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THE ROLE OF COMPUTERS IN OPERATIONS AT SEA

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ABSTRACT

This paper is divided into two parts, one dealing with presently planned and anticipated future uses of computers at sea and the other with the possibility of making decisions with a computer.

Part I begins with a discussion of the problems of command and control in the complex tactical environment of modern naval operations and the efforts to solve these problems through use of the digital computer. The general functioning and capabilities of digital computers are described and an example of how computers will be used at sea is provided by a chapter on the Naval Tactical Data System. Numerous additional uses which have been proposed for computers are listed to illustrate the scope of anticipated future shipboard data processing efforts. Finally, a proposal is made to unify all these separate efforts into one coordinated development designed to provide an integrated shipboard data processing center as an effective instrument in meeting the total information requirements of the command and control function.

Part II is devoted to the question of automatic decision-making. By way of introduction, some fundamentals of decision-making are reviewed. These include the basic human response to problems or uncertainties, the characteristics of the various kinds of military uncertainties, and the present methods of military decision-making. The weaknesses of present decision-making methods are then assessed.

The functioning of a hypothetical decision-maker (in reality it would be a computer) is outlined and the various analytical techniques available to aid in reaching decision

are considered. These techniques include game theory, statiscal decision, and gaming. The final chapter describes the types of decisions which can be made by computers and suggests that there are sound reasons why some of these should be automated.

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INTRODUCTION

The growth of data processing technology has in the past three years resulted in a powerful digital computer which is small, simple, and reliable enough to permit the application of electronic data processing techniques aboard ship. This development has opened a multitude of possibilities for the application of computers to naval operations. The first of these, the Naval Tactical Data System (NTDS), will begin evaluation at sea in 1961. The purpose of this paper is to look at the role of the shipboard computer beyond those applications planned for NTDS.

It is frankly acknowledged that the scope of this subject would be far too broad for a paper of this type were it to be treated in sufficient depth to be technically meaningful. The writer is not technically qualified, however, and has adopted the more modest aim of introducing the non-technical line officer to some of the possibilities which the computer seems to promise in improving the capabilities of naval forces in today's complex military environment.

PART I

THE CAPABILITIES OF SHIPBOARD DATA PROCESSING

CHAPTER I

THE PROBLEM OF COMMAND AND CONTROL IN THE MODERN ENVIRONMENT

The difficulty of exercising effective command and control of modern military forces has, in recent years, gained increasing attention in all the military services. For the Navy, this problem is particularly acute. The reasons become apparent when the modern naval environment is examined. In a naval force is found a wide diversity of weapons systems, each system having widely varying characteristics. These include high-performance, missile or nuclear weapon equipped aircraft; ships capable of striking air, surface, or subsurface targets at ranges up to one hundred miles; and high-speed, deep-diving submarines. This diversity of forces is a reflection of the multiplicity of threats which the commander faces. Furthermore, the geographic area of operations has been rapidly extended as a result of the increased ranges provided in surveillance equipment and missiles, and the use of widely dispersed dispositions.

Added to the problems of command and control posed by the nature of the naval environment are others arising from a tendency for many military functions to become more and more centralized at the higher levels of authority. Control of nuclear striking operations is one example of such centralization. This development has in turn created a requirement for more detailed tactical information about situations which develop rapidly, change quickly, and are extremely complex.

For naval commanders at sea, command and control is exercised, in large measure, through what has been termed the combat direction process.[1] The various steps performed in combat direction are illustrated in Figure 1. The arrangement is circular to indicate that the steps constitute a pattern known as a closed loop, with the outcome of decisions or actions continuously feeding back into the cycle to form the basis for subsequent decisions and actions.

Combat direction is today accomplished largely through the use of voice or CW radio circuits, sound powered telephones, grease pencils, plastic display boards, and human evaluation and decision. These methods, while adequate in World War II, are subject to severe stresses in the modern environment. The speeds of today's weapons cause tactical information to change quickly. The time for evaluation and decision may be short. The volume of detailed tactical data may be extremely large, and the diversity of weapons may require frequent and extensive coordination of efforts.

Under such conditions the commander has become increasingly isolated from the true tactical picture. The information he receives is likely to be too old to be useful, incompletely or erroneously processed by the radio operators, talkers, plotters, and evaluators who deal with it, and displayed in such form that it is difficult to comprehend. Yet he is utterly dependent on such data for effective command and control of his forces.

The problem is common to all services and each has undertaken programs to solve it. All of these programs are built around the application of modern digital computers, automatic data link communications, symbolic presentation of information on electronic displays, and other advanced data processing techniques.

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[1] U.S Department of the Navy, "Concept and Policy for Development of Combat Direction Systems," OPNAVINST 0330.9 of 24 July 1958.

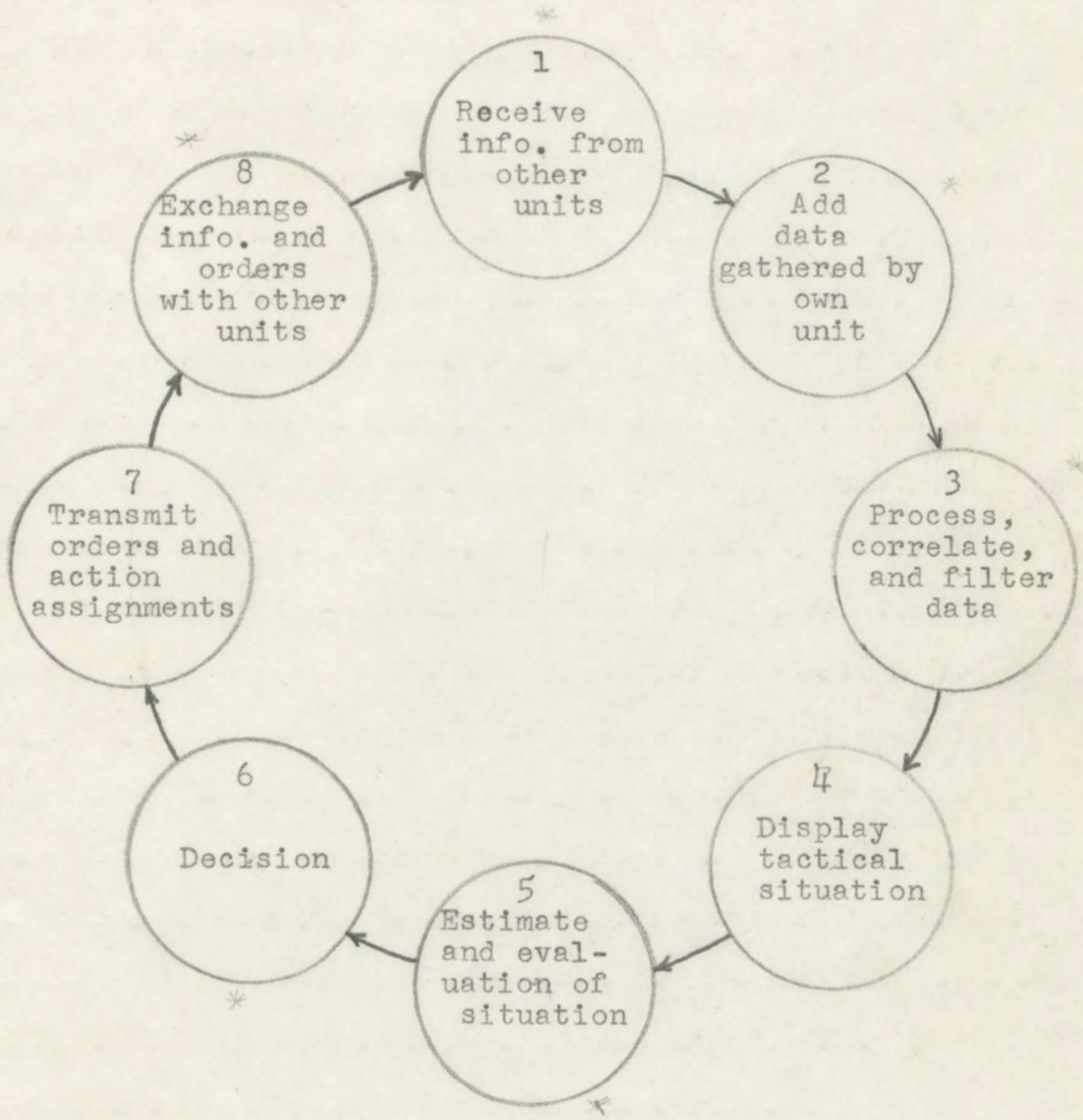

FIGURE 1

COMBAT DIRECTION PROCESS

The U.S. Air Force has already developed such systems as SAGE and the more advanced AN/GPA-73.[2] The Air Force is working toward other facilities such as those planned for the NORAD COC[3] and SAC.[4] Extensive additional work is being done in the area of command and control to provide an ultimate and complete solution to the problem.[5] The U.S. Army has such systems as the AN/MSG-4[6] near operational use for the control and direction of surface to air missile batteries. More important, a comprehensive program has been undertaken to develop and employ a family of automatic data processing equipment for a wide variety of functions at all levels of command in field armies.[7] The Navy also has developments in progress which promise significant contributions to the total solution of this difficult problem. The Naval Tactical Data System (NTDS) and the TYPHON advanced weapons system are two examples of such development which are intended for use at sea.[8] NTDS will be described briefly in a subsequent chapter to illustrate

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[2]Department of the Air Force, Air Research & Development Center, AN/GPA-73 Technical Review.

[3]Gen. L.S. Kuter, USAF, "North American Air Defense," Lecture, Naval War College, 30 Jan 1961.

[4]LGEN F. Griswold, USAF, "The Strategic Air Command," Lecture, Naval War College, 31 Jan 1961.

[5]Report of the Winter Study Group, New York Times. Oct 10, 1960.

[6]Department of the Army, U.S. Army Air Defense Board, Ft. Bliss, Lectures Relating to Missile Monitor, U.S. Army Air Defense Fire Distribution System, AN/MSG-4.

[7]Capt. W.F. Luebbert, USA "Development of Army Automatic Data Processing Equipment," Signal, March 1960, p. 18.

[8]U.S. Department of the Navy, CNO ltr ser 005P91 of 7 Jan. 1959, Navy Research and Development Program, FY 1960, Enclosure (3).

the capabilities of digital computers and other data processing equipment which will soon be at sea. First it is necessary to consider some of the characteristics of these computers.

CHAPTER II

AN INTRODUCTION TO DIGITAL COMPUTERS

"It is unworthy of gentlemen to lose hours like slaves in the labor of calculation, which could safely be relegated to anybody else if machines were used." - - Leibniz, circa 1670.

Man has used computers to perform calculations for centuries. An automatic digital computer, using essentially the principles employed today, was first designed in 1829.[1] The past decade, however, has seen an astounding growth in the capabilities and usefulness of these machines. Of the many types in use today, it is the stored program, binary digital computer which offers the greatest prospects for general use at sea. The purpose of this chapter is to provide a brief description of the design and operation of this type of computer.

The digital computer differs from the analogue in that it works directly with numbers or digits to solve problems rather than with some direct analogy of the problem as in the case of the analogue type. This difference is illustrated by the characteristics of the abacus as compared to those of the slide rule. It was the development of the digital type of machine which gave the computer the capability of universal application and eliminated the need to construct a special analogue for each type of problem to be solved.

Some digital computers operate with the familiar decimal numbering system based on tens, others employ the octal

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[1]R.H. Mcmillan, Automation, O. 64.

numbering system using a base of eight rather than ten. The computers of interest here use still another system, binary numbers, in which a base of two is used and all numbers are expressed by various combinations of zero and one. Zeros and ones are represented in the computer by the presence or absence of a voltage. This system permits the use of what are called "two-state" devices. These have only to indicate or detect the presence or absence of voltages. Thus the need is eliminated for precise voltage levels, and extensive calibration and measurement to insure accurate representation of values. The result is more reliable, less complicated equipment which is easier to maintain.

Of all the recent developments in the computer field, the successful application of miniaturization has been of greatest value in getting data processing to sea. The replacement of large, troublesome, and power consuming vacuum tubes, wires, and other electronic components with transistors, diodes, magnetic cores, and printed circuits has decreased size, reduced power requirements, and greatly improved reliability.[2] A computer which would have filled several large rooms with equipment five years ago can now be made to fit a cabinet about the size of an office desk.[3] Such a computer, five years ago would have used so much power that extensive air conditioning would have been required for cooling. Today it uses about the same power as a home toaster. This reduction in weight, space, and power requirements has made feasible the installation of computers aboard ships.

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[2] G.L. Hollander, "1960 Computer Progress," New York Times, Jan 31, 1961, p. 31.

[3] W.D. Bell, Management Guide to Electronic Computers, p. 178-181.

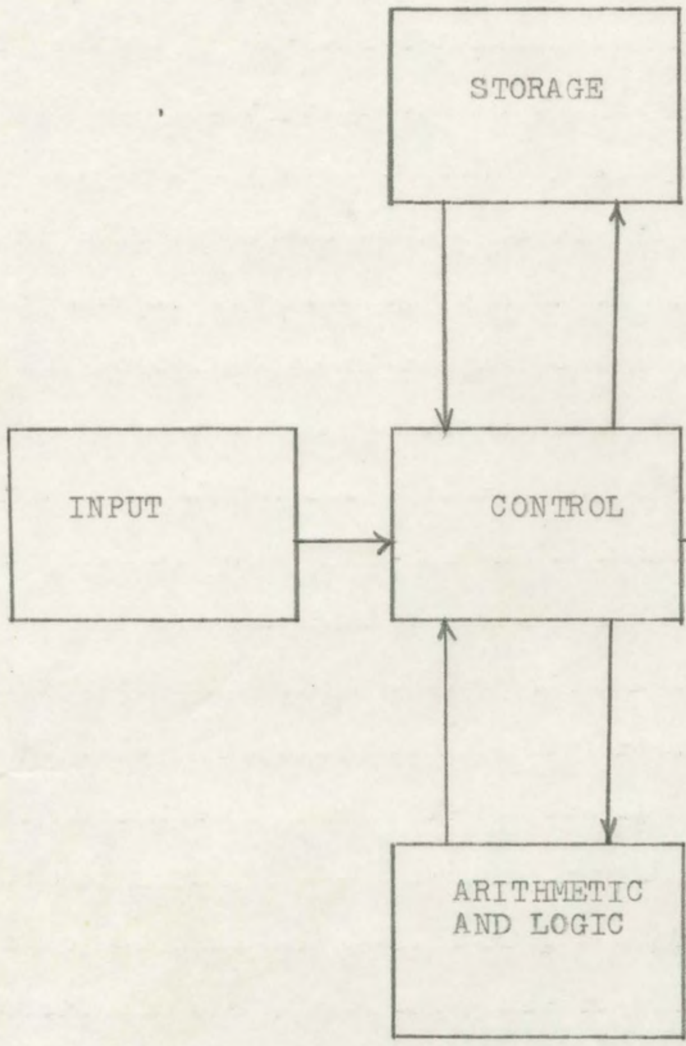

FIGURE 2

FUNCTIONAL DIAGRAM OF A DIGITAL COMPUTER

The functional components of a digital computer and their relationship to each other are illustrated in Figure 2. The input section of a computer is the hopper through which is fed raw data used by the machine. Inputs may be supplied manually through keyboards or other devices activated by coded keys and pushbuttons, or they may be supplied automatically from the output of surveillance equipment, data links, or the position of various indicators. In any case all information entering the computer must be in binary digital form. To achieve automatic, or "on line" input may require the use of converters to translate the output of radars, sonars, etc. from analogue to binary digital form unless such equipment is originally built to supply a digital output. A third method of supplying inputs is use of magnetic tape which is read by the computer as it is run through at very high speed. Using this method upwards of a million characters can be read by the computer in one minute. Inputs are received by the computer as directed by the control unit. It decides when and in what order to take information from various sources and controls all internal routing and sequencing.

Every computer has memory facilities to permit storage of information for later use. Many store data on external devices for later reintroduction as needed. Others contain all memory facilities within the computer cabinet. There are numerous methods of storing data, but only two will probably be of major importance at sea. The first is the use of magnetic cores located within the computer cabinet to provide fast access memory. Magnetic cores are tiny ferrite rings which are magnetized or demagnetized by the flow of current through wires on which they are strung.

Their magnetized or demagnetized state is used to represent a zero or one. In addition to being fast and compact, core memories are extremely reliable.[4] The second storage method of interest is magnetic tape. This provides externally located, auxiliary memory facilities from which data can be quickly recalled for use in the computer. These tapes are recorded and read by special heads under which the tape is passed. Data is represented by a pattern of magnetic dots across the width of the tape.

The arithmetic or logic section of the computer performs the arithmetic operations of addition, subtraction, multiplication, and division. The data to be operated on is called from storage, entered into the arithmetic unit, and the resulting answer returned to a designated storage position identified by an "address". The logical abilities of a computer include determination of: whether or not a number is zero, whether one number is larger than another, and whether a number is plus or minus. In addition it can, after making the above logical comparisons, automatically select the programing instructions appropriate to the outcome and proceed to the next step in the problem. These capabilities seem extremely simple for what the newspapers call "giant brains" and "thinking machines" and so they are! It is the genius of man which reduces complex problems to such logical form that they can be solved by such mundane capabilities.

The output section of the computer connects to various displays, to high speed printers, or, via data links, to other computers. Advanced electronic displays can present

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[4] Ibid, p. 84.

information geographically, in relative polar coordinates, or written in plain language. High speed printers are capable of writing out data at speeds in excess of one thousand lines per minute. As in the case of inputs, outputs from the computer are scheduled by the control system.

The routing and scheduling of data by the control system is directed by the computer program except for those functions, such as start and stop, initiated by push buttons on the operating console. In some machines the programing instructions are wired in at the time of fabrication and can only be changed by rewiring. These are special purpose, wired program computers. Other machines receive programing instructions as an input from magnetic tape and store these instructions within their own memory. These are general purpose, stored program computers. The programing instructions and hence the whole mode of operation of the computer can be changed by simply feeding in a new program as a magnetic tape input.

Preparation of the computer program is the most difficult and important part of any data processing effort. Though recent developments in the field of automatic coding offer the prospect of simplifying this process, programing is presently a job requiring a major effort over a period of many months. The first step in programing is the analysis of the function the computer is to perform in order to define the logical and mathematical relationships involved and to determine the various steps necessary to achieve the desired results. The result of this effort is usually a flow chart which depicts, step by step, the operations to be performed. If the problem is complex, it will be broken down into several smaller and distinct operations called sub-routines and a flow chart will be prepared for each. The sequence in which each of these sub-routines is performed and their relationship to each other is specified by a sort of master program called an executive routine.

The next step in programing is the reduction of the steps shown in the flow chart to a sequence of single logical or arithmetic operations and the coding of the operations into a special language understood by the computer. This is followed by extensive checking and debugging of the program accomplished by actually running it through a computer and observing the results.

It has been shown in this chapter that the computer best suited for use at sea is the miniaturized, stored program, binary digital type. Such a computer is relatively simple and reliable since it is built of solid, two-state devices. It can be operated in a variety of modes simply by changing programs, and has good speed and memory characteristics. The computer has five sections which perform the functions of input, storage, arithmetic, output, and control. Finally, while relief may be in sight, computer programing is today a complex, lengthy, but all important job.

CHAPTER III

DATA PROCESSING AT SEA-- THE NAVAL TACTICAL DATA SYSTEM

There are currently under development several systems which apply modern data processing capabilities to tactical problems at sea.[1] Of these, the Naval Tactical Data System (NTDS) is in the most advanced state of development, being scheduled for evaluation at sea in 1961 and for installation in the fleet commencing in 1963.[2] It will be described in this chapter to provide an understanding of the kinds of data processing equipment planned for installation at sea and the capabilities such equipment will provide.

NTDS seeks to integrate the surveillance, control, and weapon facilities of a ship into one system which functions rapidly, accurately, and effectively in performing the combat direction process described in Figure 1. Raw information from radars, ECM, sonars, operation orders, messages, flight plans and similar sources is fed to a digital computer automatically, or as a manual input. The data is then processed, correlated, categorized, and stored in the computer memory. There it is available instantly to users of the system or for solution of various problems by the computer. Selected information is also taken from memory and automatically exchanged with computers located on other NTDS equipped ships. This exchange is extremely rapid and is repeated at intervals of less than ten seconds using automatic, high speed data links. These are radio links

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[1] Navy Research and Development Program, FY 1960, op. cit., Enclosure (3)

[2] CDR R.E. Fowler, "Combat Direction and The Naval Tactical Data System", Lecture, U.S. Naval War College, Feb. 2, 1960. p. 47.

operating either in the HF or VHF band. They transfer information between ships or between ships and AEW aircraft, at rates thirty to three hundred times faster than the fastest teletype circuits, over ranges of fifty miles for VHF and up to three hundred miles for HF. Tests to date show a very high degree of resistance to jamming and indicate that, though the data links can be degraded by countermeasures, they will not be disrupted in an ECM environment.[3]

The processed information in the computer is presented to the human by means of electronic PPI displays, electronic plain language read-outs, or by high-speed printers. The PPI displays show information in the form of symbols in order to present a clear, uncluttered picture. They can be operated to show only those categories of information which the user needs at any particular moment. The electronic read-outs are located adjacent to selected PPI displays. They present amplifying information, in plain language, concerning tracks designated by the operator. The teletype printers will provide a permanent, written read-out of specific information as required by users of the system.

The NTDS program has developed an extremely good computer with large capacity, high-speed, and unusually good facilities for receiving inputs from a number of sources and pro viding outputs to many users while simultaneously carrying on its processing and computing functions.[4] It is a stored program, digital computer with all the

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[3] Ibid., p. 18

[4] Remington Rand Univac, for the U.S. Navy, Bureau of Ships, Naval Tactical Data System, p. 25-26.

advantages attributed to such machines in the last chapter. The same computer can be used on any type of ship for a variety of applications. The desired computing capacity for a given ship can be tailored by the use of one or more computers operating together automatically. For example, the number of computers presently planned for installation at sea varies from one for small ships to four for large carriers. The number of PPI displays can also be adapted to the requirements of the individual ship and these will range from about eight to more than twenty for large ships.

NTDS is designed to provide the following capabilities.[5]

1. Automatic, high speed exchange of tactical information between units or forces.

2. Provision of an accurate, real time picture of the tactical situation to the commander.

3. Computer-aided evaluation of the relative threat of various targets together with computer-generated recommendations for optimum assignment of available weapons to such targets.

4. Completely automatic control of interceptors using computer-generated commands transmitted by data links.

5. Automatic radar detection and tracking.

6. Automatic evaluation of ECM intercepts plus automatic trangulation and ECM tracking.

Though initially designed to meet the problems of anti-air and antisubmarine warfare, NTDS has the capability for performing a similar function for striking and amphibious operations. Plans call for the ultimate extension of the system to those modes of warfare through use of new computer

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[5]Fowler, Op. Cit., p. 10-12

programs and addition of special displays or other peripheral equipment as required.[6] NTDS is not designed to replace humans or to provide automatic decision-making. Rather it is meant to be an aid to human decision. At every critical point the system is monitored and can be overridden by humans. The computed weapon assignments are presented as recommendations and require human approval and action before being transmitted as orders.[7]

Perhaps the most remarkable innovation provided by the system is its treatment of threat evaluation and weapon assignment. It provides an excellent example of the application of computer capabilities to a function which is severely affected by the stresses of the modern combat environment. The steps which the human would perform in evaluating threat and assigning weapons are clearly evident. The present difficulty arises because men are prevented by lack of time from methodical consideration of the problem. All the required steps can easily be performed by the computer, however, and at computer speeds there is ample time for a thorough consideration of all factors involved.[8]

Since NTDS will mark the introduction of a new technology to the seagoing Navy, the program has included development of a capability for maintenance of digital data handling equipment at sea. This undertaking will provide a comprehensive maintenance concept encompassing the use of solid state devices and modular construction in design, and the employment of automatic checking and diagnosis, as

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[6] Ibid., p. 42-43

[7] Ibid., p. 28

[8] Ibid., p. 30-41

well as extensive personnel research and training efforts. It has also been necessary to provide a substantial Navy-operated computer programing capability in the form of a computer programing center assigned to each fleet.[9] In this way NTDS has provided the overhead which will permit other data processing developments to take form with substantially less effort.

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[9] Ibid., p. 42.

CHAPTER IV

TOWARD COMPREHENSIVE USE OF COMPUTERS AT SEA

Today's naval warfare environment places many stresses on the commander and his staff in exercising command and control of his forces. The preceding chapter described the capabilities which the digital computer will provide in meeting the stresses imposed on the combat direction function--an important facet of command and control. The same stresses--time, load, and complexity--extend to other shipboard functions. It is becoming increasingly obvious that the capabilities of the computer promise a similar measure of relief from stress in the performance of these functions. A number of examples, by no means a complete list, can be mentioned to illustrate this point.

Though the use of computers to solve fire control problems is not unusual, newer weapons systems such as Asroc and Talos now employ digital computers for this purpose. These fire control systems can exchange a limited amount of information with NTDS through buffering devices, but they remain essentially separate but communicating systems. Fire control computers could be connected on-line to combat direction computers to provide a smoother transition from the functions of detection, tracking, evaluation and designation to the function of target acquisition and fire control without duplication or gaps in the process. This would result in a truly integrated system encompassing all steps between detection and destruction of targets.

It is heartening to note that the TYPHON advanced weapon system has taken this approach in its development and has incorporated much of the NTDS-developed equipment into its design. As stated in the Technical Development Plan for this system:

> . . . arbitrary separation of the combat information center and weapons direction center does not appear warranted. In addition, the very rapid reaction time and the strong interaction between the detection and fire control functions in a countermeasures environment necessitate a streamlined and largely automatic central control for all functions.[1]

Only a system such as this can offer hope for such problems as the detection, evaluation, and destruction of a missile nose cone in flight.

The problem of rapidly evaluating reconnaissance type intelligence, as well as that of efficient storage and retrieval of all types of intelligence aboard ship, can be effectively reduced with the aid of computer capabilities. Reconnaissance vehicles of the near future will gather large volumes of intelligence material by use of infra-red, radar, photographic, or electronic intercept recording techniques. If such quantities of intelligence are to be made available quickly and in usable form, the use of a computer for interpreting, correlating, sorting, indexing, storing, and retrieving will be mandatory.[2]

The Navy, the Air Force, and the Federal Aviation Authority[3] have all recognized the requirement for the use of computers to improve weather services. The memory of a digital computer will store weather maps or tabulated weather information over a wide area. Through use of data

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[1] Navy Research and Development Program, FY 1960, Op. Cit., Enclosure (3), Technical Development Plan W-16c.

[2] North American Aircraft Corp., A3J Intelligence System, Report No. NA 59H-7A of Jan 30, 1960, Volume II.

[3] W.D. Bell, Management Survey of Electronic Computers, p. 182.

links, weather information can be exchanged at extremely high speeds in accordance with designated schedules or in response to special requests. Routine computations such as fall out patterns, navigational winds, optimum flight paths, or forecasts can be quickly and accurately done by computers in order to provide timely information. Delays presently resulting from slow communications, manual plotting, and human interpretation could be eliminated in this way.

The function of ship control seems susceptible to important gains in effectiveness through automation. Computer controlled operation of propulsion systems and other machinery may offer substantial savings in personnel. The maintenance of status information concerning a wide variety of equipment, conditions of readiness, and availability of such items as fuel, ordnance, water, and stores can be performed by computers. It is possible that such research projects as SURIC (Surface Ship Integrated Control) and SUBIC (Submarine Integrated Control), which have been undertaken by the Office of Naval Research, will indicate the desirability of centralized, highly automated direction of all ship control functions. Such direction must be achieved by automatic data processing. Computers receiving remote inputs from throughout the ship would process incoming data, compare it to established desired standards, spot dangerous or incipiently troublesome developments, select actions necessary to restore proper conditions, and transmit appropriate warnings, instructions of recommendations to remotely located read outs. A single, integrated display could instantly provide information on conditions throughout the ship to the commanding officer or other supervisory personnel.

Turning to the function of navigation, the TRANSIT system will require use of a digital computer in order to obtain maximum accuracy in determination of position from satellite signals.[4] Other navigation and maneuvering problems can also be solved by computers. Accurate, automatic dead reckoning, computation of position from celestial or other observations, and course, speed, and CPA data for maneuvers with respect to other ships are examples. Though the installation of computers for navigation purposes alone may not be justifiable in terms of gains vs. cost, the use of some portion of data processing equipment installed for other purposes might provide this capability at little extra expense.

In addition to those involved in the TRANSIT program, it seems likely that the Navy will soon be faced with other data processing requirements arising from space developments. The prospect of hostile reconnaissance satellites or even weapons in space may necessitate knowing the location, orbit, and identity of objects in space in order to predict the passage of those posing a threat to forces at sea.[5] The tactical use of reconnaissance satellites and space probes by our own forces would require computer interpretation of the information transmitted from such vehicles. Though none are yet clearly established, such developments may lead to substantial data processing requirements in the mid-to-long range future.

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[4]Office of Naval Research, Naval Analysis Group. <u>Naval Implications of Earth Satellites</u>, Naval Analysis Report No. 19.

[5]OPNAV, Naval Warfare Analysis Group. "The Threat from Enemy Spacecraft Reconnaissance to Naval Operations" Ser 0069P93 of 17 May 1960.

The Navy has recently adopted a policy of placing alternate command and control facilities on ships for major Navy supported unified commanders, as well as selected Naval commanders. Implementation of this policy will require a substantial data processing capability for certain selected ships. To a considerable extent, the facilities of the commander's Operational Control Center ashore will have to be duplicated at sea and kept in readiness for use in event of destruction of the primary headquarters.

Finally, there are numerous business-type computer applications in the area of logistics and administration. Activities ashore have long used computers to save personnel and gain speed in performing such jobs as inventory control, personnel accounting, and payroll computation. The Bureau of Supplies and Accounts has plans for the extension of these techniques to shipboard operations.

The foregoing survey of proposed or predicted data processing applications is not included as a persuasive argument in favor of the extensive use of computers at sea. Though the merits of such measures may be open to argument, there is little doubt that widespread application of shipboard computers lies ahead. More important, in a number of the areas discussed above, programs are already beginning to take form which will ultimately lead to plans for development, installation, and use of computers at sea. Many of these programs are being shaped in complete isolation from other shipboard data processing developments.

If continued, this piecemeal approach to the use of computers aboard ship will result if a multitude of small, separate, and costly programs designed to place a variety of data processing equipment in various locations throughout ships, each to be used for a special purpose, in a manner largely uncoordinated with the total shipboard data processing effort. Each distinct item of equipment will require different spares, different training for maintenance and operating personnel, and different computer programing. Some equipment will be overworked while other equipment is idle. When one computer is inoperative others will not be able to absorb its work. Worst of all, after all such programs are completed there will still be no complete, unified, and integrated facility for the control and direction of forces by the commander. There will be only a collection of heterogeneous systems and sub-systems, each dealing with larger or smaller portions of the total problem. This is the fallacy of any piecemeal approach to extensive data processing at sea.

What is needed is a comprehensive program to coordinate all of these developments from their inception and to treat each in its relationship to the larger scheme of operation of a ship or force at sea. Such control of development efforts would avoid repeating the costs of development, establishment of a computer programing capability, and training of personnel for each development. These costs have now been largely paid by the NTDS program. By taking advantage of this fact, the Navy can gain extensive application of data processing techniques for a relatively small additional investment. The Navy now has a good computer capable of universal use, it has computer programing centers in operation, and it has a program underway to train operators and technicians in this new technology. What the Navy lacks for achieving the kind of integrated approach proposed is a single agency for coordination of all shipboard data processing to insure the most effective use of these expensive capabilities.

The logical result of a comprehensive data processing program would be the development of an integrated shipboard data processing center. This center would contain all the computing facilities of the ship. The capacity of the center would be tailored to the total needs of the ship by the installation of the required number of NTDS or other standard computers. Thus would be provided the flexibility needed to allocate computer capacity to various functions according to their requirements at any given moment. In combat the entire facility could be devoted to those functions required to fight the ship. During condition watches, with little activity of tactical interest, some computers could be used for logistic or administrative tasks by quickly shifting them to a new computer program. Others could be placed out of operation for maintenance or assigned for training of personnel. Remotely located input or output devices could gather data and display results, situations, or solutions to appropriate areas throughout the ship. Equipment, spares, programing, and personnel training would be standard for all shipboard data processing equipment. Only in this way will expensive duplication of effort and overlapping of functions be eliminated. Only a program such as this could lead to a single, integrated, streamlined, and effective capability for every facet of command and control.

The integrated data processing center would be able to provide computer assistance to every major function in which the stresses of modern operations at sea mitigate against effective performance at present. Could such a system also be used to make decisions? If so, must it make decisions to be most effective? None of the proposed computer applications which have been described contemplate automatic decision making and this point has not been dealt with so far in this paper. Nevertheless, the kind of data processing capability proposed above would, with little change, have the <u>hardware</u> necessary for automated decision. Part II of this paper is devoted to a discussion of the feasibility and desirability of automated decision and is intended to provide at least an introduction to this controversial question.

PART II

AUTOMATED DECISION-MAKING

CHAPTER V

SOME BASICS OF MILITARY DECISION

Response to uncertainty

Effective forms, methods, and processes for decision making must have their roots in the fundamental psychology of human response to uncertainty. An understanding of how we react to problems is prerequisite to any consideration of intellectual or mechanical substitutes for human decision. Psychologists define a problem (or, as they term it, an uncertainty situation) as a change or disruption in the normal relationship between an organism and its environment. A decision arises when a novel situation is created which the organism has a compulsion to adjust to or overcome.

It can be seen immediately that the military uncertainty situation is far more complex than this. For one thing, military problems do not always involve a novel or unexpected relationship to the environment. They are more likely to involve some obstacle to achievement of a desired purpose. The existence and general nature of such obstacles have usually been anticipated but the problem unfolds only when the specific form and extent of the obstacle are determined. Military problems should be thought of in terms of individuals or organized groups faced with one of a spectrum of uncertainty situations ranging from obstacles against achievement of purposes to direct opposition by a complex relationship of hostile forces threatening individual, group, or national survival.

Faced with such an uncertainty situation, the normal human response is to cast about for various alternative solutions to the difficulty. He may find these in the knowledge of what has worked under similar conditions in the past, or he may formulate new and original alternatives. When he finds an alternative that leads him to the expectation that a favorable resolution of the difficulty will result, he makes his choice. A logical description of this process might be stated as follows:

1. Identification of the problem.
2. Search for alternative means of solution.
3. Prediction of the outcome of each alternative.
4. Selection of the alternative which best solves the problem.

This pattern is the basis for the forms and methods of decision used in the Navy today. Later it will be shown how a machine can reach decisions in exactly the same way.

Classification of decisions

It may be seen from the foregoing that military decisions are required in a variety of situations ranging from broad, long term, strategic choices to low echelon, immediate action choices in combat. It is clear that the same methods are not used to deal with all military decisions. Some means of classifying decisions is needed to permit a systematic examination of the possible methods of solving various problems.

One analytical distinction was made by Professor Simon in a lecture delivered to the Naval War College on 26 August 1957. He distinguished between decisions of encounter and set piece decisions.

> The notions behind this distinction . . . are familiar . . . . On the one hand, there are decisions required because a situation develops--either is made to occur by the enemy or by the weather or by something else--in which immediate action is called for and a

> decision has to be made as to what that action is going to be. The set piece decision occurs in situations in which there is a lot of time to plan out a future course of action.[1]

This method of classification is an important one, though by no means comprehensive. The key to the distinction is the speed required in decision--the time available to react to the situation. Encounter decisions are generally more typical of those faced at sea in combat by the lower echelons of command, though this is not universally true in the era of ballistic missiles. They tend to be made by an individual rather than by the collective action of a staff as in the case of set piece decisions. Not exceedingly complex, most encounter decisions could be handled by any well trained officer were it not for the urgency typical of such situations. The stress of time, however, makes it necessary to fall back on hair triggered, instinctive and habitual response and creates severe limitations on the capability of the best officers.

A second distinction between problem situations involves the difference between performing calculations and making choices, or, stated another way, the difference between puzzles and difficulties.[2] A puzzle is an uncertainty with one correct solution which can be found through calculation, measurement, or staff work. A difficulty is a different type of uncertainty which has no clear and final solution. Difficulties are not solved, they must be surmounted, overcome, reduced, or avoided. They yield to analysis and careful choice of action, sometimes with the aid of puzzle

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[1]Prof. H.A. Simon, "Background of Decision Making," Naval War College Review X, November 1957, p. 5.

[2]Prof. W.A. Reitzel, Background to Decision-Making, p. 39.

solutions. The difference between puzzles and difficulties can be illustrated with an example. The question of the effects of a nuclear weapon on a given target is a puzzle. There is one correct answer to this question and it can be calculated. On the other hand, an answer to the question of the general employment of such weapons in war poses a difficulty requiring a choice of policy.

This distinction is similar to the one made by Professor Simon when he classifies decisions an routine, well-structured, and heuristic.[3] Routine, and to some extent, well-structured decisions can be equated with puzzles since the methods and techniques of solution are known and can be more or less standardized. Other, less structured decisions, together with heuristic decisions are comparable to difficulties since they present no clear, systematic procedures for solution and tend to involve those qualities which have been variously identified as judgement, insight, and creativity.

It is characteristic of many decisions that they involve both puzzles and difficulties. Most responses to difficulties will require the solution of one or more puzzles before the difficulty can be surmounted. The greater the number of factors of the difficulty which can be treated and solved as puzzles, the better. It is to the credit of progress in organization and decision theory that many of yesterday's difficulties are now solved as puzzles. There is evidence to indicate that this trend will continue in the future.[4]

There remain to be discussed four other characteristics which might be used in distinguishing between types of

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[3]Simon, Op. cit., p. 18

[4]Ibid., p. 22

decisions. These cannot be considered as suitable for definition of a class since they are not mutually exclusive. They do provide additional earmarks for use in describing and distinguishing between various kinds of decisions and problems:

The first of these is a consideration of forms and methods used in solving problems. Some decisions are made through use of the formal planning process involving the coordinated efforts of a large staff. Others are made instantly by a single individual almost as a reflexive response to a specific situation. Between these extremes lie decisions using various degrees of group effort and formal processes. This distinction is in some ways a refinement of the encounter vs set piece idea, but there is a difference between the two methods of classification. Some encounter decisions, though not involving formal staff action, rely to a great extent upon the more or less coordinated efforts of a group. Those faced by a commander and his staff during air defense operations are examples of this difference. Here we may find the staff active in clarifying the situation and making informal recommendations in what is essentially an encounter situation.

Decisions can also be classified according to the type and scope of the problem involved. These will range from uncertainties concerning the most fundamental aims and objectives--the most basic concepts on the national or service level; through questions of strategy and long range plans; down to short-term operational and tactical problems; and, finally, to the most specific situations arising in the course of a day's operation. This idea can be stated another way by saying that military uncertainties can be divided into those which tend to set the stage for combat, such as planning and readiness problems, and those which involve actual operations and waging of war.

Another distinction which might be made between military problems and decisions is that of the level of authority which deals with the problem. This classification and the two previous to it are closely related. It is not always true, however, that the type and scope of the problem and the degree to which formal methods are used is determined by the level of command involved. Modern warfare is tending to involve the highest levels of command in specific problems of wartime operations. Moreover, many require the response of the individual commander either because of lack of time for formal staff action or because the best of formal responses cannot ultimately reduce the central core of difficulty which demands personal choice. For these reasons it is not unlikely that individual, informal response to very specific operational problems may at times be seen at very high levels of authority.

A final factor to be considered is that of repetition. Some decisions are unique in scope and type and are made only one time. Others may be repeated at infrequent intervals in response to problems which are related in general but involve considerable variation in number and importance in relevant factors. Many uncertainties, however, tend to arise repeatedly in more or less the same form. In these repetitions, the same considerations invariably apply and these can be identified and classified as factors in the decision. The degree to which these factors are involved will vary with each repetition of the problem but each must be considered in relation to the absence or degree of presence of the others in reaching a decision.

In the preceeding pages each of six distinctions have been discussed which, though not mutually exclusive, can be used to classify or describe a decision. These can be summarized by saying that decisions can be classified according to:

1. Whether they are of the set piece or encounter variety.

2. Whether they involve puzzles or difficulties or both.

3. The degree to which formal processes or group efforts are used.

4. The general type and scope of the problem involved.

5. The level of authority which makes the decision.

6. Whether or not the decision tends to be repetitive.

The important question of the characteristics of those decisions which might be made automatically must be deferred until a number of other considerations have been reviewed. One such consideration is the methods and forms now used in decision making.

Established methods and forms

It is characteristic of much writing on the subject of military decision to limit the meaning of that term to those decisions taken by the commander in the process of formal, staff-supported planning associated with the Estimate of the Situation. Though these writers may acknowledge that there are other kinds of decision, these are often dismissed as being outside the scope of decision-making in the military sense. The fact is that formal military decision-making accounts for only a part, and certainly the smaller part, of all the responses to military problems. Thus the numerous and important decisions which must be made quickly, by individuals, under the stress of operations or combat are frequently unrecognized in the literature of military decision-making.

For this reason, the term "decision-making process" is generally associated in military circles with the Commander's Estimate of the Situation. This form is aimed at guiding the response to problems along lines of the basic human response to uncertainty. That process, as applied to the type of uncertainty in which the estimate is used, consists of selecting or identifying the objective, finding alternative courses of action which might achieve the objective, predicting the possible outcome of each course of action, and choosing the course of action which will best achieve the objective. These steps correspond to the actions required by the first four paragraphs of the commander's estimate. The decision itself is made in paragraph four, not in paragraph five which deals with transmitting the decision. The objective is normally supplied by a higher echelon of command. The meat of the decision process thus is found in paragraphs two and three. These often involve laborious efforts by the staff requiring a great deal of calculation and puzzle-solving. If these steps are done well the decision may prove so obvious that the actual choice is little more than a formality.

For other types of decision, when formal methods are not or cannot be employed, something more akin to the historical "commanders decision" is seen. Here the procedure is focused upon the individual, relying on his mental responses to a problem as viewed by him or portrayed by his subordinates. The process in this case is to collect information needed to describe the problem, identify as many of the significant factors as possible, review the alternative solutions which can be called to mind in the time available, and choose that which seems to offer the best expectation for a favorable solution to the problem. As the time available for decision is decreased, this process becomes less precise and begins to assume the nature of an instinctive, triggered response. The situation is quickly identified, a few possible actions are rapidly considered, and the choice of one is made almost automatically. In these cases the individual is relying heavily on training and experience to suggest credible solutions to the difficulty. The important characteristic of all informal decisions is that they are made without the aid of standard, controlled, and orderly methods. They rely entirely upon the personal and human capabilities of the individual even when he may be operating under conditions of distraction and stress.

There is a kind of relationship between these two methods of decision-making. It is normal to find initial, basic decisions which are made by formal methods and extensive staff action, being executed, modified, and expanded through decisions made by informal, individual-oriented methods. As a particular operation unfolds, the commander controlling the execution is continuously altering and modifying the basic decision by individual action based on the situation as portrayed to him by his staff and upon their informal recommendations. At lower echelons of command even more informal decisions are being made, and to a greater extent, on the basis of the response of the individual as triggered by a specific uncertainty situation.

There is, then, no single military decision process. Depending upon several factors, the processes used range from something very close to the natural psychological response to uncertainty through a spectrum which terminates with very formal methods involving a large staff and using the form of the Commander's Estimate of the Situation. At the latter end of this spectrum the decision process is closely associated with techniques of organization.

Organization

As military problems have grown increasingly complex, the commander has been supported by an ever growing staff to permit him to deal with them. This has led to increased concern with optimum techniques of organization. The problem is to control and direct the response of the group in such a way that it will act as a sort of extension of the commander's intellect. The difficulty arises because the more restricted and regulated the response becomes, the less flexible, imaginative, and responsive to broad roles and purposes it is, and the harder it is to insure an appropriate degree of communication throughout the organization.[5]

A great mass of routine, detailed, and complex matter never reaches the commander, nor is it intended that it should. The situation is in sharp contrast to that of the past when problems involving a limited number of well understood factors could be personally solved by the commander.

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[5]Reitzel, *op. cit.*, p. 72-77.

This development has been termed "institutionalized command." It has, to an ever increasing extent, isolated the commander from the raw elements of uncertainty situations by presenting him with only the distilled, evaluated problem as seen by the staff. Moreover, his responses have become restricted and constrained by previous decisions and actions of the staff, some of which may have been remote in time and relationship to the difficulty under consideration. On this subject Professor Reitzel says, in Background to Decision-Making:

> . . . the military echelon arrangement of responsibility for decision still perpetuates the principal of the assigned commander being responsible for the act of decision itself, even though the areas of freedom have been steadily reduced and qualified by the organizational web in which the commander operates.

Weaknesses of present decision-making methods

The foregoing discussion implies several weaknesses in the way in which decisions are presently made. The chief shortcoming is, of course, human fallibility. This is most significant in informal, encounter types of decisions where human limitations are aggravated by stress and a high degree of distraction. This weakness grows more critical in the light of rapid technological changes in naval warfare tending to present increasingly complex problems which must be solved in ever shorter times with more and more disastrous consequences resulting from faulty decision.

A second weakness is the increasing dependence of the commander on his staff. The growth of large staffs to deal with complex problems not only poses organizational problems, it has caused an isolation of the commander and made it difficult for him to exert his personal influence on the course of routine, day-by-day events. This isolation has in turn created constraints on his actions in specific problems and restricted his ability to freely intervene in fast moving situations.

A third weakness is one generated by the vastly increased scope and complexity of modern and foreseeable future military uncertainty situations. In the face of these ever more complicated problems, decisions are still being made on the basis of data which, for the most part, is processed by human means. The task of accurately depicting such situations, calculating and computing solutions to difficult puzzles, considering and predicting the outcome of various possible courses of action, and storing and retrieving large quantities of information and intelligence are still largely accomplished by slow, manual means.

The final weakness is the difficulty in achieving uniformly acceptable decisions, compatible with the larger framework of policy, objectives, and doctrines of higher authority, while not stifling the lower echelons with detailed instructions and directives.

CHAPTER VI

THE AUTOMATIC DECISION-MAKER

Figure 3 is a diagram which will be useful in discussing the way in which an automatic decision-maker might function. It is adapted, with considerable modification and expansion, from an illustration appearing in the book Design for Decision by Irwin Bross. Figure 3 is not intended as a block diagram of hardware, but as a functional representation of the operation of a decision-maker. This hypothetical machine has been divided into four systems for convenience in discussion. These are identified as the Data System, the Prediction System, the Value System, and the Decision Criteria System. Depending upon the techniques and analytical tools employed, each system is used in various ways to reach a decision. The description which follows is based largely on the use of statistical decision methods.

The Data System has the function of connecting the decision maker to the real world in which it operates. It receives information on the tactical situation through the various sensing and surveillance devices which are connected to it, from data links or other communications, and from manual entries. The Data System also receives requests for decisions. The problem involved may previously have been fully described to it by means of the computer program as in the case, for example, of a request for weapon assignment to a designated target. Otherwise, the problem may be described by entering various inputs and parameters to flesh out what is only a generalized framework in the computer program, as in the case of a war game. To provide some decisions without the necessity for a specific

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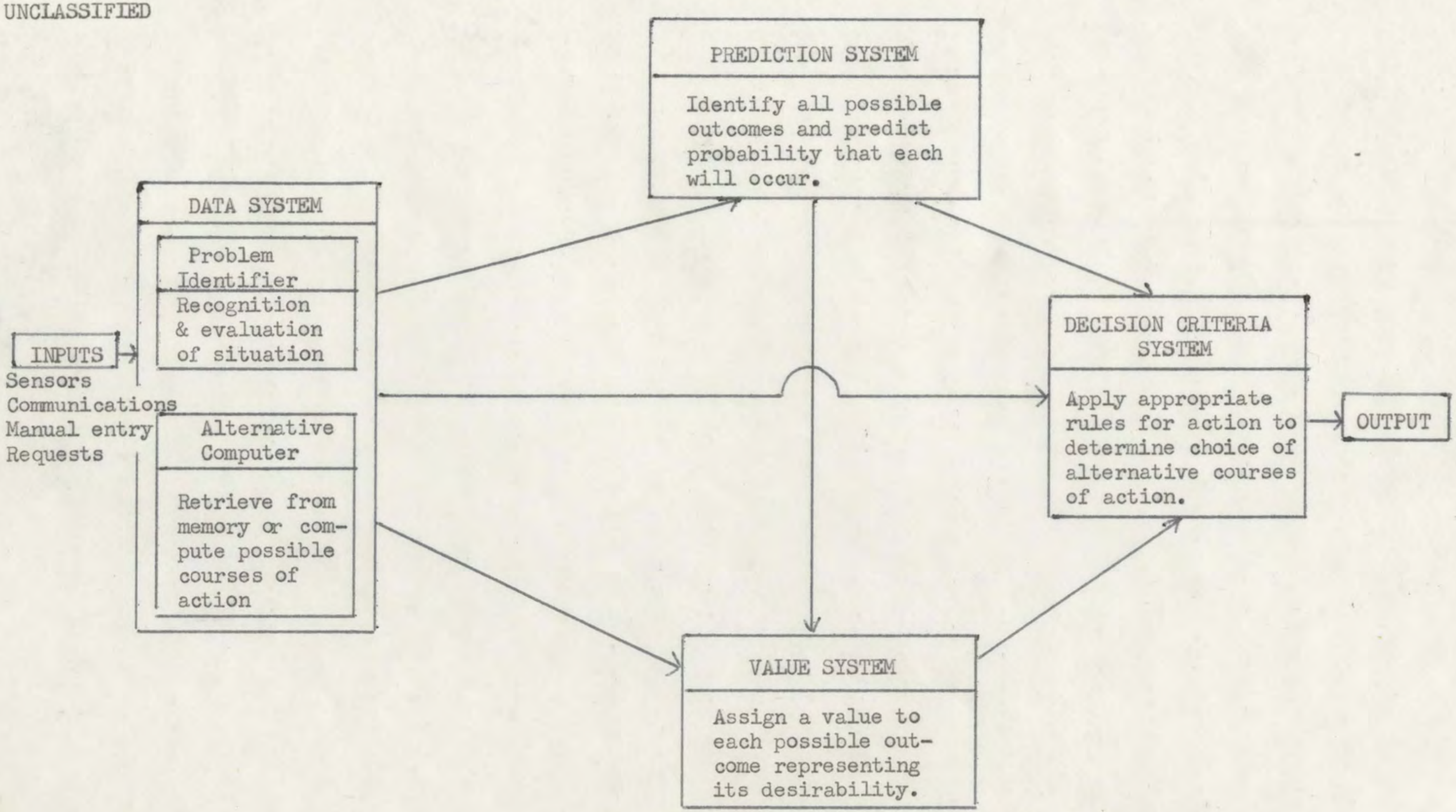

FIGURE 3

DIAGRAM OF A DECISION-MAKER

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request, a part of the Data System can be used to recognize and evaluate situations which require action by the decision-maker, the detection of a hostile or unidentified vehicle, for example.

A second function of the Data System, once the problem has been identified, is choosing all the various courses of action applicable to the particular problem. It may do this by reference to lists of possible actions which have drawn up and stored in memory, or it may apply rules provided in the program to compute alternative actions. When courses of action have been selected, the Data System passes a complete list of these, together with relevant data describing the problem, to the Prediction System and the Value System.

The function of the Prediction System is identifying all possible outcomes of each of the alternative courses of action as applied to the particular problem under consideration. A list of these outcomes is sent to the Value System after which the Prediction System calculates the probability that each of the possible outcomes will occur. All of this information, the possible outcomes and the probability of each, is then sent to the Decision Criteria System.

Meanwhile the Value System, having received a description of the problem from the Data System and a list of possible outcomes from the Prediction System, assigns a measure of value to each outcome which is an index of its desirability. These values are sent to the Decision Criteria System.

The Decision Criteria System has now been provided information on the problem, alternative courses of action, possible outcomes for each course of action, the probability of occurrence of each outcome, and the desirability of each outcome. The function of the Decision Criteria System is to apply the appropriate rules for action, which have been programmed into it, in order to choose the most suitable course of action in response to the problem at hand. This choice then emerges from the decision maker as its recommendation, or in the form of appropriate orders and assignments.

The functioning of the decision-maker in this mode can be illustrated by the sample solution of a simplified problem. Assume that the choice to be made is whether to drive to work or take the bus. The purpose of the decision is to choose the action which will lead to a general state of well-being on the following evening, i.e., home on time, without accident, without financial loss, etc. As shown in Figure 4, the two alternative courses of action are provided in the Data System. The prediction system provides three possible outcomes for the first action and two for the second with the probabilities calculated as shown. The desirability of each outcome in this case is measured in terms of estimated cost of each outcome with achievement of the desired aim set at zero cost and other outcomes resulting in financial loss representing out-of-pocket expenses or the assessed value of time lost or inconveniences resulting from delays. The result of the action by the Decision Criteria System will be dependent upon the criteria employed. These are discussed in the following chapter but it can be seen that a criteria which emphasizes security would result in choice of taking the bus whereas one which concentrates more on probabilities would result in choice of driving the car.

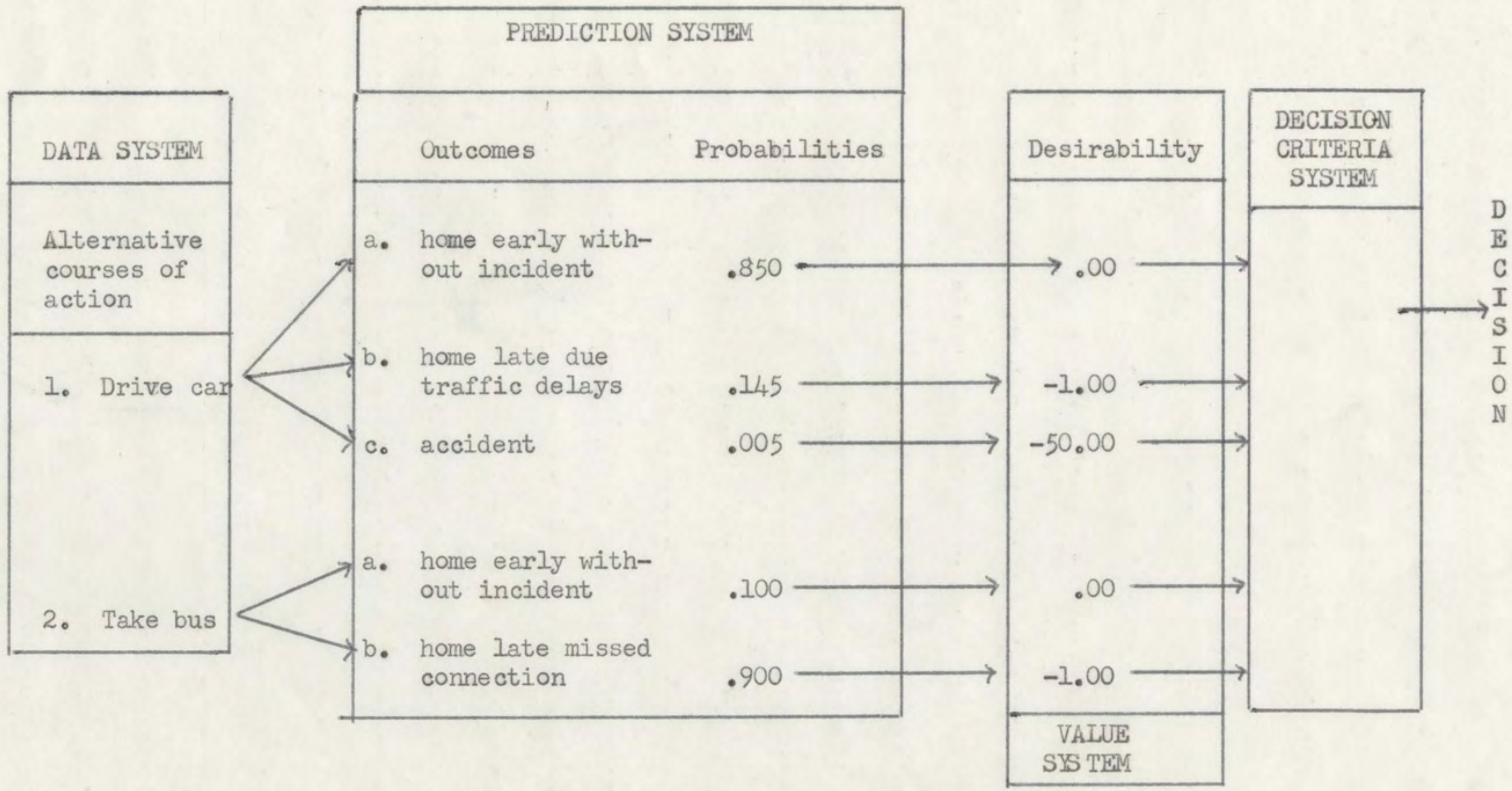

FIGURE 4

FUNCTIONING OF THE DECISION-MAKER

As stated at the beginning of this chapter, the functioning of the automatic decision-maker varies somewhat according to the analytical methods employed. A variation on the mode described above can be illustrated by the more straightforward logical processes which might be employed in the determination of optimum assignment of weapons to targets in an antiair warfare situation. The procedure to be described bears some similarity to the methods which will be employed by NTDS in performing this role.

In this case the function of the Data System is essentially the same as before. The need for decision will arise when it learns that a weapon is free and available for assignment. At that time all possible targets will be reviewed against the characteristics of the weapon available to see which can be engaged by that weapon. A list of these will be sent, in this case, <u>directly</u> to the Decision Criteria System as possible courses of action. The Prediction System has meanwhile calculated the relative threat of all targets by considering the probability that each will survive weapons presently assigned to it, whether or not each will pass through the effective envelope of other weapons before completing its attack, the direction of flight of each target, and the degree of damage which the target might impose if not destroyed. The resulting index of relative threat for each target is then sent <u>directly</u> to the Decision Criteria System. Note that the Value System is by-passed entirely in this application.

The Decision Criteria System must now choose the target to which the weapon will be assigned. It has available a list of all targets which the weapon is capable of engaging and an index threat for each target. The criterion in this case is a simple logical one which might be expressed as: "Assign the weapon to the target which is nearest in time and least engaged." More precisely, the Decision Criteria System will sort through all the targets in the highest threat category. Of these it will choose the target which is closest in time to its bomb or missile release line and assign the weapon to that target. The real life problem is, of course, more complex since coordination with other units, availability of weapons force-wide, location of defended points, and other such factors must all be considered. Despite these complexities, the problem would still be handled in the same general way.

The functioning of the decision-maker when employing another analytical technique, game theory, will be discussed in the next chapter. It can be seen from the above, however, that the methods used in automatic decision-making would be closely related to the basic human response to uncertainty and even to the form for decision expressed in the Commander's Estimate. The procedure in all cases is: recognition of the problem, search for alternatives, prediction and weighing of outcomes, and selection of an alternative which promises the most acceptable outcome.

It has been stated that Figure 3 is not a diagram of actual equipment which would be used in an automatic decision-maker. In practice at sea all the systems shown in Figure 3 would be embodied in one or more of the computers to be found in an integrated shipboard data processing center. The inputs would be taken from the same sources previously listed as a part of such an integrated system. The outputs would be displayed on command display consoles, written out by printers, or transmitted as action assignments or orders to weapons systems or to other units. In short, the use of computers for decision making at sea would require little or no equipment beyond that installed in a ship with either NTDS or the more comprehensive data processing facilities discussed in Chapter IV.

CHAPTER VII

THE INTELLECTUAL TOOLS FOR DECISION-MAKING

In the course of human history there has been a slow evolution of decision-making methods. Simple forms of life had built-in decision-makers which enabled them to make such choices as whether or not another organism was poisonous, whether to run or fight, and how to spin a web or build a nest. Since this biological mechanism was not shared by early man, he had to substitute memory and parental training. This basic training eventually grew into established cultural patterns and rules transmitted by a language.

As environments and problems grew more complex and specialization developed, a class of specialists arose whose function was decision-making. The professional decision-maker had the advantages of special training and experience at decision. We still see such a class employed today as managers and leaders. The decision-maker specialists have always employed various systematic processes for reaching decisions. The first, a long list of standard responses to specific situations, gave way to broader principals applicable to many situations. This in return required the creation of abstractions of the real world in order to apply the basic principals. These early abstractions took the form of devils and gods such as the medicine men employed, later they evolved into reason and logic, and in recent years have become embodied in a new science of decision. These scientific methods have provided the tools which might be employed by computers in reaching decisions.

Mathematical models

One tool, which is fundamental to the employment of all others, would be used in the Data System of the automatic decision-maker shown in Figure 3. This tool is the mathematical model.

Before any of the analytical methods of decision can be used, a mathematical model of the problem under consideration must be constructed. The complex, confused, and distracting mass of details of the real-life situation must be reduced to symbolic or other logical relationships which will clearly depict the real world by representing all the essential, relevant elements of the problem in their true relationships. Newton's Theory of Gravitation is an example of a very comprehensive and powerful mathematical model of the real-life solar system. The models to be used in the decision-maker will be much less ambitious but they must with equal accuracy represent the real situations and problems to be solved. The construction and testing of models is part of the analytical work which is done in computer programing and the model may ultimately be expressed only in terms of the program supplied to the decision maker.

Statistical decision theory

One of the principal tools used in the decision-maker is statistical theory. It may be employed in the Prediction System, the Value System, and the Decision Criteria System as they are depicted in Figure 3. At one time statistical theory was associated only with the processing of data. In more recent years it has been extended to deal more broadly with decision making in the face of uncertainty.[1] It can be most effectively used in making choices when there is no interaction with another choice which will be made by a hostile opponent, for example, those uncertainties arising from acts by nature or some other neutral environment.

The last chapter showed that the Prediction System of the decision-maker must calculate probabilities. Probability, which is a branch of statistical theory, provides a means of measuring degrees of uncertainty in a quantitative fashion. Although there are other methods of doing this, generally based on various kinds of projections of past data, probability is a more realistic method since it recognizes that predictions cannot be made with certainty. Applying probability prediction will yield a decimal or common fraction which expresses the chance that a particular event or outcome will occur.

A great deal of knowledge has been accumulated, organized, and applied to provide advanced methods and systems for dealing with probability.[2] There are means for combining and manipulating the probability of several events. Rules for dealing with chains of probabilities have been developed into modern inspection sampling and quality control methods. There are also a number of other techniques based on the use of normal distribution curves. In short, it can generally be said that given past data regarding a particular problem, or a clear definition of the problem, there should be little difficulty in finding effective means of probability prediction.

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[1]Herman Chernoff and Lincoln Moses, Elementary Decision Theory, p. 1.

[2]Irwin Bross, Design for Decision, p. 29-76

When the use of statistical theory in the Value System of the decision-maker is examined, the major weakness of the automatic decision-maker comes to light. It will be recalled that the function of this system is the assignment of a measure of desirability to each outcome it receives from the Prediction System. The question is how to measure desirability and what units to use in expressing it. This is a serious difficulty and one which is usually raised by critics of the analytical decision techniques. On the other hand it is sometimes overestimated in general statements. It would seem that a true measure of the difficulty can only be obtained in the light of consideration of specific problems. In some cases an inaccurate measure of values or even the inability to assign a numerical value is not critical in reaching a decision. In other cases it is a practical and effective limitation on what can be done with statistical or other analytical techniques.

One practical measure of value is money. It is widely used in the every day world to express the desirability of material goods, labor and services. In business can be found a dollars and cents measure of the value of such abstractions as good will or the loyalty of employees. This is not to say that money is an effective measure of value for all military problems, but that there is a class of objects and ends which lend themselves to measurement in dollars and cents.

The field of economics has contributed an alternative to the dollars and cents value scale. This is the utility scale, the measuring of the value of an object or outcome relative to a scale of amounts of some other arbitrarily chosen object or outcome.[3] For example, it might be found that in a specific problem the loss of one carrier is equivalent to the destruction of ten enemy submarines. This is an individual value scale rather than a consensus, but it seems likely that this point is not a serious defect in the case of military decision.

One other method for measuring values is the use of preference scales. This method involves the arbitrary rating of individual preference on some scale, such as zero to ten, or the individual preferences may merely be ranked in order. A good bit of work has been done in converting preference to utility scales.

Though the lack of ability to measure values accurately is the single most important barrier to wider use of decision theory, some impressive practical results have been achieved in the face of this limitation. The research being done in this field[4] offers hope that improved measurement techniques may be found in the not too distant future.

Another use of statistical theory is found in the Decision Criteria System of the automatic decision-maker. Here is the heart of the machine, for it is the choice of rules for action which will determine the quality of its recommendations. There is, of course, no single abstract standard for measuring the correctness of a decision. It must be judged pragmatically in the light of goals and purposes involved. It follows that no single criterion

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[3]Ibid., p. 91-94.

[4]D. Davidson, P. Suppes, S. Siegel, Decision Making, An Experimental Approach, p. 19-61.

for decision is suitable for all problems and situations. Statistics provides a number of these criteria from which might be selected the one which is most appropriate.

When the decision-maker is using statistical theory, the Decision Criteria System will be working with 1) possible courses of action 2) outcomes of each possible course of action 3) the probability that each outcome will occur and 4) a measure of desirability for each outcome. Given this information, a number of possible rules for action are available for use as decision criteria. Some examples of these are discussed below.

Rule 1: Consider the most probable outcome for each action and the desirability associated with each of these most probable outcomes. Choose the action for which the desirability of the most probable outcome is as large as possible. The reasoning here is that since the most probable outcome is most likely to occur, we should act as though it will occur. The reader will note that this rule does not require a numerical measure of desirability. The principal objection to it is its failure to take into account the possibility of heavy losses even when they have a fairly high probability of occurrence. Thus, unless the most desirable outcome has a very high probability, this rule is likely to be unacceptable in most cases.

Rule 2: Choose the action which could lead to the most favorable outcome, i.e., the outcome with the highest measure of desirability. This rule represents a most optimistic view but the objection to rule one applies even more strongly in this case since probabilities are totally disregarded. Thus the possibility that the most favorable outcome may not occur is neglected.

Rule 3: Consider the least favorable outcome of each possible course of action. Of all the least favorable outcomes, one will be more favorable than the others. Choose the action associated with this outcome. This rule reflects a more pessimistic view and emphasizes security. It would protect against the occurrence of extremely unfavorable events. Control of heavy losses is the essential purpose of rules of this type.

Rule 4: This rule applies when dealing with a repetition of the same problem over a long period of time. It involves a quantity termed mathematical expectation. The mathematical expectation of each action is obtained by multiplying the probability of each possible outcome times the desirability of each outcome, then adding up the products and subtracting the cost of the action. For example, if a course of action has two possible outcomes:

$(\text{Probability}_1)(\text{Desirability}_1) + (\text{Probability}_2)(\text{Desirability}_2)$
$- \text{Cost of action} = \text{Mathematical expectation}$

When the mathematical expectation for each course of action has been computed, choose the course of action with the largest mathematical expectation.

Rule 5: This rule can be used when exact probabilities are difficult to compute and only a range of probability is available. It combines the concepts of loss control and mathematical expectation. In this case the probability of the least favorable outcome is set at the higher end of the range, the probability of the most favorable outcome is set at the lower end of the range, and the mathematical expectation of each course of action is computed as in Rule 4. In this case the action with the largest mathematical expectation is again selected, but because of the way it is calculated, the mathematical expectation is now termed the least favorable expectation. Thus the rule is: select the action with the largest least favorable expectation.

Those are examples of possible rules for choice of action. The selection of a specific rule for a given problem is a part of the process of analysis and programming. Some general observations about these examples can be made, however.

It is obvious that Rules 1,2, or 3 would seldom be employed because they are not likely to be responsive to the complexities of real life problems. Of the two remaining rules, one (Rule 4) deals with long term, recurring problems and those where only moderate gains and losses are possible, the other (Rule 5) is applicable to unique choices where great gains and losses are possible. Its philosophy is to compromise between profit and security. These two philosophies can be expressed as "maximize and the expected long term gain" (Rule 4), and "minimize the maximum risk" (Rule 5). Most advanced work in statistical decision theory has been based on these two concepts.

The foregoing discussion of decision criteria was limited to statistical theory. There are of course other rules for choosing between alternative courses of action. Some are purely applications of logic to the problem at hand as in the case of the "nearest least engaged" doctrine for weapon assignment. Others may be found in the concepts of game theory.

The theory of games.

John von Neumann first wrote of game theory in 1928, but not until 1944 was a really comprehensive account given when he and Oscar Morgenstern completed The Theory of Games and Economic Behavior. This was a major scientific and mathematical achievement and others have since been busy in extending the general theory to all forms of specific conflict situations. Already used in certain military applications, game theory also shows promise as a useful tool for military planners and decision-makers.[5]

The Theory of Games is a mathematical demonstration that, if opposing interests in a conflict situation act rationally to achieve desired ends--ends which can be set forth in some appropriate scale for measuring expected returns for all combinations of the various opposing plans of action--then the proper strategy for each side can be deduced mathematically.[6] It is important to note the limitations implicit in this description. Not only must it be possible to predict the outcome of a clash between two opposing courses of action, it must also be possible to measure the value of this outcome (called the "pay-off" in game theory) with respect to the outcomes of other choices of action. In addition, game theory assumes that each opponent will act rationally to achieve his ends.

Since the writer believes it possible to use game theory in an automatic decision-maker, it will be discussed in this context as statistical theory was discussed in the preceding section. Each of the decision-maker's systems will be considered as it would function using game theory.

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[5] COL Oliver G. Haywood, Jr., USAF, "Military Doctrine of Decision and the Mathematical Theory of Games," Air War College Review 4, 1950. p. 17.

[6] CAPT R.P. Beebe, USN, "Military Decision From the Viewpoint of Game Theory," U.S. Naval War College, 1957, p. 4.

The function of the Data System in this case would be the establishment of a matrix of all possible courses of action (or strategies, as they are termed in game theory) of one opponent as opposed to each of the strategies open to the other opponent. Each strategy listed for both sides must be complete and all strategies must be included. Available strategies might be selected automatically when the Data System has been programmed in advance for specific problems, or the strategies might be manually introduced at the time the problem arises. Game theory is capable of dealing with two sides having almost any number of possible strategies, but not much is known at present about conflicts involving more than two sides.

The Prediction System, when using game theory, must supply the outcome of each strategy open to one opponent when opposed to each possible strategy of the other opponent. If more than one outcome is possible when two strategies are opposed, the prediction system must calculate the probability that each outcome will occur.

Next the Value System must assign a measure of value, or pay-off, to each outcome. Here are encountered all the limitations and difficulties in value measurement which were discussed in the last section. It is highly desirable that pay-offs be shown numerically or by use of a utility scale. Game theory can be used, with some limitations, if values can be shown in order of preference using such descriptive terms as "good", "excellent", "fair", etc., provided such a scale is truly discrete. By discrete is meant that each step in the scale, such as that between "fair" and "good", is equal to the next step, such as that between "good" and "excellent". Furthermore, in situations where opposing strategies may produce more than one outcome, there must be a fifty-fifty chance that the outcome, if not as predicted, will fall an equal distance either higher or lower on the scale than the outcome chosen for the payoff. In cases where these requirements for discreteness cannot be met, it is possible that game theory might still be used but only with even more severe limitations.

One other point is important to the question of value measurement. To be most effective in solving military problems, game theory requires that opposing sides have identical concepts of the value of the possible outcomes of a conflict. This means that a given ship, aircraft, or number of lives must be of approximately equal worth to both sides. The losses of one side will then be equal to the gains of the other. If this is not true it may be necessary to treat the conflict as if three opponents were involved and, as previously stated, not much is known about the solution of situations of this type.

It is in the Decision Criteria System that the meat of game theory is applied. At this point the decision-maker has produced a matrix similar to one of the two shown in Figure 5.

Own Strategies \ Enemy Strategies	#1	#2	#3	#4
#1	10	15	12	5
#2	13	19	25	7
#3	21	8	4	19

MATRIX 1

Own Strategies \ Enemy Strategies	#1	#2	#3	#4
#1	good	fair	poor	good
#2	poor	defeat	excel	good
#3	good	good	fair	excel

MATRIX 2

FIGURE 5

ILLUSTRATION OF GAME THEORY MATRIX

The numbers or words in the boxes are the value to our side of the outcome of each of the enemies strategies as opposed to each of our own. Matrix 1 uses a numerical measure of value while Matrix 2 uses preference ordering with descriptive measures of the value of each outcome. The Decision Criteria System is now ready to apply the concept of game theory to reach a decision. The criteria for decision in this case is the simple assumption that the object of each opponent is to gain as much from the conflict as he safely can in the face of a skillful opponent who is pursuing an antithetical goal.[7] This is the meaning of the term "rational behavior" mentioned at the beginning of this section. In more specific terms, this means that our side will act in such a way that the least value of what we can win is as large as possible regardless of which strategy is selected by the enemy. The choice is made by noting the minimum values appearing in each row and choosing the strategy which has the largest minimum. In the case of Matrix 1 this would be own strategy #2, in Matrix 2 it would be own strategy #3. This may be recognized as the doctrine of acting on the basis of enemy capabilities[8] and it is a sound, conservative criteria for decisions made only once. It produces what is termed a pure strategy.

In some instances a problem may require a series of decisions. In this event (unless the most that can be gained by one side happens to equal the least that can be lost by the other) a mixed strategy should be followed. This means that the optimum grand strategy will consist of

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[7]J.D. Williams, The Compleat Strategyst, p. 23.

[8]The reader will note that the doctrine of acting on enemy intentions can be represented by acting as if we know which strategy the enemy will choose and selecting for ourselves the strategy which shows the largest value in the column headed by the enemy choice.

a mix of pure strategies, each used at random in accordance with a proportion calculated by use of game theory criteria. It can be shown that this method provides results superior to the use of a single pure strategy at no increase in risk.[9]

A simple example will serve to illustrate this point and to clarify the discussion. This is the "hidden object" game discussed in various forms in most descriptions of game theory. Assume that there are two large ships in a task force, one a carrier and the other a missile cruiser, and that an attacking enemy aircraft can identify both by radar as large ships but cannot distinguish between them. If the carrier is placed behind the missile cruiser, assume that its probability of survival, if attacked, is 80%. On the other hand if the carrier is placed out ahead of the cruiser in the expected direction of attack, the carrier has only a 60% chance of survival, if attacked, because it has lost some protection from the cruiser. In either case if the enemy attacks the cruiser the carrier, of course, has a 100% chance of survival. If our object is to protect the carrier, it would seem that we should accept the 80% chance of survival and adopt the pure strategy of always placing the carrier behind. A game theory analysis will indicate otherwise. The matrix for this problem is shown in Figure 6.

[9]Beebe, op. cit., p. 14-17.

		ENEMY STRATEGY	
		Attack first ship	Attack second ship
OWN STRATEGY	CV ahead	60	100
	CV behind	100	80

Figure 6

MATRIX FOR "HIDDEN OBJECT" GAME

The pay-off appears in terms of percent chance of survival of the carrier since that is our object. The enemy plane must decide in each case whether to attack the first or second ship he encounters since he cannot distinguish between carrier and cruiser. The solution of this problem is beyond the scope of this brief discussion, but it can be shown[10] that our best strategy is randomly to shift the positions of the carrier and cruiser each time we employ the formation while placing the carrier behind twice as often as it is placed ahead. This mixed strategy will yield a chance of survival of 86 and 2/3% (a gain of 8% over the pure strategy expectation of 80%) if the enemy follows his best strategy which is to favor attacking the second ship by odds of two to one. If he follows some other strategy, we will gain even more.

Game theory has been applied to various special military problems since World War II. Though it offers great promise, widespread and general application to military decision is not possible at this time owing largely to the inability of the military to provide concise scales of military worth. It is valuable at present in two ways.

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[10] Williams, op. cit., p. 47 or Beebe, op. cit., p. 19.

First it is a framework for reaching decision which is superior in many ways to the form of the Commander's Estimate of the Situation. Second, and of more interest to automatic decision-making, it can be used to great advantage as a tool for reaching decision in a limited number of special situations.

War gaming

Through the application of modern computers, the venerable practice of war gaming has become a valuable tool for the planner.[11] It might also be of use in an automatic decision-maker. The capabilities of the computer enable very complex games to be played in a short time once the program has been written.

Such games are now being widely employed by the services to determine optimum tactics, weapon system characteristics, and composition of forces. Each war game has a number of such factors as deployment, attack methods, timing, rules of engagement, capabilities of surveillance equipment, or range and effectiveness of weapons. The basic technique in using war games to aid decision is that of holding all but one of such factors constant while varying the remaining factor over a suitable range of values. A series of games is run for each assumed value of the variable factor and the value chosen which provides the best results. Thus it is possible to learn the best values for each factor involved in a given situation and also to spot those factors to which the outcome of the game is most sensitive.

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[11]CDR G.H. Mahler, USN, Practical Applications of War Gaming Techniques to Naval Planning, p. 59.

There is no reason why these methods could not also be used in reaching decisions at sea. To illustrate this point take the case of a commander who wishes to determine the best approach routes for his attacking aircraft in a particular striking operation. Assume that he has available a computer program for an air attack game which provides for manual insertion of inputs such as number and characteristics of his aircraft, the location of all enemy targets, position and characteristics of enemy detection facilities, and the number, type, and deployment of enemy air defense weapons. A series of games can then be run in which the routes of attacking aircraft are the only variables. The results will indicate the choice of attack routes resulting in the smallest losses and greatest damage to the enemy.

While not suitable for decisions in situations requiring fast reaction and rapid decision, the technique illustrated above could be applied to a large number of problems arising in the course of planning.

Cybernetics.

One other tool available for use in the decision-maker is worthy of brief consideration. This is the science of cybernetics. Dealing with theories of control and communication, it stands at the crossroads of electronics, sociology, neurology, economics, mathematics, and many other fields.[12] Cybernetics is concerned with such things as control circuits, networks, feedback, and information theory.

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[12]G.T. Guilbaud, What is Cybernetics?, p. 5.

We can turn to cybernetics to find the best means of keeping continually updated on the progress of action toward a specific goal, for modifying or adjusting action in accordance with status of progress already made. This tool can also be used to determine the best means for communicating with a decision-making system and for communicating between the decision-maker and the external world.

Ultimately cybernetics may provide the bridge which will unify game theory, statistics, the science of behavior, and organization theory. For the present its contribution would be limited to technical assistance in the design of the various systems to be integrated aboard ship and in describing the relationships between each of them. For example, some problems involve what is termed sequential decision. Here a preliminary choice is made or an answer calculated as the first step in a process which is a series of choices leading to final decision with each choice being dependent on the outcome of that which preceded it. Cybernetics would be useful (both in design and in programming) in determining the complex relationships, feedback, and controls required for solution of problems of this type.

CHAPTER VIII

CAN DECISIONS BE AUTOMATED?

The question of automatic decision making is indeed a controversial one. It frequently provokes responses characterized by hostility, derision, or extremist views. The reason is probably found in a wealth of journalistic assertions which have painted an exaggerated and over-enthusiastic picture of the capabilities of computers. Such oversimplified statements as those which proclaim that computers "think" and "learn" are typical of the views which have culminated over the years in vigorous and indignant reactions. This hostility is often transferred to the most cautious attempts to explore the use of computers for decision-making and the usual result is an equally oversimplified assurance that "computers can never replace the human brain."

It should be obvious to the reader at this point that neither of these views is accurate. Computers <u>can</u> make <u>some</u> decisions. Throughout the foreseeable future there will also be some uncertainties which cannot be programed for computer decision. Furthermore, some decisions <u>can</u> be made by computers which <u>ought not</u> to be automated. The use of a powerful computer is expensive in terms of equipment, manpower, and programming time. Unless application of the computer results in some compensating saving in equipment, manpower, or money, or unless a sufficiently vital gain in capability can be realized, it is pointless to employ automated decision

Which decisions <u>can</u> be automated? A consideration of the methods and techniques involved will provide a general answer to this question. To automate decision-making the decision-maker (computer) must be programed. This means that humans must be able to anticipate by months that a particular uncertainty will arise. They must be able to reduce all the elements of the problem to the form of a model or to some other clear logical relationship, and they must be able to analyze it thoroughly. All possible courses of action must be clear (or the means determined for calculating such courses of action), the possible outcomes must be considered, and the method of calculating the value of each outcome established. Only when these quantities, values, and factors are determined can the general rules for solving the problem be provided to the computer. Thereafter, the computer can, of course, quickly solve any other problems of an identical type.

All these requirements dictate that if a military decision is to be automated, it must be of the repetitive type or it must be anticipated in full form many months before the decision arises. To be susceptible to analysis, it must also be a decision of the "puzzle", as opposed to the "difficulty" type.

Which decisions <u>should</u> be automated? The answer to this question may be found in the weaknesses of present decision-making methods discussed in Chapter V. One of these weaknesses is human fallibility. Since computer decisions can be no better than the programs provided, it is clear that we can not expect better decisions from computers than humans can make, given time for the human to function. However, we can expect better decisions than the human makes when he is operating under the stress of time, distraction, or pressure. Since such pressures are typical of the encounter decisions, this type is a good candidate for automation.

We can also expect uniformly good decisions from the computer when the program represents the best effort of a capable human or group of humans. Therefore, if it is desired to raise the general level of quality of decisions made by a wide cross section of officers using extensive, sometimes burdensome, policy directives and guidance, it might be done by employing automated decision. This step could provide the means of overcoming a second weakness of present methods--the difficulty of obtaining uniformly acceptable decisions without stifling the lower echelons with masses of detailed instructions.

A third weakness of present decision-making methods has been stated as the problem of "institutionalized command" which makes it difficult for a commander to exert timely influence. This problem is particularly acute when the stress of time is a factor and the commander is forced to accept much of the work of his staff without question. These conditions are found in encounter decisions involving a considerable degree of group effort. Air defense of a task force is a good example. Automation of this type of uncertainty might eliminate much of the supporting role of the staff and put the commander back into more positive and direct control of the situation. Knowing that routine decisions were beind made rapidly, in accordance with standard and acceptable criteria for action, the commander would be free to devote his attention to the larger roles of supervision and direction.

The fourth weakness of present methods, that of human processing of large data loads, provides a natural choice for automation since this is the kind of application which can be automated most easily and effectively. Here we are talking about a role which the computer may perform even if it cannot be used for making the final decision. This is the role of puzzle-solving and data handling which supports the ultimate response to an uncertainty of the "difficulty" type.

To clarify the discussion so far, it can be said that automatic decision is possible at this time only in the case of those uncertainties which tend to arise repeatedly in the same basic form, or which can be fully anticipated well in advance of the need for decision. Such problems must be of the puzzle type, susceptible to thorough analysis. Encounter decisions offer the best possibility for great gains through automation. Problems of this type tend to arise in specific operational or tactical situations at sea, are solved by informal methods without the support of large staffs, and usually involve levels of authority below fleet commander.

In addition, it is profitable to automate certain decisions, where possible, in order to overcome the weaknesses of present decision-making methods. These types include encounter decisions which tend to involve staff action, those in which great masses of data must be analyzed or otherwise processed, and those decisions now dealt with by means of extensive decentralization and delegation in conjunction with large volumes of detailed instructions.

Tabulated in Figure 7 are the earmarks of decisions which it might be both possible and profitable to automate and those which offer little promise in this regard at present. Generally speaking, those decisions which have a number of the characteristics shown in the first column are likely to be worthy of close analysis if automation promises sufficient gains to offset the cost involved. Some examples of problems involving decisions with the general characteristics in the first column are listed below:

Assignment of weapons to targets

Disposition of forces

Choice of methods, units, and techniques for attack

Measures to avoid mutual interference or damage to friendly forces in the employment of atomic weapons

Ballistic missile defense evaluation, assignment, and decision to fire

Maneuvering and navigation problems

Air and antisubmarine search operations

Air, submarine, or electronic emission classification and identification

There are several significant implications involved in undertaking the use of automatic decision-making at sea. One deals with the provision of human override of automatic decisions. This feature is both feasible and desirable but it must be remembered that when automation is used to gain speed in response to uncertainty, the override provisions should not be allowed to offset this gain. In other words a time limit for human intervention should be considered if the advantages of fast reaction are not to be lost through human indecision and vaccilation.

FACTORS USED IN CLASSIFYING DECISION. (See Chapter V)	MAY BE POSSIBLE AND PROFITABLE TO AUTOMATE	GENERALLY CANNOT OR SHOULD NOT BE AUTOMATED
Puzzle vs difficulty	Puzzles	Difficulties
Degree of repetition	Repetitive	Non-repetitive (unless problem can be anticipated)
Encounter vs setpiece	Encounter	Setpiece
Type & scope of problem	Specific tactical or operational problems	Long term goals, broad concepts and policies which set the stage for operations or combat
Level of authority	Usually low level (Force CDR and below)	Usually high level, shore based (Fleet CDR and above)
Degree of formal process and group effort involved	Informal, individual-oriented (with exceptions)	Formal, large staff effort (with exceptions). Automation may be useful in supporting role.

FIGURE 7

CHARACTERISTICS IDENTIFYING DECISIONS WHICH MIGHT BE AUTOMATED

A second implication arises in those cases where the computer may be used in support of a decision or where it reaches decision with the aid of or in cooperation with certain manual inputs. In such cases the problem of communication may arise much as it does in the operation of a large staff. Great care must be taken to insure that both computer and staff know what each is doing through an adequate and timely flow of information between them. The computer must be carefully integrated into the normal flow of information within the organization. This specific problem is related to the larger concept of man-machine relationships. In light of the amount of work done in this field in recent years, the problem does not appear to be insurmountable.

Two other implications of automated decision are closely involved with the concept of computer programing. The commander who relies on automatic decision-making must know, understand, and approve of the general provisions and criteria for decision used in the program if he is to accept the decisions produced by it. To this extent he must be prepared to accept responsibility for the work done by the programer in much the same way that he now accepts responsibility for the actions of his subordinates who exercise delegated authority. Consequently he must have an appreciation for the complexities and time-consuming processes involved in preparing and checking programs. If the work of the programers is to be responsive to the requirements of the commander, the commander must provide the flow of concepts, guidance, and specific recommendations needed by the programer. This relationship between commander at sea and programer would be similar to that now existing between commanders at sea and those who formulate, correct, and distribute tactical doctrine publications.

A final word of caution is appropriate at this point. The writer has attempted to show that there are many decisions involved in operations at sea which can be made by modern digital computers and that, of these, there are some which ought to be made in this way. However, the limitations on automatic decision have also been discussed. Much work remains to be done before such formidable obstacles as lack of valid scales of military worth can be fully reduced or surmounted. The situation today is such that the question of automatic decision can only be answered with assurance in the light of specific case by case analysis of the problem under consideration.

To a very large extent, continued progress in this field will hinge upon an understanding by responsible senior officers of the capabilities and limitations of computers used in this role, and of the general nature of the analytical methods and techniques available. Progress also depends upon the ability of these officers to recognize problems and uncertainties which, by reason of their characteristics, are capable of automatic solution, and which, because of the inadequacies of present methods of response, seem to call for the application of these new and powerful techniques.

SUMMARY

Command and control in the modern naval environment has been made extremely difficult by the characteristics of new weapons, the diverse composition of forces, and the widely dispersed dispositions employed. These characteristics of today's environment have imposed stresses of time, speed, load, and complexity which today's slow, manually operated command and control facilities cannot meet. As a result the commander is becoming isolated from the tactical situation in which he operates. The problem is shared by all services and each is turning to the capabilities of the digital computer to provide relief.

The application of miniturization has produced small, reliable computers which need little power and no special cooling. These can be used at sea. They can be made universally applicable to various problems by the quick and simple process of feeding a new computer program into the memory of the machine. The preparation of such programs, however, is a long and difficult job. The use of automatic coding techniques offers promise of some relief but the analysis of problems, which must precede programing, will remain as a complex and critical requirement.

The Naval Tactical Data System (NTDS) is an example of the way in which computers can solve command and control problems. The NTDS computer will receive tactical information from many sources, process, correlate, and store it for use on demand by the various weapons and control facilities which it serves. The system employs electronic displays of information, in simplified, symbolic form, from a multiplicity of ships and aircraft. Computers communicate directly with each other at extremely high speeds

via automatic data links. In addition to handling information, NTDS will perform evaluation and control functiona and will recommend assignment of weapons to targets. The development effort includes establishment of computer programing facilities and the training of personnel in the data processing technology.

Other computer applications are in development or can be anticipated. At present these various shipboard data processing developments are largely uncoordinated. If continued, this piecemeal approach will result in duplications of effort, unnecessary expense, and a variety of data processing equipment operating independently aboard ship to do a number of separate jobs. What is needed is a single coordinated effort to provide an integrated shipboard data processing center. This facility could not only do all the specific jobs now envisioned, but could also be designed to provide the total data processing capabilities needed for a comprehensive, unified shipboard command and control center. Such a facility would also have the capability for making decisions automatically.

There are six basic characteristics by which decisions can be classified. Present methods of decision making are all based on variations of the basic human response to uncertainty. The fundamental weaknesses of present decision-making methods are human fallibility (especially when aggravated by stress), the growth of institutionalized command which isolates and restricts the influence of the commander, inability to cope with large volumes of complex data, and the difficulty of achieving uniformly acceptable decisions without stifling subordinates with masses of directives.

A hypothetical decision-making machine (in actuality a computer) would select the various alternative responses to a specific problem, identify the possible outcome of these alternatives and predict the probability that each outcome would occur. It would then assign a measure of value to each outcome and apply an appropriate rule for action in order to choose between alternatives. There are a number of analytical techniques and other intellectual tools which might be employed by the decision-maker. These include statistical decision, game theory, gaming, and cybernetics. The major limitation in decision theory is the inability to measure military worth in many cases.

Using the above techniques, computers can make some decisions. However, some problems are so complex, the values and criteria for action so vague, that they cannot be analyzed and programmed for automatic decision. Though some decisions <u>can</u> be automated, only when the result is substantial savings or great gains in capability <u>should</u> they be automated. Generally speaking, encounter decisions which are repetitive, having the characteristics of puzzles rather than difficulties, are the types which lend themselves to automation. These decisions tend to occur at lower levels of authority, deal with specific tactical problems, and are made today by individual-oriented, informal methods.

In short, if the Navy integrated all shipboard data processing developments now anticipated, a fully effective shipboard data processing center could be provided, at less cost, to meet the total information needs of the ship and of the commander for the control and coordination of his forces. This center would provide a clear, complete, and current picture of the location, status, activity, and movement of own and enemy forces plus appropriate information as to other elements of the environment such as weather and geography. It would also perform the required calculations and assessments in support of control functions. Furthermore, if the present, somewhat irrational prejudice against automatic decision could be overcome, this facility could be designed from the outset to make those decisions which meet certain criteria. By thus allowing the machine to do what it can do best, many of the present weaknesses in decision-making could be overcome and the commander and his staff could be freed to concentrate on those problems and uncertainties which only the human can solve.

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