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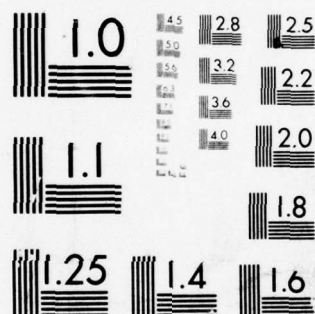
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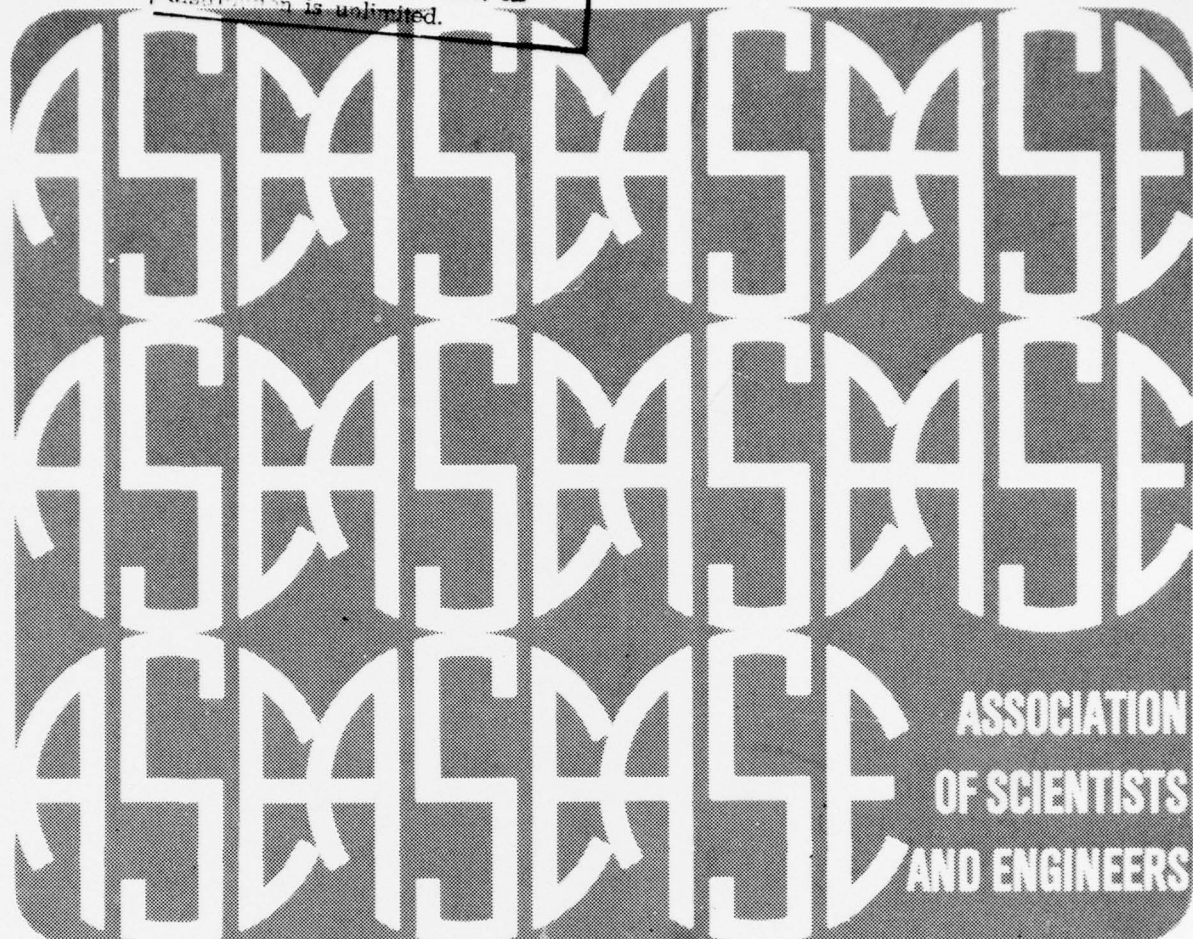
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**THE ROLE OF HUMAN ENGINEERING
IN NAVAL SHIP DESIGN**

Norman I. Stein

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**14TH ANNUAL
TECHNICAL
SYMPOSIUM**

ASSOCIATION OF SCIENTISTS AND ENGINEERS OF
THE NAVAL AIR AND SEA SYSTEMS COMMAND
DEPARTMENT OF THE NAVY — WASHINGTON, D.C. 20360

1977

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SYSTEMS ENGINEERING & ANALYSIS BRANCH
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WORK STUDY/HUMAN FACTORS SECTION
NAVAL SHIP ENGINEERING CENTER

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ABSTRACT

This paper defines the role of human engineering: why it must be integrated into the design effort; the methodology used; the applicable documentation; and the benefits obtained. Some examples of current NAVSEC efforts in human engineering relative to the AO 177 Fleet Oiler and the Amphibious Assault Landing Craft, are presented.

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INTRODUCTION

Human engineering, life support, and personnel selection and training together constitute the field of human factors. Human engineering consists of those aspects of the human factors field which are design-oriented; primary emphasis is on the design of system equipment for effective interfacing with human operators, maintainers, and users. Human engineering involves the determination of man's capabilities and limitations as they relate to the operation and maintenance of equipment and then the application of this knowledge to the planning, design, and testing of each system to ensure efficient, reliable, and safe operation by the human operator. The aim of human engineering is to ensure the level of man-machine system performance needed for mission success.

Naval Material Command policy requires that the operators and maintainers of Navy systems shall undergo the same development, test and evaluation steps that equipment elements of the same system undergo. Human factors then, is an essential part of all Navy system development and acquisition effort. In carrying out this policy, the assistance of the Navy's Bureau of Personnel (BUPERS) and Bureau of Medicine and Surgery (BUMED) is enlisted. BUPERS provides support in personnel selection and training, and BUMED in life support.

To some degree, human engineering, selection, and training can be traded off with one another. That is, in order to attain a given level of performance from a man-machine system, a deficiency in any one of these three areas may be at least partially compensated for by the other two. For example, if there simply are not enough good men to go around and selection standards must be relaxed, then human engineering can simplify system operation as much as possible, and more attention would need to be devoted to training to develop the needed skills. With respect to these trade-offs, the position taken by the author is that human engineering should never be neglected. The reason is that human engineering is accomplished once by a small corps of personnel and the total dollar figure is small. Selection and training, however, apply to much larger populations with a continuing cost impact throughout the operational life of the system. Therefore, compensating for inadequate human engineering by using either higher selection standards or more comprehensive training programs ends up invariably as the costlier alternative. The point, then, is that planning and implementation of sound human engineering programs not only directly benefit individual man-machine systems, but also help the Navy make better use of its overall resources.

A. Benefits from Systematic Human Engineering

The payoff in conducting a systematic human engineering program is realized in improved system performance, reduced training costs, improved manpower utilization, fewer errors and accidents, reduced maintenance costs, and higher probability of mission success. Without applying a systematic human engineering program, attainment of an effective ship system is fortuitous and improbable.

Failure to apply systematic human engineering can be costly - research indicates that a high percentage of all ship system malfunctions are attributable to human error. Even increasing automation of ship systems does not eliminate the application of human engineering programs, since man is still involved as a user and maintainer.

To maximize the payoffs previously cited, human engineering must be applied throughout the ship system life cycle. It starts with inputs to the Conceptual Phase, and continues throughout Preliminary/Contract Design, Development and Production, Test and Evaluation, and finally Fleet operations.

B. Overview of Human Engineering

The need for human engineering in the Navy is based on the fact that the science of man and his capabilities must keep pace with, and be included in, the hardware design technology if system effectiveness is to be maximized. Machines never fight alone; they need men to operate and maintain them. The task, then, of human engineering is to elicit the best performance from man and his equipment by combining them in such a way as to optimize the man/machine/environment system. The key concept in human engineering is that man is an integral part of any Navy system - not an adjunct to it - and, therefore, engineering, for human functions is just as important as engineering for mechanical or electrical functions.

In the past, engineers responsible for design of new systems have sometimes failed to use human engineers, citing three major reasons. First, the design engineer is a human being and thus can reasonably know what a man can and cannot do. Secondly, with or without human engineering, the operator/maintainer of the system will adapt to it eventually regardless of its design. Finally, human engineering costs money which can be better spent on hardware acquisition. None of these are legitimate reasons for omitting human engineering from a development project.

Ultimate responsibility for ensuring that human engineering gets into the system design does, in fact, rest with the design engineer. But simply being human does not qualify him as a human engineering expert. Human engineering over the years has become a separate, distinct profession complete with methods, research data, and criteria. The design engineer should be aware of what human engineering is, and where it should be used in his particular project.

Because man is so adaptable, many previous Navy systems which had little or no human engineering included in their design have operated successfully. However, the costs in terms of personnel selection, training, system errors, downtime, etc., over the total system life cycle prohibit this approach in the future. Selecting, training, and maintaining personnel often comprise the largest single expense, usually over 55% of the life cycle cost, in operating and maintaining a Navy weapon or support system. If the system can be designed to lower the training requirements or make available a larger inventory of available operators/maintainers, then system manpower costs can be reduced.

Human engineering proceeds on the basis that the capacities and limitations of man are established within certain natural limits. If system design requires human capabilities beyond these limits, maximum system efficiency is not achieved, even though the system manages to operate at some lesser level of performance. The expeditious use of human engineering during design can assure systems which are adapted to man's natural limits, and thereby reduce training requirements, increase potential operator/maintainer populations, and minimize overall system costs.

C. What do human engineers do?

In collaboration with hardware engineers, human engineers seek to develop new and improved man-equipment interface that will simplify operator/maintainer tasks and increase probability of mission success. They seek to achieve displays that will most effectively present information to the human senses, to obtain the most efficient controls for human operation, and to create an optimum work environment. Because the successful design of a system requires consideration of man's basic characteristics, human engineers study man's sensory capacities, muscular strength and coordination, body dimensions, perception and judgement, basic skills, work capacity and requirements for comfort, safety, and freedom from environmental stress. Such studies include both basic and applied experimental research, utilizing scientific methodology to collect quantifiable data. Thus, the human engineer knows and studies man in a system context just as he knows and studies equipment. Thus, this knowledge is used to create a man-machine system which combines the best of both. An example will be presented later of recent human engineering efforts conducted in NAVSEC for the AO 177 Fleet oiler and the Amphibious Assault Landing Craft Program.

HUMAN ENGINEERING DOCUMENTATION

A. Instructions

Over the past years, several instructions and general guides have been issued covering the use and need for human engineering in Navy development and procurement programs. NAVMATINST 3900.9 (1) is particularly significant for human engineering in Navy development Test and Evaluation, and production programs and projects. This instruction presents official NAVMAT policy on human factors.

As mentioned previously, the official policy requires that the human element of Navy systems shall undergo the same development, test, and evaluation steps as equipment elements of the same system. This requires, in turn, integration of appropriate human factors information into design and the use of such information in all major management and/or technical decisions and documents. As a minimum, this will involve human factors inputs to project documentation, proposal evaluations, contractual statements of work, and T&E plans.

B. Specifications

Until 1968, each branch of the military utilized its own independent human engineering specification. In February 1968, MIL-H-46855 was issued, superseding all other independent human engineering specifications and providing therefore, a single triservice specification. (2)

This document establishes and defines the general requirements for applying human engineering principles and criteria to the development of military systems, equipment, and facilities. It is to be used as a contractually binding and controlling document on all ship system development programs. It may be unnecessary to call out all sections to MIL-H-46855 on every project; however, it is the responsibility of each project manager to select those parts of the specification which should be invoked as contractually binding requirements.

C. Standards

The one standard most widely used in ship system development programs is MIL-STD-1472, (3) "Human Engineering Design Criteria for Military Systems, Equipment and Facilities". As the name implies, this standard provides specific human engineering design criteria for such items as visual and auditory displays, controls, labeling, anthropometry, operating environment, workspace, and control panel layouts. This standard is normally invoked as a contractually binding document.

D. Reports, Manuals, and Books

Besides the previously listed instructions, specifications, and standards, there are a number of reports, manuals, and books which contain human engineering design criteria. Frequently, one or more of these items are referenced in an RFP. This is particularly true of two books: "Human Engineering Guide to Equipment Design", (4) and "Human Engineering Guide for Equipment Designers" (5). Also, the design handbook, NAVSHIPS 94324, "Maintainability Design Criteria Handbook for Designers of Shipboard Electronic Equipment" (6), which presents a basic understanding of shipboard maintenance practices and philosophy.

AVAILABLE TECHNIQUES FOR HUMAN ENGINEERING ANALYSES

Over the years human engineers have developed a number of powerful tools and methods to aid in applied human engineering work. The following methods which are appropriate for use in concept development and analyses are discussed below.

A. Functional Block Diagramming

Block diagramming is perhaps the most familiar means of showing basic system organization and functions. It should be noted that much of what purports to be "functional" block diagramming is really equipment block diagramming as evidenced by the appearance of blocks labeled "display console", "data entry panel", "tape recorder", etc. Functional block diagrams should not be allowed to evolve into equipment block diagrams prematurely. As an example, "detection" is functional terminology, while "detector's console" is not; and already assumes an allocation of functions to man and machine. Since allocation of functions should always follow development of the initial system concept, it is important to avoid equipment representation and its implication that function allocation has already been completed. A premature man/machine allocation may overlook the possibility that a man may perform a given task with greater cost effectiveness than a machine. However, as the various trade-offs are considered, the original block diagrams may be refined for each of the alternatives under consideration.

B. Information Flow Charts

Information flow charting is a technique used to show the flow of information in terms of operations decisions required to accomplish the functions identified in the block diagram. The initial information flow charts should be concerned with gross functions without regard to whether functions are performed by machine or by man. The information flow chart is similar to the flow chart used by computer programmers. Both charts are based on binary choice decisions and intervening operations. That most decisions can be reduced to a binary situation is evidenced by the vast array of problems which can be computerized via simple binary logic. There are two important reasons for using binary decision logic as standard in all information flow charting:

1. To expedite communication through use of simple yet universally applicable conventions.
2. To provide for easy translation of information flow charts into logic flow charts for computerized sections of the system.

It should be noted that the flow paths employed in flow charting are complete; i.e., every path either recirculates or eventually terminates in a valid exit and no ends are left dangling. This fact is very important and is what makes the information flow chart such a powerful tool. The flow chart technique imposes a discipline upon the analyst, requiring him to consider alternatives which might easily be overlooked. The information flow chart may be the first tool to reveal serious shortcomings in system thinking or to indicate that information flow is much more complex than originally believed. For these reasons, it is considered an indispensable tool to the system designer and the human engineer.

C. Man-Machine Allocation Trade-Off Studies

With the completion of the block and gross information flow diagrams, it is appropriate to perform preliminary studies of man-machine allocations for each of the alternate designs being considered. The assignment of the functions, actions, and/or decisions to man and/or machine must be based upon: (1) the known capabilities and limitations of the human being, (2) the state of the art of hardware and software, and (3) estimated performance to be required in terms of speed, accuracy and load.

At the conclusion of this effort, a tentative assignment to man and/or machine for each function, action, or decisions on the block and information flow charts should be made. Thus, it is at this point in the system development cycle that consideration is first given to identifying specific equipment, software, and personnel contributions required to make the system work. Man-machine allocation trade-off studies must be performed for each alternative being considered. Like the flow charts, the man-machine allocation studies will be continually reworked and updated as the system continues through the development cycle. When alternative concepts may involve different manning levels life cycle personnel costs should be considered in trade-off studies.

D. Preliminary Man-Machine Analysis

In simplified terms, man-machine analysis refers to critical examination of the man-machine interfaces involved in operating, maintaining, and using system equipment under conditions approximately those of operational employment in order to identify all potential man-machine problems. Obviously, such analyses could not be completed for every man-machine combination existing in a particular system, especially if the system is large, as for example, a ship. But a preliminary analysis of selected man-machine interactions is appropriate in order to identify which problems should receive greater attention as system development progresses. As an example, these analyses might uncover a human operator performing a complex mental task during combat; an equipment function which required critical, but infrequent human operation; or a decision requiring a large volume of input data in various forms. Since the charts and allocation studies are at a gross level, the man-machine analyses must also be performed at a gross level. But this is the time to begin pinpointing potential man-machine interaction problems.

E. Preliminary Operability/Maintainability Analysis

The objective of this analysis is to make an initial assessment of the impact of human performance on the operation of the overall system for each design alternative being considered. Specifically, the human engineering analyst should address the following:

1. To what extent is system performance a function of the human operator/maintainer?

2. Which human functions are particularly critical to meeting the mission requirements?
3. What is the acceptable range of performance for these functions?
4. What areas should be called out for future study effort to ensure acceptable performance?

The analysis must include both system operation and maintenance functions. It is very important to assess the human contribution to system performance since, for most shipboard systems, machine executions are performed very rapidly with very low error rates and little variability. Thus, the bulk of system response time, error, and variability will reside in human functions. The necessity to establish realistic human operability goals follows immediately from these considerations.

F. Operability

1. Define the design goal in terms of quantity and quality of information throughout for that station under design load.
2. Make a rough prediction of the quantity and quality of information flow (throughput) which might be expected of the typical operator under design load.
3. Compare the predicted throughput with the performance goal. If the predicted quantity and quality of throughput both are equal to or better than the goal, operability may be considered to be satisfactory; if either quantity or quality is deficient, operability is unsatisfactory and the design concept should be altered as necessary to attain the operability goal.

G. Maintainability

The recommended approach to preliminary maintainability analysis parallels that for operability.

1. Define the design goal. Maintainability goals are established by analysis of the system maintainability concepts and gross man-machine allocations. The current trend in electronic system design is towards increased automation of the maintenance functions of fault detection, diagnosis, isolation, and repair so that on the surface it might appear that human engineering would play a lesser role in the design of these systems in comparison to predominantly manual maintenance systems. However, this is not necessarily, and perhaps not generally, the case. Decisions

relative to automating maintenance functions will require more rather than less consideration of man and equipment capabilities/limitations, since it is a basic shift of maintainer, not an elimination of responsibility. Also "automatic" systems are usually, in fact, semi-automatic that is, some form of human participation is required. For example, programs must be loaded into the machine, controls operated, and displays monitored, read, and interpreted. Finally, some maintenance functions cannot be automated economically; for example, removal, replacement, and repair of faulty modules.

J. Man-Machine Flow Charting

The purpose of man-machine flow charting is to aid in developing and evaluating concepts for each operator station. The man-machine flow chart is concerned basically with the man-machine subsystem or operator station. It is similar in concept to the information flow chart, but the decisions and operations with which it deals are confined to the man and the hardware and equipment closely associated with him rather than being representative of the system as a whole.

A separate man-machine flow chart is required for each manned station, as determined by the function allocation process.

In preparing such a chart, the human engineer should ensure that all logical possibilities are included, all loops are completed, and all operations are performable by the operator. He must then develop answers to questions of the following kind: (1) how will each operator decision be made? (2) what are the criteria to be used for decision making? (3) what information requirements must be met to provide a basis for decision making? Answers to such questions provide the working material for the next step; preparation of the operator station input-output chart, which further refines the operator station concept.

I. Input-Output Charting

The input-output chart begins simply as the man-machine flow chart stripped of all symbol-connecting lines. Then inputs and outputs are added. Note that every operation has associated with it at least one output (or else why perform the operation in the first place?). Every decision has at least one new input (or else why is a decision necessary?).

All inputs and outputs are indicated by arrows on the chart and are summarized in a tabular listing. If the input-output flow chart has been properly done, it will summarize all significant information categories which must be processed at the operator station.

J. Operational Sequence Diagrams (OSDs)

The OSD is a comprehensive means of showing major system functions and their interactions in sequential time. Together with the information flow charts, and man-machine and input-output flow charts developed previously, it effectively completes the base upon which detailed human engineering requirements for information, control, and display will be evolved.

The OSD uses a separate column for each operator, equipment station, or equipment unit to be analyzed. Each column shows the operations, decisions, delays, transmissions, and receipts pertinent to that particular system element. One of the main virtues of the OSD is that all major information flow between system elements, as well as within system elements, is represented. This view of the system concept may expose difficulties, omissions, or incompatibilities which would not otherwise be detected. When selectively applied, the OSD is a powerful tool for identifying and solving interface problems and for laying the groundwork for developing human engineering design details.

It should be noted that the OSD and the information flow chart are two quite different kinds of system representation. The OSD emphasizes the main activities associated with each major station and the interfaces between stations. The information flow chart, on the other hand, emphasizes the network of decisions and operations pretty much irrespective of where they occur. The OSD is particularly valuable for detecting conditions of overload and underload as well as interface problems, whereas the information flow chart checks on the logical consistency of the system concept. Together, they provide a firm base for evolving detailed human engineering requirements.

K. Link Analysis

This analytic tool is often used as a first step in developing an optimized panel, work station, or work area layout. Its purpose is to make a first estimate of the frequency with which various interactions occur between men and equipment and/or between man and man. The analysis first starts with the man and equipment interactions (links) established during the functional analysis, OSDs, and initial list of control-display interfaces. To this is added the man-man links which take the form of direct (voice) or indirect (radio, telephone, etc.) verbal conversations, walking from one place to another, etc. If the link analysis is being performed on a particular panel layout, there may be little of the man-man links involved. If the link analysis is performed on a CIC room, the man-man interactions will be extensive. Beginning with a particular design, all the interactions (links)

required to perform a particular task are examined carefully in terms of the frequency with which they occur and the importance they hold in completing the task. The importance and frequency factors are assigned some value (usually on a scale of 3) primarily based on the analyst's previous experience with similar system operators. When the frequency value is multiplied by the importance value, a "load" or "link" value is obtained. The panel, work area, etc., along with the links and their load values are drawn out permitting a visual picture of all the interactions taking place with the system under investigation. In this way, the design containing the fewest interactions, lower link loads, and smallest operator work loads can be tentatively established. An example of the link analysis procedure is provided later on.

RECENT HUMAN ENGINEERING EFFORTS IN NAVSEC

Two recent examples of human engineering efforts associated with the AO 177 Fleet Oiler and the Air Cushion Vehicle will be discussed.

AO 177 Fleet Oiler

The Ship Control Console which is to be installed on the ship's bridge is intended to reduce the personnel complement normally associated with ship movement control and to provide all necessary control requirements within immediate access to the individuals responsible for manning this console.

The descriptive data for this presentation were extracted from the AO 177 Contract Design "Ship Control Console", an excellent document prepared by NAVSEC, which details the extensive studies of HE criteria as they pertain to the design of this console.

The areas covered during this particular review and the observations, findings, and recommendations were as follows:

1. Physical Description. The Ship Control Console is a Standard Number One type of console (sit, with vision over the top), as depicted in MIL-STD-1472B. The variances between the actual console design and the standard console dimensions as depicted in the standard, are compatible with the criteria expressed in MIL-STD-1472B.

These anthropometric data used in designing this console represent the 5th, 50th, and 95th percentile of the adult male population entering the Navy. The 5th percentile was used for situations where physical proximity was involved (reaching controls). The 50th percentile was used where a range of adjustments was provided, and the 95th percentile was used for situations where physical clearance was involved (seats, access, space, and knee clearance).

The range from the 5th to the 95th percentile encompasses 90 percent of the population on which anthropometric data were obtained. For example, a measure of the 5th percentile would mean that, of a total number of people measured, 95 percent exceed that measurement and 5 percent are below it.

The 50-inch console height will not impair the view of the attendants with respect to the enlarged pilothouse windows. The attendant's seat is adjustable (raising or lowering) to compensate for the height of each individual attendant.

The detailed attention of the design engineer to anthropometric data has resulted in a console which will comply with all HE design criteria as specified in MIL-STD-1472B.

2. Functional Description. The console is designed for operation by two men, each seated. The left position is for the Ship Control Operator (SCO), and the right position is for the Officer-of-the-Deck (OOD). These positions are not interchangeable, i.e., the right position cannot assume the functions of ship control, nor can the left position assume the functions of the OOD. The console configuration consolidates many functions normally associated with pilothouse activities, thereby permitting a reduction in the number of required attendants. This same consolidation provides a more efficient complex for ship command and control.

3. Placement of Instrumentation. The placement of instrumentation on the console is based on four criteria:

- a. Priorities for location of controls and displays
- b. Grouping of controls and displays
- c. Association of controls and displays
- d. Spacing between controls

In determining the priorities for location of controls and displays, the following factors were considered: frequency and duration of use of the control or display, accuracy and/or speed with which the display must be read or the control activated, and ease of control manipulation in various locations in terms of precision and reaction time. Grouping of controls and displays was based on function, combined use, and relation to the same system component. Association of controls and displays was used in determining arrangement to aid in identification of which controls are used with which displays. Spacing between controls was based primarily on the need for blind reaching (i.e., the need to reach for and grasp a control without seeing it).

The ship control console instrumentation was separated into five physical/functional areas: steering, propulsion, exterior communication, collision avoidance system, and auxiliary devices. The steering and propulsion controls and displays are primarily utilized by the ship control operator and have been grouped for his convenience. The SCO position at the console has been established directly in front of the ship's heading indicator, since this is the most frequently observed indicator, and minimum parallax is required. The exterior communications facilities and collision avoidance system are primarily utilized by the OOD, whose position at the console has been established directly in front of the collision avoidance system for ease of observing the display area and reaching the associated controls. Both the OOD and SCO may utilize various auxiliary devices such as the intercommunication unit, ship's alarms, and general announcing microphone. These devices have been located near the center of the console for mutual benefit, with a particular device located nearest the most likely user. Individual dimmer controls have been located under the console work surface consistent with their infrequent use but within reach of both the SCO and OOD. The ship's telephone, general announcing system microphone, and sound powered jacks have been located on the vertical surface below the primary control area. This allows easy access to these devices yet prevents the cords from interfering with normal working operation. An additional feature of providing differently designed cradles for telephone handsets precludes inadvertent placement of handsets in the wrong position by the OOD.

4. Maintainability. The console was designed with plug-in instruments and controls (except for the Collision Avoidance System) to facilitate maintenance and has a frontal or side access which provides minimum disruption of operations when maintenance is required. Keyed connectors prevent improper placement of plug-in controls/indicators. Complete front access was provided with slide out and swiveling of major subassemblies for maintenance on the Collision Avoidance System.

Landing Craft Air Cushion Vehicle Program

The current objectives of the ongoing Amphibious Assault Landing Craft program are to develop and test two advanced development prototype craft (the JEFF-A and the JEFF-BB) and, at the same time, to develop in the USA an industrial capability and technology base in the ACV field. As the JEFF-A and JEFF-B are nearing completion, it has become apparent that it is necessary to move towards the next logical step in the program, namely, the engineering development of an operational Landing Craft Air Cushion.

A human engineering program was initiated, which will include the categories of crew accommodations, environmental control, deck handling, cargo handling, acoustics, and vibrations.

CONCLUSION

The need for human engineering in the Navy is based on the fact that the science of man and his capabilities must keep pace with, and be included in the hardware design technology, if system effectiveness is to be maximized. Machines never fight alone; they need men to operate and maintain them. The task, then, of human engineering, is to elicit the best performance from man and his equipment by combining them in such a way as to optimize the man/machine environment system.

With regard to the Ship Control Console, the impact of the human engineering effort generated a redesign of the navigation bridge level, which resulted in an overall reduction in topside weight, and subsequent improvement in pilot house operational visibility.

Concerning the Amphibious Assault Landing Craft project, the proposed human engineering effort will attempt to assess the impact and seek solutions to the problems of high ambient noise levels on the troops who will be confined to the cargo deck of the craft during the theoretical half hour or more, typical of a mission.

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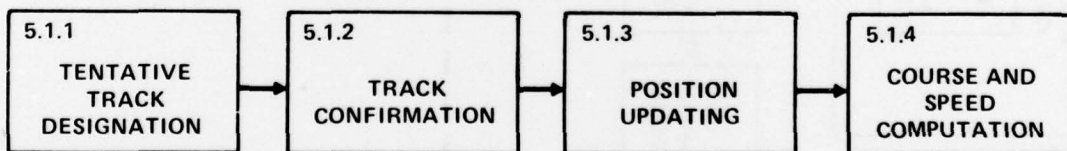
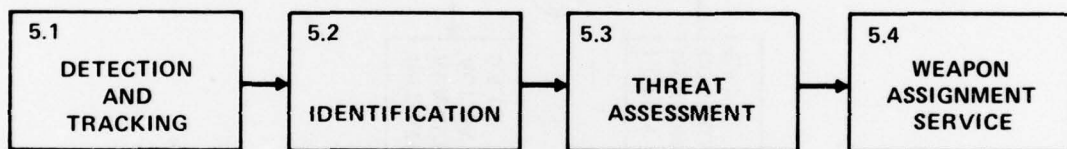
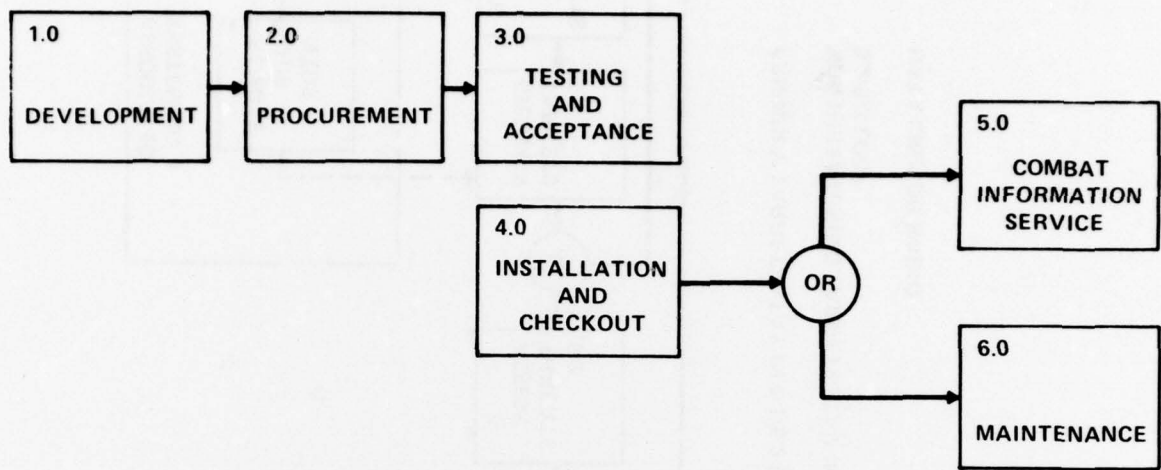


FIG. 1 LEVELS OF FUNCTIONAL BLOCK DIAGRAMMING.

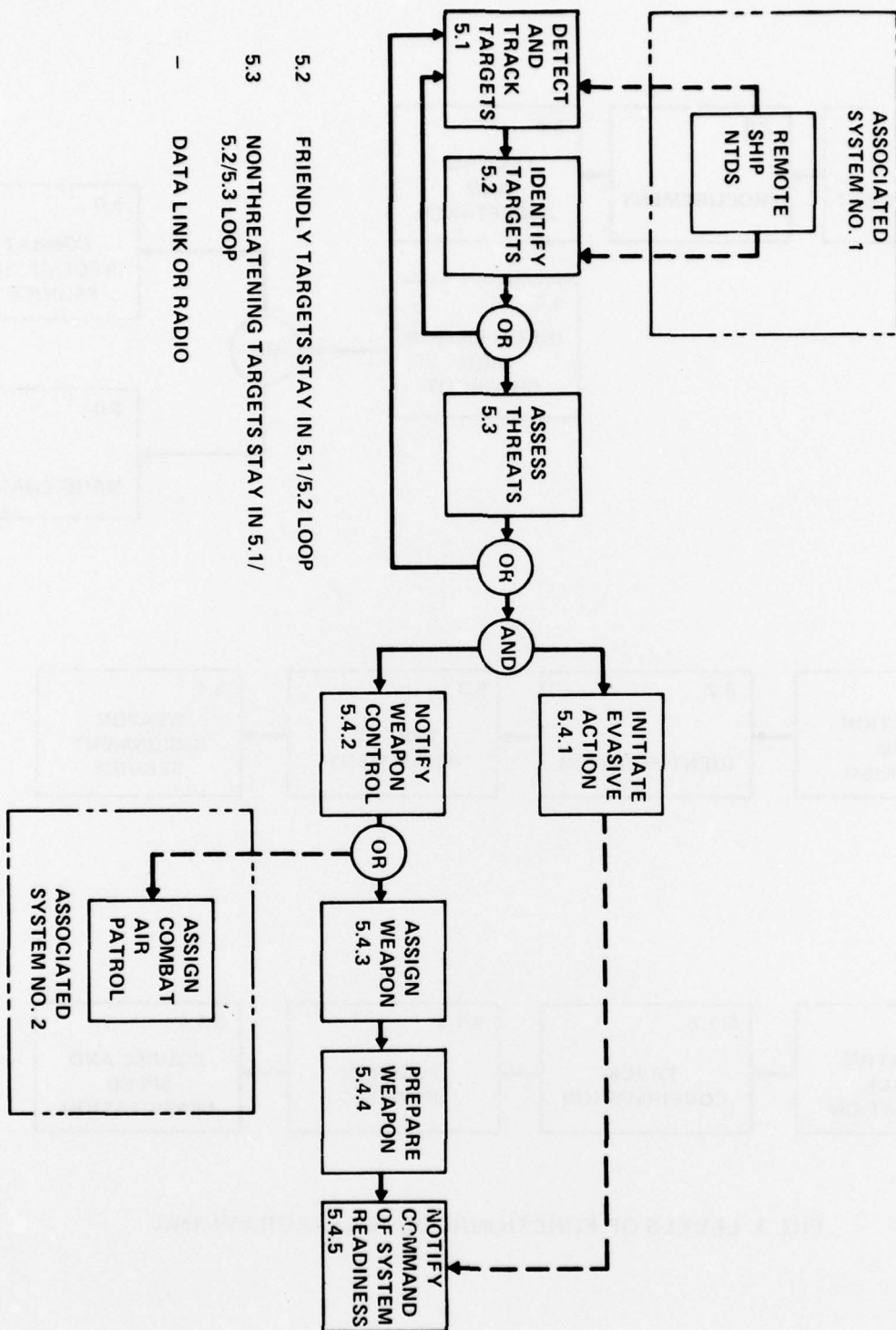


FIG. 2 ABBREVIATED BLOCK DIAGRAM, HYPOTHETICAL COMBAT INFORMATION SYSTEM.

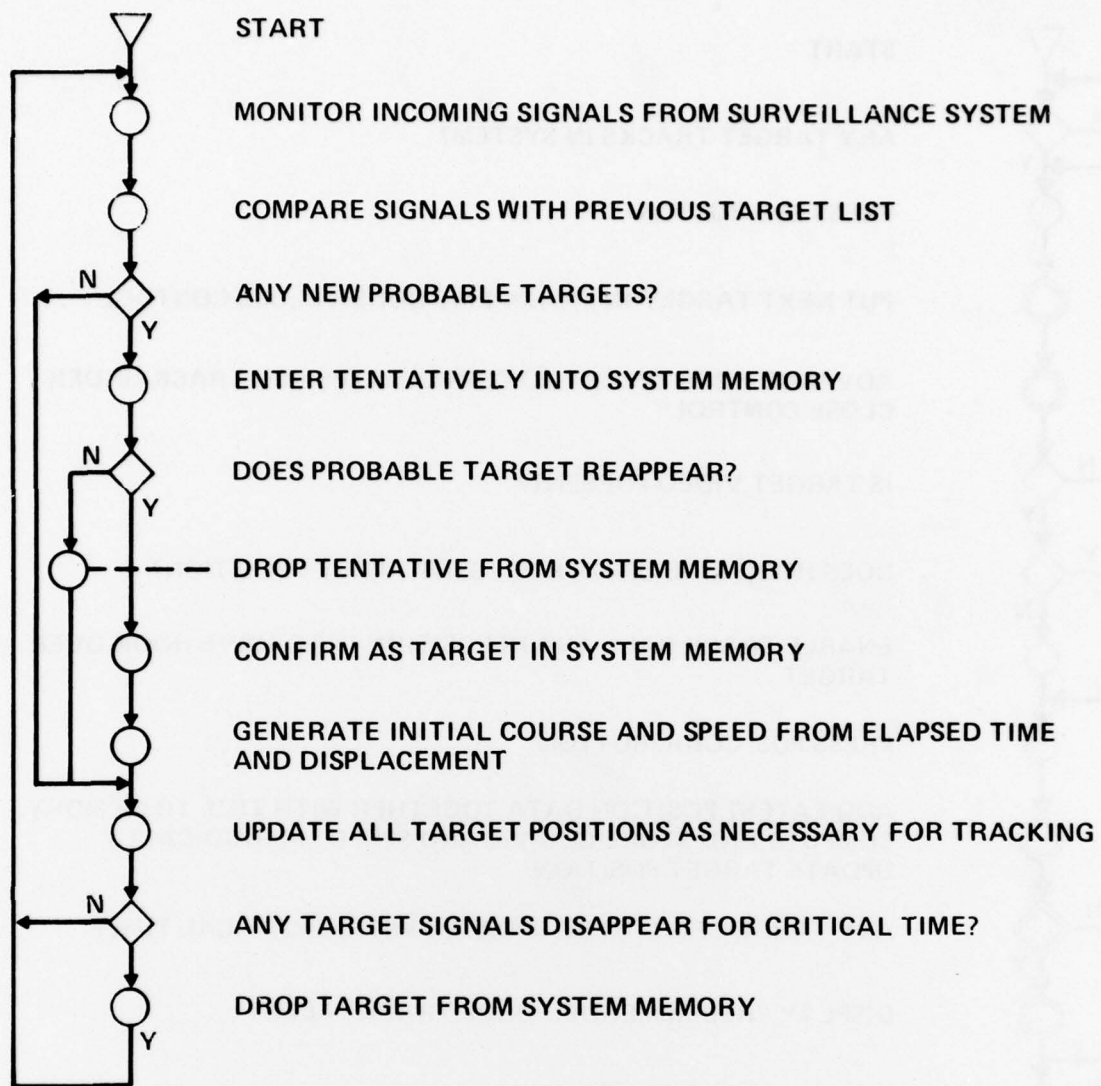


FIG. 3 GROSS INFORMATION FLOW CHART FOR DETECTION AND TRACKING
(NO MAN-MACHINE FUNCTION ALLOCATION ASSUMED).

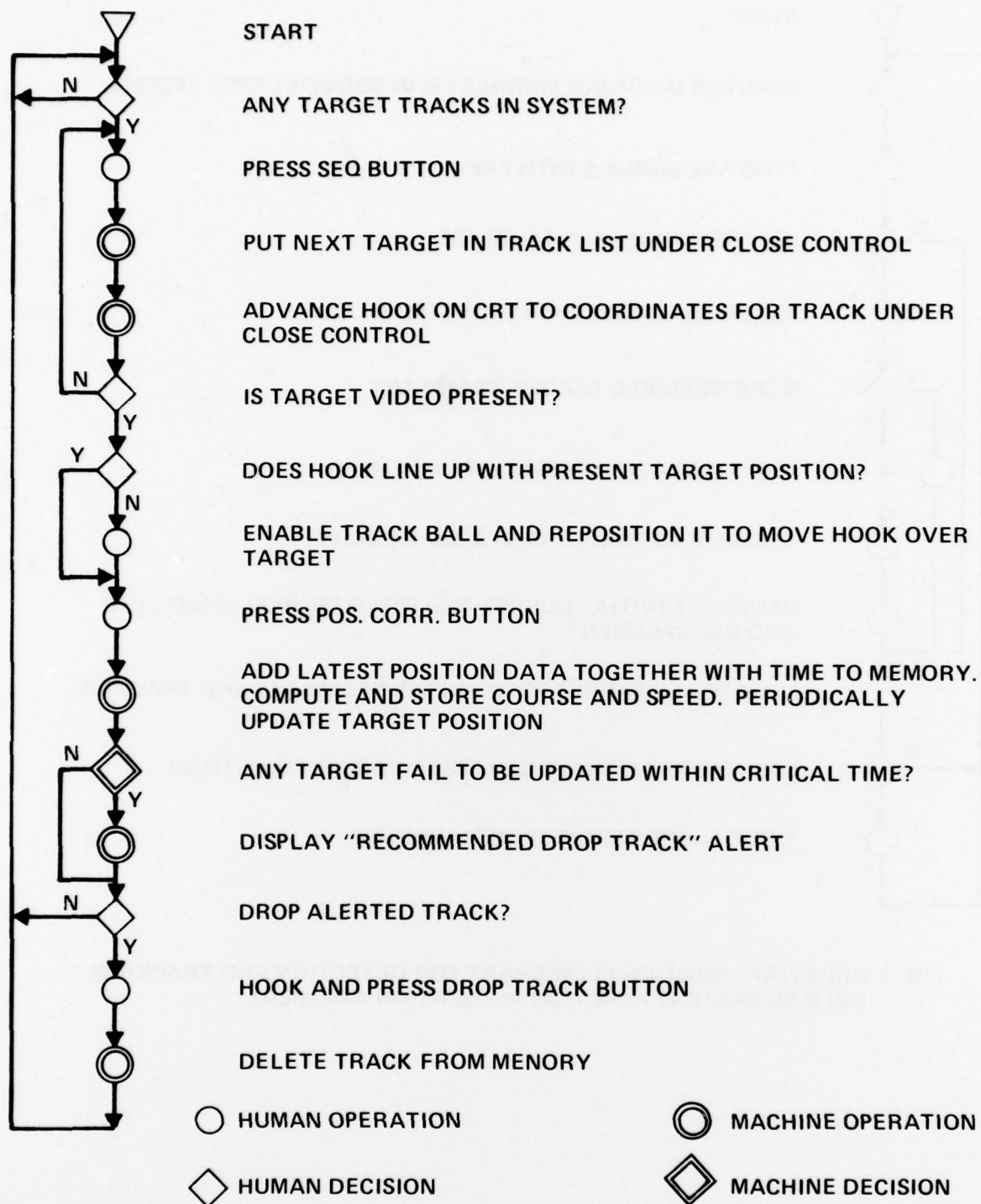


FIG. 4 INFORMATION FLOW CHART (HYPOTHETICAL – FRAGMENT OF FLOW FOR TRACKING FUNCTION).

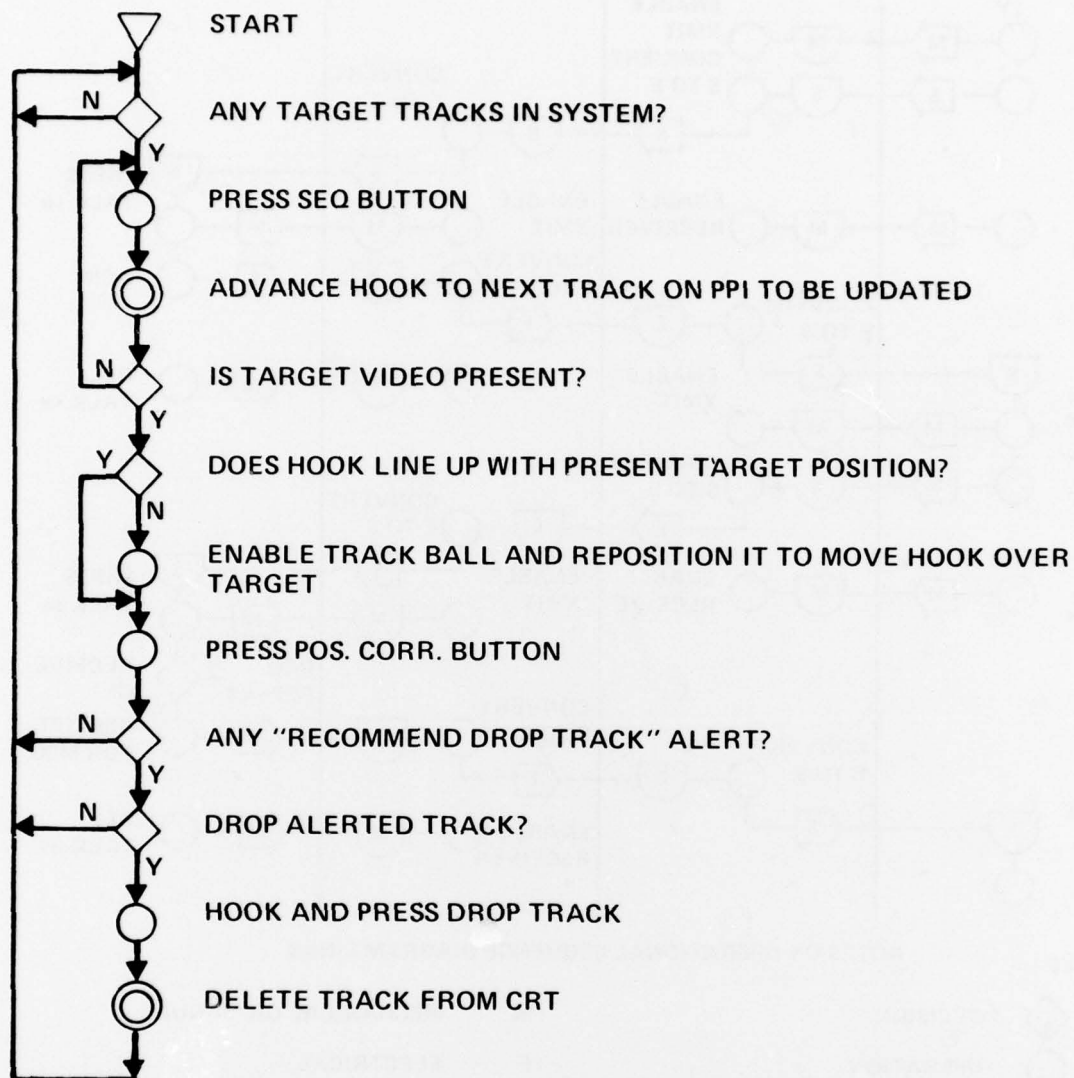
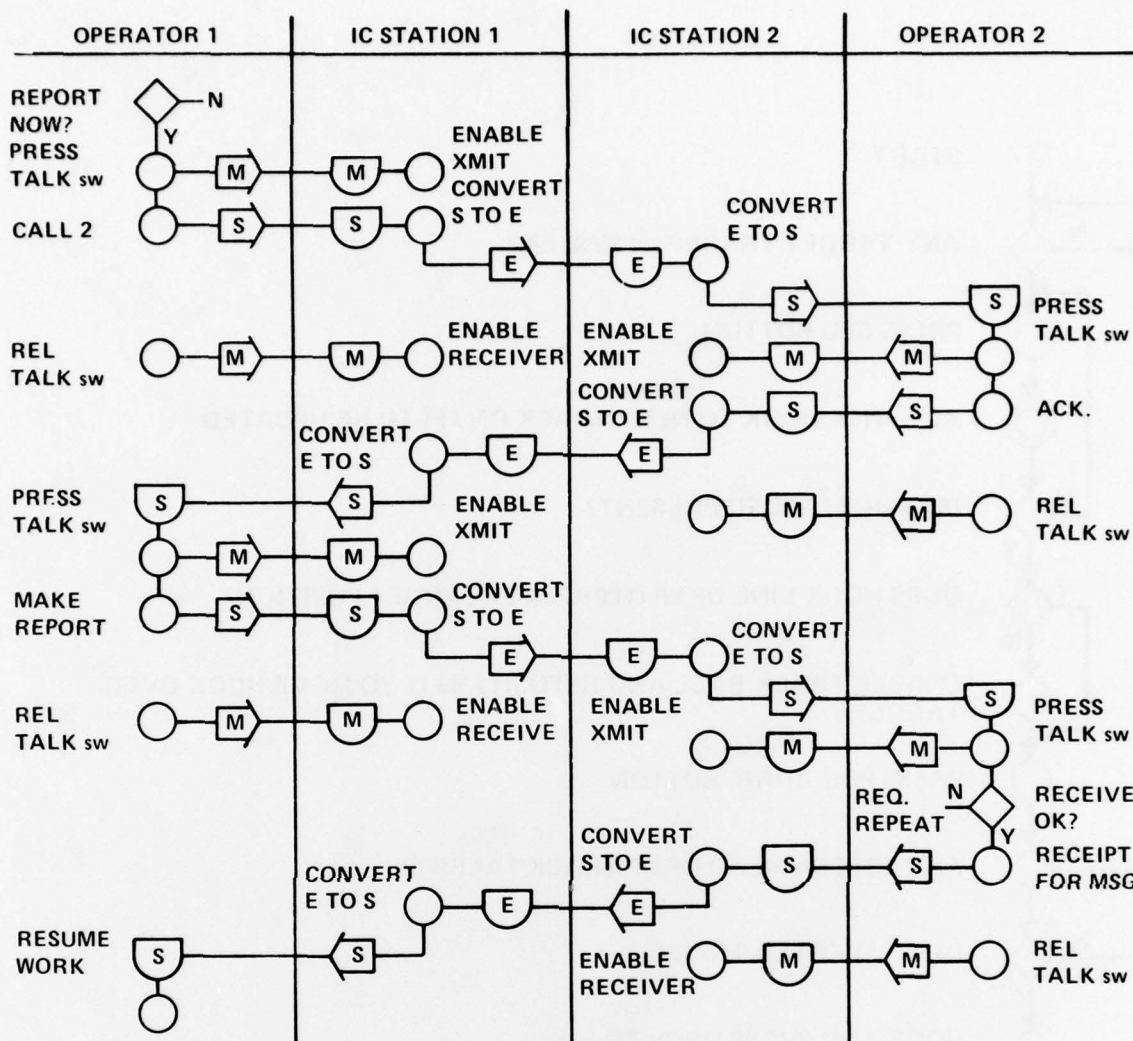
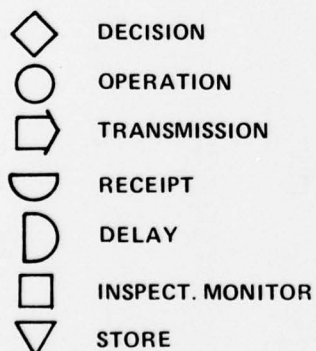


FIG. 5 MAN-MACHINE FLOW CHART.



SYMBOLS



NOTES ON OPERATIONAL SEQUENCE DIAGRAM LINKS

M MECHANICAL OR MANUAL
 E ELECTRICAL
 V VISUAL
 S SOUND
 ETC.

STATIONS OR SUBSYSTEMS ARE SHOWN BY COLUMNS
 SEQUENTIAL TIME PROGRESSES DOWN THE PAGE

FIG. 6 SAMPLE OPERATIONAL SEQUENCE DIAGRAM; TWO-STATION INTERCOM, IC STATION 1 ACTING AS ORIGINATOR.

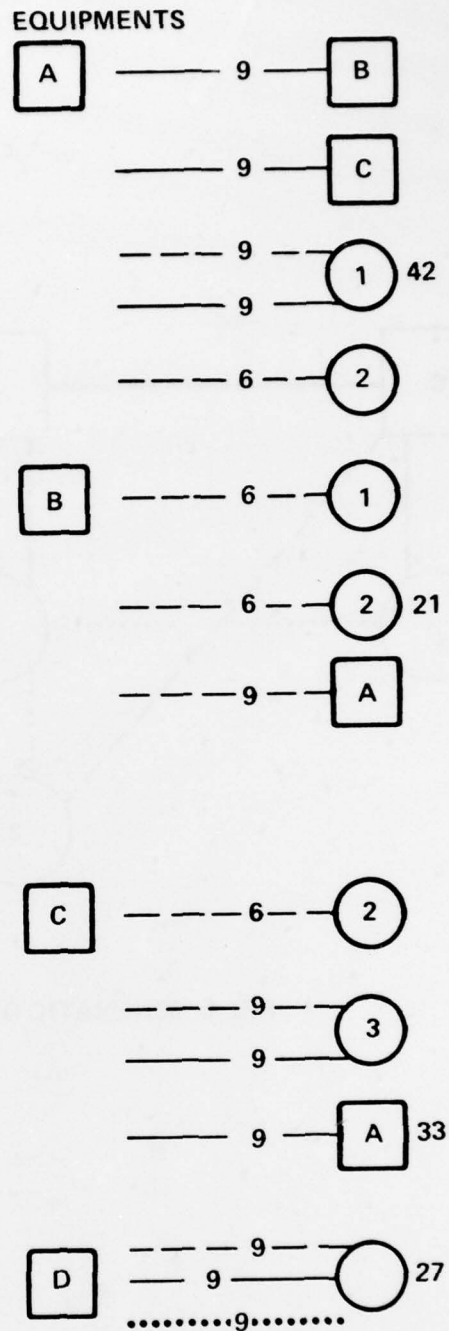
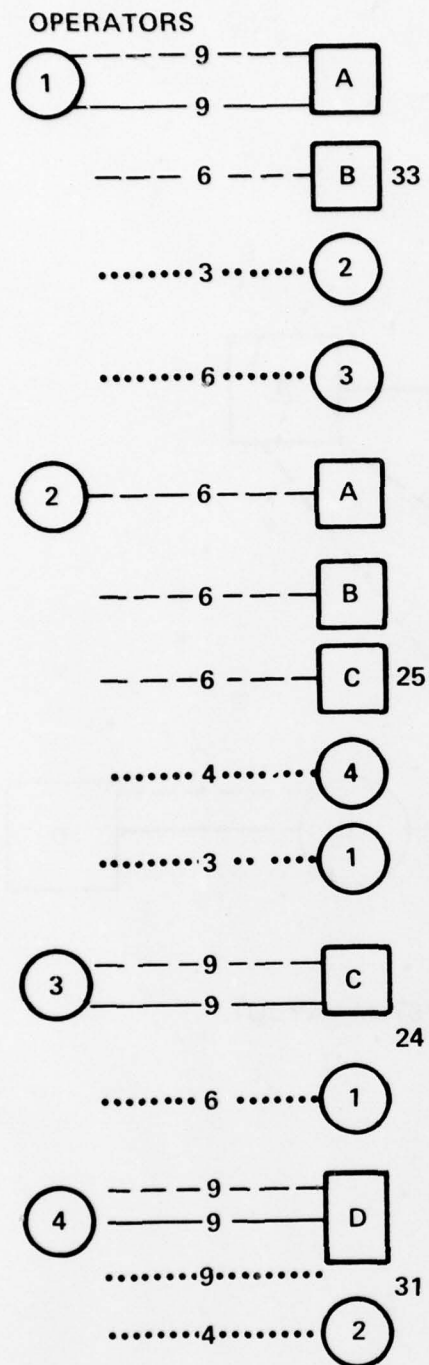


FIG. 7 SAMPLE ANALYSIS CHART FOR LINK VALUES

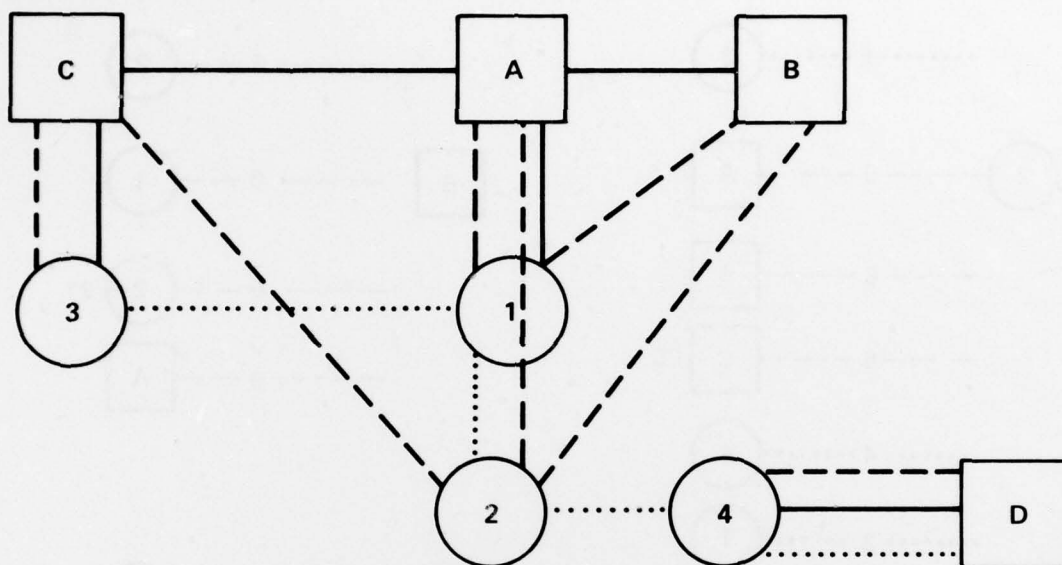


FIG. 8 SCHEMATIC OF FINAL SYSTEM LAYOUT.

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