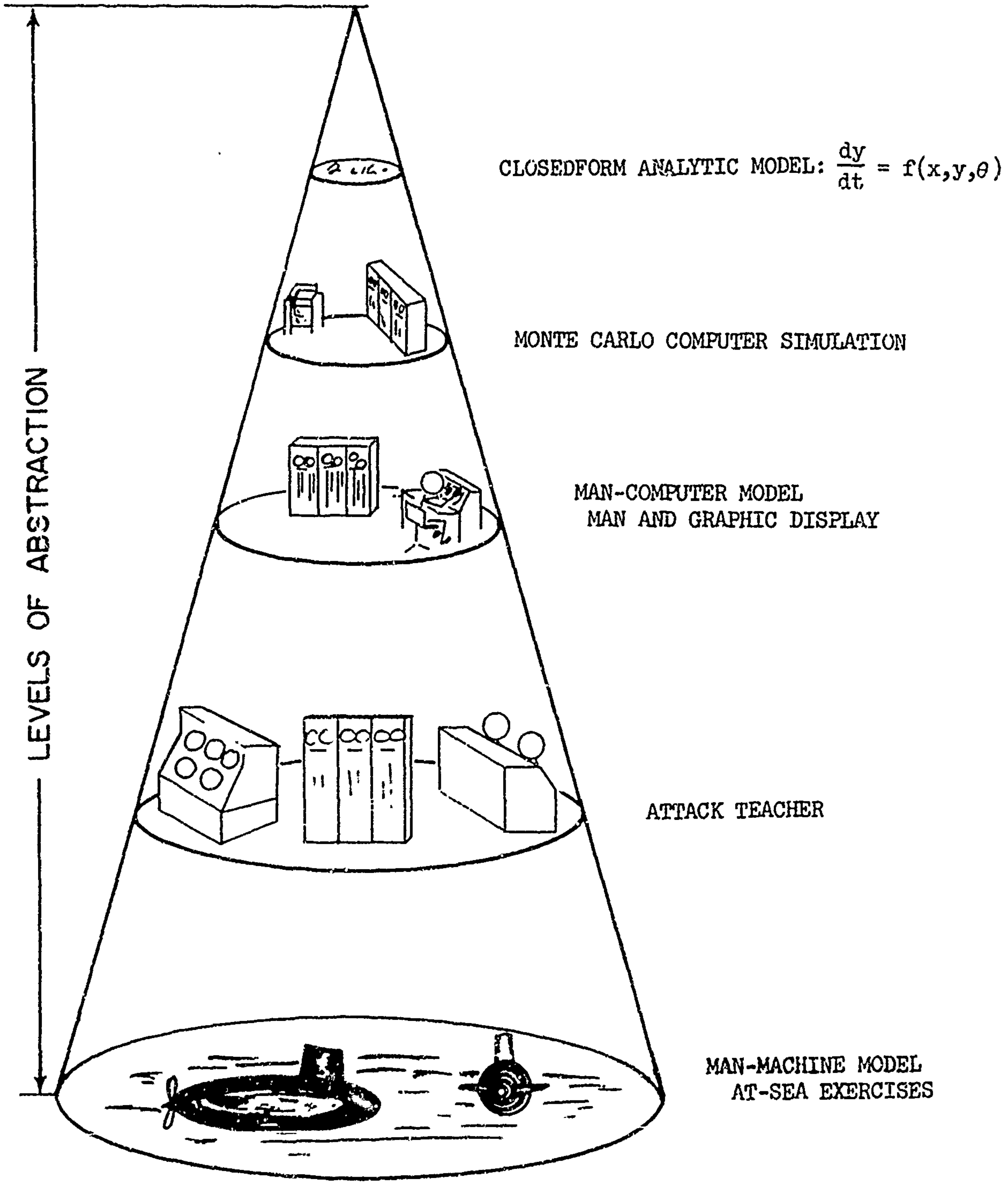


Fig. 1 - Levels of Abstraction for System Simulation Models (The same information is generated by the models at each level).

Teacher would be replaced by a display showing how the values of system variables change as own-ship is maneuvered.

A Monte-Carlo simulation might be used at the next level of abstraction. Here probability distributions, based on empirical data or assumptions, can be used to determine the probability of the occurrence of specified events. At the highest level of abstraction we find a closed-form analytic model. Approach models derived from the functions of plane geometry are of this type. Because of the complexity of the real world situation being modeled, and the dangers inherent in assumptions of linearity and independence, closed-form analytic solutions may not be feasible. The interactions between large numbers of variables, cannot, however, be assumed away. Any model which is descriptive enough to be useful must include them. In this situation, the man-graphic display level of abstraction may be useful for generating and testing functional relationships.

A number of tactical submarine models are available. Although a comparison of their capabilities and limitations is beyond the scope of this paper, two important questions must be raised about each: (1) is it useful--does it tell the tactical commander what he needs to know? (2) is it valid? Are differences between data generated by the model and data generated in the real world attributable only to chance, or are there factors acting in the real world which make observed system behavior significantly different from model results?

Although no model can ever be validated with complete certainty, any model to be used to extrapolate to the future should, at a minimum, be capable of describing the behavior of existing members of the class of system it represents.

Basically, a model is a statement of functional relationships between variables. In order to be used for prediction, a system model should show how overall system behavior would be affected by component behavior. For example, the tasks a submarine must accomplish to perform its mission are some combination of search, detection, classification, approach, and attack. The evolutionary development of the submarine has taken place among a set of component dimensions, such as displacement, speed, and endurance, which are constant for a class, but variable across classes, Fig. 2. Changes in components take place as a result of changing technology, with consequent changes in overall system performance. For example, the effect of the nuclear power plant was to change speed, noise, and endurance. We are interested in ascertaining the impact of such technical and human innovations on tactics. Although predictive capability is the only real criterion for model validity, internal consistency of the logic system on which the model is based is sometimes proposed. As Godel (Nagel and Newman, 1960) pointed out, however, there is no "right" system of logic, and no logical way of

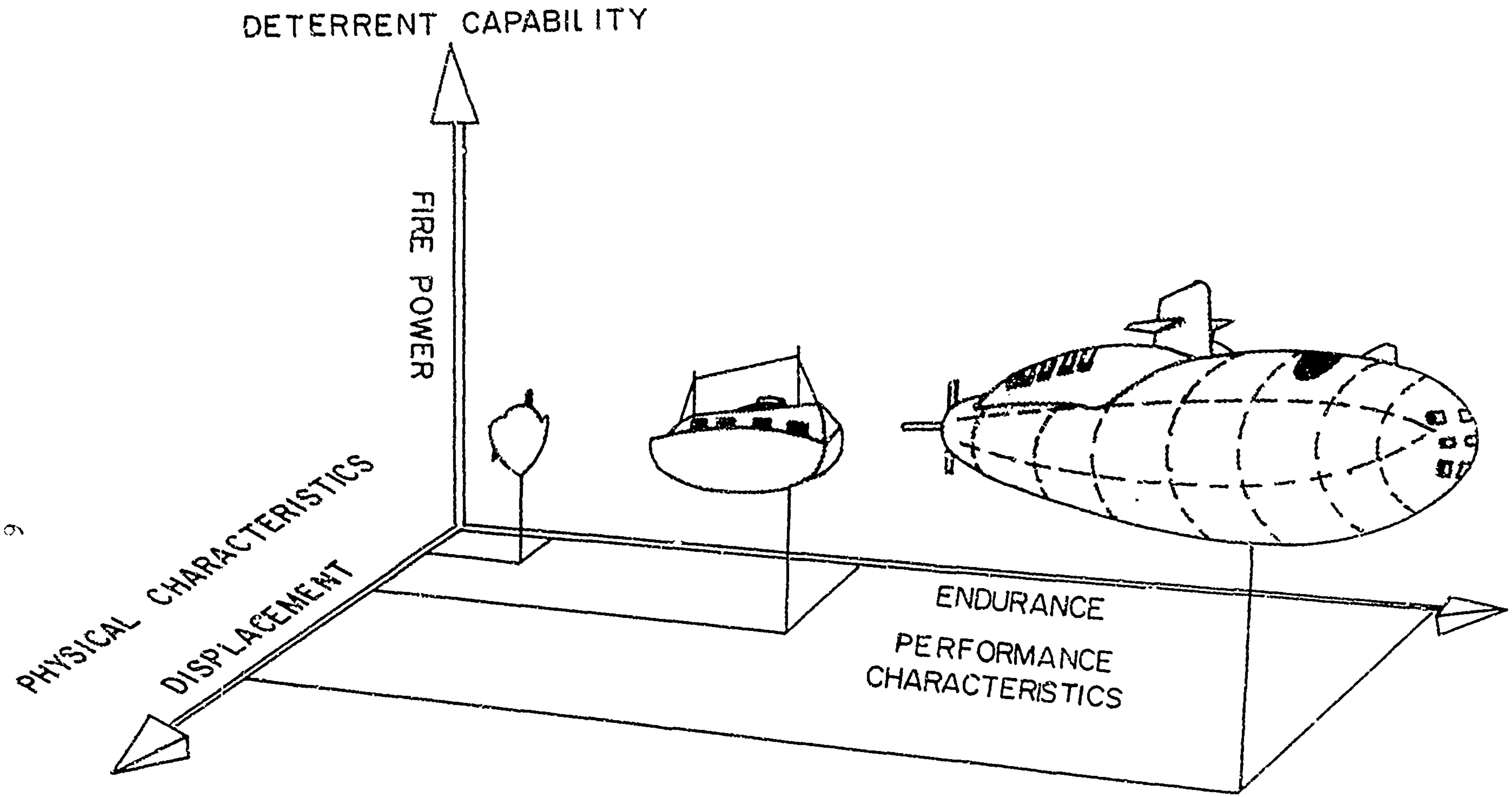


Fig. 2 - Evolutionary Trends in Submarine Design and Performance Characteristics

choosing between alternative systems. The only criterion for choice of a logic system is the degree to which logic agrees with empirical observation (Stevens, 1951).

B. PARTITIONING THE SYSTEM

With these general considerations of model building in mind, let us now see how they might be applied to the development of a submarine system model.

As a first step, it is convenient to partition a system into hierarchical, interacting levels. The interaction between these levels is represented in a set of models to show how information generated at one level is used at the others. Understanding of system behavior based on hierarchical models can lead to fruitful sub-optimization (Hitch, 1952) rather than the destructive type in which each level optimizes its own performance at the expense of the others. In addition, as Hitch (1963) pointed out, knowledge gaps exist between levels..." ... very often in working on a high level study we find we lack sufficient information at the lower level."

In order to ensure cooperative sub-optimization tactical information must be available at the strategic levels. For this reason the submarine system has been partitioned so that each level provides information to those above. The partitioning scheme is shown in Fig. 3.

1. The Tactical Level

If we examine the system at each level, identifying the management problems and the information required to solve them, a decision must be made to start at the strategic, operational, or tactical level. Many investigators recommend that modeling start at the top level. If this is done, however, assumptions must be made about tactical capabilities and limitations. In view of the fact that the "common wisdom" may be in error (i.e., assumptions about tactical unit performance may not be correct) we find it useful to start modeling at the tactical level.

The tactical problem is maneuvering a submarine so that the tasks required for mission accomplishment are performed. An important tactical question, for example, is the depth at which the submarine should search or hide. In order to answer this question, the state of the ocean environment must be known. Because of the complexity of this environment and the noise in the signals acquired through the submarine's sensors, the tactical commander relies heavily on information feedback and redundancy in making tactical decisions. For this reason, any model devised to describe his adaptive behavior must include the information feedback which is essential for adaptation. A tactical model should describe the behavior of individual submarines as they assume different

STRATEGIC LEVEL

DOD/OP NAV

Design of FUTURE forces. Alternate systems compared and selected to criteria of cost and effectiveness - systems analysis for determination of force levels and composition.

OPERATIONAL LEVEL

Force Commander

Utilization of EXISTING forces. Planning factors derived from study of tactical units - operations research models used to predict expected performance.

TACTICAL LEVEL

Force Unit Commander

Utilization of present and proposed tactical units. INDIVIDUAL tactical units maneuvered to perform assigned tasks and missions. Adaptive behavior of individual submarine represented by cybernetic model.

Fig. 3 - Levels of a Management System

courses, speeds, and depths. It should be noted that the output of such a model is deterministic, not probabilistic. The information it generates can be used, however, to construct the probability distributions used at higher levels. At any given time, for example, a submarine is at a specific course, speed, and depth with probability 1, and at all others with probability 0. It is as meaningless to attach a probability figure to the behavior of the individual as it is to talk about a family with 2.3 children. What is true for a group may be false for the individual members of the group.

2. The Operational Level

The behavior of the individual units of a force can be combined into probability distributions at the operational level of the system. These probabilities provide a basis for planning the employment of existing force units. This is the kind of information needed by a task force commander preparing his estimate of the situation. A major use of a tactical model would be to provide the data required to construct such probability distributions for proposed force units.

3. The Strategic Level

At the strategic level, the situation changes radically. The problem at this level is to design forces to meet expected future operational requirements. Planners must deal, as best they can, with enemy intentions as well as their capabilities. Characteristics of force units which are parameters at tactical and operational levels become strategic variables for the future. This is the management level at which systems analysis has been used (Enthoven, 1966). Serious management problems have, however, resulted from the use of these procedures. Some of these problems have been discussed at length in the hearings conducted by Senator Henry M. Jackson's Subcommittee on National Security and International Operation. One possible source of the difficulty is that the tactical capability of individual force units has not been accurately represented in the strategic and operational models. Since valid tactical information has not been available, unrealistic assumptions may have been made about tactical performance. For this reason, it is important that any model chosen to prepresent individual force units at strategic levels will accurately describe the tactical capabilities and limitations of such units.

C. TACTICAL MODELS

The development of tactical models presents a number of interesting problems for the model builder. Two of the most important are orientation and rationale.

1. Orientation

Orientation is the point of view adopted by the model builder. There are two possible points of view. One is "outside-in"; i.e., a representation of the system from the point of view of an outside observer. The other is "inside-out"; i.e., the system as seen by those within it. For example the aircraft instrument designer, designing a dynamic display such as the artificial horizon, must decide whether the instrument should represent the system as seen by the pilot (inside-out) or by an outside observer (outside-in). Mechanically, either is feasible and the choice should be conditioned by the ease with which the instrument can be used (McCormick, 1957). The data collected by each submarine in at-sea exercises are "inside-out"; they describe what each submarine can measure about its own behavior, and estimate the behavior of the target. Operational models, however, adopt an "outside-in" orientation. The task force commander watches a tactical situation develop from an outside vantage point. An operational "outside-in" display might take the form of a plotting board showing the relative position of tactical units so that it is possible to view the tactics of both target and attacker simultaneously. Models based on information developed by exercise reconstruction, such as the WSE model, are "outside-in."

Since the "inside-out" orientation is that of the submarine commander, an "inside-out" model would include only those factors which could be observed by the tactician. It should represent the actual behavior of an individual force unit at a specified time, not a behavioral probability. Such a model is required to generate the individual force unit performance data needed to calculate the probability of event occurrences. In addition, it may be used to study the information-decision requirements of the tactician. Since our primary concern is tactics as seen from the point of view of the tactical commander, an "inside-out" orientation has been adopted.

2. Rationale

A tactical model might be based on either a predictive or an adaptive rationale. A predictive model might predict relative target-attacker positions, given either deterministic or probabilistic information about each. Because of the number of variables which would have to be considered, the unreliability of environmental sensors, uncertainty about the target and the environment, and the effects of information feedback, it is highly unlikely that sufficient information would be available for accurate predictions. The ASW attack submarine is an open system and adaptation, rather than prediction, may be the best that can be hoped for. If we choose an adaptive rationale, the research aim becomes one of modeling the adaptive behavior of the successful tactician in response to information from the target and the environment, and to determine what values of the tactical variables correlate with task and mission accomplishment.

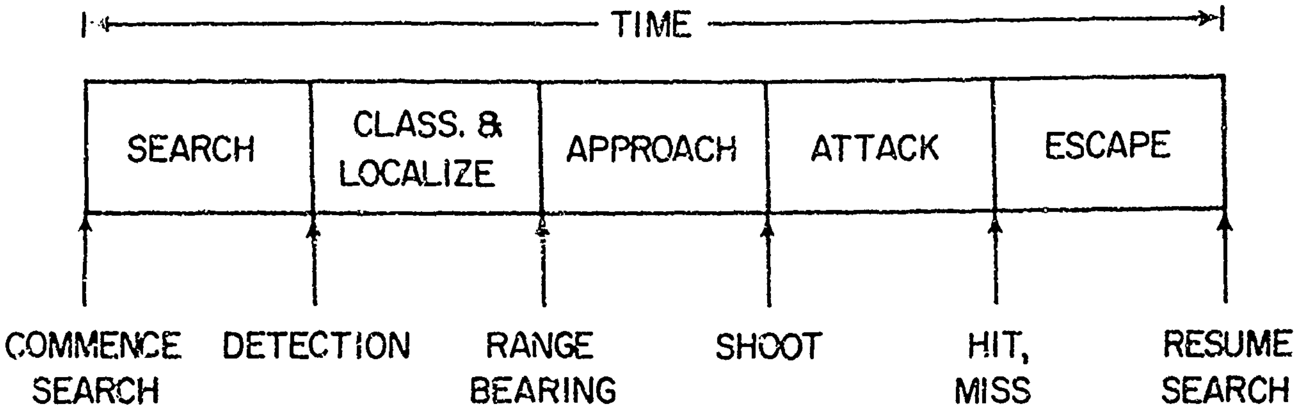
Adaptation is an individual, real-time, non-probabilistic phenomena. It is concerned neither with many trials of the same individual, nor the same trial for many individuals. An adaptive move is essentially one play of a Monte Carlo simulation. Adaptive models would not be used to predict the expected value of a large number of tosses of a coin, but rather the outcome of a single toss. In order to predict a single outcome, such things as the aerodynamics of coins, the condition of the atmosphere, and the tosser would have to be known. Even a simple coin "system" may be too complex for predictive modeling. Relative frequencies, probabilities, and expected values are therefore determined to provide probabilistic predictions for the long run, but do not predict the outcome of any particular toss. As another example, actuarial statistics make it possible to predict the numbers of deaths in a given age bracket, but tell little about the life expectancy of the individual. Since tactics are an individual, here-and-now proposition, any model designed to assist the tactical commander must provide guidance on how to use the information and resources at his disposal to adapt to the unknowns and uncertainties of the enemy and the sea.

D. THE EVENT SEQUENCE

A submarine attack can be viewed as a sequence of events which starts with a search and ends with a kill and a successful escape. In order to model this sequence, the start and end points of each event must be operationally defined. This sequence, as we conceptualize it, is shown in Fig. 4. A great deal of effort has been devoted to the task of modeling some of the events shown in the flow chart. Koopman (1956a, 1956b, 1957), Kimball and Morse (1951), Wagner (1968), and others have modeled the search process. Detection models based on the sonar equation have been developed (Downie, 1967), and there has been extensive research on the characteristics of sound for purposes of classification. Geometric models of the approach phase have been developed [(Colson, Edmonds and McLean (1967), Hunter, Long and Waterman (1964), Librascope (1960], and the behavior of weapons in the water has been analyzed extensively. In spite of all the work which has been done, however, two major tasks remain for the development of a tactical, "inside-out" model; (1) a detection model to provide the submarine commander with tactical information for a specific environment, and (2) an adaptive event model relating the various phases of a submarine attack.

E. SEARCH TACTICS

A successful attack is much like a yacht race -- the start strongly influences the finish. Since the search represents the start of an attack, the focus of this study is on development of a tactical search model to assist the tactical commander in achieving a detection, given there is something to detect. For the purposes of this analysis, detection is defined as the event: a sound has been heard at the sonar.



THE EVENT SEQUENCE

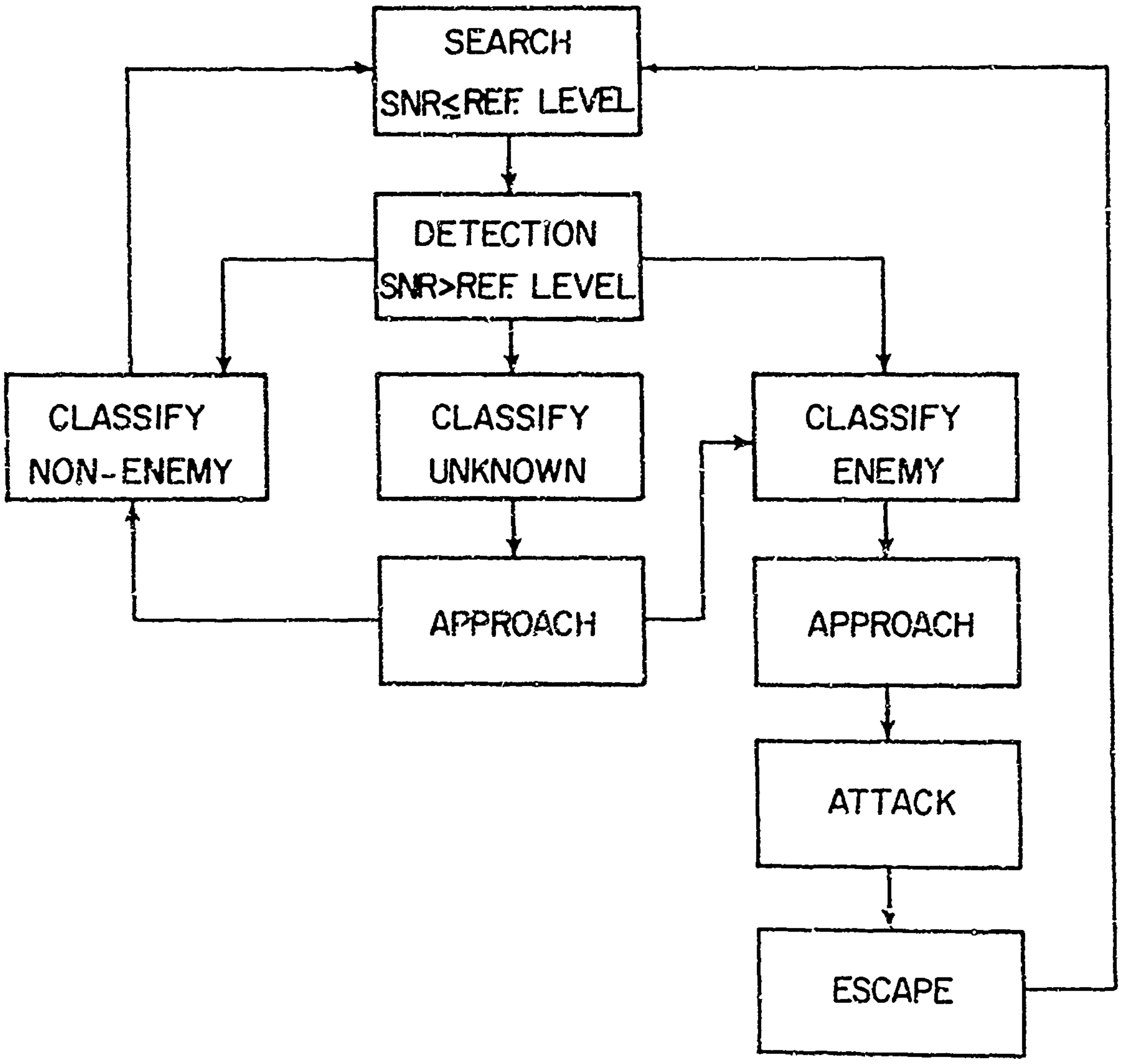


Fig. 4 - Attack Flow Chart

The detection event separates the search and classification phases of the attack. We wish to develop a model to describe the state of the system prior to detection so that the tactics leading to this event can be identified. In order to develop such a model, data describing the state of the system prior to detection must be available. The data to conduct such analyses are not routinely collected in at-sea exercises, however. The principal reason is that manual methods are too time-consuming to be practical. The availability of Autodata (SUBDEVGRU TWO, 1968) and computer methods of analysis remove these difficulties. It is now possible to collect data in real time and use it for model development.

F. MODEL DEVELOPMENT

Three general requirements for model development are: (1) a conceptual framework, (2) data, and (3) procedures for analyzing the data.

1. Conceptual Framework

Both data collection and analysis are based on a concept of how real-world phenomena behave. The more explicit the conceptual framework, the more useful it will be. The framework adopted here is based on the assumption that the commander of a submarine relies on information feedback to adapt to changes in a complex environment, and that he performs tactical maneuvers to reduce the difference between where he is and where he must be to launch a successful attack. Or, more generally, the kind of behavior to be represented in the model consists of a sequence of adaptive maneuvers to establish and maintain the desired relationship between attacker and target. Cybernetics, defined by Norbert Wiener (1961) as the study of "communication and control in the man and the machine," provides a conceptual framework to describe such behavior.

These concepts have been developed by numerous investigators to model the adaptive behavior of systems coping with their environment. For our purposes, a model proposed by Ashby (1960, p. 35) provides a convenient point of departure. This model takes the following form:

$$dy_1/dt = f_1\ (y_1 \ldots y_i \cdots y_n)$$

$$\ldots\ldots\ldots\ldots$$

$$dy_n/dt = f_n(y_1 \ldots y_i \ldots y_n),$$

where y_n is the n^{th} system behavioral variable.

This model can be used to trace the trajectory of a state-determined system; i.e., one that moves from state to state as a function of proceeding states and its own internal drives. A Markoff process, for example, represents a system characterized by the fact that its state at any one time depends only on its previous state.

Ashby's model is not sufficiently complex to describe the behavior of an adaptive system influenced by its environment and controlled by regulating the behavior of its components. We must, therefore, extend the model to include the components and environmental factors. Our extension takes the form

$$\begin{aligned} dy_1/dt &= f_1(y_1 \ldots yi \ldots y_n; x_1 \ldots x_i \ldots x_m; \theta_1 \ldots \theta_i \ldots \theta_s), \\ &\ldots \\ dy_i/dt &= f_i(y_1 \ldots y_i \ldots y_n; x_1 \ldots x_i \ldots x_m; \theta_1 \ldots \theta_i \ldots \theta_s), \\ &\ldots \\ dy_n/dt &= f_n(v_1 \ldots y_i \ldots y_n; x_1 \ldots x_i \ldots x_m; \theta_1 \ldots \theta_i \ldots \theta_s), \end{aligned}$$

and

where

y_i = i^{th} system overall performance variable,

x_i = i^{th} system resource component variable,

θ_i = i^{th} environmental variable,

and

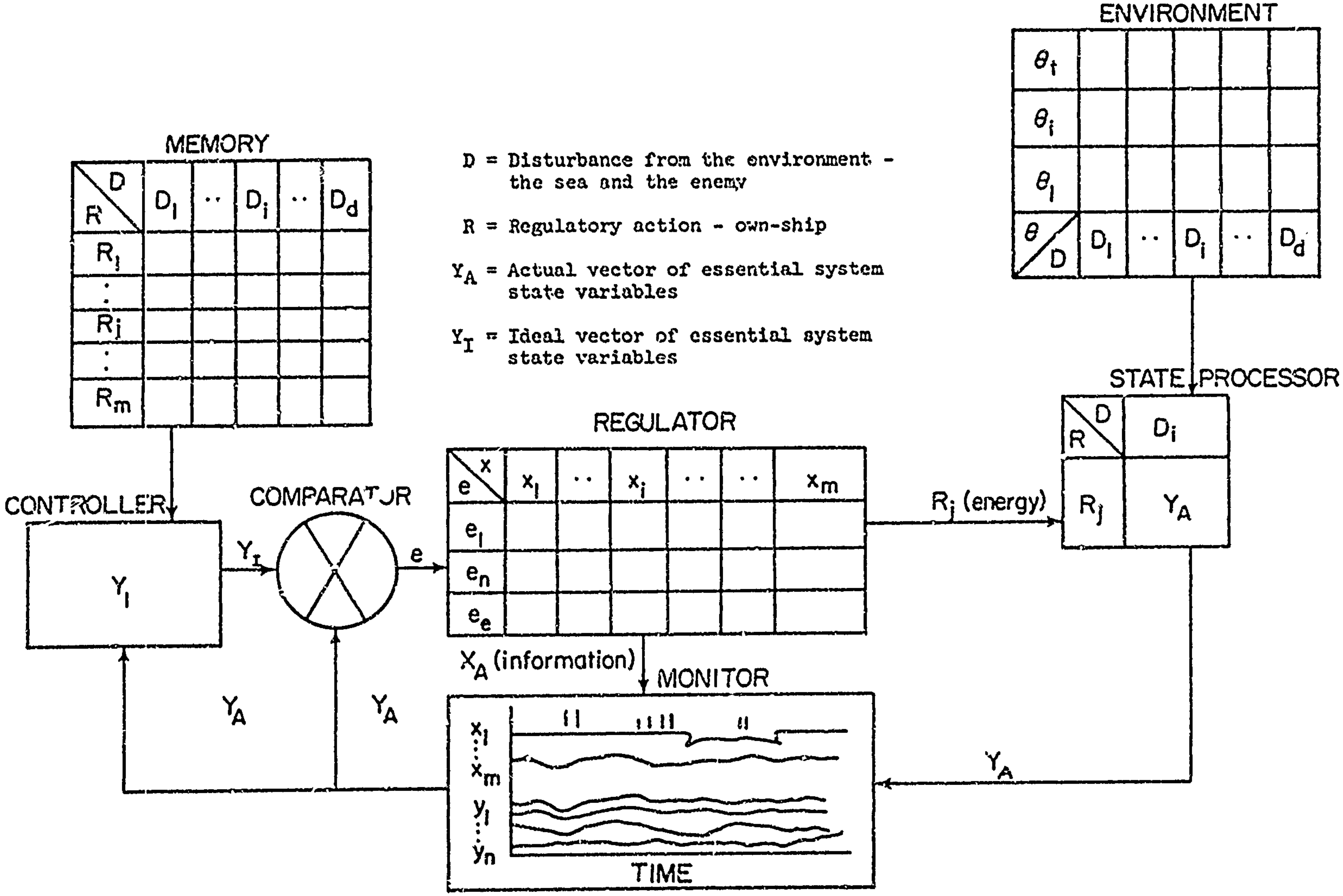
f_i = i^{th} function.

Given the functions f_i through f_n, and values of the x's, y's, and θ's, measured at specified intervals in time, the trajectory of a state-determined system (i.e., a system which moves sequentially from state to state) can be predicted.

If the functions were known, the prediction of trajectories for various resource and environmental combinations would be a deductive process and analysis would be possible. Since the functions are not known for most of the tasks of a submarine mission, and it is unlikely that mathematically tractable functions can be developed, the research problem is one of developing adaptive functions empirically and testing them experimentally.

In order to facilitate the study of the behavior of an adaptive system, it is useful to represent it schematically as shown in Fig. 5.

Referring to this figure, the STATE PROCESSOR represents the interaction of the enemy, own-ship, and the environment. It describes the state of the system, given a disturbance from the environment, D, and a regulatory counter move, R. Successive values of the State Processor, measured over time, describe the trajectory of the system.



D = Disturbance from the environment - the sea and the enemy

R = Regulatory action - own-ship

Y_A = Actual vector of essential system state variables

Y_I = Ideal vector of essential system state variables

Fig. 5 - Cybernetic Model of an Adaptive System

The Monitor records and displays the successive states of the system in time. Since many variables must be displayed simultaneously, a multi-variable plot is used.

The information displayed by the Monitor is forwarded to the Controller which specifies the desired values of the variables, and to the Comparator which forms the difference between actual and desired states. Difference information is then forwarded to the Regulator which uses its resources to reduce the difference. As a result of continuous interaction between own-ship, environment, and target, the system moves toward mission-accomplishing states, performing each task in turn.

The Memory is used by the controller as an aid in setting limits on the interaction (Y_A) variables cuh as range, bearing, and target noise. It contains the functional relationships which have been developed by research and tactical analysis in the past.

Two major types of information are provided by such a model. One is the identification of tactical patterns leading to detection, classification, approach, attack, and escape. The other is the expected tactical consequences of selecting various submarine and crew combinations; i.e., by changes in the values of the resource (x) variables. Changes in tactics are made possible by modifying the constraints on system behavior imposed by the environment and the physical and psychological characteristics of man and machine system resources. Given measures of overall system performance, the model can be used to assess the influence of changes in system resource components. Because of the complexity of the interactions among these components, simplifying assumptions (such as linearity and independence) may result in misleading results. What is needed is a method for analyzing simultaneous changes in many variables.

Finally, this approach provides a way of measuring systems effectiveness in terms of the difference between what is actually happening and what is wanted (Howland, 1965).

2. The Data

Given a conceptual framework, the next question is "What variables must be observed and measured?" Expert judgment, exercise results, and planning requirements suggest those listed in the code sheets (Appendix 1). This list is proposed as a point of departure. Once data are available for analysis, the list can be modified by experimentally determining what information is actually needed to make specific tactical decisions. Simulation experiments to answer this type of question have been conducted with data collected in a medical setting (Silver, 1965). Similarly, exercise data can be analyzed to identify the variables the submarine commander responds to in making tactical decisions.

The data required to build and exercise the model consists of continuous recording of x, y, and θ variables. If changes in these variables are infrequent, sampling schemes can be devised to reduce the record-keeping requirements.

Manual data collection is laborious, and it is unrealistic to expect the crew to record at the required level of detail while solving tactical problems. At the time that data are most needed, crew members are too busy to record it. As a partial solution to this problem, a Research Reserve Operations Analysis program is being developed by Naval Research Reserve Company 4-7 to provide trained manpower to assist in data collection and analysis (NRRC 4-7, 1968).

Autodata (SUBDEVGRU TWO, 1968) is a continuous recording device for collecting tactical data. In order to explain observed behavior, however, environmental data must be added to the Autodata system. Specifically, the sound velocity profile from the surface to greatest operational depth must be known.

Models should be designed to generate the information required to answer specific questions. It usually turns out, however, that the questions asked depend, at least in part, on the information available. As one set of questions is answered, others arise. A model may become obsolete as new insights lead to new questions. Because of the difficulty of foreseeing questions, the information-generating system should be flexible.

One way of insuring flexibility is to collect the most primitive data possible. It may be much cheaper to collect data for which there is no immediate analytical requirement than not to collect it and have to go back for it later. This would be particularly true in the case of submarine operations because of the expense involved in conducting an exercise.

In order to develop a model to represent the real-time behavior of force units, real-time system performance measurements are required. Given such data, and a cybernetic model describing the time-varying behavior of the individual submarine, the tactics leading to the occurrence of a specific event, such as a detection, can be studied. Conversely, the model can be used to estimate the kinds of system components required to obtain a desired tactical capability.

3. Analysis

Because of the mass of data which results from continuous recording, computer analysis is required. A set of computer programs has been developed to answer several questions about the adaptive characteristics of the system. The questions, and the programs which have been developed to answer them, are summarized in Fig. 6 and discussed in the following paragraphs.

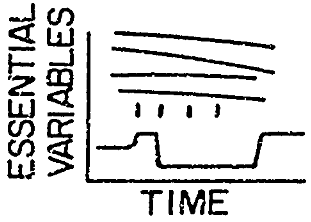
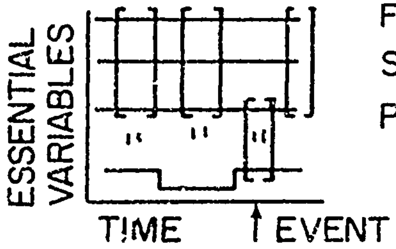
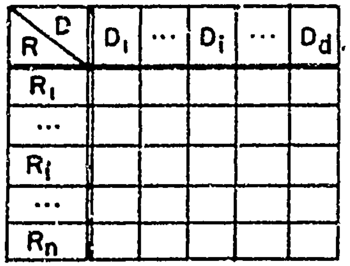
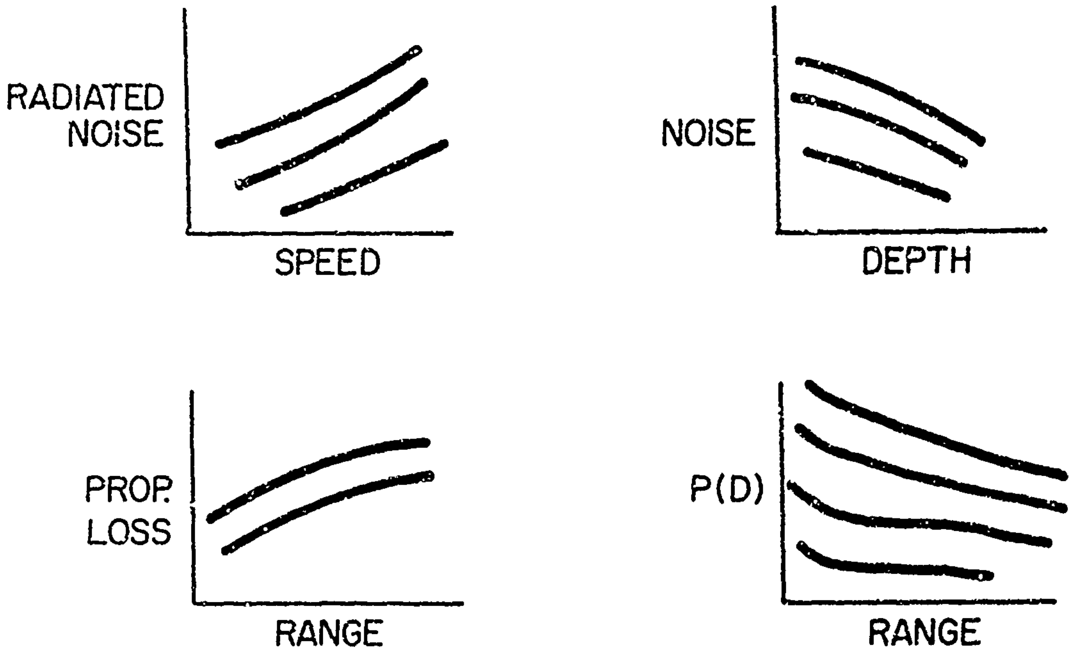
	THE REAL WORLD QUESTION	INFORMATION TO ANSWER QUESTION	COMPUTER OUTPUT	COMPUTER REQUIREMENTS
1.	HOW DOES SYSTEM BEHAVIOR CHANGE IN TIME ?	CONCOMITANT VARIATION OF SELECTED VARIABLES IN TIME		PRINTER, X-Y PLOTTER OR CRT - FORTRAN IV
2.	WHAT BEHAVIORAL PATTERNS DOES THE SYSTEM EXHIBIT ?	IDENTIFICATION OF VECTOR STATES PRECEDING & FOLLOWING SPECIFIED EVENTS		FORWARD - BACKWARD SEARCH PROGRAM PL I, IBM 360
3.	WHAT TRANSFORMATIONS CAN BE DERIVED FROM THESE PATTERNS ?	TABULAR FUNCTION DESCRIBING EFFECT OF REGULATORY USE OF RESOURCES ON SYSTEM STATES		EVENT SUMMARY PROGRAM PLI, IBM 360

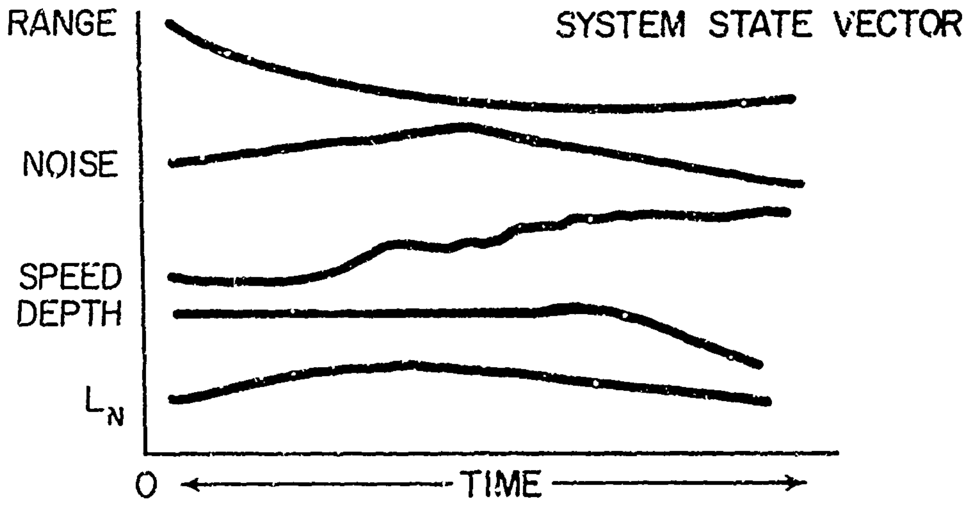
Fig. 6 - Analytical Summary Table

a. How do the values of system state variables change in time? What vector states regularly preceed and follow specific events, such as a detection? The state of the system is defined in terms of the values of the system state variables at any moment in time, as shown in Fig. 8. This method of displaying the data was adopted because it has been found that relationships between large numbers of variables, considered simultaneously to determine concomitant variation, are relatively easy to discover if the data are displayed graphically. There are, however, two basic types of graphic display. One consists of a number of two-dimensional relationships, Fig. 7A. Such a set of relationships is difficult to interpret because variables which are dependent in one relationship may be independent in another. In addition, it is difficult to show variation in time in this way. For these reasons, the type of display shown in Fig. 7B has been adopted. It should be noted that the data displayed in this way may be measured on nominal, ordinal, interval or ratio scales (Stevens, 1951). Given data plotted in this way, it is possible to locate points in time which suggest interesting interactions. These may then be analyzed in more detail. An examination of Fig. 8, for example, suggests that detections most frequently occur following a maneuver of own-ship. The analysis of additional data might disclose other interesting relationships, such as the effects of sound channels. Since it is impractical to conduct this type of analysis by hand with large amounts of data, computer programs have been written to plot variations in selected variables in time on a printer or an x-y plotter. Plots from actual data will be found in Appendix 2.

b. How do regulatory tactics influence system performance? What tactics are most effective in reducing the difference between actual and desired system states? An examination of the data preceding and following an event, such as a detection, provides clues as to what tactics work best. An examination of Fig. 8, for example, suggests that detections occur when own-ship maneuvers, or when target and attacker are in the same or adjacent sound channels. In order to identify vector states that regularly precede or follow an event, a program has been written to search the data forward and backward in time from an event or a specific time to locate specified vectors or to describe the vector states that exist. A sample of the type of information generated by this program is shown in Fig. 9. This figure contains the directions to the computer of when and where to search and what to look for. Given a detection time, or a system state vector, the computer can be instructed to search the data for specific vector states preceding a specified event, or it can record the states that exist and count their frequencies. In this way, the tactics which precede a detection can be identified. In order to obtain this information, the computer must be given a time interval for the event and a time interval in which to search. In the example, a ten-minute interval was allowed for an event to take place. For example, this program can search for the event "detection," defined as the time when a signal was found in the background noise, or SNR greater than some reference level occurs. The program then records the



A. REPRESENTATIVE TWO-DIMENSIONAL OPERATIONAL RELATIONSHIPS



B. DISPLAY OF CONCOMITANT VARIATION OF SAME VARIABLES WITH TIME

Fig. 7 - Types of Graphic Display

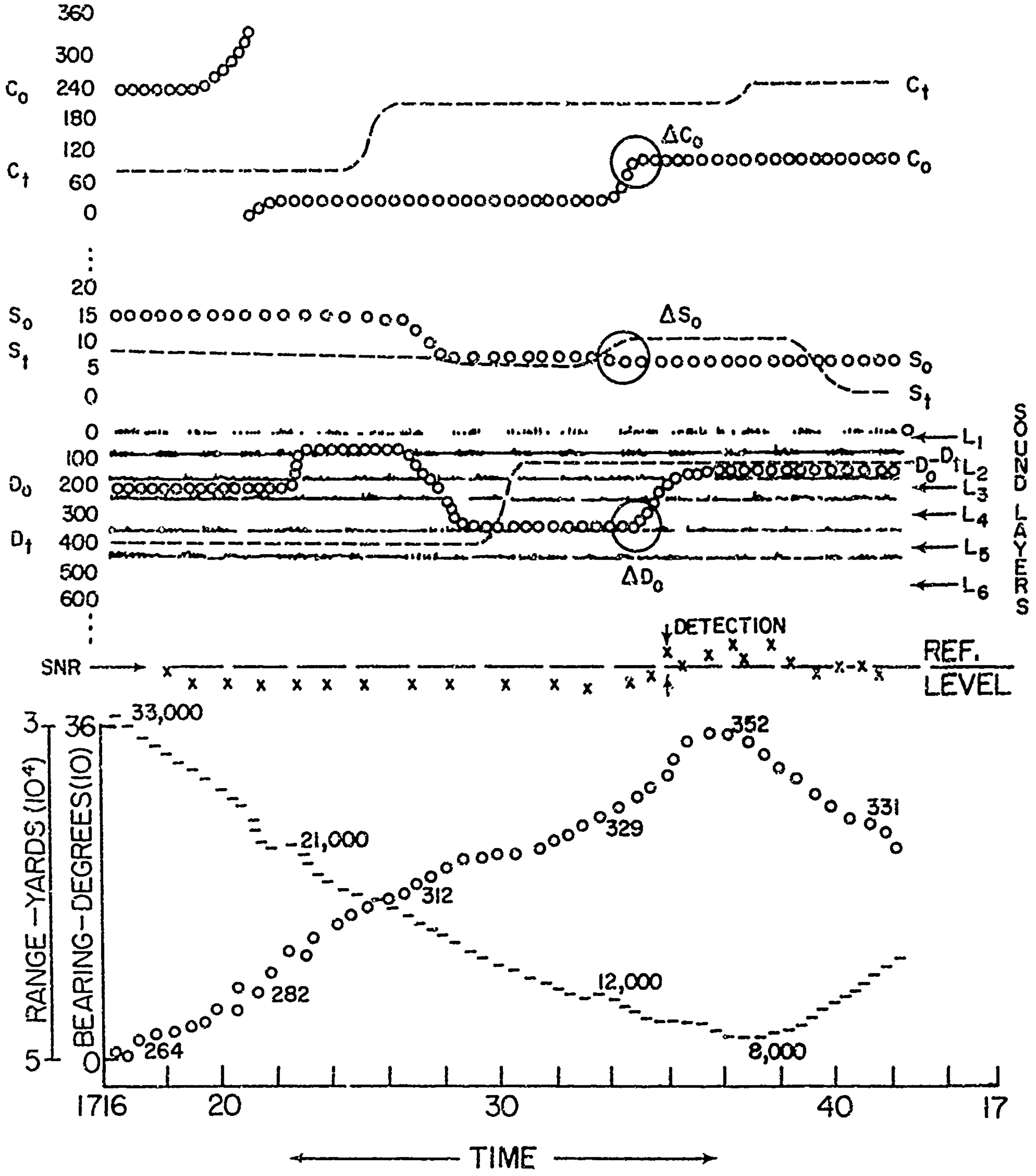


Fig. 8 - Graphic Display of Representative Data

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This is a backward search
Run number          A
Starting time   month 10  day 02  hour 04  minute 53
Termination time      10      24       18          05

For trigger vector
     event: detection  ASNR  above reference level  (SNR sonar reading)
                       ASPA  less than 10 knots     (attacker's speed)


Maximum allowable time interval for completion of detection vector
     is   10 minutes
Time interval for search (preceding detection) is 30 minutes
- - - - - - -

The trigger vector occurred 21 times in the interval (TF)
for Antecedent Search Variable(s) listed: ACRA, ASPA, ADPA
    (attacker's course, speed, and depth)

                 Variable(s)           Total    Number of    Ratio
           ACRA    ASPA    ADPA        Number   Intervals   (NI/TF)
                                        (TN)      (NI)

           030     05      300          08        02          .098

           250     07      600          02        01          .045

           060     04      600          10        04          .196

           110     08      550          03        01          .045

           030     05      600          07        02          .098

                   .                    .         .            .
                   .                    .         .            .
                   .                    .         .            .
The trigger vector occurred  21 times in the interval (TF)
for Antecedent Search Variable(s) listed:  ELD1,ELD2,ELD3,ELD4,ELD5
     (five layer depths)

                Variable(s)            Total    Number of    Ratio
                                       Number   Intervals   (NI/TF)
                                        (TN)      (NI)
           |060|100|150|200|250|        24        05          .241
           |060|090|140|180|210|        11        03          .143
                   .                    .         .            .
                   .                    .         .            .
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
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Fig. 9 - Information Generated by the Forward/Backward Search Program

number of times any specific vector state occurs prior to this time. A representative print-out is shown in Fig. 9. Various system state vectors (course, speed, and depth) which occurred prior to detection are shown in the column labeled "variables." The second column (TD) shows frequency of the occurrence of these vectors in 30-minute intervals preceding detection. The third column (NI) shows the number of 30-minute time intervals in which the vector was found.

Sound channel information is summarized in the lower columns of the figure. The numbers 060, 100, 150, 200, and 250, for example, are the depths at which layers were found.

An explanation of the process involved in the analysis of data is given by a simulated printout of the computer program designed for this analysis. This printout indicates: that, for the simulated data given, a TRIGGER VECTOR exists such that, when

(1) Attacker had a noise level reading above reference background noise (detection), and

(2) Attacker speed was less than 10 knots,

then antecedent vector states are:

(1) Attackers course (ACRA), speed (ASPA), and depth (ADPA). From Fig. 9, note that more detections occurred when the attackers depth was 600 feet and attackers speed was 4 knots (also, but not considered significant, attackers course was 060°) then for any other combination of values of variables in this antecedent vector for the given triggering vector.

(2) Sound channels number 1 through 5. From Fig. 9, note that more detections occurred when the sound channels were: 0-60, 60-100, 100-150, 150-200, 200-250, (all in feet of depth); and attackers speed was less than 10 knots, than for any other combination of values of the variables in the antecedent vector.

This example shows only one triggering vector and two related antecedent vectors. The method is general, however, and any set of variables can be used for antecedent, trigger and consequent vectors. Computer printouts of actual data is contained in Classified Appendix Supplement.

c. How can individual experience be summarized to develop functional relationships between environmental states, regulatory tactics, and the resultant state of the system? The programs which have been described were developed to analyze the data of individual runs. The third program is designed to summarize findings of many runs.

This program was based on Ashby's concepts of regulation (1957, p. 202). Although an extensive discussion of Ashby's ideas is beyond the scope of this report, he illustrates the regulatory process with a table. Column entries represent disturbances from the external environment. Row entries represent regulatory moves taken to counter the disturbances. Cell entries represent the state of the system following a disturbance and a regulation. This approach differs from game theory in that cell values represent states of the system, rather than the value or utility of a regulatory move. Ashby discusses the "variety" in the disturbances and regulator moves. This is the number of different states that each can assume, or, if it is more convenient, $\log_2$ of this number. He then develops a "Law of Requisite Variety" which states that variety in the regulator is required to cope with variety in the disturbances if the system is to be maintained in a given state.

Adapting these ideas in our model, Ashby's R x D table becomes the memory unit (Fig. 4). It represents tactical experience accumulated over a large number of runs and summarizes the results of the analyses. Such a table can be used in two ways. If the Regulator can see the Disturbance, action can be taken to obtain and maintain the desired relative position with the target. In describing regulatory behavior, Ashby defines regulation in terms of the maintenance of the values of selected system variables within "survival" limits. Since the objective of a submarine attack is destruction, rather than survival, the cells in the table can represent the relative positions of target and attacker necessary for a successful attack. Survival is a consideration in the sense that a successful attack is necessary for survival of the attacker and the higher levels of the system.

When the regulator can see the disturbance, it is usually a relatively simple matter to select a regulatory tactic. Usually, however, the disturbance cannot be seen. In this case, regulation is "error controlled" (Ashby 1957,221). A familiar example is the temperature-controlled thermostat. The heating system responds to changes in the ambient air. It cannot anticipate changes. Instead, it reacts to the fact of a change. The Regulator sees the cells of the Table, not the Disturbances. For this reason, the regulator's response may not always be appropriate. It may be possible to arrive at the same R-Cell combination given a number of different Disturbances. The regulator must then try other resource configurations to find the correct Disturbance. This procedure is what Ashby (1957, 230) calls "Hunt and Stick Regulation."

With these ideas in mind, let us consider the problem of using exercise data to build an R x D Table.

In the search phase of an attack, the desired state is one in which signal is detected in noise. The problem of localization is solved at a later stage. The tactical problem is: what search tactics should be used to detect the signal, given a target? The research problem is: how can this situation be represented in an R x D table? How can the data be used to fill the cells in the table?

An examination of the outputs from the search program shows the relative position of target and attacker prior to, at the time of, and following a detection. If we conceptualize the R x D table as a device for summarizing the states of the system when events, such as detection occurred, we can show D as target position, R as own-ship position, and the cell values as range, bearing, and signal excess combinations. Own-ship would, obviously, attempt to maneuver into R, B, SNR conditions that would increase the probability of classification and attack. Since target positions are not known at this phase of an attack, it is necessary to hypothesize what they might be on the basis of whatever information is available. The indicated regulatory move can then be made and the results observed. If no signal was heard, the hypothesis about target location and maneuver would be rejected, and other combinations tried until the desired outcome was found.

If this search procedure were followed, the submarine would take advantage of any available information. In the absence of information, it would at least result in frequent changes in search tactics which, the data suggest, are most likely to lead to detections.

It should be noted that this formulation of the problem does not depend on a "detection opportunity," as defined in the WSE model. The attacker does not know whether an opportunity exists until a detection takes place. The "opportunity" concept of a target within range of the sonar can not be used for tactical analysis since it depends on information the tactical commander does not have, that is, higher level, operational analysis.

In order to construct the R x D table, a computer program has been written to tabulate the simultaneous occurrence of

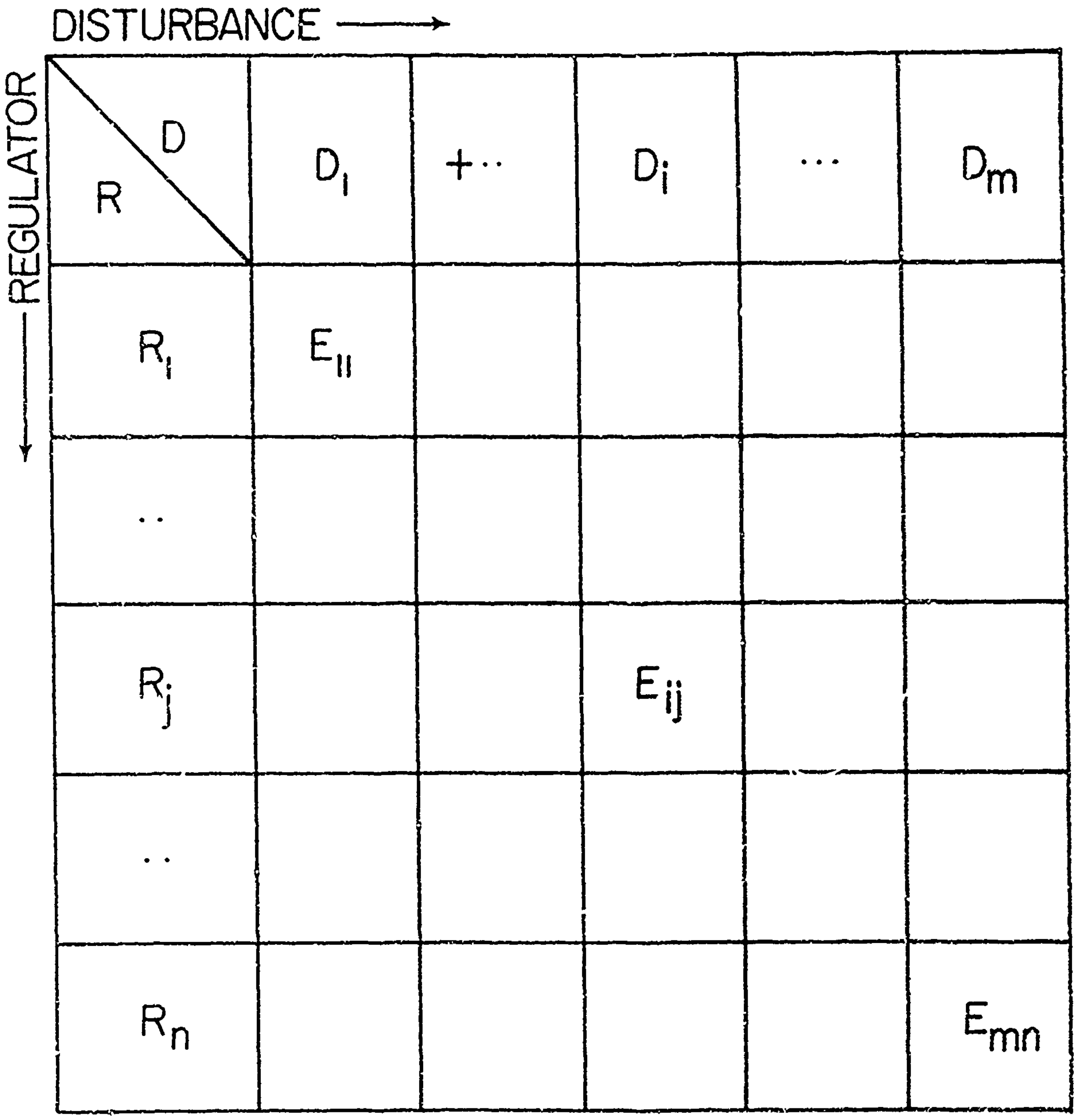
R: The state of own-ship, Co, So, Do.

D: Target and environment C_t, S_t, D_t layer, position target relative to sound channel and,

E: Interacting variables, range, bearing and received signal excess above reference level.

A representative R x D Table is shown in Fig. 10, and a figure developed from actual data is shown in classified Appendix 4.

In summary, three programs have been developed to analyze continuous time series data. The first is a time plot to locate events of interest. Having located an event, such as a detection, the second program can be used to search the data before and after the event to see



R \ D	D_1	$+\cdots$	D_i	$\cdots$	D_m
R_1	E_{11}				
$\cdot\cdot$					
R_j			E_{ij}		
$\cdot\cdot$					
R_n					E_{mn}

Fig. 10 - Regulator (R x D) Table

D_i = ith disturbance - A combination of target and environmental information.

E_{ij} = the resonance source of the target-attacker system in the environment.

R_j = jth regulating move - own-ship information.

what states of the syiem preceded and followed it. System states, expressed as vectors, can be tabulated for any desired time period. The third program can be used to summarize the relationships recorded by the second program. It develops tabular functions between disturbances from the environment, which may or may not include the enemy, and own-ship. These functions may be used to infer the nature of a disturbance from own-ship behavior and measurements of the environment.

BIBLIOGRAPHY

Ashby, W. R. Introduction to Cybernetics, New York, John Wiley, 1957.

Ashby, W. R. Design for a Brain. 2nd ed. New York: John Wiley, 1960, p. 35.

Colson, H. D., Edmonds, D., & McLean, C. R. The Analysis of Bearing Information, unpublished working paper, The Ohio State University, 1967.

Dantzig, T. Number, the language of Science. New York: Macmillan, 1930.

Downie, Thomas N. & Gasteyer, C. E. Tactical Development Methodology - SSK Transitor Model - WSE Final Report (u), General Dynamics, Electric Boat Denison 1966, revised 1967.

Edmonds, D. R. An approach to the problem of defecting changes in a time series of signals confounded with additive random noise. Systems Research Group. Division of Research, College of Commerce and Administration, The Ohio State University, 1967.

Enthoven, Alain C. Systems Analysis, Department of Defense Cost Reduction Journal. 1966, II, 2-19.

Hitch, C. J. Sub-Optimization in Operations Research, Operations Research 1, May, 1952, 87-99.

Hitch, C. J. Plans, Programs and Budgets in the Department of Defense, Operations Research 11, 1963, 1-17.

Howland, D. The measurement of system effectiveness. Proceedings, The Fourth Biennial Navy Tripartite Symposium on Operations Research. June, 1965. Annapolis, Md., 279-289.

Howland, D. A regulatory model for system design and operations. (in) J. R. Lawrence (ed) Operational Research and the Social Sciences. London: Tavistock, 1966, 505-514.

Howland, D. Toward a Community Health-System Model, Bio-Medical Computing, 1, 1970, 11-30.

Hunter, J. F., Long, J. P., & Waterman, M.D. Digital Computation of Target Position and Velocity from Bearing Measurements, Elliott Brothers (London) Limited Weapons Division Report No. T(F)3, 25 January, 1964.

Kimball, G. and Morse, P. M. Methods of Operations Research. New York: John Wiley, 1951.

Koopman, B. O. The Theory of Search: Part I. Kinematic bases, Operations Research, June 1956, 4, 326-346.

Koopman, B. O. The Theory of Search: Part II. Target detection, Operations Research, October 1956, 4, 503-531.

Koopman, B. O. The Theory of Search: Part III. The optimum distribution of searching effort. Operations Research, October 1957, 5, 613-626.

Librascope, Computer "Churn Solution", mathematic model, Librascope Company, MK 113 FCS Manual 1960.

McCormick, E. J. Human Engineering. New York: McGraw-Hill, 1957.

Nagel, E., & Newman, T.R. Godel's Proof. New York: New York University Press, 1960.

NRRC 4-7 "A Training Program in Oper . ions Analysis", unpublished working paper, 1968.

Silver, A. N. An Investigation of Information Factors upon the Performance of the Human Regulator. Unpublished doctoral dissertation. The Ohio State University, 1965.

Smith, R. H. "The Submarine's Long Shadow, "United States Naval Institute Proceedings, March, 1966, 32-39.

Stevens, S. S. "Mathematics, Measurement and Psychophysics," Handbook of Experimental Psychology, (ed.) Stevens, S. New York: John Wiley 1951, 1-49.

SUBDEVGRU TWO, Semi-Annual Report for 1 Apr. - 30 Sept. 1968 (Autodata), p IIG1.

Wagner, Daniel H., Weapon Systems Effectiveness (WSE) in Multiple-Attack Encounters (u) report Serial No. 508/105 of 31 July 1968.

Wiener, N. Cybernetics. 2nd ed. New York: John Wiley, 1961.