AD NUMBER
AD229925
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited. Document partially illegible.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; NOV 1959. Other requests shall be referred to Office of Naval Research Laboratory, 875 North Randolph Street, Arlington, VA 22203-1995. Document partially illegible.**
AUTHORITY
ONR ltr, 24 Aug 1970

Best
Available
Copy

METHODOLOGY FOR ANALYSIS OF MAN'S ROLE IN AN ADVANCED SPACE FLIGHT SYSTEM

Peter G. Nordlie

HSR-RM-59/25-SM

Report Number 6

Contract Nonr 2525(00)
Personnel and Training Branch
Psychological Sciences Division
Office of Naval Research

November 1959

human sciences research inc

HSR

FILLMORE AND WILSON BOULEVARD
ARLINGTON 1 VIRGINIA

METHODOLOGY FOR ANALYSIS OF MAN'S ROLE IN AN ADVANCED SPACE FLIGHT SYSTEM

A Case Study in System Research Methodology

By:

Peter G. Nordlie

HSR-RM-59/25-sm

Report #5
Contract Nonr-2525(00)
Personnel and Training Branch
Psychological Sciences Division
Office of Naval Research

November 1959

HUMAN SCIENCES RESEARCH, INC.
1408 North Fillmore Street
Arlington 1, Virginia

FOREWORD

In 1958, Human Sciences Research, Inc. initiated a research program aimed at synthesis of system research methodology. The program is under sponsorship of the Personnel and Training Branch, Psychological Sciences Division, Office of Naval Research (Contract Nonr-2525(00)).

The central aims of the program are to systematically review and integrate the methods which have been employed in studies of complex man-machine systems; to compare alternative methods and procedures which have been used to carry out various steps of such system studies; and to determine the major methodological weaknesses requiring concentrated research effort. Subsidiary aims are to develop a frame of reference and a common language within the system research domain to aid communication among scientists from diverse disciplines, and to suggest means of applying existing methods to new problem areas.

Phase I of the program was a feasibility study in which a general framework for analysis of methodology was developed. Phase II called for validation and refinement of this framework by utilizing it in the conduct of several on-going system research investigations. During Phase II special emphasis was placed upon integration of methods for one key stage of the system research process--establishing system and sub-system requirements.

Results of the research program are presented in a series of reports listed at the end of this paper. This is report #5 in the series. It describes the methodology used in development of requirements for design of displays and controls for the cockpit of a manned space vehicle.

The design study within which the study here reported was carried out was conducted for the Air Force by a large aircraft manufacturer.

Because it is classified, no reference is made to specific characteristics of the vehicle, its equipment, or its flight regime.

TABLE OF CONTENTS

Study Setting and Scope

The study reported here is part of a feasibility and design study conducted by a large aircraft manufacturer under contract to the Air Force. The objective of the study was design of a manned space flight system.

The total design effort was, of course, divided among a number of companies, agencies, and organizations, each having its special area of interest; e.g., guidance sub-system, booster sub-system, communication sub-system. Two parts of this larger effort were concerned with the manned aspects of the system:

1. Human factors in the flight vehicle.
2. Human factors in the ground support system.

This report will be concerned only with the former.

The human factors effort had several goals:

1. Establishment of design requirements for display faces and controls.
2. Determination of design requirements for the human environmental support system.
3. Specification of flight crew training requirements.

The present paper focuses on the first of these goals.

The research problem was defined by the set of questions for which answers were sought. The questions included the following:

1. What should be the allocation of functions between man and machine?
2. What size should the crew be?
3. What information should be presented to the operator?
4. What control capabilities should be given to the operator?

5. Where should the displays and controls be placed?
6. What form should they take?

Although these same questions can be asked in many different forms, they reduce, essentially, to two basic questions:

1. What role should man play in the system?
2. How can he best be equipped to perform that role?

The methodology employed in the human factors approach to these questions is the focus of this paper.

General Methodology

Certain system requirements were established by the Air Force as the basis upon which the system design should proceed. The initial methodological problem of the design study was to trace out the detailed implications of this set of general system requirements. For example, a performance requirement was stated which, when considered in combination with the state-of-the-art of propellants, gave rise to a maximum weight requirement. This requirement imposed a weight limitation upon every element of system design, which in turn limited the design alternatives that could be considered at each design level.

Within the human factors area, the implications of system requirements were traced out by a series of analysis cycles, designed to produce progressively more detailed statements of design requirements and specifications. The first cycle began with the general system requirements. Information was collected and synthesized into a first approximation of a final solution--a preliminary soft mockup of the operator displays and controls. The cycle was repeated several times in the course of the project, each time yielding more detailed results, more backup material for design decisions, and modifications required by changes in other aspects of the design.

The approach, consisting of a number of successive approximations rather than a step by step progression to the final solution, was chosen because of the constant state of flux in information about other aspects of system design. Such a state of flux appears to be the rule in early stages of large system design studies. The total system is divided into pieces, each being worked on simultaneously. Each part of the effort proceeds on the basis of certain assumptions about other parts of the system--but thes assumptions are constantly changing. It is not reasonable, therefore, to attempt to fix prematurely any of the parameters with which you must work. It would probably be inefficient to proceed step by step, one time, through the steps necessary to reach design conclusions concerning displays and controls, because by the time the final step were reached the information on which early steps were based undoubtedly would have changed.

Each cycle consisted of collection and synthesis of information, and appropriate evaluations. In the early cycles of the human factors research effort, evaluation was necessarily limited to logical analysis of internal consistency of the detailed requirements, consistency of the design (design integration), and capability of the design to satisfy design requirements. In later cycles, after development of the hard mockup of the interior of the cabin, evaluation included see and reach tests of the displays and controls in the pilot station.

The specific methods by which these successive cycles were carried out are described in the next section.

Specific Methodology

Phase/Function Analysis

The first major step in the human factors effort was a description of the system in terms of the functions which it must perform in order to fulfill system requirements, and a specification of the times in the mission when the functions must be performed.

The analysis began with a statement of system requirements. Then a set of functions which the system must accomplish were established by logical deduction. These principal functions were further delineated into sub-functions. They were not specifically assigned to man or machine.

At the same time, a basic mission was selected and divided into convenient phases, which represented successive time periods more or less homogeneous in goals and activities. Then the functions and sub-functions were laid out in terms of phases, and the functional activities required for each sub-function within each phase were specified. This matrix of functional activities provided the basic requirements upon which subsequent research steps were based.

Man-Machine Allocation

The second major analysis task within the human factors effort was a determination of the proper allocation of functions to man and to machine. Two general sources of information were utilized:

1. The body of knowledge concerning performance capabilities and limitations of the human in tasks similar to those called for in the system.

2. The state-of-the-art of equipment capabilities for tasks required in the system.

With respect to the former source, a review of summaries of a large number of experimental studies of man's performance under various task and situational conditions provided estimates of the performance capabilities of man with respect to the required functional activities. As to the latter source, work on other portions of the total system effort was reviewed to determine the sub-systems and associated equipment proposed for inclusion within the tentative system design, and the sub-functions and functional activities which they were designed to accomplish.

These two sets of information were brought together and related to the required functional activities which had been identified. A systematic review of each activity in terms of machine and human capabilities for its performance led to its tentative allocation to man or to various types of equipment. This tentative allocation provided a first approximation of a "design solution" from the human factors point of view.

This portion of the study methodology marks the weakest link in current human factors methodology. While a vast amount of empirical data exists, there is, as yet, no comprehensive, systematic and generalizable statement of human performance capabilities and limitations, nor is there a common language within which human and machine performance can be described and compared. Therefore, an allocation of system tasks to man and to machine still rests largely on intuitive procedures. It can be, at best, a rough approximation; and there is no assurance that it is an optimal or even a feasible solution.

Second-by-Second Operational Analysis

It was recognized that procedures were needed to evaluate the feasibility of the tentative allocation of tasks to the man, and to insure the optimal matching of man and machine capabilities. Such quantitative methods are presently in an early stage of development. However, the study took advantage of recent advances in the area by Dr. J. Sanders O. H. Lindquist, and R. L. Gross of Minneapolis-Honeywell.[1] Specifically, a second-by-second operational analysis (SSOA) of the total flight mission was conducted.

The SSOA considers the cockpit a nexus of information channels, with the pilot as the connecting link between the input and output channels. Information channels which are available for display to the pilot are considered input channels. Channels through which the pilot exercises control (introduces information into the system) are considered output channels. The SSOA analyses a typical mission or part of a mission in terms of the flow of information through the cockpit. This flow of information through the cockpit is considered to be an information exchange between the pilot and the vehicle.

The information carried by input channels is examined on a mission time-line, to determine the frequency or rate of monitoring required, in the following fashion. The error limit of each information parameter-- the value beyond which the parameter cannot go without a resulting catastrophe-- is established, on the basis of data about the physical and dynamic characteristics of the system, or similar systems, and the environment in which the system will operate. The error rate-- the maximum rate at which the parameter can change from a desired or normal condition-- is determined in a similar manner. Error rate and error limit are then used to determine the minimum time for the parameter to change from a normal condition to the limit. It is assumed that monitoring the channel

[1] Lindquist, O. H. and Gross, R. L. Human engineering man-machine study of a weapon system. Minneapolis: Minneapolis-Honeywell Regulator Company, October 1958. (MH Aero Report No. R-ED 6094)

at intervals of at least one half the minimum time enables the parameter to be controlled within tolerance limits. The required monitoring rate for each input information channel is determined in this manner. Then, the time required to fixate on and interpret each information parameter is determined, either by calculations based on existing human factors data about human response time and data processing rates, or by experimental determination. A similar determination is also made with respect to output information (control actions).

The basic SSOA data chart lists input and output information down the ordinate, and lists time, from beginning to end of a given mission, along the abscissa. The cells of the resulting matrix are used to indicate whether a given channel does or does not require attention at each second in the mission. The net effect of these operations is to reduce the total information flow through the cockpit to a common metric, time.

Note that determination of error limit and error rate is in part bound to the characteristics of the over-all design and its proposed equipment. Thus, the SSOA is not carried out independent of at least a tentative design solution. It should also be noted that the SSOA begins with a set of required information parameters. A list of input and output information which could reasonably be conceived of as valuable to the controller (automatic or pilot) is compiled. The working out of error rates, error limits and fixation times may indicate that some of the information channels are unimportant and could be eliminated. However, there is no systematic check without SSOA procedures by which additional required information can be identified.

The SSOA provides a sequential and quantified description of the information exchange which occurs between the vehicle and the pilot during a typical mission. The data provided by the SSOA is at the most specific level of detail required--whether or not a given information channel is utilized in each second of mission time. It provides the basis for a number of indices useful in evaluation of the allocation of functions and in providing guidance for design of displays and controls and for their arrangement within the cockpit.

Pilot Work Load Analysis

One form of summarization of the basic SSOA data yields indices of operator work load for each time interval in the mission. For the work load analysis, the tabular statement of each discrete information exchange between the pilot and the remainder of the system is summarized over some arbitrary time interval--say ten seconds. The time required to perform all information exchanges during any arbitrary time interval, divided by the total time interval, yields the proportion of the total time within that interval during which the operator is occupied. This proportion represents the operator load. Operator load can range from 0 to greater than 100%. Loads over 100% indicate overload on the operator during that time interval, and performance decrement would be expected.

The work load analysis provides a means for determining in advance the average load required of the pilot during each interval of the mission, and consequently for identifying points of likely overload. Since overload is associated with performance decrement, it is critical to identify sources of potential overload and to eliminate them by means of design changes prior to actual flight.

Link Analysis

A second way in which SSOA information can be usefully summarized is in the form of a link analysis. A link is defined as a shift of perceptual attention from one information source to another. The link analysis is carried out by counting the number of times each pair of channels is attended to in succession. Pairs of channels which are frequently used in succession obtain high link values while low link values are assigned to pairs of channels which are seldom or never used in sequence. The link analysis provided basic data from which decisions concerning groupings or integration of display and controls were made.

Use/Frequency Analysis

SSOA data were also summarized by counting the number of times each channel is used in the course of a mission. Sub totals can be obtained for any desired portion of the mission. The use/frequency of a particular channel can be considered an index reflecting the prominence needed for that display or control. The use/frequency counts, together with the link analysis data, were used to determine location of displays and controls. Indices of criticality, in the sense of contribution to work load, were generated from the frequency-of-use and time-to-correct-error data. Criticality indices were also used to determine the location and grouping of displays and controls.

Summary

The tasks described above represent the logical sequence of steps taken to develop design requirements for the displays and controls of the space vehicle cockpit. The phase/function analysis resulted in a set of required functional activities, which were tentatively assigned to human and equipment components. These functional activities were translated into a set of required input and output parameters, which were in turn described on a time base in the SSOA. Results of the SSOA were summarized to provide indices of work load, link frequency, and use/frequency.

(Second-by-second Operational Analysis)

These indices in turn helped to specify design requirements for the cockpit and for the displays and controls it contained.

General Approach for Follow-on Studies

The research described above was performed under a study contract in which the design process was carried only as far as full-scale hard mockups. Thus, there was little opportunity to perform validation checks on the real system. It was assumed that the research tasks described above carry the research process about as far as is possible using objective, systematic, and quantitative methods, short of direct experimentation with the system or a simulation of it.

Two major research phases should follow. A test program based on simulation of all or some aspects of the designed system is the logical next phase in the total human factors research effort. It is often, though not always, less costly to evaluate by simulation than by construction and test of the real system. Further, there are a number of tests that can be performed only by simulation for a system designed to operate in space. Finally, simulation tests permit evaluation of various design alternatives, and selection of the better ones prior to actual fabrication of the system.

The second phase would involve testing a prototype of the actual designed system. In the present state-of-the-art of simulation, various human factors tests cannot be considered completely valid. Potential advances in the simulation field, however, may well overcome many of the current limitations and provide highly valid simulation techniques from a human factors point of view. Until then, however, simulation should be considered an interim step preceding the final methodological step--an extensive test program using the actual system.

REPORTS FROM HSR STUDIES
OF
SYSTEM RESEARCH METHODOLOGY

1. McGrath, J. E., Nordlie, P. G., & Vaughan, W. S., Jr. A systematic framework for comparison of system research methods: report of Phase I. HSR-TN-59/7-sm.

   Describes the purpose of the research program; presents certain basic methodological concepts which provide a basis for systematic description and analysis of the system research process; develops these concepts into a framework for classification and comparison of methods used to accomplish different portions of a total system research problem.

2. Vaughan, W. S., Jr., & McGrath, J. E. A comparison of two diverse methodological approaches to research on complex systems. HSR-RM-59/22-sm.

   First given as a paper in a system research methods symposium at the 1958 convention of the American Psychological Association. Describes some general methodological biases frequently seen in system research, and their research consequences.

3. McGrath, J. E., & Nordlie, P. G. Research methodology of requirement-setting studies. HSR-RM-59/23-sm.

   Presents results of a review of the methods employed in some 50 system studies aimed at establishing various types of requirements for complex man-machine systems. Focuses on the applicability of available methods for establishing human performance requirements for complex, future, weapon systems. Includes description and discussion of steps for conducting requirements studies, and a bibliography of system studies covered in the review of requirements methods.

4. Vaughan, W. S., Jr. Methodology for determining requirements for command of advanced submarines: a case study of system research methodology. HSR-RM-59/24-sm.

Describes the application of research methods in determination of command requirements for advanced submarines. Study was conducted by HSR, under sponsorship of Electric Boat Company and ONR, as a part of the SUBIC program. Conduct of that study both contributed to and benefited from results of the on-going system research methodology program, especially the portion concerned with establishment of requirements (see report # 3).

5. Nordlie, P. G. Methodology for analysis of man's role in an advanced space flight system: a case study of system research methodology. HSR-RM-59/25-sm.

Describes the methodology applied to analysis of pilot functions and performance requirements for an advanced manned space flight system. Study was conducted by HSR as part of a larger system design study for the Air Force.

6. Whittenburg, J. A. Methodology for evaluation of a man [illegible] for surveillance systems: a case study of system research methodology. HSR-RM-59/26-sm.

Describes the research methodology used in determination of performance requirements for future aerial observation in support of ground forces and in assessment of human aerial observer capability in relation to these requirements. Study was conducted by HSR, under subcontract to HumRRO, as part of HumRRO Task OBSERVE I.

7. Schroder, [illegible] Monte Carlo methods as tools for system research. HSR-RM-59/27-sm.

Describes the class of research methods denoted by Monte Carlo techniques, their applicability within the system research process, the conditions under which they can be utilized, and the kinds of results which they provide. Includes a selected bibliography of studies which utilize Monte Carlo methods.

8. Robinson, J. P. Linear programming as a tool for system research. HSR-RM-59/28-sm.

Describes the class of research methods denoted by Linear Programming techniques; their applicability within the system research process; the conditions under which they can be utilized, the kinds of results which th[illegible]vide; and some of the difficulties likely to be encountered when linear programming is applied in complex system problems.

9. McGrath, J. E. Synthesis and comparison of system research methods: report of Phase II. HSR-TN-59/8-sm.

Includes a brief overview of the purposes and procedures of the study and of major results which it has achieved; a description of key methodological problems requiring concentrated research effort; a glossary of major system research concepts and terms; an extensive bibliography of system research studies; and a shorter, annotated bibliography of studies reviewed in the course of the research program.