THE ROLE OF COMPUTERS IN HANDLING AEROSPACE SYSTEMS HUMAN FACTORS TASK DATA

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FOREWORD

This report presents the findings of a study sponsored jointly by the United States Air Force and the National Aeronautics and Space Administration. The report was prepared by Computer Concepts Incorporated, a Subsidiary of Computer Applications Incorporated, of Los Angeles, California, for the Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. Dr. Irvin R. Whiteman was the principal investigator. The study was conducted under Contract AF33(615)-1557 during the period of 3 June 1964 through 3 June 1965.

This study was in support of Project No. 1710, "Training, Personnel, and Psychological Stress Aspects of Bioastronautics," and Task No. 171006, "Personnel, Training, and Manning Factors in the Conception and Design of Aerospace Systems." Dr. Gordon Eckstrand, Chief, Training Research Division, was the Project Scientist, and Mr. Melvin T. Snyder, Chief, Personnel and Training Requirements Branch, was the Task Scientist. Mr. Lawrence E. Reed, of the Personnel and Training Requirements Branch, served as the contract technical monitor.

This report is a companion to AMRL-TR-65-131, "The Role of Human Factors Task Data in Aerospace System Design and Development," prepared by the American Institute for Research, the subcontractor to Computer Concepts Incorporated. Together, these reports recommend the desirable characteristics of a computer based system for handling human factors task information.

Appreciation is extended to Dr. Stanley Deutsch, National Aeronautics and Space Administration, Washington, D. C., who served as the NASA initiator and monitor, and to Mr. Thomas E. Burke and Mr. Irwin Boris, NASA Electronics Research Center, Cambridge, Massachusetts, for their valuable suggestions and for reviewing the preliminary draft manuscripts.

The author acknowledges the assistance of Mr. Lawrence E. Reed during the course of the research, and Mr. Melvin T. Snyder and Dr. Gordon Eckstrand, who assisted in the review of the manuscript. Acknowledgement is also made to the following Computer Concepts personnel who helped in the development of this research: Joseph LaHood, Patricia Graves, Elizabeth Harvell, George Kalvin and Donald Monroe.

This technical report has been reviewed and is approved.

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ABSTRACT

The characteristics of a computer based data system for handling human factors task information generated in support of advanced system development are described. On the basis of information gathered from users and generators of data at representative Government and contractor installations, the current and potential uses of computers were assessed to determine the desirable characteristics for a computerized human factors task data handling system. The proposed data handling system will assist the human factors specialist and system design engineers in the design and development of systems by providing them with means for: (1) drawing them closer to the data through a user-oriented system, (2) comparing data generated throughout the life-cycle of an advanced system and across systems, (3) analyzing data and conducting man-machine simulations, and (4) insuring that data are made available on a selective query and a timely basis. These objectives are met within the framework of a data system concept referred to as CENTRAL. The functions of CENTRAL are: (1) data storage and retrieval, (2) data processing, (3) computer program maintenance, and (4) system operational manual maintenance. The forms of data to be housed within CENTRAL, the methods for storage, processing and retrieval, and the nature and configuration of the data handling are discussed. Recommendations are made for a follow-on prototype data handling system to be developed and exercised with actual advanced system data. The prototype system would be responsive to data which are best stored within the computer, and data which do not lend themselves to storage within a digital computer, such as data of a pictorial nature.

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INTRODUCTION

Direction

This study is directed to the determination of the need of the human factors specialist for a data processing system in aerospace system design and development, and to recommendations concerning satisfaction of his needs. Two points of view are taken: that of the human factors specialist and that of the computer specialist. Recommendations are made concerning long term objectives, and are made concerning a prototype system to be implemented as a follow-on phase to this research.

Defining the Needs of the Human Factors Specialist

The volume of human factors task data and related man-machine information* has grown so rapidly that it is incumbent upon us to determine if data processing equipment is being used to best advantage by the human factors specialist. This can only be accomplished by viewing the problem through the eyes of the computer specialist and through the eyes of the human factors specialist. A joint team was formed to make this determination: Computer Concepts, Inc. (C. C. I.) and American Institutes for Research (A. I. R.).

Design, development and testing of advanced systems are blends of many ingredients. Never lacking is the need for human factors data. How can techniques be generated which will permit the government and its contractors to identify, to describe, to store, to update, to process and to use to best advantage human factors data? Is it possible for the analyst, be he engineer, scientist, or specialist to know what human factors data is available and where he can find it? Can we communicate

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* Human factors task data and related man-machine information is for the purpose of this report defined as including the qualitative and quantitative task and performance data for operator and maintenance personnel. These task data will emphasize the behavioral and man-machine system support data of human engineering, human learning and training, and training equipment, and include for example: (1) the demands that the system, man or the situation make upon one another (e.g., the working environment, time criticality, performance accuracy), (2) the discrete task information such as expected or required task and skill parameters for fixed and/or variable task procedures, (3) the applications of skills within system mission segments and time base, where skills pertain to such functions as detecting and processing information, monitoring and communicating with or directing machines or humans, command or decision making, feedback, and self-alignment or adjustment.

data while it is viable? Can we examine relevant data through all phases in the life cycle of systems? Can we compare data from one system with data from another? Certainly these questions are in the mainstream of our thoughts concerning the human factors community. A two pronged approach is necessary: 1) Uncover the problem, and 2) Determine what can be done about it.

What is the problem? Three separate, but related, approaches were taken to specify the problem: literature review, interviews, and questionnaires. All were directed to: Was there a problem, and what was it? What were the thoughts of people in the community? What were their needs? What did they feel could be accomplished to improve the utility and handling of human factors data? In the main, responsibility for conduct of the literature review, interviews and questionnaires was in the hands of A.I.R.

An introductory letter written by A.I.R. to prospective interviewees posed numbers of questions, "We would like to be able to learn the following things about system outputs, either extant or anticipated, such as training manuals, maintenance manuals, operating manuals, and technical handbooks. When in terms of phase of system development were they completed? By what section were they prepared, and what procedures were used in their preparation? By what section and by what procedures were the data necessary for their preparation generated? When in terms of phase of system development were requirements for such outputs fixed in final form? . . .

"Then we would like to know what use has been made of the computers in any of the above efforts. How has the use of computers aided these efforts and where and for what reasons has the computer not been of material help? What kinds of classification schemes have been used and what kinds of programs and computers have been used in storing and processing data? . . . "

Questionnaires were circulated to members of the human factors community. Questions addressed included:

- What are the most important data sources and inputs with which you work? . . .

- What do you do with raw inputs that transforms them into a new useable product? List as many as you can in order of importance in your job.

- What uses do you make of computers in either retrieval, processing, or storing of data?

- In what ways do you think computers could be used in making your job easier, faster or more efficient in some way? Give examples of requests you would submit to a data processing center.

Is response time (in request for data) important to you?

What response time do you work with now?

The findings of A. I. R. are covered in Technical Report, "The Role of Human Factors Task Data in Aerospace System Design and Development," AMRL-TR-65-131, produced under this contract. The principal parts of this report describe:

1. The approach to gathering and analyzing information about the kinds of human task data involved in aerospace system development and the ways in which such data are generated, processed, stored, retrieved, disseminated, and used.

2. Results from surveying human factors literature, from information and opinions expressed by system development personnel who were interviewed, and from questionnaires sent to human factors personnel.

3. An idealized summary of the network for generating, handling, and using human task data throughout system development.

4. Categories of human task and related data which an automated system must be capable of handling, and which may be useful in the initial formulation of a language for such a system.

5. Current uses of computers and recommendations of characteristics desirable in an automated system for handling human factors data.

6. Specific recommendations for the implementation of a computerized data handling system in the immediate future.

Design of the Data Processing System

At the heart of this research is development of a data processing system to satisfy needs of the human factors specialist. Design of the data processing system is influenced in large part by the needs of the specialist. These needs must be defined and interpreted. If we examine the data processing system from the viewpoint of the human factors specialist, we are concerned with the nature of the data handled, e.g., how can we process Qualitative and Quantitative Personnel Requirements and Information (QQPRI) data? If we examine the data processing system from the viewpoint of the computer specialist, we are concerned with software and hardware. Should programs be written in FORTRAN or COBOL? What will new third generation hardware, e.g., IBM 360 or RCA Spectra, mean to the community? These viewpoints are different. They must not be conflicting. The viewpoint of the human factors specialist has been treated in the A.I.R. report. The viewpoint of the computer specialist will be treated in this report.

How the computer and related data processing equipment can best be utilized in the human factors community depends upon the problems to be solved, the tools available for the analyses of these problems, and the types of data associated with aerospace systems which will be of concern to Air Force (AF) and National Aeronautics and Space Agency (NASA). In face of rapidly changing technology, it is necessary to examine not only present day requirements but to examine future day requirements. The development of an integrated data processing system requires several years to design and implement. Real understanding of the system comes only through usage. The system is expected to have a useful life before obsolescence; the time period of now through the next decade must play a guiding role in the design of the system.

Needs of the Human Factors Specialist

The A.I.R. study points out a severe restriction in obtaining human factors task information developed in support of systems. There are times when previously generated data is unavailable to the human factors specialist because he does not know of its existence, or because the time to go through channels through which data are normally obtained is too long.

There is a need to examine relevant data generated through all phases of system design and development, and to compare these data across different systems. Also needed are efficient computer programs to store and retrieve data, to facilitate analysis of data, and to conduct man-machine simulations.

The A.I.R. study further points out that problems arising from these needs could be at least partially alleviated by the development of an automated system for efficient storage, accurate processing, and rapid retrieval of human task data and related information. Among other recommendations for an Automated Human Factors Data Handling System, they state, "In order maximally to facilitate system operation, a computerized human factors data retrieval system must be capable of performing the following functions:

> Supply data, including task analyses and manning and training requirements, for any part of a system which has been duplicated in past systems or on an experimental basis.

Implicit in this recommendation and to a lesser degree some of those which follow, is a centrally maintained data store. . ."

CENTRAL - The Recommended Data Processing System

A need exists for a human factors task data center, CENTRAL, which can be used either independently or in conjunction with existing computer facilities. The primary functions of CENTRAL are: (1) information storage and retrieval, (2) human factors task data processing, (3) language maintenance, (4) computer program clearinghouse, and (5) CENTRAL manual. The CENTRAL facility should be accessible to locations all over the country by means of "teleprocessing" equipment and should be able to process all kinds of data suitable for storage within the computer or other data handling devices.

Through use of the CENTRAL system, the human factors specialist will have at his fingertips, literally, all human factors task data generated in support of systems. He will have access to data in time to act upon it, and from another most important point of view, he will be able to obtain data that he does not even know about. By means of an efficient human factors oriented computer language, the human factors specialist will be able to determine what data are available of interest to him, and, of course, to obtain that data.

Recommendations for a Prototype Development

Though the CENTRAL system could be initiated in its entirety, it is recommended that this be deferred until a prototype of the system can be developed and exercised.

The research to be reported herein constitutes the results of Phase I of a three phase effort. The three phases are: (I) a feasibility study concerned with criteria, requirements and techniques, (II) development of computer techniques and applications to Air Force and NASA systems, and (III) testing of methods and uses in system(s) development.

It is recommended that three complementary information retrieval techniques be developed during Phase II. These are:

1. an information storage and retrieval system
2. a human factors-oriented computer language for handling general inquiries

3. a collection of computer program routines for certain frequently required analytical tasks.

The developed system, though a research tool, can be used and tested with real data. The system is responsive to retrieval of the two kinds of data: 1) data which are best stored within a digital computer and 2) data which are not amenable to storage within a digital computer, e.g., data of a pictorial nature.

The extent to which the system can be exercised depends upon the size of the data bank (human factors task data stored within the data processing system), and the numbers and types of inquiries made upon the system. It is recommended that cooperation of other agencies be secured to obtain "live" data, and to obtain queries and usage based upon real operational needs.

SECTION II

THE NEED FOR AN INFORMATION CENTER

Introduction

The A.I.R. study points out a severe restriction in obtaining human factors task data developed in support of systems. The needs indicated and recommendations made show the problem is not one alone of obtaining information nor of being able to determine what information exists, but consists of a highly interacting complex which heaps delay upon delay. Even at those contractor locations where communications channels have been partially automated, interviewees felt that though the systems were valuable that they had as not yet achieved full potential.

The Need for Improved Data Flow

Three separate, but related, approaches were taken to specify the problems of the human factors specialist in dealing with task data: literature review, interviews and questionnaires. Let us take a look at our findings.

The A.I.R. study reveals a potpourri of practices conducted by different contractors and at different levels of management. The following conclusions were drawn by A.I.R. concerning computer-related questionnaire items: (1) about 80 percent of the respondents feel that some use of computers could be made in their work, (2) data retrieval time is important to at least 80 percent of the respondents, (3) current modal data retrieval times are from one to six days, (4) about half of the respondents are dissatisfied with current data retrieval times, (5) data retrieval times of less than one day would probably not be used more than twice a month by each respondent. A more accurate prediction of the frequency of use of rapid response time requires a consideration of the number of users. Thus, if 2000 users require response times of less than one day twice a month, the total number of requests would add up to 4000 per month.

The A.I.R. study points out a severe restriction both in obtaining information and in communicating information. The result is redundancy, the redundancy caused by the duplication of efforts stemming from ignorance concerning what has been done. Complementing the inefficiencies which plague poor communication is poor usage of time. A need exists to be able to act quickly and to respond quickly.

To satisfy the need for better and more efficient means of communicating human factors task data, an information center is indicated. Some possible uses for such a center are shown by the following excerpts from the questionnaire in response to the question "In what ways do you think computers could be used in making your job easier, faster, or more efficient in some way? Give examples of requests you would submit to a data processing center."

Some typical excerpts follow:

"I would like to be able to ask a data processor: "What ECP's have been approved for the training equipment, and what is their total cost?" "What ECP's have been approved for the hydraulic system?" "What parts are short for this MTU, and what is their class, gov't furnished or contractor furnished?" "Where can I find info on design of displays for color-deficient students?"

"1. Data Reduction and Storage
   a. Trouble Reports
   b. Experimental Analysis
   c. Library

2. System Analysis
   a. System Decision Trees
   b. Link Analysis
   c. Human Reliability

3. Mission Analysis
   a. Human Reliability Requirements
   b. Time Requirements

4. Construction and Testing of Hypothetical Models."

"They permit the instantaneous extraction of selected data and timely incorporation of revisions.

Examples - What are the tasks and subtasks involved in the removal of a (equipment) on the flight line during a preflight inspection? During an unscheduled removal? During a 100-hour inspection? What personnel and/or equipment hazards will be encountered when installing a (equipment)? How many 30153 personnel will be needed during the installation of a (equipment) at the unscheduled maintenance hangar? At an isolated site?"

"We could do a more thorough job in considerably less time if a computer could assort previous work done in areas of interest. Examples are: What research has been done on acoustical ear-pads? Who has available specialized test facilities?"

"Task & task element bank related to existing AFSCs.
Task & task element bank related to system/subsystem component functions.
Task & task element bank related to knowledge requirements."

This listing is not meant to be exhaustive nor comprehensive, but is meant to show common accord of the need for an information center. What are the objectives of such an information center? These are shown in the recommendations of A.I.R. for an "Automated Human Factors Data Handling System," and include:

1. Throughout development, the system should produce automatically and as needed those system-specific documents identifiable today as, for example, QQPRI, and Training Equipment Planning Information.

2. In the event that special situations should arise which require data which are unavailable in handbooks, or when latest updated data are required, the computer system should generate replies to specific queries. (While it is not suggested that this be the normal mode of operation, the option should be available.)

3. Provide summaries of basic data likely to be required in developing a particular system and based on early planning specifications regarding the nature of the final products.

4. Be amenable to frequent updating.

5. Simulate any proposed system or portion thereof at any time during the system life cycle and at various levels of detail.

6. Indicate rapidly and at any time during the system life cycle the availability of the facilities, training aids, aerospace ground equipment, and trained personnel necessary to design, develop, operate and maintain the system.

7. Supply data, including task analyses and manning and training requirements, for any part of a system which has been duplicated in past systems or on an experimental basis.

Task Data Interactions

It must be possible to integrate both Air Force and NASA systems. But information of interest to the human factors specialist cuts across agencies, across systems, and across subsystems. Unfortunately, data are usually identified in terms of convenient labels such as names and titles of equipment identifiers rather than in terms of the contents of the data. To aid the human factors specialist, efficient storage and retrieval techniques are required.

The needs indicated and the recommendations made show the problem is not one alone of obtaining information nor of being able to determine what information exists. The problem consists of a highly interacting complex which heaps delay upon delay. A direct correlation exists between the difficulties of information location and retrieval, analysis, and excessive time response.

Each step taken by the human factors specialist takes time. The specialist may take many of these steps alone, but frequently, he must depend on others to provide him with information he does not have or to guide him or help him in the solution of problems. This interdependency is characterized throughout all steps taken by the human factors specialist.

Consider, for purposes of illustration, some relationships among elements of a QQPRI and its input and output elements. In support of the QQPRI, numbers of elements must be generated. Typical of these are elements such as "quality of personnel" and "quantity of personnel." The specialist responsible for generation of these elements utilizes human factors task data. Task data are required in terms of elements of: task, system, subsystem, number of personnel required to perform task, skill requirements, knowledge requirements, time to perform task, personnel classification, and task sharing classification.

The elements so generated for the QQPRI are not an end unto themselves. They can conceivably constitute an input to generation of still other elements used by other specialists. The human factors specialist responsible for generation of TEPI elements such as "number of persons to be trained," and "number of instructors required" has need for the elements ("quality of personnel" and "quantity of personnel") generated for the QQPRI.

Another case in point showing need for elements generated in support of a QQPRI is the writing of a maintenance manual. For example, "job crew size" to accomplish an element of work must be defined in the manual. This element of the maintenance manual depends in turn upon elements of the QQPRI such as team performance, and quality and quantity of personnel per shift. The elements of the QQPRI depend upon elements generated for task analysis. Task data are required in terms of elements of: task, system, subsystem, number of personnel required to perform task, skill requirements, knowledge requirements, time to perform task, personnel classification and task showing classification. Other data may be required in the form of elements generated for maintainability such as maintenance hours/specific maintenance action, and frequency of preventative maintenance.

Each element of the hierarchy can be related to some combination of other elements in the hierarchy. The definition of any element by the human factors specialist depends upon those elements generated by other specialists to satisfy perhaps his specific need, but perhaps more likely some other need. The cyclical effect is clear. Elements are generated by diverse groups of specialists which in turn are used by other specialists, and so on and on.

The Human Factors Specialist and PERT-Like Considerations

The time of the human factors specialist is spent in determining what data are available, in obtaining data, in analyzing data, in performing simulations involving this data, and in relating his findings to his associates. He spends his time in a world of data and analysis. What he is able to accomplish depends upon the quality of his data and the quality of his analysis. The two, analysis and data, are not independent of each other. The collection and presentation of data depend upon the requirements of analysis; the analysis performed depends upon the form and availability of the data; development of one is affected strongly by the development of the other. Data and analysis define the time requirements of the human factors specialist. And if the specialist can respond in the time frame of the time allowable to obtain solutions to the problems he handles, he can participate in problem solving.

Many interviewees reported there are times when previously generated data are unavailable to them because they do not know whom to ask and because the time required to go through channels through which data are normally obtained is too long. Using time honored manual methods, it is physically impossible to search for data, obtain data, and handle the detail and mathematics required to do an adequate analysis of human factors data, in the amounts of time allowable.

What are the amounts of time allowable? This depends upon the aerospace system, and the time schedule for implementation of the system. The relationship between the system and time is brought out very clearly by the tremendous interest and development expended by both Air Force and NASA upon Program Evaluation and Review Technique (PERT) and other management systems.

A large aerospace system can be defined in terms of a network of activities necessary to complete in order to develop the aerospace system. The principles of PERT are well described in the literature and do not require redeclaration here. It is important to note, only, that consistent with activities and time estimates associated with these activities that a latest allowable time is associated with the completion of each activity if the total elapsed schedule time is not to be exceeded. And, by the same token, there is a latest allowable starting time for any activity to begin if the overall schedule is not to be delayed.

What happens when the time to make a decision runs out and the work to be accomplished in preceding activities has not been completed. Two alternatives crop out: (1) delay the schedule, or (2) make decisions in absence of complete information. A case in point is the utilization of elements generated for a QQPRI by a specialist concerned with determining the number of instructors for a training program. If, by the latest allowable time to develop training facilities and to secure the staff for instructional purposes, the numbers of personnel to be trained have not been established, the decision which must be made concerning staff and facilities becomes clouded by uncertainty due to lack of information.

The costs associated with the inefficiencies stemming from poor judgments made in the absence of data are compounded when the data does exist, and are not used because of unawareness or of inaccessibility. If the element of the QQPRI concerning the number of people to be trained has been defined, but is not used because the specialist concerned with instructional requirements is not aware of the existence of the element, then in large degree the monies expended upon the development of the QQPRI element have been wasted.

Allowable Response Times

Fortunately the human factors specialist need not be forced into the position of having to make decisions in the absence of existing information. There need be no loss of data today; indeed, the amounts of data which can be accumulated and maintained are astonishing. And the human factors specialist can search these data and obtain these data in amazingly short periods of time. The human factors specialist can adjust his thinking from terms of the small data set to that of the large data set. He can base his decisions upon the totality of available data. He can execute this technique in amazingly short periods of time. There is no reason to settle for less. What is the vehicle? The vehicle is the high speed computer.

In discussion of computer applications, time always plays an important role and it is worthwhile to define what is meant by time. Computer processing can be divided into two types: real time and non-real time. A real time problem is characterized by a well defined short interval between the time an item of data is presented to the computer system and the time when the computer system must provide an appropriate response. The tracking of our astronauts orbiting around the earth in a Gemini capsule requires computations to be made in real time. Any delay in computation could be a matter of life and death. Most problems in human factors task analysis do not reflect this time urgency. This does not mean, however, that there is no time constraint governing analysis.

What are the time characteristics governing reporting of human factors data? Quantitatively, time is related to the rate at which information is reported and the rate at which it changes. If the time required to report information is much greater than the time it takes for information to change, then the files maintained, though perhaps most important for historical reasons, may not be adequate for operational usage. For files to be useful from an operational point of view, the information must be reported at a rate commensurate with the rate at which the information changes. No real advantages are gained by reporting the information more frequently than the rate at which it is changing, and, indeed, there is the disadvantage of increased reporting costs. From a human factors point of view, reporting must be accomplished frequently enough so that only a small time lag is associated with any data change.

What is the time magnitude of concern? In a manual reporting system, the time lag between writing of a source document and delivery of the final report may be measured in weeks or months. With a high speed computer and an automated data acquisition system, this time lag can be reduced to units of days, hours, minutes, or even seconds. Current feeling, as indicated by the questionnaire, indicates a need for reporting measured in the interval between hours and days. If the time lag lies within this range, depending upon the specific application, reporting may be considered to be satisfactory.

What the Human Factors Specialist Looks for in an Automated Data System

The results of the survey show different practices conducted by different contractors and at different levels of management. Each group, each level, in absence of a well established standardized practice, reflects its current needs and difficulties. Each respondent reflects his sensitivity to the squeak of his wheel. That the survey conducted reflects immediate needs of the individual respondents rather than a common statement of the overall needs of the community comes as no surprize. Bourne et al, "Requirements, Criteria and Measurements of Performance of Information Storage and Retrieval Systems." Office of Science Information, National Science Foundation, 1961, conducted a survey of workers in selected technical fields. Included in this survey was a study of the user's needs. They comment on the difficulty of using the user to specify his own needs. "The user himself is frequently a poor source for direct comment on his needs; he is usually influenced by the tools and facilities that he is familiar with, and he usually cannot discriminate between his actual needs and his way of performing work."

Each respondent is in common accord that response time must be reduced. But they differ in detail. And, of course, the striking of a common note is hampered by the necessity of using subjective reactions of human factors specialists as criteria. One point seems to be clear. Respondents establish their needs and desires for a human factors data bank in terms of their past experiences with libraries and other kinds of information centers. Thus, it is likely that replies to the questionnaires by the respondents reflect not so much criteria that they would like to see operative, but rather represent an adaptation to the existing services to which they have been habituated.

If we weave a central theme into the fabric of replies, what are the things that the human factors specialist looks for in an automated system for efficient storage, accurate processing, and rapid retrieval of human factors task data? He looks for the following:

1. Comprehensiveness
2. Effective response time

3. Flexibility of usage
4. Simplicity of usage
5. Quality
6. Efficiency

1. Comprehensiveness

The human factors specialist needs to make effective and efficient use of all available data. During the course of system design, he must be able to examine relevant data through all phases of his design. He must be able to compare data from one system with data from another. The human factors specialist concerned with human performance within the subterranean confines of a missile silo requires access to data accumulated within a command and control center located in the side of a mountain. The data bank housed within the information center must be complete and responsive to the needs of the human factors specialist.

2. Effective response time

Response time is defined by each prospective human factors specialist and his particular application. This time is probably a function of two variables. The first variable is his estimate of the useful life of the information that is being sought, and the second variable is the effect on his time schedule of having to wait for the information he requests. In command and control, and management control systems, some information obviously has a very short useful life, whereas in scientific and technical work the useful life of information is probably much longer, ranging from a matter of months to a matter of years. When most users state that they prefer short response times to requests, they are probably reflecting the latter variable, i.e., the effect on their schedules of waiting for responses to their requests. If the time delay in answering requests becomes excessive in the judgment of the analyst, he will probably tend to take action in the absence of specific information and to depreciate the services of the information center.

3. Flexibility of usage

Frequently, the human factors specialist will have only a vague idea of his information needs. Initially, he may only wish to determine what is available in the files of the data bank. After his first search, he may wish to expand, to elaborate, or even to restrict the scope of his request. It is important that provision be made to accommodate this process. Too much general or peripheral information would be useless and inefficient. Too little specific information would reduce the efficiency of his search.

4. Simplicity of usage

The user is in a dilemma, because he must often request identification of data by authors whose vocabulary usage he does not know. Thus, when he prepares a question or information request, he has to predict the words or terms that authors of unknown or requested documents might use in writing about a particular field of interest. This is more of a problem in the social and behavioral sciences than it is in the physical sciences. However, the problem is encountered in every field of specialization unless the information center is prepared to process natural language text directly and to admit virtually all words.

It must be possible to browse through the files. The human factors specialist would like to interrogate files in the data bank in terms of the particular interests of his group and to receive outputs of relevant information in a timely manner. If possible, it would be nice to have an active system rather than a passive system. Most conventional existing systems are passive in that the specialist must initiate requests prior to any action being taken. In an active system, statements concerning the specialist's long term interests in certain subject specialties are maintained in the form of an interest profile. Each new set of acquisitions can then be compared with the specialist's interest profile. In this way, the specialist's information needs are active and are sought for automatically as new acquisitions come into the system.

A case in point is the example of generating an element for TEPI involving the number of instructors required. Specialists concerned with this type of determination need to be informed automatically each time a piece of data enters the "data bank" which indicates a change in the number of personnel to be trained.

5. Quality

The human factors specialist must have confidence in the search coverage provided by the system. Coverage depends upon acquisition philosophy, classifying and indexing schemes, the degree of fit between search statements and indexed data and, of course, the efficiency of the search procedures. When a request is processed by the information center, part of the response should be a specification of the types of data that were searched.

6. Efficiency

Interestingly this criterion does not seem to be perceived as important by many respondents. It seems reasonable, however, that as long as data are hard to come by, the amount of irrelevant material received is of minor importance; the specialist can perform a gross screening of the material very rapidly. If, however, large amounts of data are made available the amount of time or energy that must be expended will also become large. Under these circumstances inclusion of irrelevant material becomes highly undesirable.

The Information Center

This need for an information center is not unique to the human factors community. An overwhelming need exists in all areas of research. The problem is well described in "The Information Center: Some Selected Examples," by Emory H. Holmes, S. D. C. (SP-1702).

" Information centers have evolved as a result of the inability of traditional libraries to meet the needs of scientists, researchers, and scholars. These centers have become active repositories of documents in contrast to the role of traditional libraries, which have been unable to meet the information needs of scientists for at least three inherent reasons. First, the library is a passive receptacle for documents. The concept of a library is that of a passive repository of written or recorded knowledge to which users come to request particular entries, or to browse, or to scan index files or actual documents. Second, the classification and indexing schemes used by the libraries must encompass the entire range of human knowledge, and such schemes represent compromises or arbitrary divisions of knowledge not fitted to many of the more specialized information needs of working scholars, scientists, and technicians. Third, the time cycle or the updating cycle for the traditional library is out of phase with the updating cycle required by many scientific and technical activities in modern times.

"The emergence of information retrieval centers can be attributed to the necessity for meeting information needs--a function traditional libraries have been unable to fulfill. Among the areas in which better performance is sought are the capability to accept or accommodate deeper probing or questioning of a classification structure, better current awareness of literature, and active rather than passive service to users. While it is true that information centers serve more restricted users' needs than do traditional libraries and while it is also true that the range of the subject matter input to an information center is more restricted than for a large library system, it is felt that these two distinctions are not crucial to the emerging concepts behind the information center and that such distinctions obscure some of the major differences between libraries and information centers. [A characteristic of the center for human factors task data] is that the volume of documents to be stored is very large, or the documents are in other ways inaccessible; the information user can not browse through the documents directly to accomplish his task. Once this condition is present, some very important consequences follow in regard to the functions outlined above. Regardless of whether the system is an entirely manual operation or a partially mechanical or automated one, it becomes clear that other individuals must perform services for the information user in each of the various functions. For example, the information user delegates to others such functions as the analysis of documents for relevant information, and the searching and selection of pertinent documents.

"The main point here is that once many of these functions have been delegated to other persons, a host of problems become crucial-- problems relating to communication, terminology, and general specification of particular questions or search requests. Of course, as long as all functions are manual, the information user can talk directly to those performing the functions. He can make sure that his request is clearly understood, or he can readjust his query to fit the context of the system. If the system is incapable, in its current form, of responding to his request, he has at least a reasonable chance of talking the human personnel into reprogramming some of their operations. Mechanization or automation makes the problem of reprogramming operations an indirect one as far as the information user is concerned. Also, a certain amount of system flexibility is lost as functions are mechanized or automated."

Information Processing

How quickly can the information center respond to the demands of the human factors specialist? In response to a request, we are not so concerned with speed of the fastest portion of the data processing cycle as we are with the slowest portion of the cycle. To achieve a satisfactory response time, the computer system must be free of human intervention as much as possible. We must avoid the multi-faceted cycle in which each step of computer execution is interspersed with human intervention. We must avoid the following situation: The human factors specialist concerned with searching for and obtaining data should not have to specify every specific detail for the computer. In the generation of an element of a QQPRI, he should not have to continually examine computer output to determine what task elements have been formulated. He should have a computer program available to him which can carry out the search independent of his intervention.

Centralization

Decisions concerning the information center for human factors data are not relegated solely to the internal workings and contents of the data bank. Other considerations arise which are of considerable import. These consist of the tie-lines between the specialist and the information center.

Shall the data bank of human factors information be located in a central facility or shall it consist of a number of localized centers? At the present time there is no common centralized facility. True, at a number of locations, contractors have developed information centers which could be considered "central" to their own needs, but no central location exists as a common melting pot to facilitate requirement of an overall objective of: comparing data across systems, longitudinally within each system through all phases of system design, development, test and operation, or both simultaneously.

As indicated in the A.I.R. study, a number of methods exist for transmission of data:

- Documents are transmitted by internal and public mail systems.
- Localized central offices redistribute data on scheduled intervals.
- Phone calls and personal visits between analysts.
- Requests by phone, mail, and direct visits to libraries.
- Meetings of design team at scheduled intervals.

Some or all of these methods may be used in any system network, and networks are only differentiated in the degree in which all methods are used. It can be noted, however, that in those instances in which localized centralized data store methods were employed, delays resulted from overload both in quantity of data stored and in the number of demands made.

The problem of information flow is not confined to the communication process. It is a problem of knowing what to ask for and whom to ask. As shown in the A.I.R. study, "Many interviewees reported that there were times when previously generated data had been unavailable to them because they did not know whom to ask, and/or because the time required to go through the channels through which data were normally obtained was too long."

Even at those contractor locations where communications channels have been partially automated, interviewees felt that though the systems were valuable that they had as yet not achieved full potential. This was usually attributed to lack of sophisticated programming and delays in entering data. At the present time, we have a number of information systems which function independently of each other. The result is not satisfactory. We must look to and examine carefully the role of a true centralized facility.

SECTION III

HUMAN FACTORS TASK DATA AND THEIR SPECIFICATION

Introduction

Human factors task data may be categorized in terms of the numbers of different formats which are used to contain the data. Some of the forms lend themselves to storage within the conventional digital computer. Others do not. In the past, access to human factors task data has been hampered because programming efforts are time consuming and costly. To provide the human factors specialist with quick and timely access to data housed within an information center, a human factors-oriented computer language must be developed.

The Forms of Human Factors Data

The need for seeking improved techniques for handling human factors data has been established in the A. I. R. study. But what are the data, and what do they look like? Many definitions exist, one of which is described by government document, "System Program Office Manual," AFSCM 375-3, which defines data as that collection of forms, drawings and publications, the generation and subsequent distribution of which is essential to the development and operation of a system and which is contractually required by the procuring activity. Human factors data are further defined, at least implicitly, as those aspects of system development identified in regulations and manuals as the "personnel subsystem."

The human factors data which were observed by A.I.R. during the research are listed in Figure 1. Shown are the form of data, the characteristics of data, and examples. These forms of data can be categorized as follows:

I   Functional flow diagrams which are characterized by blocks and connections to identify system functions and indicate their interrelationships at various levels. (Figure 2.)

II   Highly formatted forms which are unambiguous with regard to keypunching procedures. Each field of the form is punched in specific card columns and each type of card contains a code to identify the card type and, consequently, its format and information content. (Figure 3.)

III   Tables of numeric information. (Figure 4A. /4B.)

IV   Equations which describe functional relationships between variables. (Figure 5.)

Form	Characteristics	Examples
Standard forms as req'd by regulations, etc.	Highly formatted information.	Task analyses, maintainability analyses, malfunction reporting forms.
Narrative reports.	Verbal description of situation or requirements, results of study.	Some specifications, journal articles, oral communication.
Engineering drawings.	Line drawings showing scale plan of relevant equipment.	Panel layout plans.
Isometric drawings.	Line drawings showing relationships of parts and/or operators.	Crew position diagrams, control operator pictorials.
Schematic drawings.	Formalized diagrams showing functional relations of elements of systems and subsystems.	Flow charts, functional analyses.
Graphs	Linear or rectangular drawings showing relations between two or more variables.	Line or bar graphs presenting summarized experimental results.
Discrete information units with one variable.	Simple statement of fact or direct relationship.	Data extracted from table or report.
Tables.	Large amounts of data, usually numerical, presented in columnar or matrix form.	Summarized results of investigations, math or statistical tables.
Discrete information units with more than one variable.	Statement of fact relating more than one variable.	Data extracted from table or report.

Figure 1 -- Forms of Data

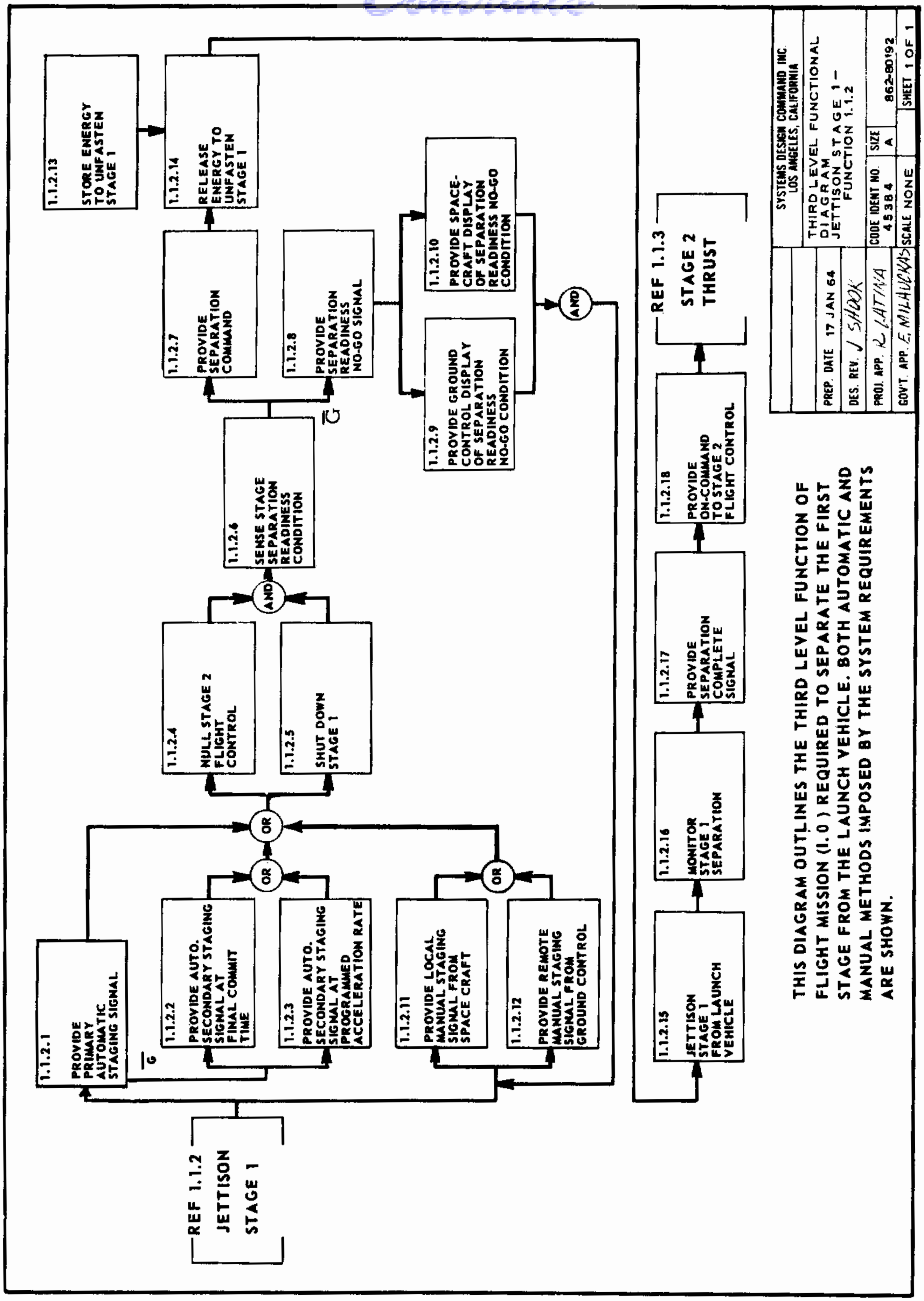

Figure 2 -- Example of a Functional Flow Diagram

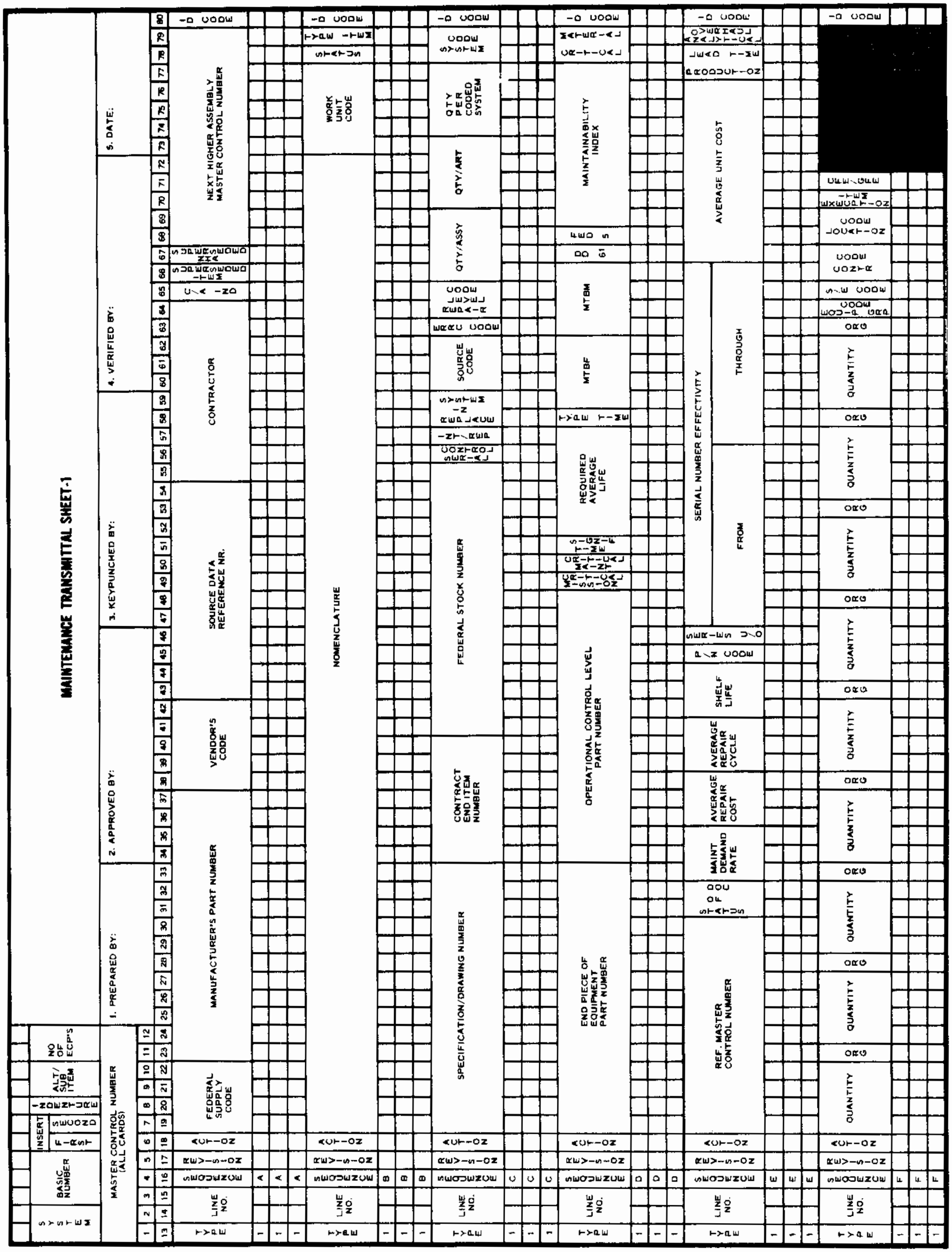

Figure 3 -- Example of a Highly-Formatted Form

RIGHT ARM ON AIRCRAFT CONTROL STICK (POUNDS)					
DISTANCE IN INCHES FROM		PUSH	PULL	IN	OUT
SRP*	MIDPLANE				
9	8 (left)	12	26	24	34
	4-1/2 (left)	18	28	31	31
	0	26	34	30	23
	4-1/2 (right)	34	39	26	15
	8 (right)	37	39	26	12
12-1/2	8 (left)	18	33	23	31
	8 (right)	43	49	22	16
15-1/2	8 (left)	23	39	20	25
	0	43	54	24	20
	8 (right)	53	55	24	13
18-3/4	8 (left)	36	45	16	22
	0	64	56	8	15
	8 (right)	70	58	22	14
23-3/4	8 (left)	29	51	11	19
	0	54	62	14	13
	8 (right)	56	58	20	12

*Forward; control is 13-1/2 inches above seat reference point.

RIGHT ARM ON AIRCRAFT CONTROL WHEEL (POUNDS)					
DISTANCE IN INCHES FORWARD FROM SRP*	CONTROL POSITION	PUSH	PULL	IN	OUT
10-3/4	90° (left)	32	23	23	27
	45° (left)	48	40	21	24
	0	52	44	26	20
	45° (right)	40	39	31	24
	80° (right)	19	18	21	15
13-1/4	90° (left)	32	33	26	21
	90° (right)	25	31	25	19
15-3/4	90° (left)	32	42	27	19
	0	61	66	27	27
	90° (right)	32	49	29	20
19	90° (left)	37	60	22	27
	0	64	73	25	30
	90° (right)	33	61	33	22
23-1/4	90° (left)	82	73	21	26
	0	105	77	20	35
	30° (right)	49	74	26	22

*Wheel grips 18 inches above SRP and 15 inches apart.

Figure 4A -- Example of Tables

Degrees from Midplane	Distance Above Seat Reference Point (Inches)									
	-6	0	6	12	18	24	30	36	42	48
0°	-	-	22.7	25.1	26.6	26.3	25.9	24.5	20.8	15.4
15°	-	-	21.6	27.2	28.7	28.7	28.1	25.7	23.5	16.8
30°	-	21.2	25.5	28.7	29.8	30.1	29.4	28.1	24.6	18.3
45°	-	22.4	27.3	29.7	31.2	31.1	30.6	28.1	24.5	18.2
60°	-	23.5	28.6	31.1	32.5	33.0	31.9	29.6	26.5	20.1
75°	12.0	24.5	29.6	32.1	34.1	34.0	33.5	31.1	27.3	21.7
90°	11.9	24.8	30.3	33.2	34.6	35.0	34.4	32.0	29.0	21.9
105°	15.0	25.5	30.5	33.1	35.0	35.1	34.6	32.7	29.7	24.6
120°	15.1	25.2	30.6	33.5	35.1	35.6	35.2	33.1	30.0	23.5
135°	13.0	24.4	29.4	32.3	34.7	35.2	34.5	33.3	30.1	25.7

Seated Arm Reach Dimensions (95th Percentile) (Inches)

Figure 4B -- Example of a Table

$$(1) \qquad M_Y = \frac{MTBF}{MTBF + MDT/F}$$

(A definition of Maintainability Index)

Figure 5 -- Example of Equations

REQUIREMENTS ALLOCATION SHEET	Functional Diagram Title and No. [illegible] Stage 1 - DWG. NO. 220663 or Nomenclature and No. of CEI		Equipment Identification		PERSONNEL AND TRAINING EQUIPMENT REQUIREMENTS				Procedural Data Requirements
Function Name & Number	Design Requirements	Facility Requirements	Nomen-clature	CEI or Detail Spec or Index or Master Control Number	Tasks	Time Req	Performance Requirements	Tng & Tng Equip Req	
1.1.2.6 Sense Stage Preparation Readiness Countdown	Means shall be provided for guidance and control to sense the position of the Stage 2 thrust chamber and condition of the Stage 1 engine after the staging signal is transmitted.		A/B G&C Module	12 4010 A					
1.1.2.7 Provide Separation Command	A separation signal shall be generated by guidance and control when sensing indicates that the condition of the engines will permit separation (see Functions 1.1.2.4 and 1.1.2.5).		A/B G&C Module	12 4010 A					
	The separation signal will be 28 VDC ± 1.5 and shall be transmitted to a device which releases energy for physical separation of the stages.		A/B Electrical Distribution Box	12 4020 A					
1.1.2.8 Provide Separation Readiness NO-GO Signal	A no-go signal shall be generated if sensing indicates that the condition of the engines will not permit separation (see Functions 1.1.2.4 and 1.1.2.5).		A/B G&C Module	12 4010 A					
	The no-go signal shall be transmitted to ground control as ___ RF telemetry data.		A/B G&C Module	12 4010 A					
	The no-go signal shall be transmitted to the spacecraft as a 28 VDC ± 1.5 electrical signal.		A/B Electrical Distribution Box	12 4020 A					
1.1.2.9 Provide Ground Control Display of Separation Readiness NO-GO Condition	The no-go signal will be received by ground control, decoded, and visually displayed on a control console.	50 foot candles are required at console surface	Ground Control Console	12 2030 A	1.1.2.9a Perceive NO-GO Display	2.05	Performance under time stress crew coordination.	E Class 1	21M-LGM26C-1 21M-LGM26C-1-2CL-3
1.1.2.10 Provide Spacecraft Display of Separation Readiness NO-GO Condition	The no-go signal shall be converted to a visual display in the spacecraft.		Spacecraft Systems Control Console	12 5010 A	1.1.2.10a Perceive NO-GO Display	2.03	Performance under time stress crew coordination.	E Class 1	21M-LGM26C-1-2CL-3
1.1.2.11 Provide Local Manual Staging From Spacecraft	Means shall be provided for manually generating a staging signal to the engines from the spacecraft. The control shall be guarded to prevent accidental activation.		Spacecraft Systems Control Console	12 5010 A	1.1.2.11a Activate Manual Override Staging Control	3.08	Performance under time stress. Communicate action required to second astronaut. Requires making a decision. Involves use of safety procedures.	F Class 1	21M-LGM26C-1-2CL-4
	The staging signal from the spacecraft shall be transmitted to airborne guidance and control.		A/B Electrical Distribution Box	12 4020 A					
	The staging signal shall activate airborne guidance and control by transmission of 28 VDC ± 1.5 signals to the Stage 1 and Stage 2 engines (see Functions 1.1.2.4 and 1.1.2.5).		A/B G&C Module	12 4010 A	1.1.2.11b Observe feedback display of staging in spacecraft and ground console.	3.05	Performance under time stress.	E Class 1	
1.1.2.12 Provide Remote Manual Staging Signal From Ground Control	Means shall be provided for manually generating a staging command to the engines from ground control. The control shall be guarded to prevent accidental activation.	Floor area required, 4 ft x 3 ft (6 ft high) for equipment	Ground Control Console	12 2030 A	1.1.2.12a Activate manual (ground) staging control.	3.05	Launch crew coordination making decision safety procedures.	F Class 1	31X7-24-6-1
	The staging command from the ground control will be transmitted to airborne guidance and control.		Command & Control Transmitter	12 2020 A					31X7-26-3-1
	The staging signal shall activate airborne guidance and control by transmission of 28 VDC ± 1.5 signals to the Stage 1 and Stage 2 engines (see Functions 1.1.2.4 and 1.1.2.5).		A/B G&C Module	12 4010 A	1.1.2.12b Observe feedback display of staging signal in spacecraft and ground console.	3.05	Performance under time stress.	J Class 1	

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Figure 6A -- Example of Free-Format Form

PERSONNEL UTILIZATION SHEET		MAN-MONTHS BY MAINTENANCE LOCATION								TOTAL MAN-MONTHS
		1	2	3	4	5	6	7	8	
AFSC	TITLE AND AFSC NO.	Mobile Unit Deployed	Tactical Car Turn Around	Personnel Car Turn Around	Weapon Transfer	RV - GC Replace	Carrier Maint	SRA Maint	Field Maint	
1824	Operations Officer	.170	.046							.216
30452	Ground Comm Equipment Repairman (Light)	1.411		.0304			.20	.018		1.479
31150	Guidance System Mechanic						.0014		7.451	7.452
31450	Missile System Analyst Specialist	5.629	17.209	.306	1.480	3.760	.029	.006		28.420
42153	Aircraft & Missile Equipment Repairman	.426	13.010				.016		.001	13.453
60350	Vehicle Operator				1.760					1.760
64650	Organizational Supply Specialist		2.296							2.296

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Figure 6B -- Example of Free-Format Form

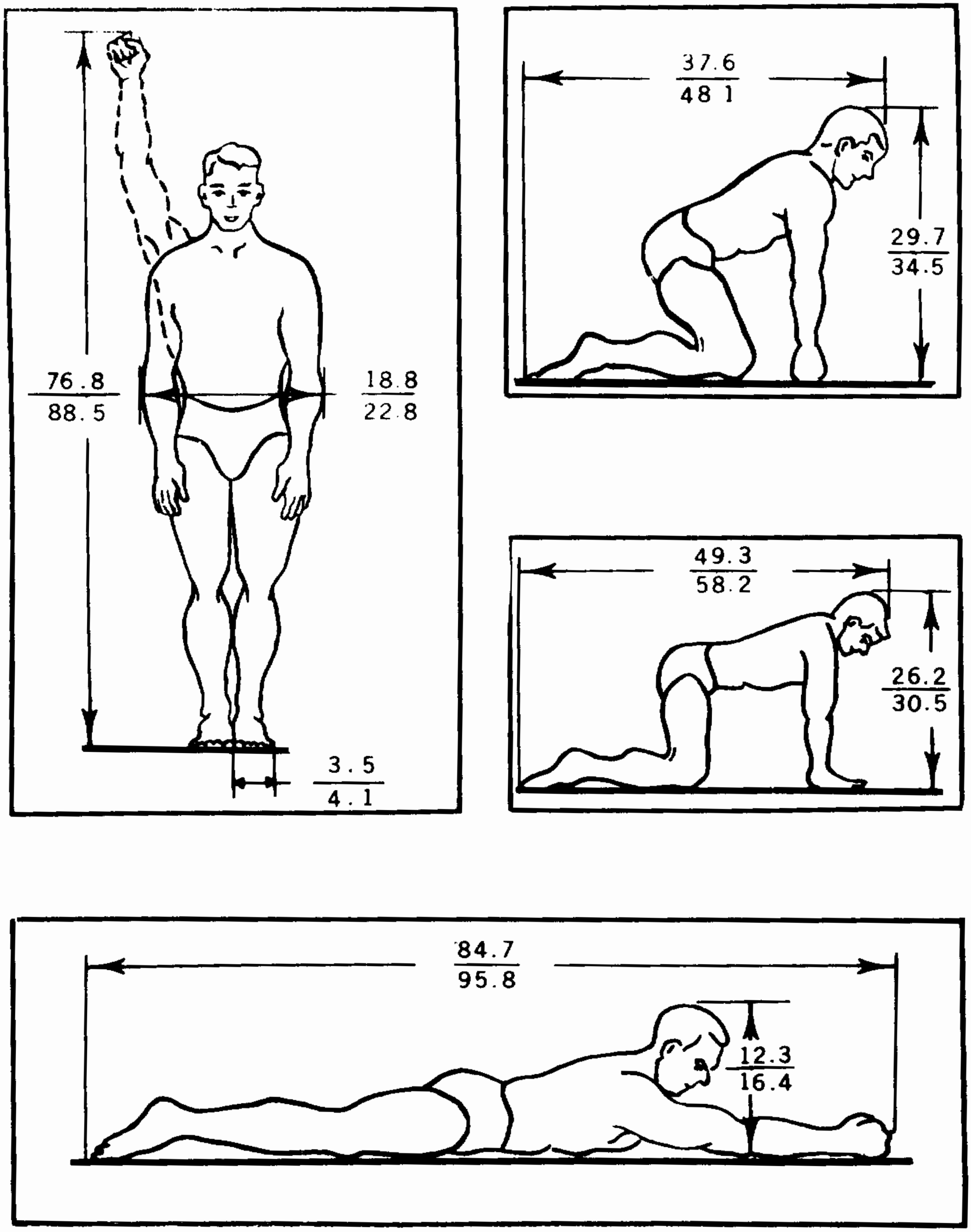
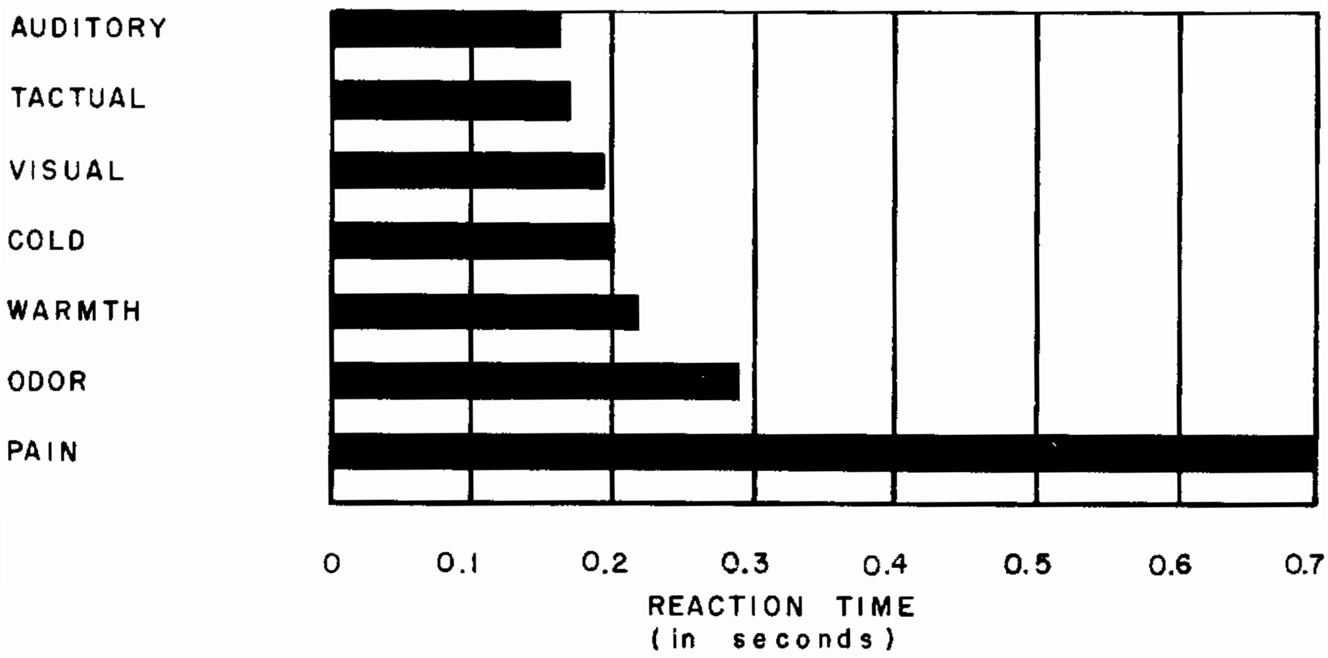


Figure 7A -- Example of Pictorial Data



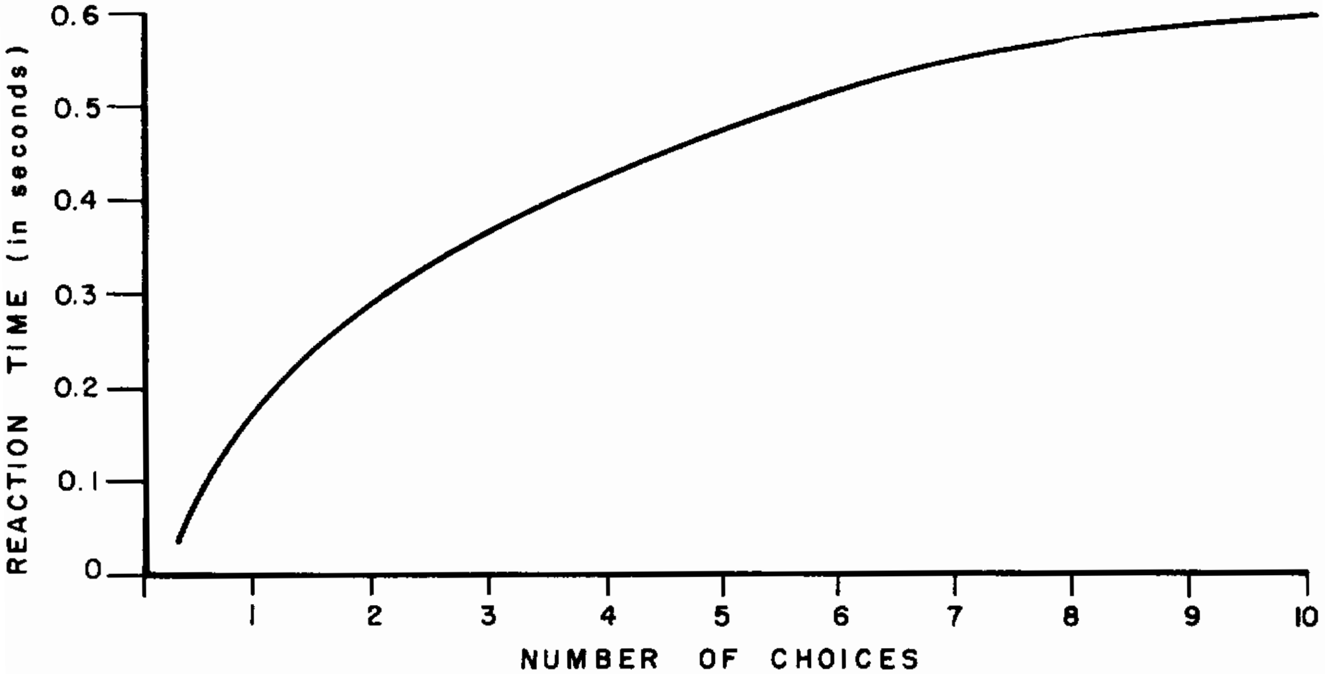
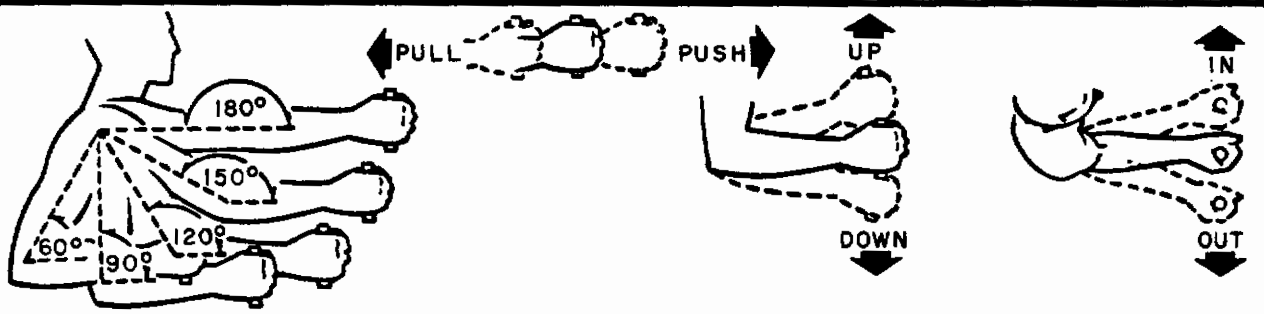


Figure 7B -- Example of Graphical Data

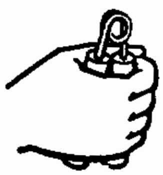
ARM STRENGTH*



ELBOW FLEXION	PUSH R	PUSH L	PULL R	PULL L	UP R	UP L	DOWN R	DOWN L	IN R	IN L	OUT R	OUT L
SEATED												
180°	50	42	52	50	14	9	17	13	20	13	14	8
150°	42	30	56	42	18	15	20	18	20	15	15	8
120°	36	26	42	34	24	17	26	21	22	20	15	10
90°	36	22	37	32	20	17	26	21	18	16	16	10
60°	34	22	24	26	20	15	20	18	20	17	17	12
PRONE												
180°	31	26	31	18	8	5	13	7	12	10	9	4
150°	29	24	29	21	13	7	15	10	15	8	12	5
120°	29	21	31	22	13	11	15	11	15	9	11	6
90°	26	18	24	23	15	15	16	12	16	13	13	6
60°	24	17	21	17	13	13	13	10	16	11	12	8

HAND STRENGTH*

GRIP



	R	L
MOMENTARY	59	55
SUSTAINED (1 MINUTE)	42	38

THUMB-FINGER GRASP

PALMAR — 13

TIPS — 13

LATERAL — 15

LEG STRENGTH*

	R	L
MOMENTARY	387	413
SUSTAINED (2 MIN.)	300	300

ANGLE: KNEE 111° ± 5°
ANKLE 60° ± 5°

* IN POUNDS; 5TH PERCENTILE

Figure 8 -- Example of a Combination of Data Categories

3. Reliability
4. Safety
5. Parameters to be Measured
6. Anticipated Work Environment
7. Time
8. Equipment
9. Training
10. Aptitudes
11. Maintainability
12. Operability

Using the above set of requirement areas as a guide, requirements information will be obtained from:

1. A review of applicable specifications, requirement documents, the Bendix proposal, and technical reports and systematic extraction of relevant requirements.

2. Interviews with WADC, Air Weather Service and other Air Force personnel to determine operational utilization parameters.

3. Interviews with Bendix and Boeing personnel, including meteorologists, air-sampling specialists, upper air physicists, and engineers.

The result will be a detailed list of the system requirements. Later these requirements will be keyed to various types of missions and to the various segments of each mission. In this way, estimates will be obtained of the variation to be expected in these requirements for various types of missions and the tolerances and time limitations imposed on the human operator by each requirement.

It is anticipated that each requirement consideration affecting the personnel subsystem will be summarized on a punch card. A multiple classification scheme will be used which will permit rapid and easy collation of all requirement considerations affecting a particular human factor design parameter, e.g.,

Figure 9 -- Example of Narrative Data

V Forms which are in a free format but have sufficient structure to allow keypunching if certain data delimiters and keypunching standards are established. Information in this category may include a mixture of narrative and fixed format entries. (Figure 6A. /6B.)

VI Information in the form of blueprints, photographs, sketches, etc. This data category does not include the "flow-charts" of Category 1. (Figure 7A. /7B.)

VII Reports which contain any combinations of two or more of the above categories. (Figure 8.)

VIII Reports which are completely narrative. (Figure 9.)

Figures 2 through 9 illustrate the eight categories of data. The first five categories contain data which lend themselves to storage and retrieval within a digital computer. And in each of these categories, it is possible to record all information conceptually by means of keypunching. The latter three categories do not lend themselves to storage within a digital computer. Information of a pictorial nature, e.g., photographs or sketches, in general, are more easily stored upon some media such as microfilm or videotape. Category VIII, reports which are completely narrative, can be stored in digital fashion, but generally speaking, this is not usually done free of some formatting restrictions to facilitate subsequent retrieval.

The Need for a Human Factors-Oriented Computer Language

Though analysis of the questionnaire shows that over 80 percent of the total number of respondents indicate some possible use of computers in their work, little commonality exists between the work done at different installations. Each human factors group, as its efforts are expanded, tends along an uncharted course. Human factors analysis is hampered by absence of commonality even to describe basic terms of data, let alone the sophisticated intricacies of data manipulation. The A.I.R. report states,

> "The selection of categories and subcategories is a critical part of the development of a centralized data store. It is important that categories be used which are appropriate to the content of the data and the uses made of them. At the present time no universal method of classifying all human factors task, performance, and related data exists. Formal and detailed classification schemes exist only for small areas of the field and these are not universally recognized as being acceptable. . ."

We know what the forms of data look like. To make use of the data contained on these forms, we must be able to process the contained data; we must be able to manipulate the data; and we must be able to do this within a computer. Unfortunately, this implementation is not always easily accomplishable. Implementation upon the computer requires a two-step procedure: (1) formulation of the specification in terms of a computer program, and (2) processing of the program within the computer. Of the two steps, the former, computer programming, is the bottleneck. Though processing may be conducted at speeds measurable in nanoseconds, the specification and preparation of the computer run are measured in magnitudes of time more commensurate with human performance.

The past programs written for human factors analyses have been written as independent entities and for digital computers not designed specifically for execution of complex simulations. Consequently, the following evils have emerged:

- Programming efforts are time consuming (several have required years to complete).
- Programming efforts are costly.
- Once written, computer programs are difficult to debug (render free of error).
- Unless computer programming is optimal, use of the program can be extremely costly.
- The resulting program tends to be inflexible, and the cost of introducing desired changes is often unacceptably high.

These effects have metastasized throughout all human factors analyses. In many instances because programming efforts are time consuming and costly, the algorithm for problem solution has been compromised for ease of solution. Thus, there is a need and a clear opportunity for a human factors-oriented computer language specially adapted to problems of human factors analysis. There are other reasons, and they too command respect. They are the reasons of (1) improved quality, (2) standardization, and (3) reduced costs.

(1) Improved quality

Better analysis would result from using a human factors-oriented computer language. At the present time, in absence of the ability to respond quickly, speed can only be achieved at the expense of the quality of specification and calculation. By reducing the time and effort required for computer programming, the power of the computer can be used to obtain the requisite quality.

We note in our example illustrating generation of elements for a QQPRI that different specialists have need for numbers of elements of task data. These specialists, in large part, may work independently of each other. And in the development of a large aerospace system, this may prove to be more the rule than the exception. In the absence of a human factors-oriented computer language, each specialist is faced with development of computer programs to extract specific elements of task data. If sufficient time is not available for programming, the analyst may be deprived of use of the computer to obtain desired information.

(2) Standardization

Standardization possesses many blessings. In particular, similarity of output format and notation would reduce the human factors specialist's task of adjusting to the idiosyncrasies of each individual submitter of data. Also, by using the same language, it would be feasible to combine the contributions of individual contractors into one overall program for a given study. A case in point is that of the PERT system for scheduling in which submissions from many parties are used to create an overall network.

A basic problem limiting human factors is the difficulty of establishing and obtaining data from a common base. In a complex system, this is difficult because of sheer magnitude of the number of tasks involved and diversity of interests represented. Major portions of the system fall under the responsibility of different contractors, and the maintenance of a steady flow of information is difficult due to diffusion of responsibilities throughout the program. This is not to be interpreted as a lack of a spirit of cooperation, but as indicative of the troubles which flourish in communications that flow through many diverse lines of command. A human factors-oriented computer language can facilitate the interchange and selection of data from a central source.

(3) Reduced costs

At the present time, each individual agency, contractor and subcontractor connected with a project conducts human factors studies: In many of these studies, computer programs are written specifically patterned for the study at hand. This duplication of programming which is non-interchangeable and of a non-general nature is done at high cost to AF and NASA, and is underwritten each time a project is conducted. This recurring cost would be reduced by creation of a human factors-oriented computer language.

The Characteristics of a Language for Handling Human Factors Task Data

Early human factors information is essential. Design changes for obtaining optimum trade-offs between man and machine capabilities become increasingly difficult as the system hardens. Unfortunately, many decisions which involve examination of data and mathematical analysis must be made independent of the information because decisions have to be made before computer programs can be developed. The lifeline to all these areas is stifled by lack of quick response. To achieve a fast-response, the computer programmer must be relieved of the tedious details of general purpose coding and must have at his disposal a specific human factors-oriented computer language to facilitate problem solution. He must have a language written specifically for human factors analysis.

Languages developed to solve a broad class of problems within a limited area of application may take either of two forms: procedural or non-procedural. A procedural language requires the specialist to prepare an ordered list of operations to be performed. The list may contain operations which affect the execution of other operations or may contain those which vary the order of execution but are nevertheless performed one-at-a-time in some determinate sequence. In a procedural language, there may be statements of a non-procedural declarative nature, but they do not alter the basic step-by-step approach to the solution of the problem.

Whereas a procedural language provides the analyst with a means for describing the solution of his problem, a non-procedural language is concerned more with a description of the problem itself. In a non-procedural language, the method for solving the problem is built into the language processor, and need not be a matter of concern to the analyst.

A good procedural language will often be found useful in areas far removed from the problem area for which the language was originally developed. In contrast, a non-procedural language usually will not be applicable to problems other than those for which it was specifically designed. And depending on the requirements and structures for the non-procedural language, the language may take many forms, e.g., a table, a set of control parameters, or a set of descriptive statements in "pseudo English."

The effective use of a procedural language is possible only if the user is trained in the use of procedural computer languages, i.e., is a "computer programmer." He need not be a professional programmer, but he must possess considerable training in the general art of computer programming.

The user of a non-procedural language will not generally be a trained programmer, but rather someone who is intimately familiar with the problem area in question. If the problems to be solved have complicated, many-faceted descriptions, the user of the non-procedural language may have to devote considerable time and effort to learning the details of this language; however, for a given problem area, the learning effort will always be far less for the non-procedural language.

What are the characteristics of a language for handling human factors task data? The language must permit the human factors specialist to query the data bank without specific knowledge of the contents of the data bank. And he must be able to write his inquiries in a simple form, and in a language akin to the language that he uses in an everyday sense, in dealing with human factors task data.

The human factors specialist must also be able to extract specific data from the files, and he must be able to perform calculations upon this data, in the form of analysis or simulation. He must be able to specify all steps necessary to describe handling of his data in a relatively simple and straightforward manner without need for assistance from a computer programmer. He requires a human factors-oriented computer language to do this.

SECTION IV

REQUIREMENTS GOVERNING COMPUTER PROGRAMMING

Introduction

The human factors specialist uses the computer in many different ways. He uses the computer for information storage and retrieval, analysis, and simulation. Though the human factors-oriented computer language should permit the specialist great latitude in its use, nevertheless, there is need for standardization in the specification of data formats. To aid the specialist in using the language and to facilitate access to human factors task information, a glossary must be created containing the names of fields on format descriptions. Statistical analysis and simulation are important tools of the human factors specialist. And with increasing use of the computer, they are assuming even greater importance. Computer programs must be developed and made available to the human factors specialist to facilitate use of the computer in these areas of problem solving.

Usage of the Computer

The human factors specialist needs a human factors-oriented computer language. He needs this language to facilitate handling of human factors task data in each of the steps taken in use of the computer. What are some of the specific requirements that the language must satisfy? This depends, in the main, upon how the computer is used by the human factors specialist. Respondents to the questionnaire indicated that current usage of the computer is divided fairly evenly between "Storage and Retrieval" and "Processing." "Processing," in turn, is divided fairly evenly between "Analysis" and "Simulation." Let us turn our attention to how the computer can be used in these three areas:

- Information Storage and Retrieval
- Analysis
- Simulation

Information Storage and Retrieval

Different types of data are of interest to the human factors specialist. He must be able to store the data, and he must be able to retrieve the data. Regardless of how elements of data are generated, regardless if they are directed to task data, to the QQPRI, to the TEPI, or some other required data, the elements must be stored and described in a manner which is amenable to subsequent retrieval. Prior to storage of data, it must be realized that the data may possess potential utility to a human factors specialist who is not aware that the data have been generated and stored within the data bank. From the A.I.R. study, "A file system capable of accumulating all human factors data must be capable of storing data in all of their various forms, at any one of several levels, and in a way that they are retrieved by reference to their content."

The "data bank" contains data in computer readable form. To store and retrieve these data, the computer system must be able to:

- Accept input to the data bank in a multitude of input data formats.
- Accept inquiries in a form convenient to the requestor.
- Retrieve data in response to specific inquiry.
- Process the selected data.
- Output the results in a form meaningful to the requestor.

Format Descriptions

New data forms are always being created. The computer system must not only accept information concerning the old, but must be capable of revising the old and of accepting the new. All human factors data to be processed by the system must be converted to a standard internal computer form. The computer must have a precise description of each format in which input data may appear. For each format acceptable to the computer, a record must be maintained in a "manual." This manual provides the analyst with necessary format description information.

Format description information will show, e.g., a printed form, how the data on the form is going to be made machine-readable (keypunching instructions), what information is pre-printed on the form, what type of entry is expected in each field (alphabetic or numeric, and if numeric in what form), and so on. The format description is itself an item of fully-formatted data consisting of the following items of information:

- A unique number identifying the format (actually identifying a particular revision).
- The name of the format.
- For each field in the format described:
  - The length of the field (or an indication that the field is variable-length).
  - The nature of the field contents (alphabetic or numeric, if numeric, the units involved and scaling conventions).

  - The name of the field.
  - The representation of the field (e.g., punch card columns used).

- If the format consists of a variable number of lines, each line having the same arrangement of fields, then a description of the organization of the fields in a line must be included.

We have previously broken down human factors data into eight categories (Figures 2 - 9). The first five categories contain data which lend themselves to storage and retrieval within a digital computer. It is necessary to capture these data in a machine-readable form. This is accomplished, typically, by a human operator seated at a typewriter-like keyboard, e.g., the keyboard of an IBM Model 026 keypunch. Let us examine how some of these data categories can be treated.

Functional Flow Diagrams. Of the eight categories of forms of data described in Section III, the first, Category 1, covers functional flow diagrams. Figure 2 provides an example of "Third Level Functional Diagram, Jettison Stage 1 - Function 1.1.2." This diagram can be captured in machine-readable form. Let us examine how this can be accomplished. The language required is relatively easy to use, and all diagrams are described in the same language. It is only necessary to identify the format which consists of:

- a number identifying the format
- the name of the format - "Functional Flow Block Diagram."

Each block diagram entered into the data bank will carry identification for subsequent retrieval. Either the entire diagram, or any portion thereof can be retrieved. And, of course, whenever a request is made for the retrieval of a functional flow block diagram, the computer system will retrieve and print it. Or if it is desired, the data can be retained in computer usable form for subsequent data processing such as a simulation. The computer printed diagram will be logically equivalent to the original hand-drawn one though the function blocks may not necessarily appear in the same exact position on the page. The computer will always attempt to follow the same rules as for hand-drawn charts, e.g., maintaining flow from left to right on the page, and juxtaposing parallel and alternate function blocks.

Let us examine how the flow diagram shown in Figure 2 would appear in machine-readable form. The description is shown in Figure 10. The language is used to describe the diagram in a pictorial fashion, with each function block or summing gate together with its exits described by a set of consecutive lines on the form. Each line is subsequently punched on a card according to the card column indications at the top of the form.

FUNCTIONAL FLOW BLOCK DIAGRAM

Description Form

1 5	6	7 Sample Description 72	73 80
REF		1.1.2, JETTISON STAGE 1	
EXIT		1.1.2.1, 1.1.2.11, 1.1.2.12	
BLOCK		1.1.2.1, PROVIDE PRIMARY AUTOMATIC STAGING SIGNAL	
NOGO	X	1.1.2.2, 1.1.2.3	
GO		1.1.2.1 OR	
BLOCK		1.1.2.2, PROVIDE AUTO. SECONDARY STAGING SIGNAL AT FINAL	
		COMMIT TIME	
EXIT		1.1.2.2 OR	
BLOCK		1.1.2.3, PROVIDE AUTO. SECONDARY STAGING SIGNAL AT	
		PROGRAMMED ACCELERATION RATE	
EXIT		1.1.2.2 OR	
BLOCK		1.1.2.11, PROVIDE LOCAL MANUAL STAGING SIGNAL FROM SPACE	
		CRAFT	
EXIT		1.1.2.11 OR	
BLOCK		1.1.2.12, PROVIDE REMOTE MANUAL STAGING SIGNAL FROM	
		GROUND CONTROL	
EXIT		1.1.2.11 OR	
OR		1.1.2.2 OR	
EXIT		1.1.2.1 OR	
OR		1.1.2.11 OR	
EXIT		1.1.2.1 OR	
OR		1.1.2.1 OR	
EXIT		1.1.2.4, 1.1.2.5	
BLOCK		1.1.2.4, NULL STAGE 2 FLIGHT CONTROL	
EXIT		1.1.2.4 AND	
BLOCK		1.1.2.5, SHUT DOWN STAGE 1	
EXIT		1.1.2.4 AND	
AND		1.1.2.4 AND	
EXIT		1.1.2.6	

Figure 10 -- Functional Flow Diagram (Fig. 4) in Machine-Readable Form

For each function block and summing gate, the following set of lines are entered:

Line 1.

columns 1 to 5	- "BLOCK"	for function block
	"REF"	for function reference
	"TENT"	for tentative or questionable function
	"OR"	for summing gate on alternate functions
	"AND"	for summing gate on parallel functions

column 6 - blank

columns 7 to 72 - The function number followed by a comma, then the test to be printed in the block. The function number assigned to a summing gate will be the number of the lowest - numbered block entering (or leaving as the case may be) the gate, followed by "OR" or "AND." If the same function number would be assigned to more than one "OR" ("AND") gate, the gates would be numbered by appending "OR1" ("AND1"), "OR2" ("AND2"), etc. to the function number.

Line 2.

columns 1 to 5	- "GO"	for "GO" paths from a block
	"NOGO"	for "NO-GO" paths from a block
	"EXIT"	for other than "GO"/"NO-GO" paths

column 6 - an "X" on a "GO"/"NO-GO" line to indicate that "G"/"$\overline{G}$" is to be printed adjacent to the path(s) leaving a block on the flow diagram.

columns 7 to 72 - the function numbers, separated by commas, indicating the block(s) to which the output paths are to be drawn.

Each "BLOCK," "REF" AND "TENT" line on the form must be followed by either an "EXIT" line or both "GO" and "NOGO" lines. Each "OR" and "AND" line must be followed by an "EXIT" line.

Line 3.

columns 1 to 5 - "SEE" for references to reports in the data bank

column 6 - an "X" to indicate that the references are to be printed in the block following the text. In any case, the references will be noted in the block diagram records in the data bank.

columns 7 to 72 - the report reference.

The "SEE" line is optional. When used, each reference must begin on a new line.

All lines can be continued onto succeeding lines by leaving columns 1 to 5 blank on the continuation lines. Blanks embedded in function numbers will be ignored; blanks embedded in text will be printed.

Well Formatted Forms. The sea of paper that constantly threatens to drown us is made up of many forms, many of which are extremely well defined as the "Maintenance Transmittal Sheet" shown in Figure 3. To store this data in the computer, a formal description would have to be written as shown in Figure 11. The data can then be keypunched in accordance with the format description.

For highly formatted forms the format description will completely specify the card columns for each field, as well as name of the field and nature of the contents. If a field is numeric, the submitter of the data must take care to follow the units and scaling specifications of the format description; otherwise the data in the field will be incorrectly interpreted by the computer system and the data bank will become contaminated.

Tables of numeric information can be reduced to machine-readable form either as highly formatted forms or as forms in a free format. If a maximum length can be determined for each type of entry in the table, then each can be treated as a field with that fixed length. With most tables, this will be the case.

As an example, consider the bottom table of Figure 4A. As machine-readable data, the second column of entries in the table is ambiguous, since each entry is part numeric and part alphabetic. For purposes of convenience, the column should be subdivided into two separate fields. The following is an example of how the fields might be specified for the format description:

Field Name	Type	Units	Card Columns
Distance in Inches Forward from SRP	Numeric	Inches	1-10
Control Position - Distance	Numeric	Degrees	11-20
Control Position - Direction	Alphabetic	---	21-30
Push	Numeric	Pounds	31-40
Pull	Numeric	Pounds	41-50
In	Numeric	Pounds	51-60
Out	Numeric	Pounds	61-70

It might be noted that since the first field of the form is described as numeric with the units in inches, the first entry would be punched 10.75 and not 10 - 3/4. The latter representation would be acceptable only if the field were described as alphabetic. If the purpose for storage of

Format Number:	1234.567/1/1/64	
Format Name:	Maintenance Transmittal Sheet-1	
Field Name	**Type**	**Card Columns**
System	Alphabetic	1 - 2
Basic Number	Numeric	3 - 5
First Insert	Numeric	0 - 6
Second Insert	Numeric	7 - 7
Indenture	Numeric	8 - 8
Alt/sub item	Numeric	9 - 10
No of ECP's	Numeric	11 - 12
Line		
Type	Constant = 1	13 - 13
Line No.	Numeric	14 - 15
Sequence	Constant = A	16 - 16
Revision	Alphabetic	17 - 17
Federal supply code	Alphabetic	19 - 22
Manufacturer's part number	Alphabetic	23 - 37
Vendor's code	Alphabetic	38 - 42
Source reference data nr.	Alphabetic	43 - 54
Contractor	Alphabetic	55 - 64
C/A ind	Alphabetic	65 - 65
Item superseded	Alphabetic	66 - 66
NNA superseded	Alphabetic	67 - 67
Next Higher Assy. Mcn	Alphabetic	68 - 79
ID code	Alphabetic	80 - 80
Line		
Type	Constant = 1	13 - 13
Line No	Numeric	14 - 15
Sequence	Constant = B	
(. . . and so on . . .)		

Figure 11 -- Sample Format Description

the table in the data bank is for subsequent retrieval and printing, the two representations are equivalent from the user's point of view. However, if numeric manipulations of the data are to be performed by the computer, the field must be specified as numeric.

Representation of Equations. Equations to be entered in the data bank will be specified on coding sheets (and later keypunched) by following the standard FORTRAN rules for writing arithmetic expressions. Their format description will consist only of a number identifying the format (as an equation-type) and the name of the format.

Let us look at the equation for a maintainability index shown in Figure 5.

$$(1) \quad M_Y = \frac{MTBF}{MTBF + MDT/F}$$

This would appear keypunched as:

```
EQ1 . . . . MY = MTBF/(MTBF + (MDT/F))
```

Free Formatted Forms. For forms in a free format, the representation of each field (which is the punch card columns used for highly formatted forms) in the format description will be a three-digit number identifying the field. This number will be unique for each field of the form. The format description identifying number will contain a code indicating that the description is a free format.

For example, a format description for the Personnel Utilization Sheet of Figure 6B is displayed in Figure 12. Each field is punched on a card preceded by its three-digit identification number. Since all fields are thus identified on the cards, blank fields on the form may be ignored. In line 1 of Figure 6B, (AFSC 1824) locations 3 through 8 do not contain data; these fields can be omitted. Some of the keypunched cards are shown in Figure 13. Variable length fields which overflow a card can be continued on succeeding cards by placing a "C" in column 1. The field immediately following a variable length field must always begin on a new non-continuation card, e.g., a variable length field must always be the last field on any card. Since the format description specifies the length of fixed length fields, they are continued on succeeding cards without a "C" in column 1.

Variable-length items are a special problem for a computer system, both in reduction to computer-readable form and in storage in the data bank. In keypunching variable-length items, there must be a provision for continuation cards to hold data which overflows the space allocated on a single card. A special mark must be provided to identify continuation cards. In the data bank, each variable-length item must be preceded by an item which specifies its length.

Other Data Categories. When a new format is first supplied to the

Format Number: 6789F/01/2/2/64

Format Name: Personnel Utilization Sheet (Man-Months By Maintenance Location)

Field Name	Type	Units	Length	I. D.
AFSC	Numeric	-	5	001
Title and AFSC No.	Alphabetic	-	variable	002
Mobile Unit Deployed	Numeric	MM	10	003
Tactical Car Turn Around	Numeric	MM	10	004
Personnel Car Turn Around	Numeric	MM	10	005
Weapon Transfer	Numeric	MM	10	006
RV-GC Replace	Numeric	MM	10	007
Carrier Maint	Numeric	MM	10	008
SRA Maint	Numeric	MM	10	009
Field Maint	Numeric	MM	10	010
Total Man-Months	Numeric	MM	10	011

Figure 12 -- Format Description for Figure 6B

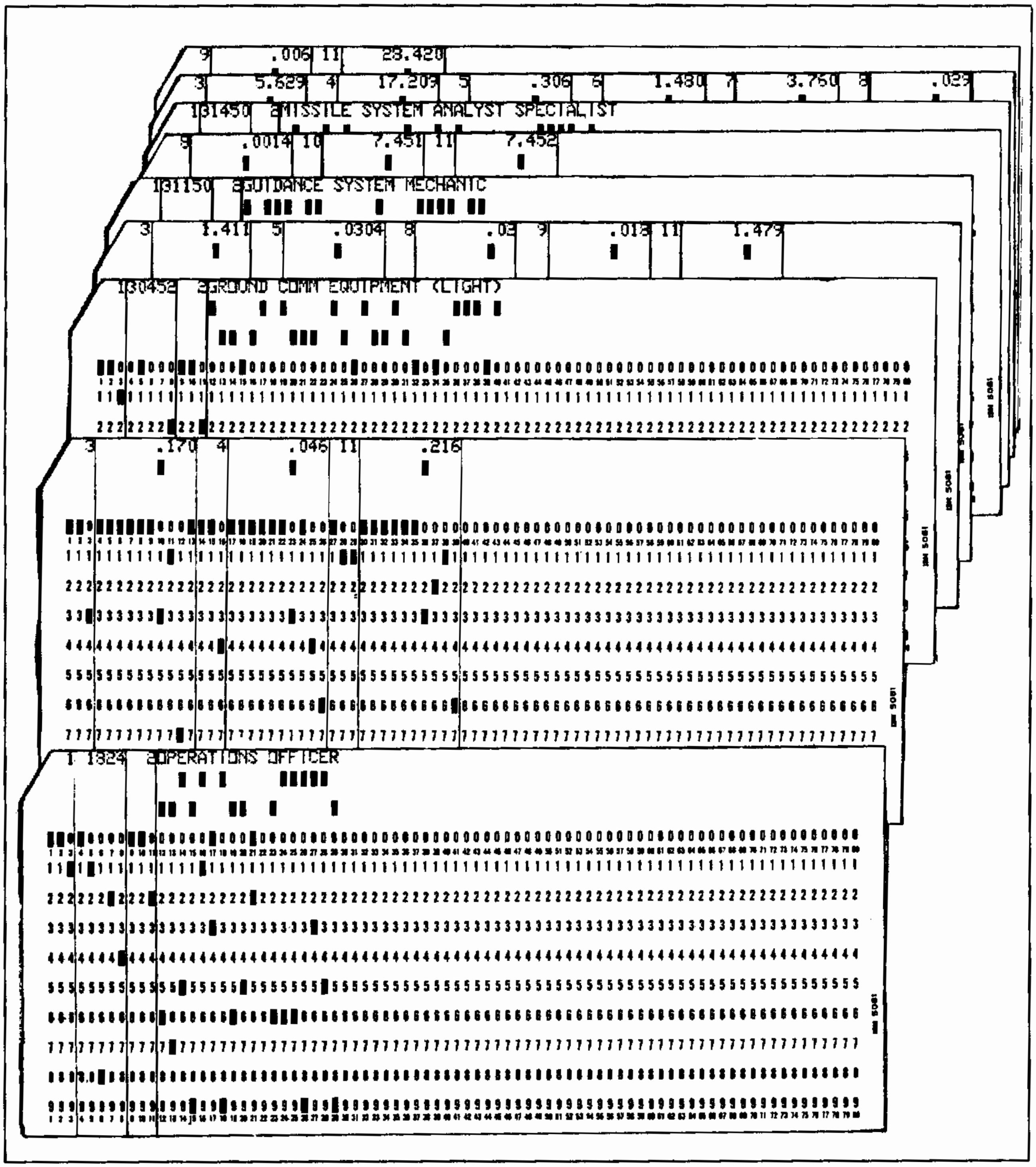


Figure 13 -- Keypunched Cards

computer system, a format description must be prepared and placed in the data bank. Thereafter, data of that format may be entered into the data bank by reducing content to machine-readable form according to the rules described in the format description.

Other data categories exist, however, which do not lend themselves to storage in machine-readable form. In the processing of human factors data a large quantity of information processed may be in the form of narrative, graphs or pictorial data such as shown in Figures 7 and 8. It must be possible to process and store this type of information.

In recent years, a number of systems have been developed which lend themselves to handling of data not in machine-readable form. In the main, these systems are based upon the use of video tape or microfilm. They differ, however, from a conventional system of picture storage in that provision for codifying a description of the contents of each document is provided to permit retrieval based upon a classification system. The essence of a pictorial retrieval system is the ability to search files efficiently in terms of a description of the picture.

Inquiry Processing Procedure

Each request for information from the data bank constitutes an inquiry. When an inquiry is processed, the following steps must occur:

- The inquiry must be presented in computer-readable form, and in a format acceptable for the statement of inquiries.
- The machine must first translate the inquiry into internal computer form. This involves replacing words as written by the analyst by more compact code numbers, and putting all numbers in standard internal form.
- The requisite items of data must be selected from the data bank.
- The selected items may require processing (summation, averaging, or complex statistical analysis) as specified by the requestor.
- The results must be put into readable form and delivered to the requestor.

Of the steps which must take place, a number are concerned with translation of the language of the specialist - the source language - into the language of the machine - the object language. Historically, computers were programmed initially in what is called machine-language coding. But through use of the human factors-oriented computer language, it is possible for the human factors specialist to address the computer in a language more similar to the language he uses in his everyday work.

Conceptually, it is possible to develop a system which accepts language identical to the language the human factors specialist uses in his work. Computer programs could conceivably be developed to accomplish this type of processing. However, it is much cheaper programwise, and there are fewer opportunities for error within computer processing if some rules are specified for the human factors specialist.

If references to elements of data are standardized, then fewer opportunities for ambiguity in data retrieval occur. But, of course, standardization is always accompanied by loss of freedom and flexibility. On the other hand, if words are permitted not to take on only one meaning, but many possible meanings, then a much more sophisticated translation program must be developed for the retrieval process.

The Glossary. The naming of fields is crucial to the retrieval of data. The computer system must be able to correlate a name specified in an inquiry with the name specified in the format description. Names created for form fields are unique and must be used. To assist the specialist interested in storage of data, a glossary of words must be generated and maintained which may be used in naming fields on format descriptions. This same glossary may be used by requestors when wording inquiries.

To make the task of phrasing inquiry requests easier for the specialist, the glossary should be as large as practical, and should contain many synonyms. However, efficient searching of the data bank requires brief unambiguous codes for the identification of data fields. These two requirements can be reconciled by providing, as a first stage in the processing of inquiries, a translation procedure which is a computer program that puts the inquiry into internal form. During the translation procedure, the words from the glossary are replaced by corresponding code numbers, and all synonyms of a single word receive the same code number. Also the form of the inquiry message is converted from a flexible-field typewriter-oriented format to a fixed-field computer-oriented format. The problems associated with development of the glossary or of a thesaurus of terms will be treated in greater detail in "Indexing," Section V.

An Example of a Data Inquiry. Let us examine a simple inquiry for data from the data bank. The example posed is a simple one. It does not involve any sophisticated search, and is used only to illustrate the use of an inquiry language for purposes of retrieval. The use of this simple example is not meant to indicate that the computer system would be so limited. Assume that data developed in support of a particular AF system is in the form shown in the bottom table (force to operate an aircraft control wheel) of Figure 4A. A human factors specialist wishes to retrieve some data from the table. Let us assume that he desires "push" and "pull" values when the distance forward from SRP is 19 inches and the control position is at zero. He consults the manual description of the format of the table and the glossary of terms. He writes his request, in terms chosen from the glossary, on a coding sheet and submits it for keypunching. The request might appear as follows:

```
      JOB QUERY OF ARM FORCE DESIGN VALUES
      TABLE . EQ. RIGHT ARM ON AIRCRAFT CONTROL WHEEL
X     *DISTANCE FORWARD FROM SRP . EQ. 19
X     *CONTROL POSITION - DISTANCE . EQ. 0
      SELECT PUSH, PULL
      END
```

Note how closely the form of the inquiry approximates an English-language statement of the retrieval task to be performed. "JOB QUERY OF ARM FORCE DESIGN VALUES" signals the beginning of an inquiry and serves to identify the answer when it is returned to the requestor. The abbreviation ". EQ. " means "equals" (the requestor may also specify "is greater than," "is less than," etc.) and the asterisks indicate conditions which must all be simultaneously satisfied. Thus, this request specifies a table whose title is "RIGHT ARM ON AIRCRAFT CONTROL WHEEL" in which a value of 19 appears in the column labeled "DISTANCE FORWARD FROM SRP" and a value of 0 in the column labeled "CONTROL POSITION - DISTANCE." When the line of the table containing the specified values has been located, the values "PUSH" and "PULL" are to be selected and written out.

The specialist's request is batched for processing with all other submitted data bank inquiries, and in a matter of hours he can receive his response. The computer printout consists of a reproduction of the request, followed by:

PUSH = 64

PULL = 73

The example is a simple one. A request was made for tabled entries which did exist. But what would happen if the specialist requested entries in the table which did not exist (for example, specified that the distance be 18 inches rather than 19)? Several possibilities are evident. One possibility would be to have the computer print out a statement that no tabled values existed. Another possibility would be to have the computer program select tabled values close to that desired and print out these values. Still another possibility would be to have the program interpolate between the closest values to satisfy the desired request. In essence, a trade-off is evident between the quality of computer processing and the cost of computer programming.

Additional examples of inquiries, and how computer programs such as those included in the Biomedical Computer Programs (BMD) series can be used for: 1) monitoring estimates through time, 2) comparing data across systems, 3) simulation, and 4) statistical procedures, are shown in Section VI.

Selection Procedures

The actual retrieval of items from the data bank in response to inquiries is the process referred to as "selection." The method employed in selection can vary considerably and depends upon the type of computer equipment being used. Two alternative selection procedures can be considered: one oriented to magnetic tape and one oriented to random access storage.

First, let us assume that the data bank is stored on magnetic tape, and that a large computer such as an IBM 7094 is used. In face of a large number of requests, from the viewpoint of economy and time, we must consider batch processing of requests.

A batch of inquiries is first processed by the inquiry translation procedure to yield a set of selection criteria. Each selection criterion specifies the characteristics of a data field or set of data fields to be selected. For example, a selection criterion might specify selection of all data fields giving the time to repair a particular piece of electronic equipment together with the environmental conditions for which the time figures are valid. The defining feature of a selection criterion is that it provides a test which is either satisfied or not satisfied by each field in the data bank. Selection consists of copying from the data bank all of the data fields which satisfy selection criteria.

Before the selection procedure begins, the inquiry translation procedure encodes all selection criteria in compact form and stores them in high-speed computer memory. The inquiry translator also encodes for each inquiry a set of inquiry processing rules which are stored on magnetic tape. These rules dictate how the selected data are to be processed.

Selection consists of comparing each data field in the data bank against all selection criteria, and writing out on tape the contents of each data field which satisfies any selection criterion. These outputs form the selected data file. This file contains each selected value, together with enough information to identify the inquiry to which it pertains.

Sorting Considerations. After the entire data bank has been processed and all selected field values have been written on tape, the resulting selected data file must be sorted in order to bring together all selected data pertaining to a single inquiry. The inquiry processing rules are then read from their tape and the selected data values are processed according to these rules to yield the desired report.

Several techniques may be employed to speed up the selection process.

Of primary importance is the organization of the data bank. Since data in the data bank cannot be referenced except in conjunction with the proper format description information, and since considerable computer processing is involved in setting up computer processes to interpret data according to the format description, it is imperative that all data corresponding to a format description be located together in the data bank. Then the format description can be used to set up a data processing routine which efficiently scans all correspondingly-formatted data.

Another technique for accelerating the selection process is to examine each format description as it is encountered and tabulate the selection criteria which could possibly be satisfied by data in the corresponding format. (For instance, a selection criterion involving "time" could not possibly be satisfied by a format which contained no "time" field.)

Selection Techniques Using Random-Access Storage. The A.I.R. study, as pointed out, indicates a need for improved response time, but not necessarily an immediate response. If it were desired, however, to provide very quick response, random disk storage could be considered. Disk storage provides the ability to maintain up-to-date records for diversified applications and the ability to process non-sequential and intermixed input data for multiple application areas.

The ability of disk storage systems to process input data of various types for multiple applications in-line, along with the ability to immediately update all effected records, makes it possible to request information directly from storage and the reply displayed in readable form.

When using random-access storage, it is not necessary to batch inquiry activity. This consideration rules out an exhaustive search of the data bank, and necessitates the establishment of an indexing system. In the indexing system there must be sufficient cross-reference capability to enable the computer system to single out a desired data field by its simultaneous appearance on all of the indexes corresponding to the parts of a selection criterion.

Analysis

Of processing (not information storage and retrieval) currently executed upon computers, respondents to the questionnaire indicate that almost one-half is devoted to analysis. This type of processing is indicated as "general processing, statistical analysis, generation of random series, and integration." Other than the catch-all "general processing," statistical analysis is the modal response (5 percent of the total).

Closely related to the steps required for analysis is the practice of simplification. Not only is the real situation reduced to a few idealized factors, but these few idealized factors are then altered so as to produce still further simplifications. The possibility for doing analysis rests on the question as to whether or not there exist parts approximately independent of one another or which interact with each in simple ways, for which we can account. We must be able to express the way in which a system is exercised in terms of sub-systems, in terms of missions, and missions in terms of crews and crews in terms of tasks, and tasks in terms of specific environment.

The Need for a Computer in Analysis

The human factors community is made up of a diversity of viewpoints, a diversity of approaches. This was brought out in interview after interview. It is evident that no magic analysis, no single panacea, exists or is likely to exist. This comes as no revelation. Indeed, the size and complexity of analysis is well illustrated in the following section from "Bridges Over the Gulf Between Man-Machine System Research and Man-Machine - System Development" (AFOSR - 1127), by J.C.R. Licklider.

"For many years, the randomized-block full-matrix experimental designs developed and popularized by R.A. Fisher have been the hallmark of sophisticated research. Coupled first with regression analysis and analysis of variance, and more recently with uncertainty analysis, they have brought careful experimentation and orderly interpretation into areas in which, formerly, authority and opinion were unchallenged . . .

"However, the use of randomized blocks and full matrixes constitutes an admission that we enter the experimental theatre with almost no a priori knowledge of its terrain. In fact, the only assumption it implies about the terrain is a kind of continuity -- an essence of important fine irregularities that would preclude the sampling of experimental conditions. But rarely do we undertake an experiment with so little knowledge of the region under investigation.

"In order to escape the combinatoric impasse, we must use more of our a priori knowledge. We must incorporate it into a strategy of search for solutions . . .

"But how, one may ask, can we experiment efficiently if we make only one or two observations, then stop to calculate results and replan the experiment? Will that not waste more time than it can possibly save?

"The reply, of course, is that the laboratory assistant who tests the subjects and processes the data will from now on be a digital computer. The program will be, not a list of tests to make, but a procedure for finding solutions through progressive interrogation (i.e., probing stimulation) of subjects or systems. Each question, each stimulation will be selected in the light of past responses. The human experimenter may guide the procedure by introducing hypotheses or altering weights in the decision process, but the trial-to-trial conduct of the experiment will be the responsibility of the computer. The computer will keep all the data processes, all the graphs plotted and displayed, right up to the moment, test-by-test, trial-by-trial."

The scope of potential and future analysis is limitless. How can a computer system be defined when there are so many different types of analyses of interest. Fortunately, we are able to define a large number which can play an essential role in human factors analyses. Many problems in research require extensive analyses of large amounts of recorded data. An indicator which provides a clue to the types of statistical analyses required for human factors task analyses is the Biomedical Computer Programs Manual (BMD 1964) developed at the Health Sciences Computing Facility, School of Medicine, UCLA. The programs developed were guided by the demands arising in the UCLA Medical Center for statistical and mathematical procedures to assist with many different research problems.

Statistical Analyses. Preparation of the basic research data for computer analyses differs greatly from problem to problem. Problems in research involve data covering many variables for each case or many observations on fewer variables. Typical of the analyses included in the BMD programs to handle these problems are: multiple regression and correlation analysis, factor analysis, discriminant analysis, time series analysis and analysis of variance. It cannot be specified *a priori* which programs will be of interest to a given project. Computer program development has and will continue to be guided by the demands arising from researchers for statistical and mathematical procedures as an aid to research. When these needs can be generalized to a class of computations which can be handled by specifying parameters, general purpose programs are written. As problems become better defined, new computer programs are developed to complement and supplement the existing set.

How can the methods of statistical analysis, such as contained in the BMD programs, be applied to problems of human factors? If the computer is to be used to carry out studies, it is mandatory that information, be it of men or of machines, be presented in suitable functional form. When a unique relationship between variables exists or can be postulated, then the variables are said to be functionally related. It is necessary to represent this relationship by a mathematical model. Though any set of data may be fitted with a model, the model need not of necessity be a good fit. What, of course, is desired is a model which hopefully possesses some intuitive appeal, is as simple as possible, and fits the data well. If a simple model is not satisfactory, additional terms or appropriate transformations must be included. With respect to the formulation of any functional representation, two situations are of interest: (1) the model is known and (2) the model is unknown.

The model is known . . . In conducting an investigation, the specialist often knows or is willing to assume that the distribution governing the failure rate is of a certain functional form and that the parameters are not known but are the quantities to be determined through test. For example, it might be known from theoretical considerations or from previous investigations that the distribution of failure rates is normally distributed, but that the average rate is unknown for the component in question. In this case the average rate is the unknown parameter. The procedure followed is to obtain data from tests of the component under study, and on the basis of these observations try to determine the value of the unknown parameter, or to decide whether the parameter is equal to some preconceived value. When the model is known but contains unknown parameters, the general procedure is to collect data and estimate or test hypotheses about the parameters.

The model is unknown . . . .This problem is more complex than the problem in which the model is known. An additional step is required -- the determination of the model. There are various ways in which a scientist may determine the functional form. He may determine it from a knowledge of more fundamental facts; he may collect such a vast amount of data that he can perceive certain trends; or he may evolve a function by intuitive or visionary inspiration. Once the model is evolved, the problem is reduced to that of parameter determination.

The model, as ultimately defined is affected by two strong influences: (1) the natural laws governing the phenomena in question, and (2) the subsequent usage to which the model will be placed, e.g., the type and method of calculation. Knowledge concerning the former is obtained from the laboratory and the physical scientist; knowledge concerning the latter is under the province of the mathematician and statistician. Both of these viewpoints must be intimately intertwined.

In the absence of a suitable model, conclusions drawn from acquired data are limited to the environmental and operational conditions surrounding the test as conducted. It is well known that the failure rate of a component under one set of environmental and operating stress conditions will change when exposed to some other set of conditions. Changes in environment are often quite drastic even in the operation of one and the same system, and even more drastic from system to system.

How does the specialist dealing with human factors data apply these mathematical techniques to a given problem? Clearly, the approach depends upon the problem. There is no one problem which can serve as a "good" example. So much of what is "good" will depend upon the viewpoint and direct activity of the reader. Let us examine an example, not from the viewpoint that the problem area is of particular import, but from the viewpoint of how analysis proceeds in establishing a desired functional relationship.

Analysis of Measurements of Human Performance

N.H. Mackworth's "Researches on the Measurement of Human Performance" Medical Research Council Special Report Series, H. M. Stationery Office, No. 268 (1950), [Selected Papers on Human Factors in the Design and Use of Control Systems, edited by H. Wallace Sinaiko, Dover Publications, 1961] covers wartime research done at the Applied Psychology Research Unit, Cambridge, in two areas of human behavior. The first part is that of signal detection (auditory and visual) and the second part concerns experiments on human tolerance to poor physical environmental conditions.

One of the experiments is "The Wireless Telegraphy Reception Test." Eleven experienced wireless operators were given their accustomed task of rapidly writing down Morse code messages heard over their headphones in different atmospheric temperatures. Messages given consisted of letters and numbers mixed at random. Messages containing more than a fixed number of incorrect symbols were regarded as faulty.

"The observed data suggested that deterioration as measured in this way bore a logarithmic relation to atmospheric temperature changes. This hypothesis was tested by fitting a curve of the general formula,

$$\text{Log } Y = C_0 + C_1 x$$

where C_0 and C_1 were constants, x - room temperature and Y - the incidence of faulty messages. The goodness of fit of the theoretically constructed curve to the observed data was found to be highly satisfactory and the equation for the theoretical curve was

$$\text{Log } Y = 1.1077 + 0.0957x\text{"}$$

In view of large differences in operational ability among the subjects, the men were grouped in terms of merit. The results are shown in Figure 14. Further tests investigated the effects of prolonged operation over time. These results are shown in Figure 15. Both sets of curves show an increase in the number of mistakes made with increasing severity of environment.

The Similarities Between Human Performance and Machine Performance.

The phenomena of decreased performance with increased severity of environment is not limited to human performance. Examination of failure rate information of electronic and mechanical gear indicates that stress curves exhibit a strong similarity of functional form. Failure rate, as a rule for electrical and electronic components, is a function of temperature which may stem from ambient environment or as the result of internal generation of heat. Mechanical gear are subject to stresses related to associated physical phenomena. However, in general, it may be stated that failure rate increases monotonically with increasing ambient temperature and with increasing wattage or percent of design rating.

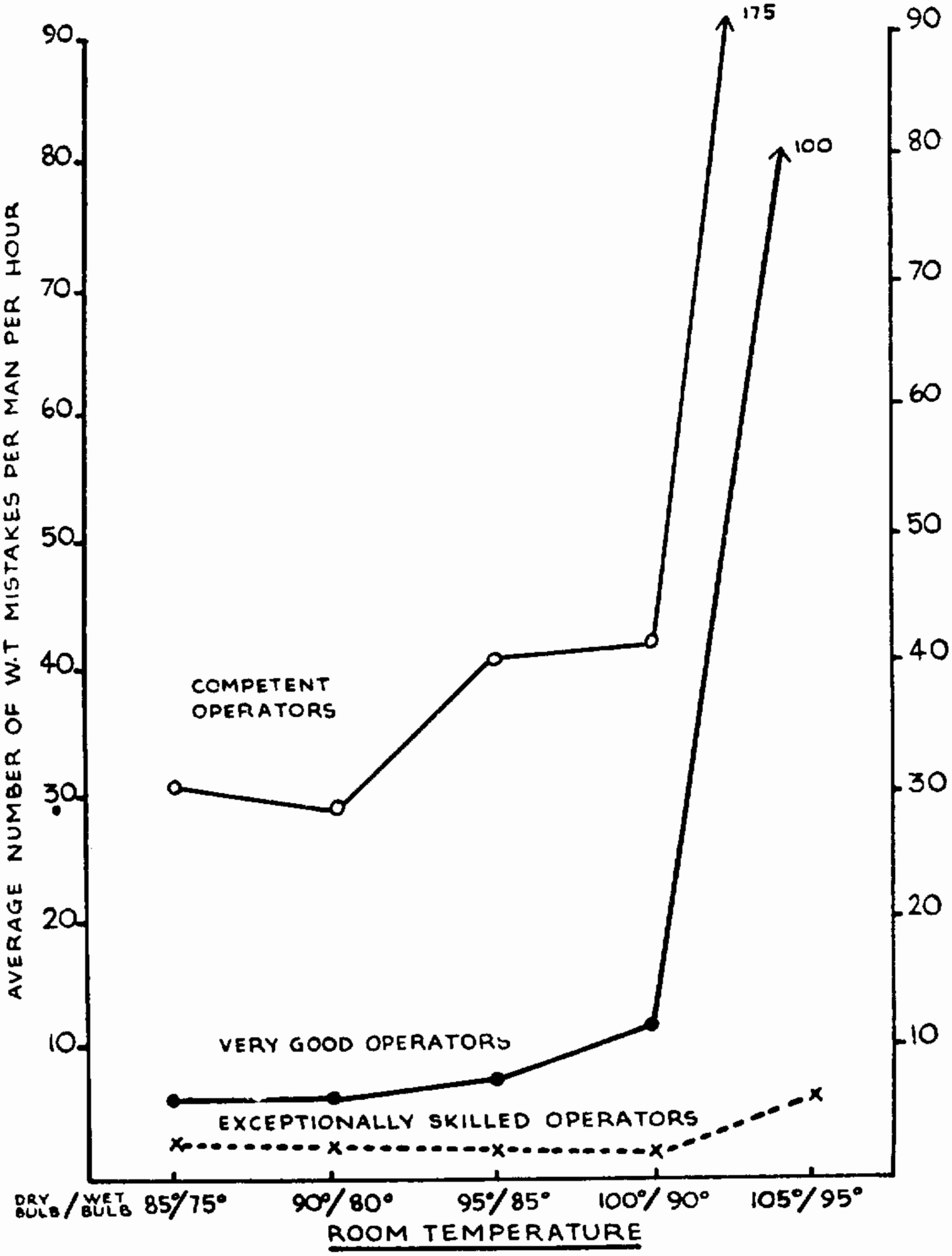


Figure 14 -- Operator Characteristics - Temperature

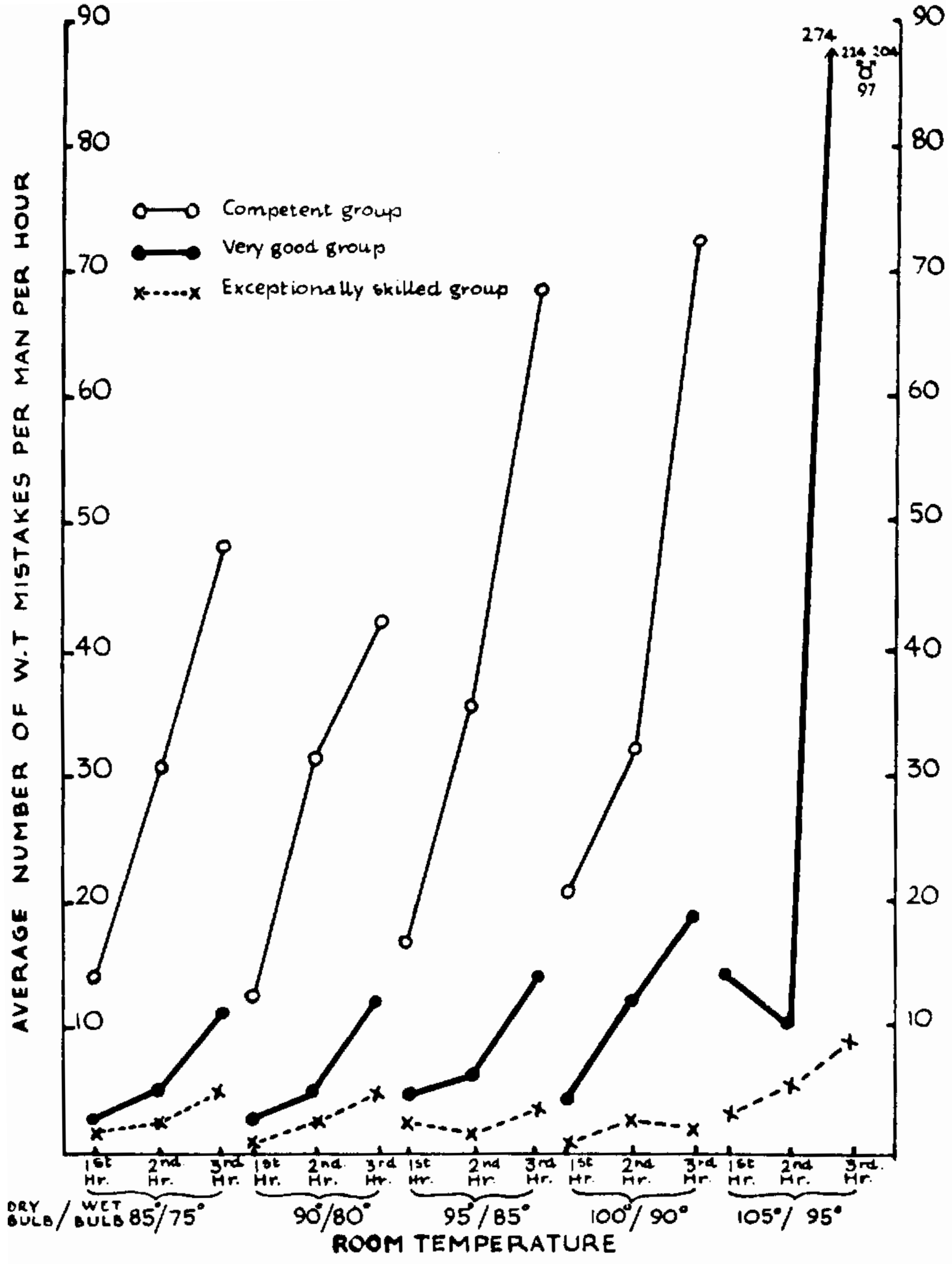


Figure 15 -- Operator Characteristics - Temperature/Time

We have examined the graphs showing the incidence of faulty messages in terms of temperature and time. These graphs are important. Failure rates are important in determining maintenance procedures, content of training, manning, and so on. Let us now examine characteristic curves for machines, and specifically failure rate curves for electronic components. A widely used practice in reliability analysis is to derive electronic component failure rates from sets of curves such as in Figure 16. The abscissa is temperature and the ordinate is failure rate in logarithmic units of percent failure per thousand hours of operation. Thus, a failure rate of 1 percent per thousand hours corresponds to $\chi = 0.00001$ per hour of a mean time between failures of 100,000 hours.

Each curve in such a graph represents the component failure rate as a function of temperature at a given fixed voltage or wattage operating level. If the operational stresses are increased above the rated level, the component failure rate increases rather rapidly above the normal failure rate. Conversely, the failure rate decreases when the stresses are decreased below the rated level.

Note the similarity between Figures 14, 15 and 16. Let us compare Figure 14 and Figure 16 specifically. The ordinate of Figure 14 is average number of mistakes per hour. The ordinate of Figure 16 is failure rate per hour. The abscissa for both figures is temperature. In Figure 14 the third dimension is competence. In Figure 16, the third dimension is percent of rated wattage. These are equivalent terms: The greater the ability of the component or of the man to do the job, the smaller the likelihood that failure will take place.

The characteristic form of failure rate curves indicates a strong possibility that the models used to describe stress curves would all be strikingly similar. It is conceivable that components may be categorized into relatively few classes each of which can be represented by a single function, differences between components affecting only the parametric values. Such a mathematical representation would enhance the possibilities for subsequent usage by the man-machine analyst as well as the reliability engineer. Indeed, if the computer is to be used efficiently to carry out studies, be they of men or of machines, it is mandatory that failure rate information, be it of men or machines, be presented in suitable functional form.

The power of mathematical functional representations is striking, and particularly in dealing with man-machine relationships. Certainly there is an intuitive appeal to our mind strings that if we can use the same relationships to describe man as we do machines that the problems in dealing with both, the man-machine relationship, will be simplified.

Multivariate Representations. The need for an iterative approach to the problems of human factors task analysis and related man-machine

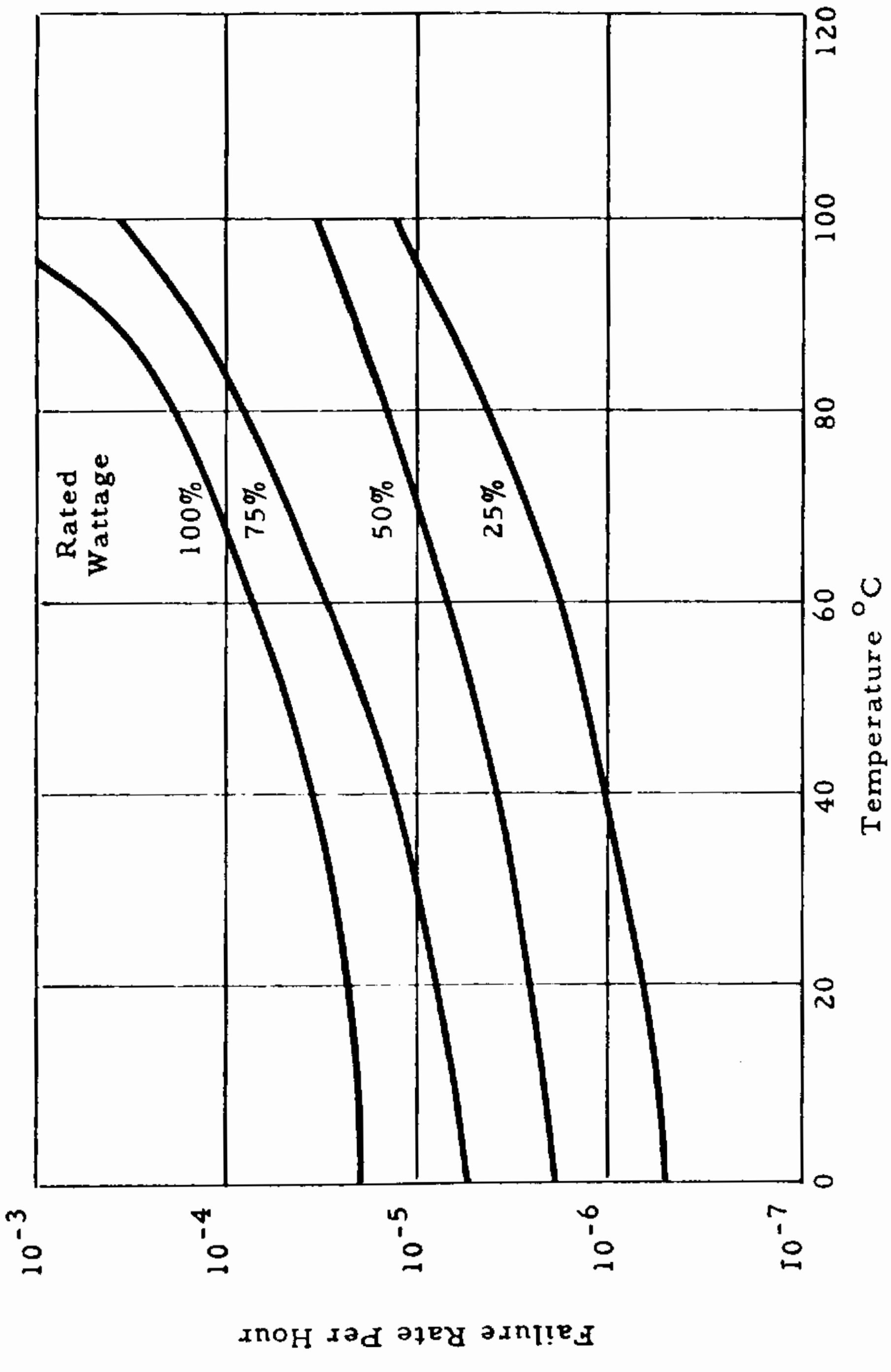


Figure 16 -- Failure Rate Curve

information is not confined to problems of optimization. The characteristic step by step advance is evidenced by the work accomplished by Mackworth and his associates in establishing suitable functional relationships to describe the "wireless" tests. Initially, results of the "wireless" tests were represented in terms of Y - the incidence of faulty messages and X - the room temperature.

$$Y = f(X)$$

As a result of tests conducted, it was found that differences between operators were sufficiently significant to warrant differentiation into three groups - (1) competent operators (2) very good operators, and (3) exceptionally skilled operators. A new factor was isolated - operators. To account for this difference functionally, a new variable was introduced

$$Y = f(X, O)$$

where
Y = the evidence of faulty messages
X = room temperature
O = operator competence

In Figure 15, still another factor was introduced - time. The functional representation now became

$$Y - f(X, O, t)$$

where t is time and the others are as previously represented.

The tools developed for analysis must lend themselves to multivariate representation. As the analysis proceeds the ability to understand becomes defined in greater and greater detail and is necessary to be able to specify this detail mathematically. Problems are not confined to multivariate representation, however, they stem also from the mathematics employed. This does not mean that it is necessary to restrict mathematical relationships to any particular type, but certainly there are types which are easier to deal with than others.

In dealing with functional relationships, we find it convenient to think in terms of the dichotomy of linear relationships and non-linear relationships. Of the two, the former, linear relationships, are by far the easier to handle. In dealing with the latter, non-linear relationships, two possibilities exist. The first is to fit an appropriate non-linear relationship directly to the data and the second is to seek a transformation of the data such that the relationship between the transformed data appears approximately linear. The most commonly used transformations are the logarithmic, reciprocal, and successive powers of a single variable; a judicious choice of these can encompass a wide variety of non-linear relationships. There is no reason to restrict the equation to any particular type, but in general equations which are linear in the parameters are of greatest interest. This does not imply that other equations are not important but only that linear equations have received more attention from mathematical statisticians and that methods of treatment are available for them. An example of non-linearity is shown in the data obtained in the "wireless" tests. We can see the attempt to linearize the parameters by means of the logarithmic transformation indicated.

Few General rules can be given for the handling of problems involving many variables, and a good deal of reliance must be placed upon informed opinion concerning the relative importance of the variables. If, however, a regression is fitted using all independent variables, the standard errors of the coefficients give some guidance as to which may be omitted. When the number of independent variables is so large that it is preferable to avoid the fitting of a regression on all variables simultaneously, it is common practice to begin by fitting a regression on that single variable which is thought to be most likely related to the dependent variable, and then to introduce other variables in turn. This step by step procedure was illustrated in the "wireless" analysis.

Analytical Representations

The field of human factors is large. The fact is, we cannot do research on a whole system any more than we can do research on a whole man. Small wonder that the computer is playing an ever increasing role in this type of analysis. Partitioning is an absolute prerequisite to research, but the partitioning cannot be accomplished arbitrarily. One of our most crucial needs is to analyze the functions that men are required to fulfill (or to serve jointly with equipment) into a small set of fundamental components with reasonably simple interactions.

With the aid of such elements, we should be able to partition complex systems into subsystems small enough to study in the laboratory. Having determined their properties accurately, we would be in a better position to understand their interaction when combined in systems. In short, by working with a system of modular functional parts, we could develop the orderly understanding required as a basis for rational man-machine system design. We can never achieve such an understanding through study of an infinite, multi-dimensional continuum of tasks and problems.

As soon as there is such a set, it will become profitable for system designers to use standard human operations and modular man-machine functions in designing their systems. System designers prefer operations and functions that are measured and known to others, e.g., efficiency of an observer viewing a radar scope, expressed in mathematical terms. When off the shelf man-machine functions are available, therefore, system designers will use them. Widespread use of a small, standard set of functions and operations should tend to simplify the problem-space of man-machine system research. Human capabilities could then be better measured and charted within that simpler pattern, thus, making it increasingly worthwhile for system designers to employ the model operations and functions.

<u>The Use of Models.</u> How can human tasks be represented by some small set of models? If it is known that a dependent variable y and some number of independent variables x_i, i = 1, 2 . . . m are functionally related, then an approximation to the form of this relationship over given ranges of the variables can be estimated empirically from the measurements of the corresponding values of y and x_i varied over the given ranges. In the case of the "wireless" tests (Figure 15), Y = f(X, O, t), Y would represent incidence of faulty messages, x_1 - room temperature, x_2 - operator competence and x_3 - time. Through the use of additional terms, other factors could be included, e.g., x_4 - humidity and x_5 - interaction between factors 2 and 3, and written as

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n$$

The numbers of possible models are manifold. Representation of incidence of failure for numbers of routine tasks should be such as to be accomplished with the fewest number of different mathematical models which fit the data well. By doing so, it may be possible to represent an entire class of man-machine tasks with but a single model; differences between tasks which make up that class would be reflected in the parametric values.

<u>Task Functional Forms.</u> For example, the numbers of tasks of interest could be broken down into numbers of classes. Each class in turn would contain a listing of the tasks included in its description and identified by an appropriate task number. Thus, in order to obtain task information, only the class of task need be identified; the appropriate mathematical function can then be obtained from the library. Information contained within the library would be shown in Figure 17.

By establishing functional relationships for given tasks, it is possible not only to obtain the expected value for a task under a specified environment, but it is possible to establish a confidence interval for the expected value. This is of obvious value for purposes of prediction and simulation.

There is more to be accomplished, and this in the area of analysis. It was established earlier that it is necessary to partition tasks into a reasonable number of classes. This cannot be accomplished arbitrarily. By establishing appropriate models for each defined task, we can test new sets of data in terms of whether the new data sample set could reasonably fall within the population of the old or if the set differs from existing characteristics significantly.

The first step in examining a body of data is to assemble them in a form such that the main features can be readily appreciated, particularly the degree of spread and the manner in which the results are distributed over the range, e.g., whether they are distributed uniformly or tend to be concentrated round a central value.

Class	Function
Task 1	$y = 12 + 2x_1^2 - 3x_1x_2 - 0.5x_2^2$
Task 2	$y = 10 + 1x_1^2 - 2x_1x_2 + 0.7x_2^2$
.	
.	
.	$y = 6 + 3x_1 + 2x_1^2x_2 - 0.5x_2^2$
.	
.	
Task M	$y = 4 + 2x_1 - 6x_1x_2 + 1.1x_2^2$

where y - incidence of failure

x_1 - temperature - ^oC

x_2 - operator competence

Figure 17 -- Task Functional Forms

In the simplest cases of analysis data are plotted in the form of a histogram or frequency distribution. The method of arranging the data is to divide the whole range of variations into a number of groups, count the number of observations falling in each group, and plot accordingly. When grouping or classifying, we divide a suitable interval which includes all observational results into a number of class intervals. Any grouping is arbitrary, as the boundaries of the class intervals may be chosen at will. How should the class intervals then be chosen? When representing the distribution of our observations graphically, we aim at choosing our class intervals in such a manner that the characteristic features of the distribution are emphasized and chance variations are obscured.

In the more sophisticated cases of analysis the philosophy must be the same. We want just as many intervals as there are significant differences to portray. Unless analysis is conducted to determine the significant differences between tasks as defined, we run the risk of generating a new task description for every new set of data. In the limiting case, each experiment constitutes a new class interval and our library constitutes a reflection of stochastic variation at its worst.

What is required if we are to establish a reasonably small set of partitions is to establish some reasonable set of mathematical models which can house all tasks of interest. We will then achieve the building blocks, the modules upon which man-machine systems can be structured. Once this is accomplished, we possess the ability to approximate a real situation by synthesis from relatively simple parts. With the aid of elements isolated through analysis, we can partition complex systems into subsystems small enough to handle within the computer. With the aids of mathematical models and appropriate computer techniques, we can simulate the real world within the computer.

Simulation

What are the current uses of computers? From the respondents to the questionnaire (about 80 percent of the total number of responses), there is general agreement among all groups that some use could be made of computers in their work. Currently usage appears to be divided fairly evenly between "storage and retrieval" and "processing." Of the types of processing being conducted, better than one-half is directed to simulation. Seven categories of simulation are enumerated: (1) human performance estimates, (2) equipment performance estimates, (3) general simulation, (4) management tool, (5) manning estimates, (6) cost estimates, and (7) hardware requirement estimates. Of the seven categories, the highest response (human performance estimates) constituted 4% of the total response. This is not a large number. And certainly this type of response cannot be considered mandate for any given type of simulation.

If we examine the replies concerning "potential" uses of computers, we find an increased need for simulation, all kinds of simulation, but not for one given simulation as opposed to all others. Under potential uses of computers, eight categories of simulation are enumerated: (1) human performance estimates, (2) equipment performance estimates, (3) manning estimates, (4) hardware requirements estimates, (5) general simulation, (6) reliability estimates, (7) cost estimates and (8) maintainability estimates. The highest response, (human performance estimates and equipment performance estimates) show 5% of the total response.

Nevertheless, though there is no one simulation which can be singled out, there is a clear cut case for the utility of simulation in human factors analysis. This point is made quite clear in the recommendations of the A.I.R. report. Well defined Air Force contract requirements for simulation exist and especially for training purposes. The importance of product simulation as a tool for facilitating design and development of training devices was stressed by representatives of one contractor who reported that their organization always relied heavily on computerized product simulators, irrespective of contractual requirements. Similarly, representatives of another contractor reported that, owing to computer simulation early in one of their primary programs, design changes were made which under any other circumstances, would have been impossible.

An increasing need for all types of computer simulations is evident. Unfortunately, implementation may be hampered, as pointed out earlier, by cost and time requirements associated with computer programming. And for the same reasons (1. improved quality, 2. standardization and 3. reduced costs) as enumerated in "The Need for a Human Factors-Oriented Computer Language," in Section III, a need exists for a computer language developed for simulation. This language should provide facilities for:

1) Selecting data from the master data file;
2) Processing the selected data;
3) Generating reports.

A single language in which all of these processes could be programmed would be a valuable tool. The ultimate in a simulation language would be to permit the specialist to conveniently and easily specify his desires in a language very similar to that of man to man talk and then press a button and receive the printed report in exactly the form that he wishes. There are languages written in which this is not only possible but in which this is feasible. Our purpose is to determine how possible this is and how feasible this is for the human factors specialist.

An Existing General Purpose Simulation Language

Let us look at a language in existence which possesses attributes which, if they existed in a language written specifically for the human factors specialist would be of great interest. A language now in existence which encompasses the second two objectives (for processing data and generating reports) is the SIMSCRIPT language. SIMSCRIPT was designed and implemented to facilitate computer simulation of real systems. Nevertheless, though it is a language specifically for simulation, it is at its best when it is used to study that class of problems which can be characterized by a "job shop" analogy. The SIMSCRIPT language has a strong processor and strong report generator. It does not really have a selection portion in that the analyst specifies that little data which is usually required in this type of problem. The language is simple to use and where applicable has many advantages.

The language was developed at RAND Corporation and is an outgrowth of a simulation programming system developed earlier by General Electric Manufacturing Services. SIMSCRIPT is not a simulation program; it consists of a language in which simulation programs can be written by a professional programmer, and of a computer system to enable execution of the language. SIMSCRIPT programs are translated to the FORTRAN language; then compiled and executed via the FORTRAN system.

In addition to the language which facilitates writing of simulation programs, SIMSCRIPT provides a report generator. The user specifies format of the report with a pictorial layout resembling the desired report. The values to be printed are specified with SIMSCRIPT statements written on the same form and interspersed with formatting information. This approach is possible because the report description form (when punched on cards) becomes an integral part of the source language program input to the SIMSCRIPT translator. Values to be printed can be specified by names which are the same as those used in the portion of the program which generates them.

One question which comes to mind is the wisdom in developing at this time a language such as SIMSCRIPT for the human factors specialist. There are difficulties which now exist in being able to specify such a language. At first thought, the human factors effort appears as an extremely specialized endeavor, nevertheless, as the survey shows the activity encompassed by the group is remarkable in its breadth. At one end of the spectrum we have in the space industry the problems of adapting highly specialized machinery to some few highly unique men. At the other end of the spectrum we have earth bound problems of training people to staff and satisfy the requirements of highly unique and specialized machinery. Little commonality seems to exist in the tools which are used to attack these diverse problems. Perhaps this is because of the differences between applications. Perhaps it is because of the infancy of the fields. Whichever, as of this time, it is not clear that there are sets of analyses which all analysts concur are of paramount importance.

If it were desired to develop a language as simple and as convenient to use as a SIMSCRIPT it would be necessary to isolate some necessarily small set of possible analyses to be handled by the language. Would it be possible at this time to develop such a language for a given application such as "time-line analysis?" The answer is yes. Would it be possible to develop such a language for all the analyses used in the human factors community? The answer is at best questionable. Until we reach common agreement as to what are the important tools and until we have established a commonality within these tools it is questionable as to how to proceed. If we try to make the specialized language do everything it is not really a specialized language; it is a generalized language and suffers from the problems of being too broad.

In order to design a language useful to the community of human factors, it is necessary to isolate from all analyses a set which has achieved a level of acceptance. It must be further considered that even if concurrence were established that effort and time would be required to design the language and implement the system. SIMSCRIPT was a long time in the development stage. And even then the reason it was possible to develop the language was because of the effort which preceded the language in the form of analyses of the "job shop" problem. The essential work required for queuing applications was well developed at the time SIMSCRIPT was yet in its infancy.

Time-Line Analysis -- A Computer Application

The results of the survey show great diversity in problem areas and methods of solutions. We have seen what a cross cut of the community appears to be. Of all simulations conducted by human factors specialists, there is none which would be of import to all. Nevertheless, it is important to discuss the pros and cons of simulation, what direct experience has been achieved using simulation, what the costs are for manual calculation as opposed to computer calculation, and so on.

In order to make the discussion more specific, a single application "time-line analysis" has been isolated. To obtain information on this application Messrs R. Stump and J. Peacock of North American Aviation's S. & I. D. Life Sciences Division were contacted. Questions were directed to both gentlemen, and were answered by either one or both in an informal manner.

Is it felt that time-line analysis is of interest to all working in task analysis? The answer to this question is no. Different systems have different objectives. Analysts will seek out different types of analyses to accommodate these differences. Time-line analysis is essential to development of the Apollo Capsule. The analysis plays a unifying role in establishing both design and procedural aspects of any given mission. In our case, the astronauts are singularly unique. The process of design is centered about the development of hardware to accommodate these three men. Obviously not all task analysis activity is so oriented. In dealing with more customary, or perhaps more conventional, analysis, the tables may be turned. Here an inheritance of hardware may exist and the problems are concerned with manning and training of large groups of people to satisfy the restraints of equipment.

Is the computer important to time-line analysis? The answer is that it is difficult to understand how such analyses can be conducted without the computer. This does not mean that the analyses cannot be conducted manually. Most assuredly it can. The problem of manual calculation is that it just takes too long. If we, the group responsible for time-line analyses, cannot respond to the needs of the participating design groups in the same time frame that design decisions are made, no real contribution can be made. Why is the computer important? It permits our group to respond much quicker. Not as quickly as we would like to, but much more so than we could otherwise.

What are the savings in time? Some initial experience was accumulated performing the analyses manually. Some computer assistance was used, but not the more formalized system we use now. The time required for analyses took approximately 100 man months of effort over a time duration of about one year. This is the total effort, not computational effort alone. Much energy was devoted to writing of data, design reviews, hardware changes and to feedback essential to the design process. It is not possible at this time to accurately apportion the effort into a computational and non-computational dichotomy. But it is possible to say that total time required for time-line analyses by manual calculation cannot be reduced appreciably because of the intimacy of the relationships which are being described. Specifically, a mission concerns the conduct of three astronauts. At any time, all three may be active, two out of the three may be active, or perhaps only one out of the three may be active. The analyses are such that they cannot be broken down into component studies carried out by isolated analysts at their convenience. So much common effort is required that little can be accomplished to reduce the time required to carry out the total analysis by the usual expedient of increasing the number of analysts assigned to the study. A comprehensive manual study requires about one year to perform.

How much time is required using the computer? With the computer, the time required is approximately three months. The manpower required is 25 to 30 man months. This is again the total effort and includes satisfying the needs of the design process. What are the savings occasioned by use of the computer? A very broad brush calculation shows a reduction of both time and effort to one-quarter of the initial manual calculation.

How about the quality of the results using the computer? In general, the comparisons between man and computers which hold true for other types of calculations hold true here. Results are presented in a uniform, easy to understand form and are free from computational errors. The quality is improved also, and more importantly, in yet another way. The time-line analyses produced at the end of the three month cycle contain the results of two interim analyses conducted prior to the final analyses. The amount of machine time required to carry out the calculation is approximately nine hours of IBM 7094, (3 hours per month).

What are some of the examples of costs associated with doing calculations manually or by machine? Let us determine the costs associated with one analysis based upon calculating the times required for the 13,000 elements which are in Apollo. If we assume that it takes five minutes per manual calculation, the total calculation requires over 1,000 hours. At a cost of $15.00/hour for analytical time, the cost is in excess of $15,000.00.

Upon the computer, the entire calculation takes between 1/2 hour and one hour, at a cost of perhaps $750.00. This comparison is dramatic. The cost of analysis, conducted upon the computer, is 5% of the cost of the manual calculation. Again, a word of caution is in order. It is not reasonable that all calculations will show such marked gains. This is not a truly random set of calculations. It is used because it happens to be one for which cost calculations are relatively easy to come by.

If the time-line analysis program is as good as it is reputed to be, what considerations govern the use of the program by other users? Other users could use the program if they possess an IBM 7094 with discs and with sufficient tapes. But a word of caution, problems would be occasioned in its use. As of this time there is little documentation available describing either the program or its usage; this knowledge exists primarily only in the minds of the select few that now use the program. This obstacle could, of course, be remedied by the writing of suitable documentation.

Is it recommended that the program in its present form be circulated among all users? The answer to this question is one clouded with mixed emotion. Though the program is much better than anything else available, there is still much to be accomplished. And, indeed, the program is constantly being refined and improved. This accounts, in good part, for the lack of documentation.

Wherein does a need exist for improvement? At present, much of what the program accomplishes may be likened to sophisticated bookkeeping. What is needed are optimizing routines. At present the program accounts for any established potential network of tasks. If non-permissible overlaps in time occur, these are duly noted. Corrections, as required, are accomplished by subsequent human interpretation and judgment. Routines must be written to permit this type of juggling to be accomplished within the computer. In addition to processing routines, numbers of improvements can be made in the types of reports produced and the format in which they are presented.

What kind of model is employed in time-line analysis? Basically the model is an expected-value model. No probabilistic estimates are directly inserted into the analysis. However, it should not be concluded that because constant time estimates are inserted that we are not concerned with those variations which are ever present and which do take place. To arrive at a suitable analysis, estimates are used which may represent maximum values as opposed to average values, and judgments are made so that a reasonable amount of slack is present to avoid the possibility of critical situations arising. Though the computer output provides the expected or average time, nevertheless the judgments made are tempered by those variations in time which can take place.

What steps could be taken to make a time-line analysis program more convenient to use and more acceptable from a general purpose point of view? Not only are improvements desired for the program before general release, but some adaptations would be necessary before it could be used as a general purpose program. Though much of the program is of a general nature, there are portions which are unique to the Apollo Capsule. A seemingly trivial detail can be of consequence to the computer program. An example is the computer output produced to describe a mission. The printed sheet is formatted into three columns, each of which describes the activities of a single astronaut. This type of output is limiting to a crew of three. Another system in which a crew of four was envisioned could not use the program without modification.

What is the estimated cost of writing a computer program to carry out time-line analysis? It is estimated that about one man year of programmer effort would be required. This is not the large contributor to the cost of the program. The cost is in the analysis of what the program should do to satisfy needs of the community, not in the coding of the program. Differences exist between programs written to satisfy a specific need, e.g., the Apollo Capsule, and a general need, e.g., time-line analyses for all systems and all missions. The program to be used as a general purpose program to be sufficiently flexible should be written with this viewpoint in mind.

What other comments are worthy of note concerning the time-line analyses program? The present program is much better than anything else available for use on Apollo. It takes three months to analyze a mission. This, though much better than the manual response time, is still much too long. We must improve our data flow through centralized data sources and improved programming such that our response time is cut down to a week or less. Only then can we shoulder our real responsibility in the design cycle, and in the mission execution cycle. It cannot be reiterated too strongly that time response is important. Certainly if a centralized data bank did exist, this would expedite analysis considerably. However, if the time to obtain the data were longer than a week there would be little value to the center. And, it follows the quicker the response the better. Complementing the data bank would be standardization of format to make it possible to use the data from the centralized data bank without revision. Also, a common problem-oriented language would be beneficial. At the present time the time-line analysis program is written in a modified FORTRAN. Other users would have to become acquainted with the particular modification.

A Language for Time-Line Analyses

A need exists for development of a problem-oriented language for simulation of human factors task analyses. The diversity and breadth of the language must mirror the diversity and breadth of applications encompassed. It could be in the form of one single general purpose simulation computer program, it could be in the form of a number of more specialized purpose computer programs.

What, in face of this uncertainty, can be said about objectives governing development of problem-oriented languages for simulations of human factors task analyses? Again, in an attempt to be more specific let us refer to the application discussed, "time-line analysis."

Models will be developed by time-line analysts to represent specific man-machine relationships to accomplish specific simulations. We cannot, today, specify in complete detail the models that will be written tomorrow. We can, however, provide the time-line analyst with tools to facilitate his efforts. Though basically the listing of tasks and times is the basic requirement of time-line analysis, there is much more that is desired from a detailed point of view. For example, in the specific case of time-line analysis concerning three astronauts in an Apollo mission, an analyst might wish to isolate information solely concerning a given astronaut. Or he might be concerned about specific causes of time delays, or queuing of tasks, or delays caused by specific sets of activities, or controls, or displays. The point being made is that once an analysis is conducted, different analysts with different viewpoints are interested in examining the analysis in different ways. The analyst is not only interested in knowing how good or how bad a mission appears, but he is interested in knowing the why's and wherefore's of any difficulties which are evidenced in the analyses.

Each group of endeavor within "time-line analyses" is marked by use of analyses peculiar to the needs of that group. What, in face of the diversity of analyses being conducted, and what in face of varying requirements for computer usage, can be accomplished? The answer does not lie in the development of some one or two important reports. Needs of the many groups are different and are constantly changing. What is needed are production tools, jigs and fixtures as it were, that can be used to facilitate solution of all types of time-line analyses problems upon the computer.

Tools do exist, but not in the form of production tools. Despite the development of sophisticated mathematical techniques, application of these techniques has not been exploited to the fullest. Stated generally, the problem concerns the difficulties, complexities, and obstacles to employing digital computer techniques in time-line analyses. These techniques require a high degree of specialization and sophistication in mathematics and computer technology. And the necessary computer programs for the desired analyses must be prepared for each specific application. Unless something is done to make these analytical tools more accessible to the specialist, the application of such refined and sophisticated analyses will be possible only under a very limited set of circumstances.

Problems of time-line analyses may be divided conveniently into two categories. In the first category, requirements are specified in advance, and the problem is to design a system which satisfies these requirements. In the second category, a system with given characteristics is defined, and the problem is to define how well the system satisfies the requirements. To carry out either kind of analysis, it is necessary to use a mathematical model to portray the system.

One of the most important questions the model must answer is simply "How can we improve human performance?" A careful formulation of this question leads, of course, to problems of optimization, i.e., what choice of hardware design leads to improved human performance with respect to variables of importance, e.g., weight, cost, alternative usage, and unusual environments. In many problems, optimization procedures are of small importance. The performance is not particularly sensitive to the choice of operating parameters, and experience provides a satisfactory guide. This is not usually the case with large aerospace systems; human performance is extremely sensitive to small changes in design. Aerospace systems are large and overwhelmingly complex with strong interactions between the different subsystems; the number of variables that have a significant effect on any one quantity is generally such as to make intuitive judgments difficult and incorrect.

What are the characteristics of models which are useful for time-line analyses? We can view the dichotomy of the expected-value model and the probabilistic model. In the expected model the picture of the world ignores most of the effects of uncertainty. In the real world, random events occur and it is usually impossible to say precisely what is going to happen in any particular set of circumstances. However, it is often possible to calculate what happens on the average.

The expected value model assumes (in the calculation at least) that the average result actually occurs. It is sometimes found that even when the expected value model computes the average result reasonably accurately, it can still be misleading, particularly if realistic objectives are considered.

How can the expected value model be improved upon? Where required, a probabilistic, as contrasted to the expected value, model can be employed. Taking into account probabilistic effects is simple in principle. The actual computations can, however, be laborious and complicated. In fact, for all but the simplest problems the calculation is too long even for a high-speed machine to do in any economically reasonable, or even unreasonable, amount of time. Most such models utilize the approximate method of computation known as the Monte Carlo method.

Probabilistic models are not only more accurate, but they also permit quantitation in terms of probabilistic objectives. It is sometimes said that Monte Carlo is required in order to put detail into the problem. Whether or not this is true depends upon the problem and what one is trying to do. However, it is almost always easier to put detailed consideration into Monte Carlo models. Which kind of model should be used? This depends on the problem and level of detail required. If the expected-value model is good enough, does the job, is cheaper, it certainly should be used. However, if greater detail and accuracy is required, the probabilistic model must be employed.

The need for an iterative approach to problems of time-line analyses is not confined to problems of optimization. At the beginning of a system design and lasting perhaps through a major portion of the life of the system is the absence of an adequate data base. Initially, estimates may be revised, improved and completely replaced by experimental data. Despite all attempts to improve the data base, however, some components of the system may not be specified well, and it may be necessary to estimate task values based upon small sample size.

Wherein does a need exist for more sophisticated modeling for time-line analyses? The system, as indicated, by the very nature of its newness, is data poor. System characteristics based upon insufficient data can be notoriously misleading and sensitivity studies become increasingly important to find out true trouble areas. By establishing the essential factors and levels thereof of those variables of interest, and by varying appropriate parameter values, it is possible by systematically controlling the input to obtain answers to more sophisticated questions.

The man-machine estimate for any overall system depends on the parameters which enter into the various functions which contribute to the estimate. There is a distribution of values that each parameter may assume, and, as a result, the overall system estimate is correspondingly sensitive to those inaccuracies associated with the parameters. If the resulting distribution has little spread, then the man-machine estimate is relatively insensitive to the parameter; if there is much spread, there is an indication that the parameter may be crucial.

The need for an iterative approach is again evident. Sensitivity can be established by perturbating the values of each parameter, in accordance with its distribution, a number of times to determine the resultant distribution of the overall man-machine estimate. The inclusion of a random number generator and associated selection routines permits the use of Monte Carlo techniques in the determination of man-machine relationships. Through the use of the computer, thousands of samples can be made of each variation, enabling a comparison of simulated operation of different model configurations for the selection of that with the highest probability of success. It is exactly this type of problem which the computer handles exceedingly well.

SECTION V

THE NATURE AND CONFIGURATION OF A DATA PROCESSING SYSTEM

Introduction

Computers play a vital role in human factors analyses. There is much to be gained by providing each existing computing facility with improved programs and standardized techniques to promote data interchange and processing. Limitations do exist, however, in what can be accomplished without a centralized information center. A need exists for a human factors task data center, which can be used either independently or in conjunction with existing computer facilities. Let us call this center CENTRAL. The primary functions of CENTRAL are: (1) information storage and retrieval, (2) human factors task data processing, (3) language maintenance, (4) computer program clearinghouse, and (5) CENTRAL manual. The CENTRAL facility will be accessible to locations all over the country by means of "teleprocessing" equipment and will be able to process both codified and non-codified data.

CENTRAL

The A.I.R. study points out difficulties experienced by human factors specialists in obtaining information and in communicating information. There are times when previously generated data are unavailable to the specialist either because he does not know of its existence, or because the time to obtain data through normal channels is too long.

There is a need to examine relevant data through all phases of system design. There is a need to compare data from one system with data from another system. There is a need for efficient information storage and retrieval, and for computer programs to facilitate analysis and simulation by the human factors specialist.

Some computer facilities and programming systems used by human factors specialists are meagre, other facilities and programming systems are quite sophisticated. But regardless of individual circumstance, there is much that can be gained, from a non-centralized viewpoint, by providing each human factors specialist with improved facilities and improved programs. As a minimum, this would provide more efficient access to data at his disposal, and would save costs by elimination of redundancies in the development of similar computer programs.

There are limitations, however, to the comprehensiveness of any computer system which is developed independent of other systems.

This comes to light when any attempt is made to compare data from one aerospace system with data from another data system. The contractor concerned with human performance for a command and control station within the confines of an artificial cave may be quite unaware of data governing human performance in the manning of a missile within the confines of an underground silo.

To complement existing computer facilities, a central agency is required. This central agency is not meant to do away with or replace existing facilities; its purpose is more to satisfy common needs of individual facilities without incurring costs of overlapping duplications, and to house and provide interchange of data so as to permit comparisons across aerospace systems.

Let us note that though a central agency is required, this does not mean necessarily that the central agency is one single installation or one single main computer facility; the agency may consist of a number of centers which are linked together to serve the central need as required.

There may be one government processing center, there may be several, containing system support human factors task data submitted to the government (e.g., see AFSCM 375-5 and AFSCM/AFLCM 310-1, Vol II). Supporting these centers are the computing centers located at the various prime contractors. These computers contain data that must be submitted to the government, plus other data used to generate information to be submitted to the government, but retained by the contractor.

Centers, whether maintained by a governmental agency or a prime contractor, are not duplicative in their function. Though both may use the same data, they may do so in different ways, and they may examine the data from different points of view. Nevertheless, the techniques for storing and processing the data can be common or at least compatible to both. The central agency, if made up of multiple locations, can be joined by teleprocessing equipment which link up computers in the chain of information flow as required.

Now what about examining data across systems? Circumstances arise when information should not be made available directly to contractors through the central agency because of various proprietary restrictions. In this event, the government can examine this information and distribute applicable data to qualified users on a need-to-know basis. Of course, prime contractors can examine data across systems they have developed.

In addition to restrictions such as proprietary restraints governing distribution of information from the central agency, problems arise in dealing with classified information. In dealing with these data, security practices would have to be incorporated such as those used in the transmission of intelligence data between military units.

For descriptive purposes a central data handling concept is suggested. It may consist of several centers, or may be housed at one location. This focal point will be referred to hereafter as CENTRAL.

Some Examples of the Use of CENTRAL

The role of CENTRAL depends upon the needs of the individual human factors specialists. Although it is difficult to envision every possible situation, some of the more common applications of CENTRAL can be identified as illustrated in Figure 18. CENTRAL is seen from the viewpoint of five human factors specialists: A, B, C, D, and E.

Specialist A wishes to update his knowledge concerning a specific subset of elements of task data housed within CENTRAL. In order to use the facilities of CENTRAL, he must know how to address CENTRAL, and he must be familiar with the glossary of terms which describes the formats of data contained within CENTRAL. This information is contained in the CENTRAL manual. The human factors specialist consults his manual for the list of descriptors, puts this information on cards, transmits the data on the cards to CENTRAL, and receives a listing of the subset of requested data which is available to him through CENTRAL.

Specialist A may have an inquiry for data. He might, also, wish to add data to the data files. The procedure followed is basically the same. The human factors specialist consults his manual for a list of descriptors, puts this information on cards and transmits the data to CENTRAL. Upon receipt of data at CENTRAL, several steps take place. One step, of course, is updating of CENTRAL files. Another most important step is the examination of "search profiles" to determine if there are human factors specialists who wish to be notified of acquisition of this type of data. And if there is an existing interest, these specialists are notified.

Specialist B possesses a listing of data available to him from CENTRAL (perhaps upon completion of the steps taken by specialist A), and wishes to obtain specific data for one of the entries upon his list. For example, he may know that manning estimates to support a SAC Bomber Squadron are available, and he wishes to obtain the actual numerical values. The steps he must take are similar to those taken by Specialist A. He

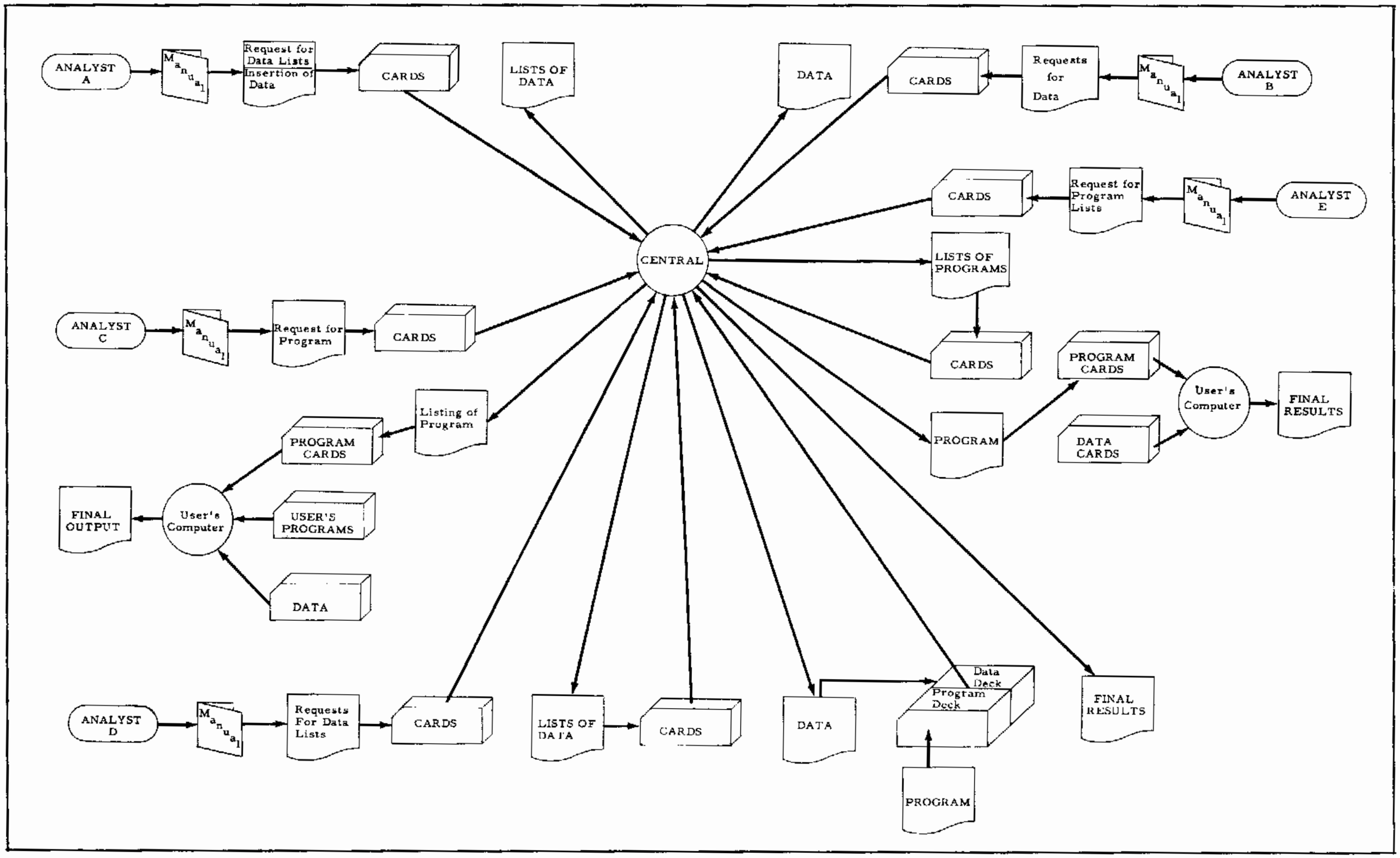


Figure 18 -- Examples of CENTRAL Data Flow

consults his manual, writes his request on cards, transmits the data to CENTRAL, and receives his requested data back from CENTRAL.

Not all requests forwarded to CENTRAL are for data or for listings of data. Other information maintained by CENTRAL includes computer programs of specific interest to human factors specialists. Specialist C desires a particular computer program which is available from CENTRAL. He consults his manual, writes his request for the program, places this information on cards, transmits his request to CENTRAL, and receives a copy of the program.

This is not the end of the road for Specialist C. He can use the program received from CENTRAL by itself or in conjunction with other existing programs upon his own computer. The data that he uses may be data from his own files which in turn may be a mixture of his own data and data previously obtained from CENTRAL.

Specialist D may wish to perform analysis on data contained within CENTRAL, and he may wish to use the computational facilities available at CENTRAL. If he is unaware of the exact contents of the data bank housed within CENTRAL, he consults his manual, writes and transmits his request and obtains a listing of available data. From the listing, he chooses the data that he wants. He obtains these data, and adds them to a program which he has written or obtained, and transmits both to CENTRAL for subsequent processing. CENTRAL provides him with the final results.

In the final example, Specialist E, has much the same problem as Specialist D, with the exception that he desires a computer program which he wishes to run on his own computer. The procedure is fairly similar with the exception that Specialist E uses his own computational facilities.

Functions of CENTRAL

There are many possibilities and many combinations of possibilities for information interchange between the human factors specialist and CENTRAL as may be seen from the few examples listed. Let us now turn our attention to some of the primary functions of CENTRAL:

- Information Storage and Retrieval
- Human Factors Task Data Processing
- Language Maintenance
- Computer Program Clearinghouse
- CENTRAL Manual

Information Storage and Retrieval

First let us look at the problems of information storage and retrieval. As we have noted before, there are two basic kinds of information which we must be prepared to handle: codified and non-codified. The forms of these data were discussed in Section III. Of the eight categories illustrated in Figures 2 through 9, the first five categories contain data which lend themselves to storage and retrieval within a digital computer; the remaining three do not. Data may take many forms, and a document associated with a personnel subsystem may contain all. Characteristically, non-codified information is highly diversified, of low direct information content and is in a form which the analyst must filter to suit his own specific taste. Codified information, as its name implies, is information which has been processed and readied for subsequent usage by the specialist. It is the essence extracted from non-codified data. Both kinds of information must be maintained by CENTRAL.

What information is placed in CENTRAL, and who passes judgment upon the content of the files? CENTRAL has the responsibility of acquisition. Let us look at the non-codified data files. They are the easiest to deal with. CENTRAL must review data used and generated in support of systems on a continuing basis to determine what is to be stored. It must obtain system support data generated by contractors, agencies, universities and research groups and keep these on file. A prime responsibility of CENTRAL is the acquisition of all such information. A line of demarcation must be drawn, of course, with data generated in support of systems, and that data which normally would better be channeled through the Defense Documentation Center (DDC), or through Scientific and Technological Information (STINFO) analysis centers. It is not the purpose of CENTRAL to duplicate existing efforts.

How is codified data handled? Codified data because of its highly regimented nature is in a form which can be encoded and stored on magnetic tape or disc. How is this information acquired and how does the procedure differ from the handling of non-codified information? How does data enter into the files and who makes this judgment? Several possibilities exist. The simplest possibility is that any individual, contractor, or agency which wishes to enter data into the codified file does so.

Interservice Data Exchange Program (IDEP). An example of this type of file maintenance is the Interservice Data Exchange Program (IDEP). To utilize IDEP, a contractor mails a summary sheet and two copies of the report to the data distribution center of the cognizant service. The center microfilms the entire report and adds the microfilm to a summary card based upon that accompanying the report from the contractor. Only such alterations in submitted material are made as may be necessary to make it comply with standard formats. The film card combination is then mailed to all contractors interested in the topic. Every month the data distribution center distributes to all participants a listing which includes a monthly index of reports distributed for all categories. The information in the report summary sheets is encoded in a standard format and is readily convertible to a computer input medium.

This type of system is perhaps the easiest to establish. This ease, however, is accompanied by a cost. The cost is that codified data files so established can easily become contaminated and that no assurance can be given as to the credulity of the information in any given file.

CENTRAL Data Files. If it is desired to have a set of data files in CENTRAL which inspire real confidence in the mind of the user, then it is necessary to establish rigid requirements and high standards with respect to the data which are permitted to enter into the file. How can this be accomplished? Perhaps we can get an insight by looking at how data of high standards are established today in the literature. Our scientific journals of highest repute maintain rigid standards by requiring that each manuscript submitted to their attention be judged by peers, by referees, who are learned and can pass judgment on the quality of information. Only after this surveillance is accomplished is the information made available to the public. To establish files in CENTRAL the agency could use a similar approach.

The inclusion of data into the files will depend mainly upon requirements for data generation. For example, if a requirement has been established for generation of task analysis data for input into the QQPRI, it is these data that the files should contain.

There are other restraints which govern insertion of data into the files. Two that come to mind are: (1) security classification and (2) proprietary considerations. As the data bank files are developed, it may be desirable to house different classes of data in the sense that not all data will be available to everyone. This should pose no real difficulties conceptually with regard to the content of the files. By suitable identification as to the class of data and as to the class of the need of the analyst, the computer can check upon whether data should or should not be made available for any specific request.

Indexing. At the heart of the automated storage and retrieval system is the index. What are the words that should be in the index of the library of human factors data? This is not a simple question, but a complex question made up of many parts. The answer will depend upon many decisions. It will depend upon the decision to establish CENTRAL control. It will depend upon whether CENTRAL is to be human factors oriented, man-machine oriented, task analysis oriented or if it is cut across all of such areas as defined. Only after such decisions have been made can the index be reasonably initiated. The index is not a fixed listing, any more than a language is fixed. It must be flexible, it must change to be responsive to the needs of the community it serves.

There is a need for a "glossary" as shown in Section IV. Names created for form fields are unique; a glossary must be used in naming fields on formal descriptions. A need exists also to refer to subject content rather than form content. And indeed, in documents which do not lend themselves to storage within the computer, but must be stored upon some media such as film or videotape, no common format may exist. It is necessary then to be able to reference the document in terms of the subject matter of the document. The index is used for this purpose.

The concept of level of detail is important. Managers want information about numbers or kinds of personnel required in summary form. Designers need data related to the performance of the whole individual and to specific and detailed movements in subtasks or task elements. Technical writers need detailed information about performance when they prepare technical orders and maintenance manuals. In each case the level of detail is different.

Selection of categories and subcategories is critical to the development of a data bank. At the present time no universal method of classifying all human factors data exists. Formal and detailed classification schemes exist only for small areas of the field and these are not universally recognized as being acceptable.

Problems of classification become even more difficult, of course, when non-coded data are processed. Difficulties stem at least in part from the imprecise nature of regulations and specifications governing preparation of personnel subsystem documents. And, of course, the problem is compounded if portions of a document, such as a QQPRI, are released to files as they are generated. Each portion must be suitably indexed if it is to be recoverable.

The index must serve as a basic vocabulary to describe all phases of interest defined in CENTRAL. At the same time it must not exist as an equivalent Webster's Unabridged Dictionary. How can the index be initiated to satisfy the as yet undefined requirements of CENTRAL? This can be accomplished by obtaining copies of existing indexes used by present contractors and agencies.

This first effort can be augmented by Life Sciences and Research Department contributions of agencies of both Air Force and NASA.

Dictionaries, thesauri and encyclopedia can be used as references for alteration or insertion of descriptors. Words in the index can be compared with entries in DDC's Thesaurus. This is an excellent guide, but, of course, greater detail will be required which can only be supplied by specialists in the field. However, the index so formulated, circulated among interested departments of both Air Force and NASA and among the major contractors such as those contacted during the survey will produce an index which should be reasonably satisfactory and operational by the time CENTRAL comes into being.

Again, it must be re-emphasized that this is an initial index. A more meaningful index can only be established after usage and through analysis conducted upon the results of this usage. Among the computer programs to be written for CENTRAL would be an "index analysis" program. This program would provide a listing of all words included in the index. Opposite each word would be printed columns of numbers, indicating the number of times each type of user has used the descriptor. This information can be used in the evaluation of the descriptor as a part of the vocabulary of the index. The frequency of its use also determines the characteristics of each user and aids in establishing search profiles. We can determine which descriptors should provide each user with a maximum of information and when combinations with other terms will be required for more specific retrieval results.

Automatic Indexing -- During the past five to ten years, increasing interest has developed in the use of machines as a substitution for human intellectual effort in the indexing or classification of the subject content of documents. The practical difficulties incurred by straight coordinate indexing arise primarily because the effect of viewpoint can never be eliminated. It will occur wherever decisions are made. In a superficial experiment, conducted at North American Aviation's S. & I. D. Division, on indexes produced by non-trained indexers, the following trends were noted:

> Those who indexed documents within their own specialization tended to read (rather than scan) the document and pick many more than the average number of terms.
>
> Those with technical background who had not specialized in the field tended to be more selective and pick terms that seemed to be emphasized either by frequency of occurrence, placement in quotes, or other attention-drawing devices of the author.
>
> Non-technical people tended to pick a fair number of terms, chiefly selecting those which looked "technical" and often ignoring "common" terms with a meaning specialized in the particular documents.
>
> Certain individuals consistently pick few terms, others pick

many. Citing the most extreme example, a document on mathematics was indexed by one person (a mathematician) with 52 terms and by another (an aeronautical engineer) with 5 terms.

There was no effort to evaluate document relevancy as a function of the resultant indexes.

In terms of practical applications, the greatest interest to date has been in keyword indexing from the significant words actually occurring in titles, abstracts, or full texts. Pioneering use of computers for this purpose has been followed by the development of a number of KWIC (keyword-in-context) and similar programs.

Small-scale experiments in automatic assignment indexing have also been conducted at the National Bureau of Standards in recent months. The SACSACT (Self-Assigned Descriptors from Self and Cited Titles) automatic indexing method uses an ad hoc statistical association technique in which each word may be associated either appropriately or inappropriately with a number of different descriptors. In the subsequent indexing procedure reliance is placed on patterns of word co-occurrences and on redundancy in new items to depress the effects of non-significant or inappropriate word-to-descriptor associations and to enhance the significant ones.

CENTRAL Indexing -- Initially it is recommended that an index be initiated based upon indexes in existence at appropriate contractors and agencies. It is further recommended that appropriate statistical programs be developed to provide the essential feedback required to create an efficient indexing system which accurately reflects the needs of the community being served. At the present time much effort is being expended upon making indexing more of a science rather than an art. It is reasonable that by the time CENTRAL comes into operation that a more efficient indexing scheme can be adopted than now exists in which untrained people exercise personal judgment in assigning index words.

In our discussion, we have likened CENTRAL to a library in many aspects. Of course, it is not a library in the conventional sense, nor does it try to compete with centers such as DDC or STINFO. It's primary objective is the storage and retrieval of data used and generated in support of systems, e.g., data generated for the QQPRI. Nevertheless, the problems associated with the storage and retrieval of data are independent of the content of the data.

As evidenced by the survey, existing manually operated information systems with inadequate indexing cannot cope with the expanding technology of human factors. The problem of the library for processing human factors data is well illustrated by the problem of the conventional library. How serious the problem is can be seen by the abundance of literature written concerning the plight of libraries and the steps which are being taken to improve their service through use of computers.

The point being made is clear. The conventional system, limited by manual restrictions of search and retrieval is inadequate. Indexing based upon title cards are incomplete descriptors. Only in an automated world because of speed of search can indexing become meaningful. And as such, indexing can and must become more comprehensive. No longer is it necessary to restrict subject description to title, a definitive subject indexing can be established. By describing each set of data in terms of subject content, a computer can be used to search out those data which best satisfy needs of the users.

Search Profiles. Accompanying development of an effective index is the development of search profiles. A search profile is defined as the specialist's field of interest developed by the use of descriptors. For example, an engineering group working on the development of training equipment for the navigational subsystem of a system may want to know whether a task analysis for that subsystem has been generated by other groups. This request becomes a standing request. Each time a new set of data is acquired, it is examined to determine if it is of interest to this group. Extensions of these applications can be seen in the examples treated in "Task Data Interactions" in Section II.

In part the development of a search or interest profile stems from statistical analysis of the user's requests in terms of the frequency count of descriptors as described in the section governing indexing. Again, as in the development of the index, the development of the profile is improved with usage of CENTRAL. As more people use CENTRAL, the more efficient CENTRAL becomes.

Several types of searches are possible. It is possible to initiate a specific request for information and to search all files for any data which matches the request. It is possible to maintain also a set of master subject profile files which may be updated or corrected as the need occurs. The profile files are then matched against the regular new accessions to CENTRAL and notifications are sent to individual users in terms of specific acquisitions which possess a high likelihood of being pertinent and of interest to the user. These notifications are also of use in improving the search profiles. Based upon whether or not documents are ordered from the notifications, the profile can be refined.

How discriminating should the profile search be? Initially, it might be decided that the profile search could be delayed until the contents of CENTRAL were reasonably developed. Regardless of the time that it was initiated, however, the discriminating power of the profile search could be developed independently of the development of the library. One method of interest would be to have each subject profile possess some minimum value given for any document the search is to retrieve.

The document value is determined by the sum of weights of the descriptors common to the search profile and to the document in question. The weight value given to a single descriptor is determined by the importance of the descriptor to the user's request and by its frequency of use in the system. The requestor may limit the search further by listing descriptors that would make a retrieval undesirable to his particular field of interest.

Human Factors Task Data Processing

To carry out its role, CENTRAL must be highly automated; it must have a computer to carry out the steps of information storage and retrieval, and the steps associated with indexing and maintenance of search profiles. Of data received by CENTRAL, some will be placed into the data bank in an "as received" condition. Other data, or groups of data, may be subjected to analysis and computer processing by CENTRAL before being placed into the files. Basically, CENTRAL will consist of a computational facility.

The agency, once established, and directly accessible to specialists all over the country, need not confine its processing capabilities to its own needs. It can act as a service bureau to all human factors specialists if desired. And, of course, it is possible to directly couple the computer of the specialist with that of CENTRAL. This would greatly extend the capacity of the specialist's computer as it would permit direct access to CENTRAL and permit reception, at computer speeds, of libraries of data and programs. Restrictions of data capacity of the specialist's computer would become a thing of the past, and the data bank of CENTRAL would become the data bank of the analyst.

Language Maintenance

The prime role of CENTRAL is "information storage and retrieval." There are other needs, however, which must be satisfied. Though all data have been stored and identified properly, it is necessary for the human factors specialist to specify his needs easily and quickly. He must have a computer language at his command.

The computer language like our everyday language can live and it can die. It is subject to constant growth and decay. Old words die out, new words are added and existing words change their meaning. To sustain our English language, dictionaries are revised, and new grammars are written. In an analogous fashion, the human factors-oriented computer language must be maintained. The job of maintenance would become a logical responsibility of CENTRAL.

If we look at other computer languages we find that some group must take upon itself the maintenance of the language. The group could be an industrial firm or it could be a committee. The language of FORTRAN is an example of a language developed by a company. The language of COBOL is an example of a language developed by a committee.

FORTRAN. Along with the development of the 704 hardware, IBM established a project to develop a suitable compiler for the new computer. This resulted in the first FORTRAN compiler. It was the development of FORTRAN II that made it possible to use FORTRAN for large problems without using excessive computing time. With FORTRAN II in full operation, the use of FORTRAN spread very rapidly and many 704 installations started to use nothing but FORTRAN.

It is interesting to note that though FORTRAN was a prime result of IBM that a relatively simple assembly system, FAP, and a very basic operating system, the FORTRAN Monitor System, both originated at customer installations, and not by the manufacturer, became the most widely used systems on subsequent computers. The language of FORTRAN is of prime importance because of its direct applicability to the needs of CENTRAL.

COBOL. In the spring of 1959, the office of the Secretary of Defense summoned representatives of the major manufacturers and users of data processing equipment to a meeting in Washington to discuss the problem associated with the lack of standard programming languages in the data processing area. This was the start of the Committee on Data System Languages (CODASYL), that went on to produce COBOL, the common business oriented language.

Preliminary specifications for the new language were released by the end of 1959. Computer manufacturers assigned programming people to the committee, essentially on a full time basis. COBOL 60, the first official description of the language, was followed by 61 and more recently by 61 extended.

Languages can be maintained by companies or by interested groups. For the moment it is not important which. The point being made is that if a language is to survive and to grow and to become useful it must be maintained by some group, company or otherwise. In the case of the language developed primarily to handle human factors data this group should be CENTRAL.

The Computer Program Clearinghouse

The group concerned with maintaining the language would certainly have a vested interest not only in the language but in all computer programs which were pertinent to use of computers in dealing with human factors data. There would be a real need to be satisfied by a clearinghouse which would collect and maintain such computer programs.

Programs written by human factors specialists which have general application can be submitted to CENTRAL. These programs can be stored on tape, and copies provided to any contractor or agency that wishes to use the program. The procedures followed would be essentially the same as for retrieving any other kind of data from CENTRAL.

In the computer field, developments of hardware and software provide the human factors specialist with tools to more effectively satisfy his needs. In adapting the computer into his world, he can learn a lesson from the actions of early users of computer equipment - the lesson is the need for cooperation. It was learned early in the game to cooperate; not out of a spirit of altruism, but out of the hard rock of economic return. It pays for computer users to cooperate and it pays for the computer manufacturers to encourage use of the computer.

Ten years ago organizations operating IBM 701's in the Los Angeles area were going through a period of self-examination. Plaguing all organizations was mismatch between the machine and its language and the human and his language. Elapsed time from problem origination to solution was frequently intolerable. Problem check-out was difficult and expensive. People who had estimated that it would take a one-shift operation to handle their production load found themselves operating two shifts. Not because they had missed their production estimate, but because they had overlooked a shift devoted to code-checking. It was evident that computer users had to cooperate among themselves or drown in a sea of inefficiencies.

This was not the first time attempts at cooperative efforts had been made. But seldom in early efforts did individuals from different organizations sit down to develop something which each could take back to his own installation and use. When the IBM 701 came along, almost everyone continued along his own way. But this time the amount of redundant effort was horrendous - the cost of developing a system for using the machine, and a set of routines to go with that system, was usually in excess of a year's rental for the equipment. No longer was there any question of the need for cooperation. The result was PACT, Project for the Advancement of Coding Techniques. The PACT System on the IBM 701 set a precedent as the first programming system designed by a committee of computer users. The important thing about PACT is that it is representative of the kind of cooperation where individuals from different organizations did sit down together to develop a system that each could take back to his own installation and use.

Computer users having been pleasantly surprised by the successful cooperative effort of PACT found themselves more than willing to continue and formalize this type of cooperation. The mutual respect that participants had for the competence of others brought the realization that an "isolationist" attitude no longer existed. Almost all professed themselves as quite willing to accept the ideas of others, even to the extent of obsoleting work already accomplished within their own installations. The result of this unity resulted in the SHARE organization, made up principally of users of IBM equipment. Though initially, this type of cooperation was only a spark, today, every major manufacturer of computer equipment supports similar group efforts, and the flame burns brightly.

Use of the computer has been marked by development of "hardware" and development of "software." This development has shown that cost of software can match cost of hardware. It comes as no surprise that development of software is governed by two considerations, money and time. It is a moot question as to which of the two is the most important. Money and time are synonymous. What are tangible expressions of the result of cooperation in the software area? Tangible expressions are the numbers of programs which have been written and which are available to all computer users and, best of all, at no additional cost. This kind of cooperation must be kindled and encouraged in the human factors effort.

For example, in the case of a computer program written specifically to perform time-line analysis the initial group would contribute this program to the central clearinghouse. In the event that some other contractor were interested in performing time-line analysis on the computer they would contact the central clearinghouse to determine if such a program had previously been written. And, indeed, if a program did exist they would obtain a copy of the program and would have it at their disposal. A word of caution--we do not mean to over-simplify and say that such a program would completely satisfy the needs of the new user, nor, indeed, if it would, that it would be completely acceptable to his computer system. We do believe, however, that blest with a problem-oriented language, programs written would tend to be more compatible across different computing systems, and through cooperative efforts supervised and guided by CENTRAL we would begin to approach the point where such interchange would become truly feasible.

CENTRAL Manual

CENTRAL has a number of functions to perform. It can receive and supply data. It can receive and supply computer programs. It can maintain search profiles. In order for the human factors specialist to make use of CENTRAL facilities, he must possess a set of instructions which tell him about CENTRAL, and how to communicate with CENTRAL. These instructions are encompassed in the CENTRAL manual.

Realizing that CENTRAL is a dynamic entity and that it will be in a constant state of refinement, the CENTRAL manual might be published in looseleaf form. If we examine manuals produced by other organizations, we note that of necessity they are updated periodically. And of the sections which make up the manual some are updated much more frequently than others; these are those sections containing data. Sections which are updated infrequently are narrative sections which describe philosophy, use of the manual, and how to execute calculations. Again the portions which change most frequently are those dealing with data. In the case of CENTRAL, data will be stored at CENTRAL and will be made available upon demand. Of consequence those portions of a handbook which normally require frequent updating will not exist in the CENTRAL manual. However, the more static portions will remain.

What information does the CENTRAL manual contain? In the introductory portions the manual would describe the overall functions of CENTRAL, and how CENTRAL is used. A section must be included covering "information storage and retrieval." To aid in search of information contained in a document such as a QQPRI, the manual must spell out the methodology for retrieving data from CENTRAL. Included in this section would be listings of index words and perhaps tabulations of frequency counts. Information would be provided as to how to initiate a user's request profile. The section covering codified data would provide specific information as to the exact informational content of the files and exact format to be used. The manner in which this information should be specified and obtained would be explicitly treated.

A section of the manual would be devoted to the computer language. The words of the language would be defined. How the language is used and how the language would be implemented would be treated. A description of how the system is operated and the relationship to FORTRAN would be described.

Another section would be provided describing the "computer program clearinghouse." A listing of programs available would be provided. Also included would be the manner in which programs can be obtained from CENTRAL. Specifications would be provided for the preferred style of writing programs for submission to CENTRAL and what the desired documentation should contain.

Maintenance of the CENTRAL Manual. We must note that as a natural consequence of this type of operation that there is no premium upon not updating CENTRAL files immediately when new information becomes available. There is no premium on releasing information only at set intervals. Information within the data bank can be made available to a specialist within seconds of its generation.

As noted, sections of manuals which customarily need be updated most frequently are those containing data. In the CENTRAL concept, data are contained within the "data bank" and are made available only upon demand; the result is that the CENTRAL manual need not be revised at frequent intervals.

This type of computer system is more efficient than the non-automated type of system, and yet at the same time presents reduction of cost in the maintenance of the manual. The cost for the manual of the non-automated system is high. Books are usually published in a professional manner and are of textbook quality. Each section requires a great deal of effort to prepare properly. To avoid excessive preparation costs, sections are only updated periodically and are only mailed periodically. Upon the basis of an initial need to know, recipients get their names on the mailing list of the issuing agency. And, based upon this mailing list, new sections, as they are updated, are forwarded to the listed recipients. In a manner of speaking, this is a shotgun approach, i.e., all users, whether or not they have an active interest, receive all updated data.

The non-automated method possesses some serious handicaps. It is expensive. It is wasteful, and perhaps worst of all, material may be obsolete by the time it is issued. On the other hand, the CENTRAL system only provides data upon request. If a human factors specialist wishes information, he can obtain it. There are no costs other than for the active user.

How to Communicate with CENTRAL?

The A.I.R. study shows that eighty percent of the total group indicated affirmatively that data retrieval time is important, and that every Personnel Group felt data retrieval time is important. The study further shows that current modal data retrieval times are from one to six days, and that approximately half of the respondents are not satisfied with current data retrieval times. A computer based data system designed to satisfy the needs of the human factors specialist must be one which satisfies requirements of the data processing cycle in times less than those available currently.

As indicated previously in Section II, a fundamental need for the computer system is time. If we had all the time in the world at our disposal for each decision we had to make there would be little need for a computer system. In discussing time, we are not so concerned with speed of the fastest portion of the data processing cycle as we are with the slowest portion of the cycle. The slowest portion of the information cycle is the bottleneck which restricts flow of information from the data bank to the user. If the specialist uses his own computer facilities, he can usually exercise direct control in obtaining his information quickly. But if he is to use the facilities of CENTRAL, then considerations of geographical location may take on major importance.

In considering the pros and cons of CENTRAL, we must give direct attention to the means of communication between each of the specialists and CENTRAL. Many means of communication exist, and currently the postal system, personal phone calls, and personal visits are the media. To obtain improved response times, we must examine "teleprocessing" equipment, we must examine automated methods for data communication and exchange. By this we do not mean to say that we no longer can use existing media, of course we can, but other alternatives are current and do warrant consideration. Hardware exists which permits direct communication from a transmitter-receiver to a computer even though each are located thousands of miles apart from each other. A case in point are the now conventional steps necessary to purchase a ticket on any airline flight.

The entire purchase can be consummated in but just a few seconds. Upon request from the prospective purchaser, the ticket agent, through a set located at his counter, can query the central computer as to whether or not a seat is available for any given flight upon any given date. If the seat is available he asks the customer whether or not he wants it. If he does, the ticket is sold and the computer notes the transaction and adjusts the inventory of remaining seats immediately. This real time system is available and has been for some time in the commercial world. When we talk about equipment used for the purposes of communication of information, we are talking about hardware which has been well established.

If we consider CENTRAL for the retention and transmission of human factors data, we envision a hardware system which is tried and tested. Regardless if CENTRAL were housed in one single location or in a number of centers located in different parts of the country, it would be possible for any contractor to have access to those files in a matter of seconds. Let us consider that such a centralized system were in existence. How can we envision use of this system? The user would use the CENTRAL manual to determine availability of kinds of data in the same manner that airline agents use their airline schedule manual. If agent or customer wishes to know about travel accommodations in general, he uses the manual. If he wishes to know about specifics concerning a given flight, he uses the computer system.

A user of CENTRAL will read his manual to determine what kind of data are contained in CENTRAL. If he sees something of interest, he can query the computer through his transmitter as to whether there are data in the section of interest and as to the time of the last updating. If the reply is in the affirmative, i.e., there is information in the section of interest and it has been updated recently, then the analyst may initiate a request for this section. All of this in a matter of seconds. To obtain his data he need only wait until the printer at his location prints out the requested data section.

The Computer Configuration

The computer configuration must be able: (1) to handle a large column of data, (2) to access the data rapidly and (3) to process the data. And, of course, as hub to the communications network, it must service the remotely located terminal devices.

Access to the computer must be quick. The computer must be able to service numbers of calls simultaneously. By this we do not mean that the system must continuously process a high number of calls, but we do mean that when a number of calls do arise at one time the system must be capable of processing them without unreasonable delay.

Third generation computers are better suited to these demands than second generation computers. Of course, a second generation computer can be used, but computers such as the IBM 7094 and IBM 7044 do require a separate computer as a buffer device to control the flow of information. The new third generation computers do not. Another important innovation of the third generation computer is the multiplexor channel. This channel provides for use of many slow I/O (input/output) devices simultaneously. Since equipment that would be used at a remote location would be slow (in line speed), this feature would make a new generation computer the choice for CENTRAL.

Further comparison of specific computers is possible. However, since the network is ill-defined and depends upon decisions which must be made at some future time, the discussion, for purposes of description only, will treat equipments of specific manufacturers. This does not constitute nor even indicate the slightest endorsement of the equipment. In the Appendix, a number of equipments produced by different manufacturers are presented for further comparison. At the time the decision is made to implement CENTRAL, detail of specifications and costs can be treated. At this time discussion can be limited to differences between specific equipments.

The new third generation computer possesses advantages which a comparable second generation computer does not. At the time the decision to implement the network is made, the words "new third generation" will, in all probability, have been replaced by "existing third generation." We will, therefore, concentrate on presenting a possible third generation configuration and the reasons why such a configuration appears reasonable. Let us consider a CENTRAL IBM 360/50 configuration and a remote location IBM 1050 Teleprocessing system as shown in Figure 19 and Figure 20.

Requests directed to CENTRAL fall into three categories: (1) translation, codified data search, manipulation and transmission, and (3) translation, non-codified data search and transmission. Let us turn our attention to the first two categories. The third category includes data which requires data processing equipment, e.g., Ampex Videofile, which has not been discussed but will be treated later.

All requests for information from CENTRAL require that an information search take place. However, before the search can take place, the request must be translated into machine language in terms of a set of identifiers upon which the search can be based. The demands for translation for search are similar to the demands for translation for other data processing. All require a comprehensive instruction set serviced by a high speed computer. The entire process must take place quickly.

How can we speak in terms of computer speed? Computer speed depends upon computational requirements of the request posed and depends upon many interactions including programming, overlapping of I/O and main frame operation, interleaving of instructions, and core size. Customarily these complications are avoided by restricting discussions concerning speed to that of cycle time.

Cycle time is the time required to read or write a word into a core position. And instruction times are usually stated in numbers of cycles required for execution. The cycle time for the IBM/50 is 2.0 microseconds per 32 bits. The cycle time for the IBM/7090 is 2.19 microseconds per 36 bits. Note the difference in the number of bits handled. The new generation computer provides the ability to address bytes (8 bits) instead of words (7094 word - 36 bits). This is a tremendous advantage in that very often information is byte size and not word size.

One question which comes to mind is as follows: Disregarding obvious differences in the handling of multi-channeled requests, what second generation computer is the IBM 360/50 similar to? It would appear, glossing over many considerations, that there is a great deal of similarity with respect to an IBM 7094 Model II.

We have discussed some of the characteristics of the central processing unit. What other characteristics must be treated? An important

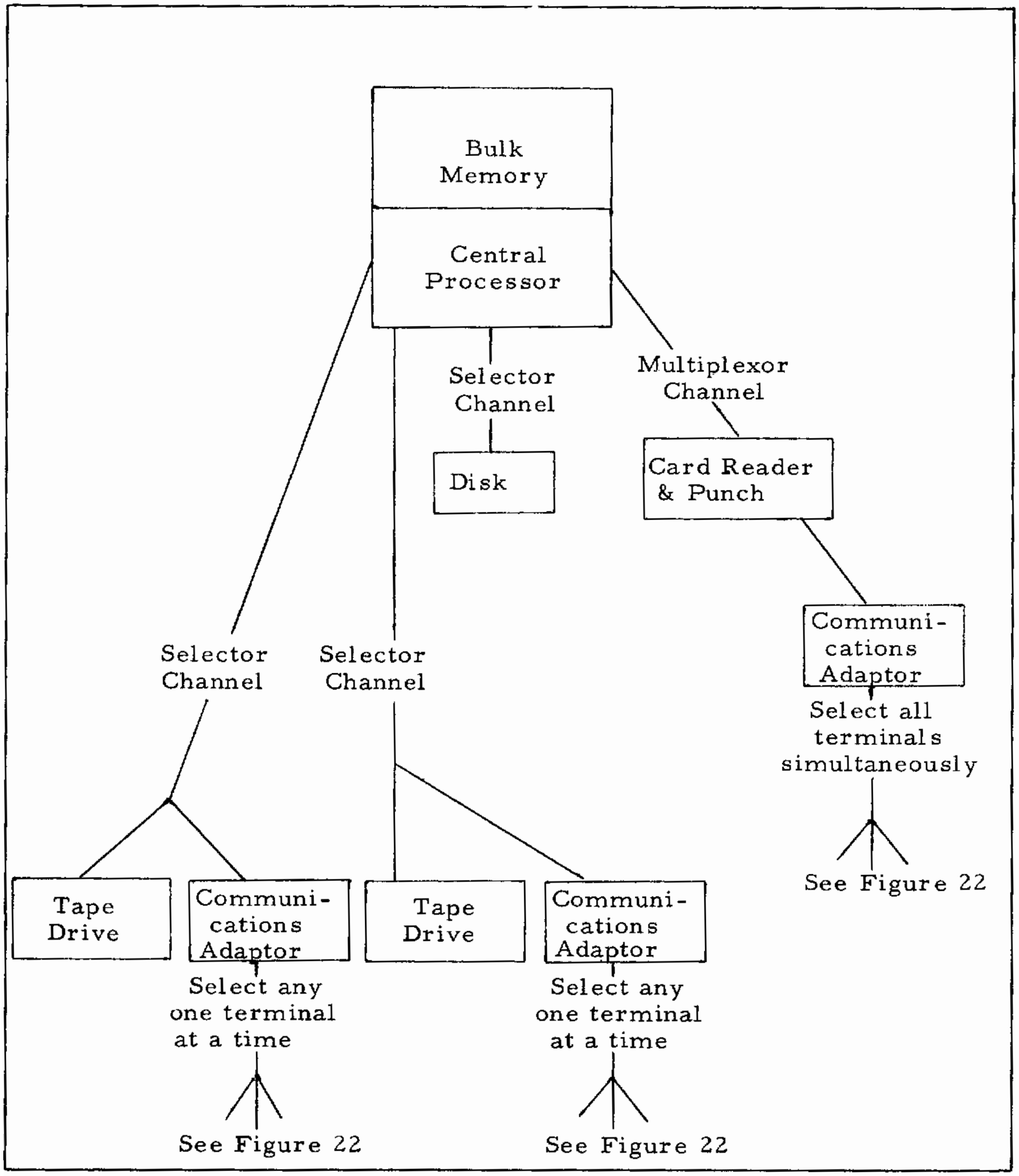


Figure 19 -- Central Computer Configuration

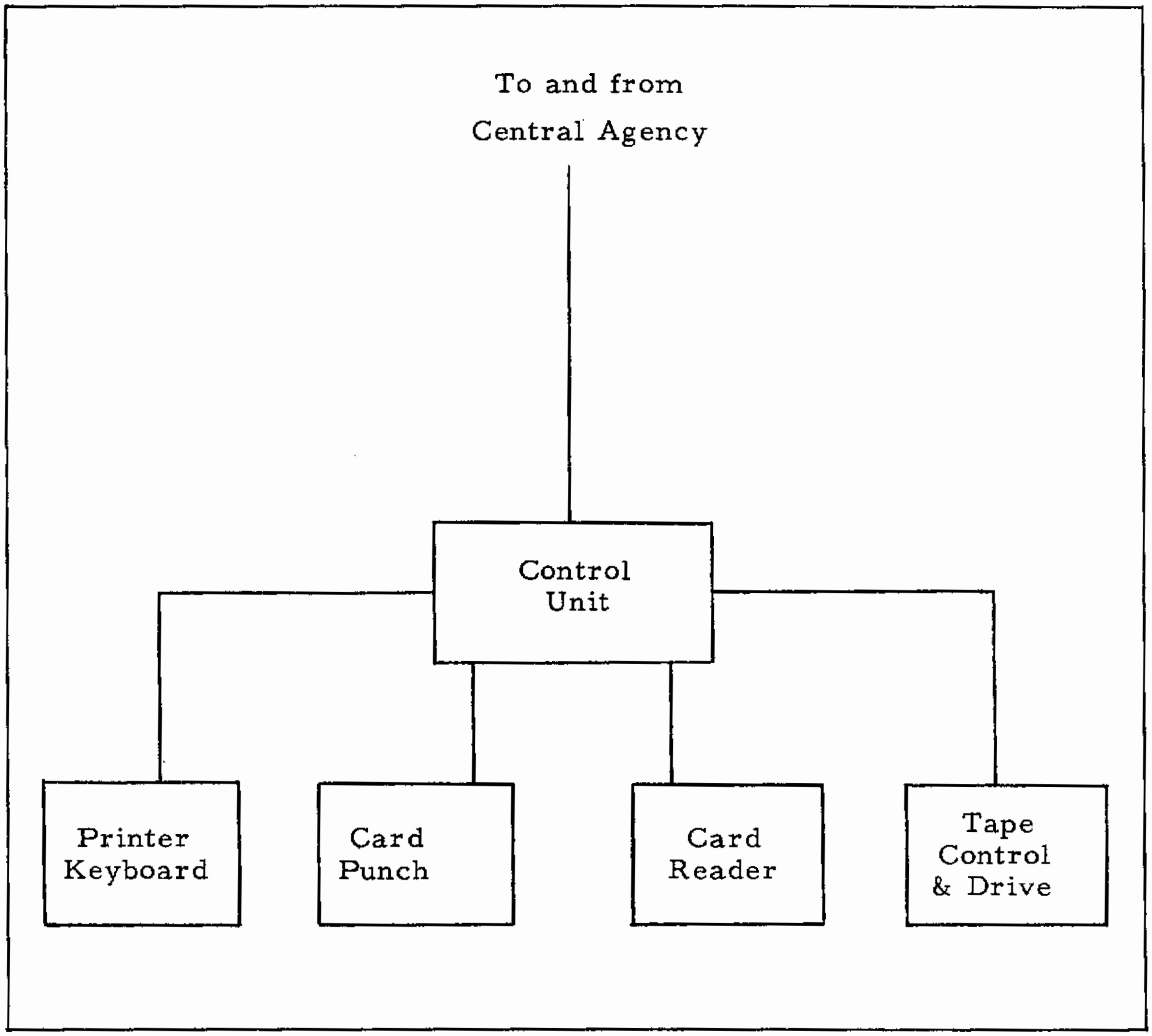


Figure 20 -- Requesting Agency System

consideration always is storage media to house the information located in the human factors data bank. Many means of storage media are available. One convenient method is magnetic tape storage. But though this method possesses many advantages, there is a serious disadvantage when large amounts of data are to be stored which have to be quickly accessible.

The inconvenience of magnetic tape storage is that data is only accessible in a serial manner. To obtain data located at one end of the tape, the entire tape must be processed. A full tape could take 4 to 5 minutes to process. In order to have quick access times to large amounts of data, it is necessary to use random access storage media. We can use drums, disks or data cells. Of the three, disk storage appears the best tradeoff between capacity and speed.

Available IBM drum storage has a capacity of 4.1 megabytes. This is probably too small for an operational human factors data bank. However, access time is good, a maximum of 17 milliseconds, and transfer rate is very good, 1.2 megabytes per second. The data cell is at the other end of the spectrum; cell storage is extremely large, 400 megabytes per unit. However, access time is relatively slow, 600 milliseconds, and transfer rate, 55 kilobytes per second, is still lower. Disk storage appears to be the best tradeoff. One 1302 model N2 disk can store 22 megabytes (equivalent to about 10 magnetic tapes) with a maximum access time of 180 milliseconds and a transfer rate of 156 kilobytes per second.

Though the human factors data bank may be housed within magnetic disks, this does not obviate the necessity for magnetic tape. Tape will be used for receiving data from remote locations. These tapes can be used for processing data received, and for evaluation prior to placing of data upon the disks. Tapes containing the entire contents of the disk should be generated, stored and updated periodically as back-up copy to the disk file.

Information stored reasonably permanently or even in a transient status can be handled by disk or by tape. For storage required during processing, additional capacity is required. It is necessary to store requests and answers during periods of processing and transmission. Bulk memory is similar to main memory except that cycle time is 8 microseconds (4 times that of main memory). Main memory is available up to 262,144 bytes. Bulk memory is available up to 4,194,304 bytes on the model 50. Core size for the IBM 360/50 can be 30 times that of the IBM 704.

Information can be stored in each of the media enumerated. And transmission can take place between the media, e.g., tape to tape, memory to memory, or memory to tape. Each request for information requires that files be searched and that data be transmitted. All of these transactions must pass through core. And since all information must pass through core it appears reasonable to store this data in core until it is to be transmitted. Normally, responses to data requests would not be so large data wise that it would not be possible to store all the information within bulk storage.

What are the characteristics of the I/O equipment? Four channels are envisioned, 3 selector channels and 1 multiplexor channel. This number enhances both transmission and overall operation of the configuration because all channels can function simultaneously. It is possible for a single channel, once instructed where and how much data to work with, to process that data, independent of computing being accomplished within the central processor unit.

One selector channel will contain only the disk. Only one I/O device can be serviced by a channel at any one time, and the disk, which will be in almost constant use, will require a channel almost full time. The other two selector channels will contain a tape unit and provision for transmission to a remote terminal. In the event that a large amount of data is to be transmitted from a given location to CENTRAL, these channels will be available. Both channels could be used to send information from CENTRAL memory to a remote tape at a rate of 5100 bytes per second.

Some of the data interchanges between a remote location and CENTRAL will be long. These, as indicated, will be handled by the 2 selector channels. Other requests for information will be relatively short, but more frequent. These will be handled by the fourth channel, the multiplexor channel. The multiplexor channel allows simultaneous operation of 64 terminal devices for a main core storage of 65,536 bytes, or 256 terminal devices for a main core storage of 262,144 bytes.

Access to CENTRAL from each location can be had through the multiplexor channel. Let us turn our attention to the other end of the transmission link, the remote terminal. Each terminal location can consist of an IBM 1050 teleprocessing group as shown in Figure 20. The character rate for all IBM 1050 devices is 14.8 bytes per second. Requests can be typed into the keyboard printer, and short answers can be received back via card punch or keyboard printer. Of course, longer answers should be received on tape. Though we have discussed the IBM 1050 as a possibility for terminal equipment, numbers of other devices exist and are available for consideration. Certainly, the configuration at each of the terminals need not be the same and can be tailored to meet the needs of the particular terminal.

Ancillary Peripheral Equipment

The computer configuration for processing of codified data has been discussed. Other types of data must be handled, however, In processing human factors task data, a large quantity of information processed may be in the form of narrative, graphs, or pictorial data.

It must be possible to process this kind of data.

In recent years, a number of systems have been developed which lend themselves to handling of non-codified data. In the main, these systems are based upon the use of video tape or microfilm. They differ, however, from a conventional system of picture storage in that provision for codifying a description of the contents of each document is provided to permit retrieval based upon a classification system. The essence of a pictorial retrieval system is the ability to search files efficiently in terms of a description of the picture.

Let us discuss this most important contribution to CENTRAL in terms of the Ampex Videofile system. Ampex is taking an active interest in long distance transmission, and their system possesses several advantages of note. Data stored in videotape is erasable and reusable as opposed to microfilm which is not. The capacity for storage is high. It is possible to place 250,000 8-1/2 x 11 documents on a 7200 foot reel. The search speed is high. It is possible to search 54,000 documents per minute.

Two phases of data handling merit discussion--document insertion and document retrieval as shown in Figure 21 and Figure 22, respectively. Let us examine first, insertion of documents into the file. Consider that the human factors data bank is large. For our purposes, large is defined to mean 10,000,000 document pages. This number of documents can be stored on 40 reels of tape. This number is, in itself, not critical. It is only used to gain some perspective concerning size of the system.

Maintenance of the system could be accomplished over the course of a day in shifts. During the first shift, identification of documents by technical people could be accomplished, and cards could be punched on the typewriter/cardpunch. Subsequently, the cards could be sorted on the card sorter. During the second shift, the cards would be used to pre-address a tape. Identifiers for each document would then be keyed into the recorder and the accompanying document inserted. Each recording takes approximately 15 seconds per document page. The result of this operation is the generation of an ordered reel of documents.

It is necessary to insert the new accessions into the existing library of tapes. In our case this would be 40 reels of tape. The time involved for this operation is approximately the same as the time required for generating the ordered reel for each of the 40 reels. Manual mounting time is about 1-1/2 minutes per reel, with automatic reel mounting available at additional expense. Based upon manual time considerations, it would be possible to insert about 800 document pages into the master file in one 8 hour shift.

It will be noted that insertion of documents into the files has been divided into shifts. During the first shift, work includes identification

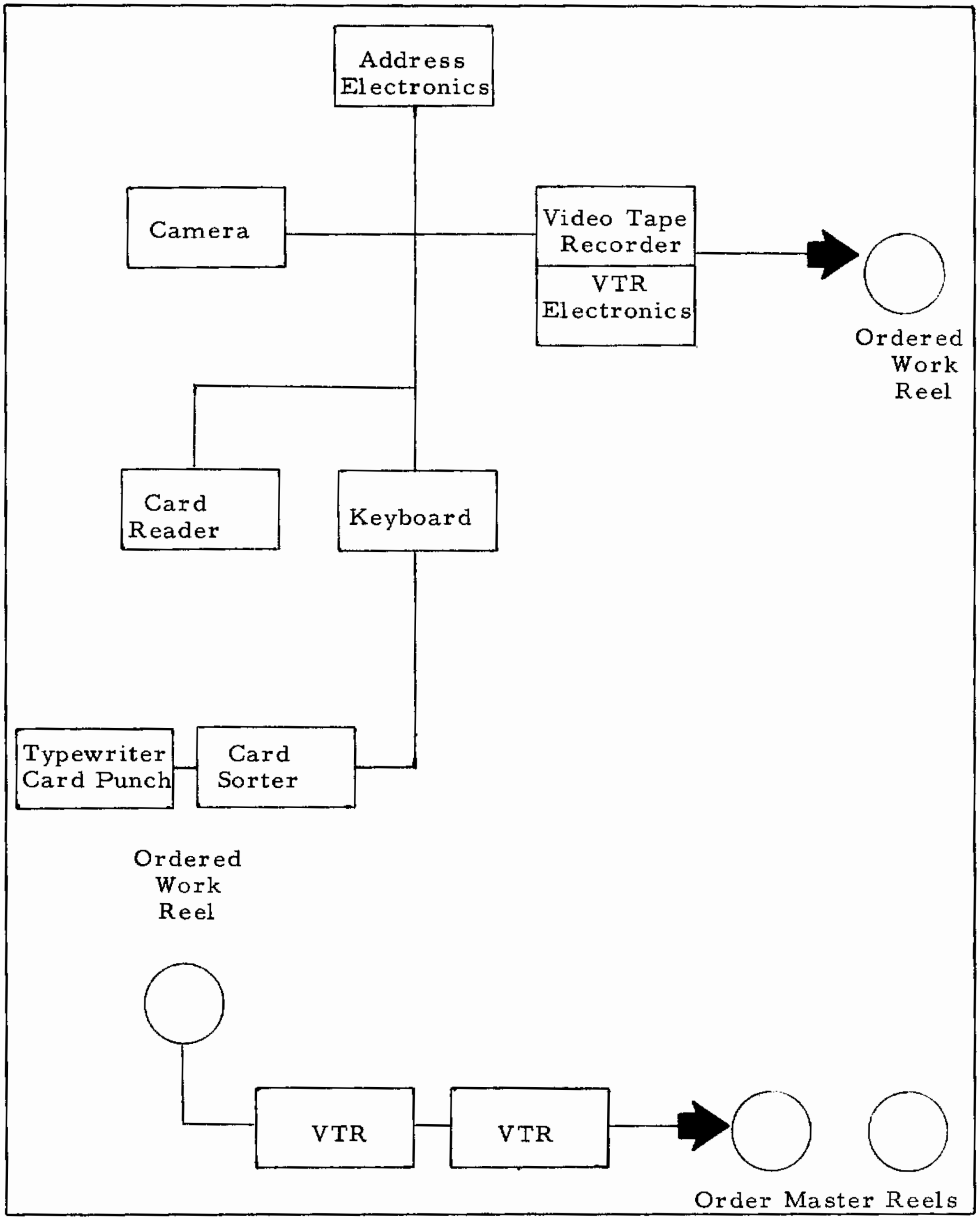


Figure 21 -- Central Agency Document Insertion - Videofile

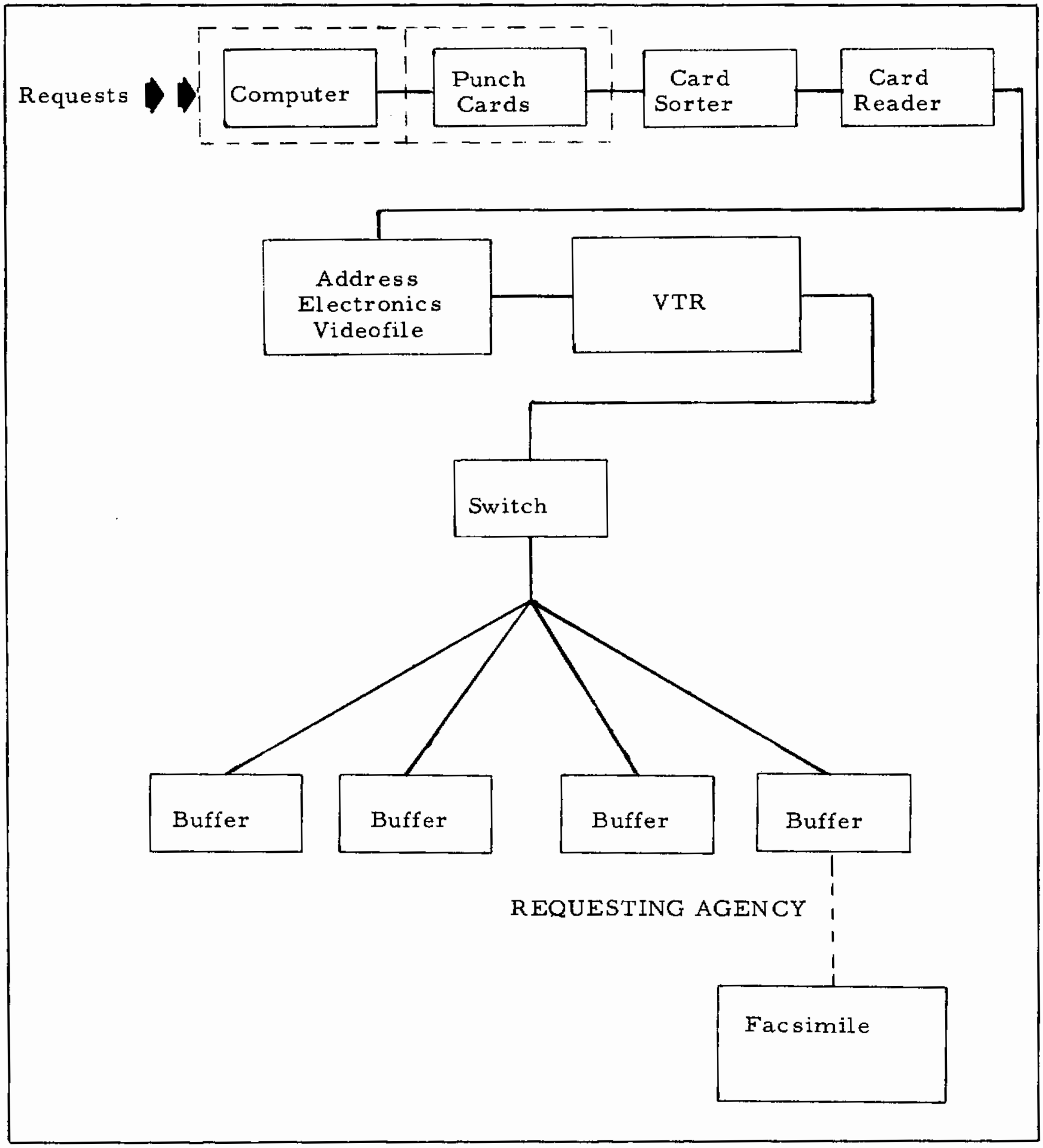


Figure 22 -- Central Agency Document Recall - Videofile

and key punching, i.e., work which can be accomplished independent of the Ampex equipment. During the second shift actual use of the video equipment is made. For the phase of document retrieval, the process is inverted. During those periods of time in which equipment is not used for insertion, the equipment can be used for retrieval.

To come to grips with times involved for data retrieval, let us assume that a request requires a 50 page answer, and that the 50 pages are contiguous on the file. Granted these assumptions, it would take an average of 3 minutes to retrieve the information and place it in the buffer for transmission. Transmission time would be one page per minute at 48 kc bandwidth. Thus, it would be possible for one Video Tape Recorder (VTR) to supply 20 locations (buffers) with continuous information. Each buffer would be switchable to any location in the network.

Each remote location would need a facsimile to receive the picture. This would provide a capability of receiving one document page per minute. If this capability were not deemed sufficient, additional facsimiles could be obtained. And, of course, the capacity of the entire system could be expanded by inclusion of additional equipment and more sophisticated equipment.

Transmission

One possible means for transmission to and from remote locations to CENTRAL is the Western Union Broadband Exchange System. The overall system includes three types of transmission; memory to tape or tape to tape, memory to 1050 teleprocessing unit, and facsimile. Each of these types has a different data rate and requires a different bandwidth for transmission. The cost of transmission depends on the width of the band.

Western Union intends to make 5 bandwidths available. Presently only the 2 kc and 4 kc bands are available, but Western Union expects to have the 8 kc, 16 kc and 48 kc bands available within the next two years. The 2 kc and 4 kc bands have a 2400 bit (300 bytes) maximum transmission rate. This is suitable for the 1050 teleprocessing equipment but too slow for tape to tape, memory to tape, or facsimile transmission which would be better suited to a 48 kc band. Facsimile transmitted at 4 kc would produce one 8-1/2" x 11" page per 4 minutes. At 48 kc this speed would be raised to a page a minute.

Costs of Operation

Costs are difficult to estimate. They are particularly difficult to estimate when it is not known if the costs are to be shared by a number of communities or by the human factors community alone. They are particularly difficult to estimate when it is not known exactly when the system is to be implemented. The state-of-the-art is advancing. At the time the system is implemented, the configuration chosen may be quite different than the one discussed. Even during the time this report was in preparation, significant changes have taken place. The multiplex channel was added as an option to models 60 and 70 of the IBM 360 line. These models possess advantages over the model 50 discussed. They can execute 7090 programs by means of a read only memory. Their core sizes are bigger and faster. The possibilities for transmission are undergoing tremendous changes. Satellites should provide greater speeds and lower costs. When the system is finalized, another appraisal of existing hardware must be made.

Nevertheless, despite this uncertainty concerning so many major aspects, we can provide some cost estimates based upon provisional acceptance of the configuration discussed. These are shown in Figure 23 and Figure 24. On Figure 23 are shown costs for the computer configuration for both CENTRAL and the remote location. On Figure 24 are shown costs for the videofile for both CENTRAL and the remote locations.

In addition to the costs of equipments at both CENTRAL and the remote locations, there is a cost for transmission of data. Within the orientation of the Western Union, usage of service is recorded on toll ticket devices located in the Telegraph Company's exchange and connected to the calling subscriber's individual channel facility. These devices record on each individual call (1) the numbers of the calling and called stations, (2) the service classification, that is, Schedule 1 (2 kc) or Schedule 2 (4 kc), and (3) the number of minutes and/or fractional minutes of usage. Chargeable time is recorded in tenths of minutes and begins when the connection to another subscriber station is established and ends when the connection is terminated by the calling station or by the called station. Very generally speaking the charges can be likened to those of telephone calls. In addition there are some nominal installation charges.

CENTRAL AGENCY COMPUTER CONFIGURATION

RENTAL COST PER MONTH (APPROXIMATE)

Central Processor	65 kilobytes storage	$ 8, 350
Bulk Memory	1 megabytes storage	6, 500
Bulk Memory Attachment		75
Disk Storage	224 megabytes storage	7, 900
Disk Control Unit		525
Disk Control Unit Attachment		250
3 Selector Channels	700 each	2, 100
2 Tape Drives	885 each	1, 770
1 Card Reader-Punch	200 each	875
3 Communication Adaptors		600
		$28, 945

REMOTE LOCATION

RENTAL COST PER MONTH (APPROXIMATE)

Control Unit	$ 85
Printer Keyboard	65
Card Reader	90
Card Punch	96
Tape Drive	1, 100
	$1, 435

Figure 23 -- CENTRAL Computer Costs

CENTRAL AGENCY		PURCHASE PRICE	RENTAL COST Per month on a 60 month lease
Typewriter Card Punch			$ 120
Card Sorter			44
Card Reader			90
Camera		$ 25,000	550
Address Electronics		64,000	1,408
2 Video Tape Recorders	26,000 ea.	52,000	1,144
2 Video Tape Recorder Electronics	36,000 ea.	72,000	1,584
Switch (64 way)		66,000	1,452
20 Buffers (50 page)	23,000 ea.	460,000	10,120
Basic System Equipment (Including Power Supplies etc)		71,000	1,562
40 Video Tapes	300 ea.	12,000	
Installation Charge		162,000	3,564
			$23,279
REMOTE LOCATION			
Facsimile (Stewart Warner)		$ 5,000 ea.	

Figure 24 -- Videofile Cost Schedule

SECTION VI

RECOMMENDATIONS FOR A PHASE II AND PHASE III PILOT STUDY

Introduction

Though the CENTRAL system could be initiated in its entirety, it is recommended that this be deferred until a prototype of the system can be developed and exercised. It is recommended that three complementary information retrieval techniques be developed: (1) an information storage and retrieval system, (2) an inquiry language for handling general inquiries and (3) a collection of analytical program routines. It is not recommended that any additional computational hardware facilities be acquired. The advantages of testing the system with "live" data, and by human factors specialists concerned with the informational content of the data cannot be overemphasized.

Objectives of Subsequent Development

The needs of the human factors specialist are well delineated in the A.I.R. study. To satisfy these needs, a CENTRAL system is recommended. The ultimate system depends upon development of software: (1) information storage and retrieval (2) analysis and (3) simulation; and upon acquisition of hardware: a central computer, pictorial data processor, and transmission equipments.

Though the CENTRAL system could be initiated in its entirety, it is recommended that this be deferred until a prototype of the system can be developed and exercised. From the viewpoint of research, in contrast to production, it is possible to develop and exercise the system short of purchase of CENTRAL equipment. This is not without real advantage in that ultimate purchase of equipment and establishment of CENTRAL operational characteristics will be influenced greatly by results of the subsequent research.

Before making recommendations for the research, it is felt worthwhile to establish the following objectives for Phase II (see Section I):

- The system should be capable of being used to advantage by workers in the human factors field.
- As many as possible of the features of CENTRAL which are not contained in the Phase II system should be visible as logical extension of the prototype system.

- The system should require a modest investment of effort for its initial development and should be working in a reasonable period of time.

- The system should be expandable both in form and function; it should not be limited to a single equipment configuration, but should be able to utilize new equipment as it becomes available.

Equipment Considerations for Phase II

Consistent with the goal of developing maximum problem-solving capability with minimum expenditure of resources, it is recommended that work in Phase II be accomplished utilizing equipment which is currently and widely available. At the same time, it is important to develop the computer programs so that the capability of utilizing more sophisticated equipment is retained. Where possible, the functions of unavailable sophisticated equipment should be simulated. Specifically, it is recommended that a current-generation large-scale general-purpose magnetic tape computer, e.g., the IBM 7090, CDC 3600 or Univac 1107, be used for Phase II.

Inquiry devices, essential to the operation of CENTRAL, need not be used, but can be simulated by having inquiry requests prepared on punch cards. Display output can be replaced by normal computer printout. These substitutions will result in delay in response time but in no loss of function. The physical retrieval of non-codified data (books, photographs, drawings, etc.) will have to be done manually, but can be done by direction of the computer, i.e., a computer printout can be used to direct a file clerk to a numbered drawer or cabinet and to the precise location of the desired data. This will effectively simulate the function of a computer-directed automated retrieval system, with exception of physical delivery of retrieved data. The important point being made is that the computer will have produced sufficient information to direct the operation of automatic document-fetching machinery (microfilm vidiotape, etc.) when it becomes a part of the system.

In the event that random-access equipment is not available, a fully capable small scale data system, such as the one proposed for Phase II, can be developed based on magnetic tape storage. Development of indexing techniques for efficient utilization of random-access storage can safely be postponed.

Specifications for Phase II

It is recommended that three complementary information retrieval techniques be developed during Phase II. These are:

1. An information storage and retrieval system.

2. A human factors-oriented computer language for handling general inquiries.

3. A collection of computer program routines for certain frequently-required analytical tasks.

Information Storage and Retrieval

Two facets must be discussed: (1) storage and (2) retrieval. Let us turn our attention first to the problems of storage. Regardless if data are generated in support of a QQPRI or any other document, it is of a form enumerated in the eight categories of data discussed in Section III, and illustrated in Figures 2 through 9. These data or the locations of such data are stored with associated format descriptions on magnetic tape. For pictorial information, descriptions are stored in conjunction with cabinet and file locations. This facilitates subsequent physical retrieval.

Even using this relatively simple approach to data storage, establishment and maintenance of the data bank is a complicated task. (Since there is a constant flow of new information and new data formats into the data bank, no attempt will be made to separate the initial task of establishing the data bank from the task of handling the normal flow of data. There will be a special logistic problem to be dealt with initially, but the system design considerations will remain the same.)

After the data have been prepared, i.e., keypunched in accordance with a specified form, the data are processed by an input-conversion program. This program alters the form of the data to make them more compact and easier to manipulate in the computer. At this point, in a binary computer, some numeric items are converted from decimal to binary. Also, other operations such as scaling and conversion to a standard unit of measure are performed.

In order to reduce the probability of contaminating the master data file, validation procedures need to be incorporated in the updating process. When updating an existing record, redundant information (such as both TASK ID and NAME) are inspected to assure location of the correct record. Variable values are checked against acceptable ranges before being inserted in the records. Whenever data are found to be suspect, the updating routine outputs a printed message identifying the suspect data and indicating which "accepted test" the data failed to pass. After printing the warning, the routine may proceed with the updating or not, depending upon the type of failure.

After conversion and validation, information entered into the data bank is sorted and merged with the "old" data bank to produce a set of tapes containing the "new" data bank in which all data, both old and new, are arranged properly to facilitate subsequent retrieval.

We have discussed requirements for storage of information. Let us now turn our attention to problems of retrieval. The difficulty in data retrieval is that in most cases the human factors specialist does not know very much about the data form he is trying to locate. He frequently does not even know whether such data exists. Typical of the questions asked are: "Have acoustical earpads been developed for rocket maintenance during the operational phase?" and "What maintenance displays have been developed for color deficient system maintenance personnel?"

The key to the document-retrieval system is in the assignment of descriptors to each item of non-codified data, such as are stored in files within the cabinets, as it is entered into the system. A descriptor as used here is a word or short phrase which describes some aspect or field of interest touched on by the data. Anywhere from five to fifty or more descriptors are assigned to each piece of data. The language used for the descriptor words is ordinary technical English, but the composers of the descriptors are urged to consult a specially-prepared human-factors index, which increases uniformity of spelling and choice of words. Correct choice of descriptors is crucial to the retrieval system, as a document is irretrievable if a key descriptor is omitted.

When the human factors specialist wishes to initiate a search for data on a particular subject, he prepares a list of descriptors in two categories: those which must be present and those which are desirable. The computer processes each batch of such requests against the file of data descriptors and lists out the title, author, date and location of every piece of data satisfying the request; this list is in order of probable interest, i.e., data having the highest correlation with the specialist's list of "desirable" descriptors are listed first. The specialist can then indicate which data he wishes to receive, and they are deliverable to him. As mentioned, delivery of data is performed manually initially, but the mechanism for automating this operation is present and can be activated as soon as the appropriate equipment is available.

Human Factors-Oriented Computer Language

The purpose of the human factors-oriented computer language is to enable the human factors specialist to obtain and process codified data such as shown in Figures 2 through 6, without knowing how the data entered the data bank (and, often, without knowing at first whether the data exist!). The language is intended primarily as a research tool and as an aid to the human factors specialist.

The human factors-oriented computer language enables the specialist to specify a desired data field by giving its characteristics rather than its location in the data bank. For example, if a human factors specialist wishes to know the number of man-months per year required to maintain a certain type of military vehicle, he composes an inquiry specifying the type of vehicle and the maintenance time figure required. He does not have to know in which form this information had been entered into the data bank.

To use the language the human factors specialist prepares a deck of punch cards containing his inquiry requirements and specifications for processing to be performed on selected data. A number of such requests are batched together and processed simultaneously. The responses to the inquiries appear as computer printout, which can be logically separated and distributed to each of the individual specialists.

As the data bank expands, it will include equations for certain standard types of calculations, and it will also include functional flow diagrams. Through use of the human factors-oriented computer language, it will be possible for the specialist to retrieve equations from the data bank, and to have the computer execute these equations using selected sets of data retrieved from the data bank. It will also be possible using the language to retrieve functional flow diagrams or portions thereof, and to obtain a list of all reports referenced by a particular flow diagram if it is so desired.

Computer Program Routines

A number of analytical computer programs incorporated into the computer system could be of great value to the human factors specialist. Use of such programs permits the production of a report, in an arbitrary and pre-determined format, containing results of a set of calculations. Illustrative of these types of reports are those presented in the collection of statistical analysis programs in the BMD series. This set consists of more than 40 general purpose statistical analysis programs, including many multivariate analysis, regression analysis, time series analysis and analysis of variance programs. The human factors specialist can specify data upon which calculations are to be performed and the report procedure desired. The computer system performs the previously defined set of calculations and prints the report. A number of these programs are now in existence, and if felt adequate, need not be developed specially for Phase II. The closed report procedures suggested for incorporating into the computer system are the following:

1) Monitoring Estimates Through Time

This program provides a capability for following estimates associated with system tasks through the various phases of system development. By comparing estimates through various phases, patterns may well be discovered which can be applied to estimates of future systems. A valuable tool for determining such patterns is the statistical procedure, multiple regression analysis. Consideration should be given to incorporation of this tool into the program.

For example, prior to start of a new system, estimates are made of the tasks associated with the system for all phases in the development of the system. These constitute the initial estimates. But it comes as no surprise that although estimates are made as best possible that at the conclusion of system design actual values will differ from the initial estimates. Because of uncertainties and unforeseen circumstances, actuals seldom duplicate estimates and we must revise and modify our plans accordingly.

Though at the start of system development, there is no "actual" information available, we arrive at the conclusion of system development with all "actual" information available. There is no alternate to the initial estimates but once actual data comes to hand, we must take steps to incorporate this data and revise our estimates accordingly.

By using a formula or equation or set of equations, a model as it were, that relates actuals to estimates, we can improve our estimates by feedback of the quality of past estimates into the remaining estimates governing remaining future events. Solution of the error model can be handled by the techniques of multiple regression analysis. An application of this technique is shown in "Models For Forecasting Contractor Performance," by Irvin R Whiteman.

2) Comparing Data Across Systems

This program will provide a capability for comparing task and other man-machine data across systems, rather than longitudinally through time. The approach is the same as for comparing estimates through time. Comparisons of "actual" values and corresponding estimates of tasks within one system can be described by a mathematical model using the techniques of multiple regression. The resultant equations can be applied to the estimates of another system to obtain a more refined approximation to "actual" values as they will come into being.

3) Simulation

This program simulates time-wise, the performance of a sequence of system tasks and prints out the results. The human factors specialist describes the system by specifying the number of tasks, the number of individuals available to perform them, the time required to perform each, the required sequence of performance, etc. The program simulates their performance, and prints out the results with pertinent comments at the conclusion of each task. Eventually, though not in Phase II, the analysis procedure could be combined with the inquiry mechanism so that many of the required parameters can be automatically retrieved from the data bank.

4) Statistical Procedures

There are a variety of statistical procedures such as those contained in the BMD series which could prove to be invaluable tools for the human factors specialist. However, at this time, it is recommended that only a few of the most commonly used analyses be incorporated into the computer system: multiple regression analysis (referred to above), time series analysis and analysis of variance. In the future, as the need for other statistical procedures develops, they can be readily added to the system.

Initially the BMD programs would be used as an independent set of routines available to the human factors specialist as needed. To use the programs, data would be prepared in accordance with the input requirements of the particular program. Based upon statistics of subsequent actual usage of the routines, the more important programs could be built into the operating system.

Phase II Design Requirements

In order to develop the computer programs just described, a number of initial design decisions must be made. These include:

- General rules for capturing data in computer-readable form.
- Detailed rules for the construction of format descriptions.
- Detailed rules for the internal storage of format descriptions and data in the data bank.
- The general form and degree of sophistication of data validation rules.
- The specific format for statement of inquiries.
- The specific format for the statement of document retrieval requests.
- The external and internal formats for the document-retrieval descriptor file.
- Construction of a computerized glossary of human factors terms.

Programming

It is recommended that programming standards be laid down and followed throughout the development of Phase II to ensure uniformity and transferability. It is not sufficient that programs work individually or even that they work correctly together; the programs must be constructed in such a way that they can be easily read, understood, and modified by programmers other than the original authors. This requirement is regarded as normal good programming practice, but is worthy of special attention, in this instance, because the programs developed in Phase II are intended to form the basis for the development of CENTRAL. The programs should be written in a clear, self-explanatory style, avoiding subtleties and devious programming tricks. They should be self-documented (by embedded comments and descriptive choices for internal labels) and should be accompanied by extensive external documentation. An overall programming style should be developed and followed uniformly in all programs.

A basic step in the establishment of an overall programming style is the choice of a computer language for program development. Some or all of the following choices are available, depending upon the model of computer selected:

1. Symbolic assembly language
2. Macro assembly language
3. FORTRAN
4. COBOL
5. Special Programming Systems

1. Symbolic assembly language is one step removed from the basic machine language of the computer. It offers the programmer the greatest freedom and can be used to produce the most efficient program possible. It also puts the greatest burden on the programmer and requires the greatest amount of effort in the writing of correct programs.

2. Macro assembly language is symbolic assembly language with the addition of specially constructed combinations of program steps called macros. A set of specially tailored macros can be written by a highly skilled programmer for one particular application; these macros can then be used by less-highly-skilled programmers. Macro assembly language provides advantages over symbolic assembly language in ease of standardization of program style, and reduction in overall programming effort, but still requires considerable programming skill and effort, and, like symbolic assembly language, its use is likely to result in programs which are difficult

to read, understand, and modify. Also, like symbolic assembly language, macro assembly language is different for different computers, and the resulting programs become "married" to a single class of machines.

3. FORTRAN (FORmula TRANslation) is a computer language which permits the specification of a program in terms independent of the design of a particular computer. Virtually all present and proposed large-scale computers accommodate programs written in FORTRAN. While programs written in FORTRAN are not as efficient as the most efficient programs that can be written, they compare well in efficiency with the work of the average assembly-language programmer. FORTRAN enables programmers to write programs quickly and to quickly detect and correct programming errors. FORTRAN programs tend to be easier to read than programs in symbolic assembly language, and it is simpler to impose a standard programming style.

4. COBOL (COmmon Business Oriented Language) is very much like FORTRAN, but is oriented toward the solution of business data processing problems. COBOL processors are available for virtually all large-scale computers. COBOL programs are likely to be slightly less efficient than programs written in FORTRAN, but not seriously so. Because COBOL is a verbose language while FORTRAN is concise, COBOL programs take a little more time to write, but are a little easier to read.

5. A number of special programming systems exist, many of which have FORTRAN as an integral part. In general, such systems are available only for single classes of computers.

Language Selection

The human factors-oriented computer language must possess a strong information storage and retrieval capability coupled with characteristics of scientific data processing. As indicated in the previous portion "Programming" a number of alternates present themselves as a basis upon which to structure the human factors-oriented computer language. Of these, FORTRAN and COBOL contain attributes which could well be incorporated into the new language as developed.

To fulfill Phase II programming requirements, it is recommended that either FORTRAN or COBOL be selected as the starting point from which the new language is developed. No other languages presently available can provide the same degree of compatibility with existing and future computers essential to the further utilization of Phase II programs. Whether FORTRAN or COBOL is selected as the basis around which the human factors-oriented computer language is developed, there will be areas in which a symbolic assembly language will be required, either because the task is beyond the capabilities of FORTRAN or COBOL (e. g., the initial interpretation of variable-format information on input) or because the utmost in efficiency is required (e.g., the searching of a table of selection criteria looking for a match against a particular data field). The amount of such programming will be very small and will not seriously hamper the transfer of programs from one machine to another; the parts in question will simply have to be reprogrammed.

With the exceptions just discussed, it is possible to do all Phase II programming in FORTRAN. It is possible to do almost all of it in COBOL; the analytical program procedures could not be programmed conveniently or efficiently in COBOL, and in fact, important statistical analysis subroutines which could and should be used therein already exist in FORTRAN. However, it would be possible to program these tasks in FORTRAN and all other Phase II tasks in COBOL.

Since no compelling reason dictates a choice between FORTRAN and COBOL, the decision must be based on secondary considerations. Among these are the availability of programmers skilled in each language respectively, the relative merits of each of the language processing programs provided by the manufacturer of the machine selected, and the convenience of use in the environment in which the programs will be checked out. This last factor may well prove to be decisive. If the development of Phase II is done at a computer center where COBOL is the primary programming tool, a group attempting to check out a large complex of FORTRAN programs would meet with considerable difficulty in scheduling computer time and overcoming unfamiliarity with the programming system on the part of the computer operators and other computing center personnel. The same difficulties would be experienced trying to develop and check out COBOL programs in a "FORTRAN shop."

Sorting

With use of magnetic tape as the storage media for the data bank, consideration must be given to the reduction of access time to the data files. Considerable savings of dollars and time can be achieved by batch processing of requests. Interestingly enough, the time required to select and sort a number of requests might not be appreciably longer than the time to process a single request. (See Section II)

Several of the computer programs discussed will require a large-scale sorting procedure. Development of such a sorting procedure is itself a major undertaking, but fortunately a number of acceptable sorting procedures already exist. For example, there is IBM 90 SORT for the IBM 7090 and 7094 computers; also, most computer manufacturers can be expected to add sorting capabilities to their COBOL processors in the near future. Thus it will not be necessary to program a special sorting routine; the only programming which will be required in this connection will be to provide a smooth transition from the program which prepares the file to be sorted to the sorting program and thence to the program which utilizes the sorted information.

Phase III Implementation

How can the programming system of Phase II be implemented and tested? The answer to this question depends upon the specifics developed upon conclusion of Phase II. It depends upon the programs written and made available, and upon the actual computer configuration.

It depends upon the type of data made available for testing, and upon the types and amounts of cooperation made available from other participating groups. We cannot over-emphasize the advantages accruing from testing the system with real live data nor for having these tests performed by human factors specialists motivated by concern for the informational content of the data.

Computer Configuration

The computer system described in Phase II could be implemented upon a variety of computer configurations. However, to be specific let us recommend the following equipment: an IBM 7094 with at least 12 IBM 729 magnetic tape units, and an IBM 1401 (or its equivalent) for card-to-tape and tape-to-printer conversion.

The computer programming language recommended is FORTRAN IV. In addition, the IBM 90SORT program is recommended for the required sorting procedure.

The 12 tapes referred to are the following:

- Input tape
- Output tape
- Operating System (FORTRAN IV, etc.)
- Programming System (see below for breakdown)
- Data Bank 1/Document Directory 1
- Data Bank 2/Document Directory 2
- Six scratch tapes

The implementation of FORTRAN IV on the IBM 7090 and 7094 computers includes an "overlay" feature which allows a number of program "segments" to be placed on magnetic tape and brought into the computer memory as needed. In this implementation example, it is assumed that the overlay feature will be utilized to make each of the processing programs (described in detail below) an overlay segment or collection of overlay segments. Thus all the programs for Phase II would be stored together on a single program tape and would be called into use by a master program (also stored on the program tape) depending upon the operation to be performed.

Since the data bank will probably be a multi-reel tape, two units will be alloted to it. If there are more than two reels, the additional reels will be mounted alternately on the two units during execution. Thus, time will not be taken up during execution with mounting successive reels on the same unit. Since requests for data bank and document directory processing will be batched separately, the two need not be mounted simultaneously and can share the same two tape units.

Computer Programs

The programming system will be a FORTRAN IV overlay tape containing the following programs:

Control Program

1) Identifies the type of input: data bank inquiry, data retrieval request, etc.
2) Causes the appropriate program to be loaded from the overlay tape.

Data Bank Maintenance

1) Inputs and validates the updating information.
2) Sorts the updating information to correspond to the ordering of data in the data bank.
3) Merges the updating data with the data bank.

Document Directory Maintenance

1) Inputs and validates the new document descriptions.
2) Sorts the new descriptions to correspond to the ordering of the document directory.
3) Merges the new descriptions with the document directory.

Data Bank Inquiry Processing

1) Inputs and translates a "batch" of data bank inquiries into sets of selection criteria (stored in core) and sets of rules (output on tape).
2) Selects data from the data bank, in one pass through the

bank, satisfying each set of selection criteria and outputs the data on tape.

3) Sorts the selection tape according to inquiry.

4) Performs any requested computations upon the selected data as indicated on the rules tape.

5) Prints the reports containing the data.

Document Retrieval Request Processing

1) Inputs and translates a "batch" of retrieval requests into sets of selection criteria (stored in core).

2) Selects file locations from the document directory whose descriptors satisfy each set of selection criteria and outputs the locations on tape.

3) Sorts the selection tape according to request.

4) Prints the reports containing the locations of requested documents.

Computer Program Routines

These procedures are (see Section VI): Monitoring Estimates Through Time, Comparing Data Across Systems, Simulation and Statistical Procedures. Each performs the following general functions:

1) Inputs the data to be analyzed.

2) Performs the requested analysis.

3) Prints a report containing the analysis results.

Establishing the Data Bank and Document Directory

The data to be entered initially into the data bank consist of tables, and filled-out forms, and are in the form of marks on paper. Section IV discusses the techniques to capture these data in computer-readable form. For each format, a capturing rule, keypunch instructions, must be devised, and a corresponding format description prepared. Then all forms in that format must be keypunched. The resulting computer-readable data from all formats, together with the corresponding format descriptions, in computer-readable form, are then input to the computer and processed by the data bank maintenance program. The tapes written by this computer operation constitute the initial version of the data bank.

Data Bank Inquiry

Once the data bank has been established, data can be retrieved by specifying the criteria for selection and the values to be retrieved. The requestor first consults the glossary printed in the manual in order to obtain the field names, meaningful to CENTRAL, with which to express his request. He then writes his request on coding forms and submits it for keypunching. His request along with others is batched for processing by the CENTRAL computer. Within a matter of hours (or perhaps overnight) the user receives the response to his request.

In order to illustrate the way in which a requestor could express a data bank inquiry, the following description of an inquiry language is given. This presentation is not intended to be the final specifications for such a language. It is intended to indicate the type of language recommended for implementation.

A set of selection criteria could be specified by a set of arithmetic statements in which the fields are referred to by names obtained from the manual's glossary of names. For example, the statement:

SYSTEM .EQ. APOLLO

would indicate that data associated with the APOLLO system (as opposed to any other system for which data is available in the data bank) is to be selected.

In order to construct a set of criteria, the statements could be connected by the symbols '+' and '*' with '+' denoting the logical operator 'or' and '*' denoting the logical operation 'and.' As in conventional usage, the operator 'and' will be more binding than the operator 'or.' For example, the set of criteria:

SYSTEM .EQ. APOLLO * SUBSYSTEM .EQ. GUIDANCE

+SYSTEM .EQ. GEMINI * SUBSYSTEM .EQ. GUIDANCE

would indicate that data is to be selected which is associated with either the guidance subsystem of the APOLLO system or the guidance subsystem of the GEMINI system.

For ease of usage, parentheses might be inserted within the sequence of statements. The following set of selection criteria:

TASK .EQ. REPAIR * ITEM .EQ. RADAR *(SYSTEM .EQ. APOLLO +

SYSTEM .EQ. GEMINI) * SUBSYSTEM .EQ. GUIDANCE

would cause all data to be selected from the data bank which is associated with the repairing of radar in the guidance subsystems of either the APOLLO or GEMINI systems.

In the above examples, TASK, ITEM, SYSTEM and SUBSYSTEM are used to denote field names; REPAIR, RADAR APOLLO, GEMINI, and GUIDANCE denote field values. It is assumed that within the data bank, each field will take on many values.

Within a statement, specifiers other than .EQ. (equals) may be used:

.NE. (not equals), .GT. (greater than), .LT. (less than), .GE. (greater than or equals) and .LE. (less than or equals). These last four, of course, are meaningful only when the variable value is numeric, rather than alphabetic as in the above examples.

Once the criteria for selecting data have been specified as described above, the next step is to specify the values to be selected. These values might be specified via a SELECT statement, consisting of the word "SELECT" followed by names of the fields which are to be selected separated by commas. For example, the statement:

SELECT DATE, TIME

would cause the fields DATE and TIME to be selected from the records which satisfied the selection criteria.

The following is an example of a data bank inquiry expressed in this language:

```
    JOB QUERY ON APOLLO
C   CRITERIA FOR SELECTION
    SYSTEM .EQ. APOLLO
X   * POSITION .EQ. COCKPIT INSPECTOR
X   * OPERATION .EQ. PREFLIGHT INSPECTION
X   * DUTY .EQ. COCKPIT CHECK
D   DATA TO BE SELECTED
    SELECT MANNING ESTIMATES
    END
```

In this example, the "C" in the first column is used to indicate a comment statement which is to be ignored except for listing when the request is input. The "X" denotes a continuation of a statement onto another card. On cards, the "C" and "X" are punched in Column 1; the statements in columns 2 through 72 with blanks freely interspersed.

Document Retrieval

The procedure for specifying document retrieval requests is very similar to that for data bank inquiries. The requestor expresses his request on coding forms in terms meaningful to CENTRAL and submits it for key-punching. His request is batched for processing and in a few hours he receives his response. In this case his response consists of the file location of the desired documents, rather than data retrieved from the data bank.

The following is an example of a document retrieval request with the selection criteria expressed in the inquiry language described in the previous section:

```
    JOB RETRIEVAL OF APOLLO DIAGRAMS
C  CRITERIA FOR SELECTION
    SYSTEM .EQ. APOLLO *
X   POSITION .EQ. COCKPIT INSPECTOR
X   OPERATION .EQ. PREFLIGHT INSPECTION
C  DOCUMENTS TO BE RETRIEVED
    RETRIEVE MANNING ESTIMATE DIAGRAMS
    END
```

In this example, the word "RETRIEVE" is used in place of "SELECT" to notify CENTRAL that this is a document retrieval request and not a data bank inquiry.

This example document retrieval request might have been submitted along with the example data bank inquiry of the previous section in order to obtain the supplementary diagrams required.

The Operational System

The developed system, though a research tool, can be used and tested with real data. The system is responsive to retrieval of the two kinds of data: 1) data which are best stored in machine readable form and 2) data of a pictorial nature. In Figure 25 is shown how the system is used to retrieve machine coded data. In Section VI, we have an example of a data bank inquiry concerning a "Job Query On Apollo." This request could be keypunched, and the cards placed into the computer. We see also that the tapes housing the data bank and the program are called into play. The program interprets the request, selects the data from the data bank, arranges the data in proper format, and prints out the desired report.

Though the illustration shows the procedure for inquiry processing, the process for updating the files is essentially the same. The data to be inserted into the files, are keypunched and inserted into the computer. The program tape calls in the data bank tapes and carries out the updating procedure.

In Figure 26 is shown how the system is used to retrieve documents containing information of a graphical, narrative or pictorial nature. The prototype system is built around the IBM 7094. No provision has been made for acquisition of new equipment in which to store data of a pictorial nature. Storage of physical documents containing data of a pictorial nature will be accomplished within a conventional set of cabinets. A document will possess a cabinet number, a drawer number, a file number. Each document which is filed, will have a description of the documentation and its location (cabinet, drawer and file) recor-

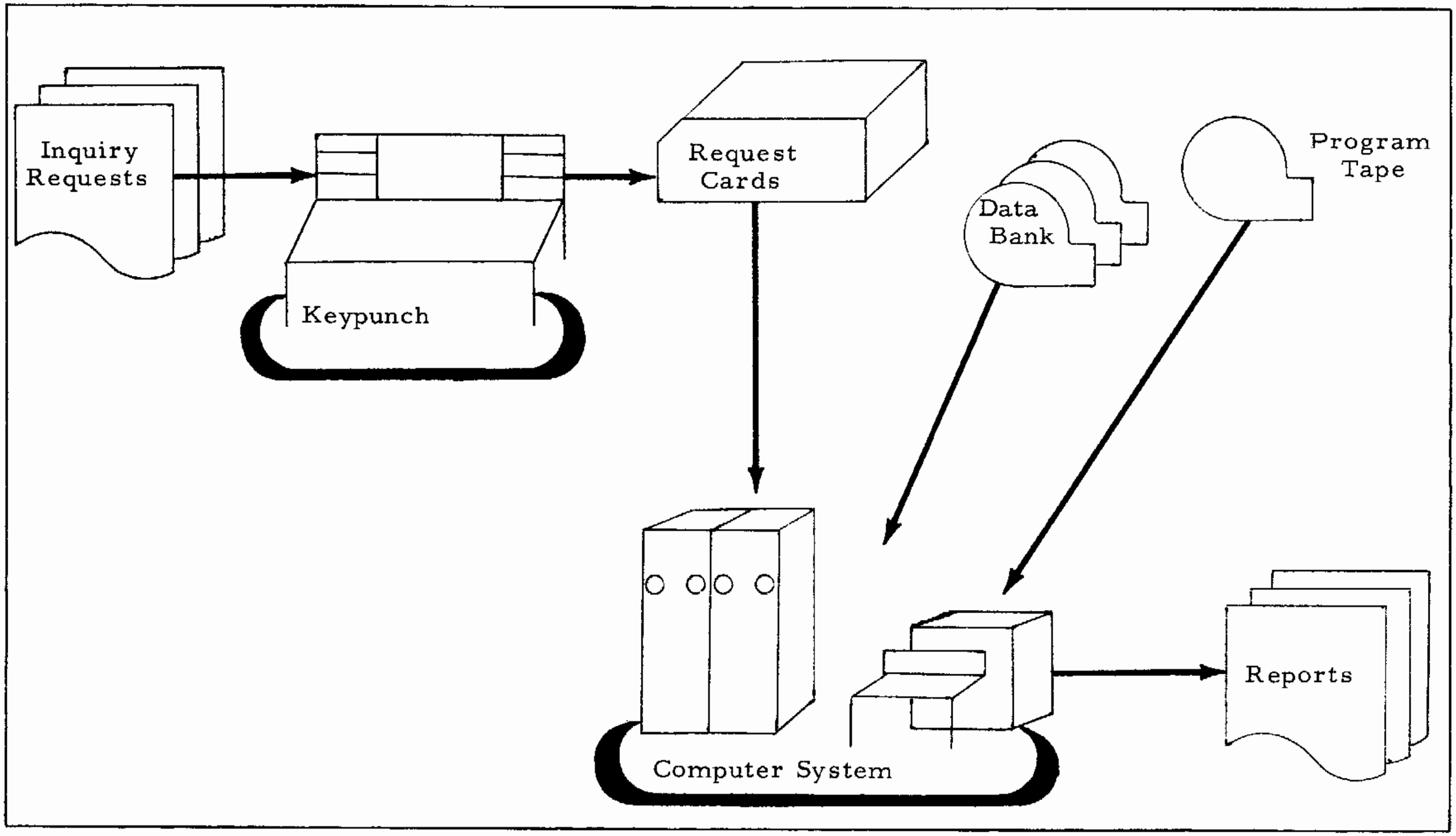


Figure 25 -- Inquiry Processing

ded within the document dictionary tape. Requests for documents will be written using the inquiry language, and keypunched. The search cards will be inserted into the computer. The program will read the cards and search the dictionary tape to obtain a listing of those documents which best satisfy the requirements of the request. These data are output on the bibliography report.

The specialist can then obtain the documents desired from the cabinet. This should be easy to do as the location of each data item is well documented.

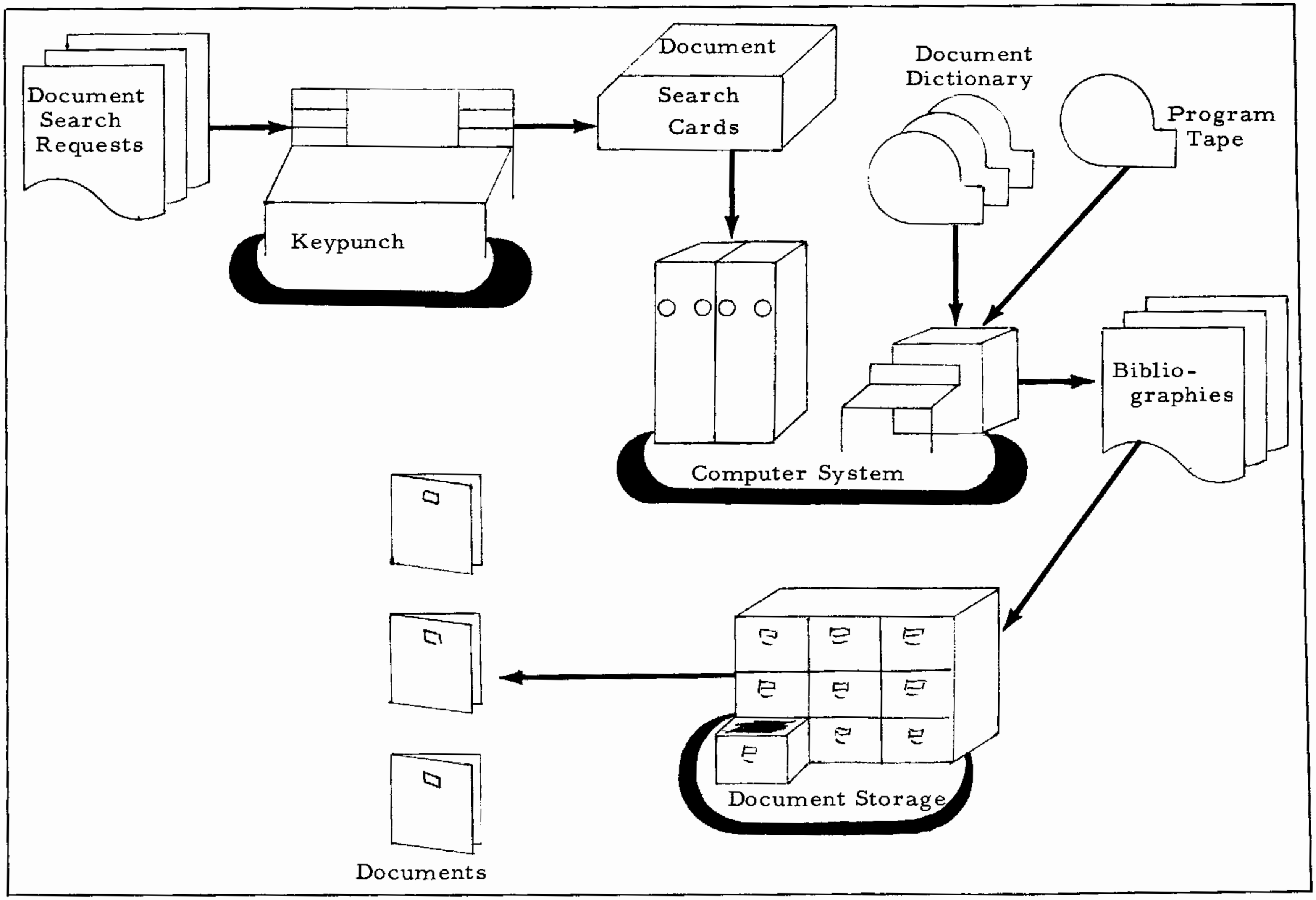


Figure 26 -- Document Retrieval

SECTION VII

THE FUTURE OF CENTRAL

Introduction

Today, virtually all engineering schools in the country have computers, and the graduate of tomorrow who has not been exposed to a course in computers will be the exception. As the state-of-the-art is pushed, making decisions in absence of a complete data set becomes more commonplace. To continue exploration under these circumstances, it becomes necessary to use more sophisticated analytical tools. The computer has become a fundamental tool to analysis. There is no alternative to its use.

CENTRAL and Human Factors

If we look back over the past 20 years, we see a complete metamorphosis within our industrial complex and in particular in that area known as aerospace. At the time of World War II approximately one out of every ten workers was an engineer. This was at a time when the high speed computer was still yet a vision in the minds of its most serious proponents. Today, only some five years or so since the advent of the large solid state computer and in an era in which every large manufacturer and governmental agency without exception possesses a computer, we find that one out of every three workers is a scientist or engineer. We must note the use of the words scientist or engineer. Accompanying the use of the computer has been the use of the scientist.

The increased ratios of analytical personnel from one in ten to one in three have a startling significance. The correlation is clear to see. Increased use of computers is directly correlated with an increased need for scientific man-power. The use of the computer does not decrease the need for scientific support. It only increases the need for scientific support.

Just a few years ago projects initiated by both Air Force and NASA were conducted by a majority untutored in ways of the computer. It was inevitable that whenever possible a known time-tested manual approach was taken. Each passing year reduced this majority. The advent of the electronic computer has created a new approach to engineering problems. The costly "build and try" method is now replaced by "construct mathematical model and simulate."

What is the status of the computer in industry today? To most engineers practicing in industry the high speed digital computer is an unknown quantity. Just five years ago an engineer's chance of having an introduction to computing while in college was slim indeed. Today, virtually all engineering schools in this country have access to digital computers. Within the next five years the engineer who graduates without an introductory course in digital computers will be the exception. It is not difficult to see that the new generation will only exponentiate still more the rocketing pace of our computer technology.

The Need for More Sophisticated Analysis

Many articles have been printed in professional publications on the solution of difficult engineering problems by the use of electronic computers. Not as many have been written about human factors task analysis. But even among those which have been written, these applications have only scratched the surface of possible use, and only lack of knowledge and experience prevents the full use of the computer as an analytical tool. It is highly desirable, therefore, that every specialist understand how problems can be formulated for solution by electronic computers.

How are problems of human factors solved? Though elegant analytical techniques have been developed which successfully handle a large class of mathematical problems which arise in the description of the physical world, a vastly larger number of mathematical problems are not subject to the normal analytical procedures of algebra, analytical geometry or calculus. Human factors analyses are made up of these kinds of problems: problems which are more apt to require comprehensive solutions. A large solution may stem from two sources: (1) the iterative nature of the solution and (2) the time dependency of the problem. Both of these two aspects are a result of present day technology, a technology developed from the point of view of the entire system. Creation of missiles, satellites and spacecraft permit no alternative.

Not only do the numbers of possible environments, and the numbers of possible internal configurations overwhelm the specialist, there are also the numbers of equipments involved. In the past, problems of analyses were confined essentially to machines - machines produced in relatively large quantities. However, when the equipments of interest are limited production or one-of-a-kind items, such as space capsules and laboratories, not confined to machine alone but intimately related to man and his characteristics, special problems in proper interpretation and application arise.

In large scale production, deviations from expected mean values are not too significant because of averaging effects. But when equipments in question are high cost, limited production items, this is no longer true. There is no opportunity for averaging effects to take place. No longer is it sufficient to predict mean values in a given set of specifications. It becomes of paramount importance to determine the range of possible values that an equipment built to specification may have, and to determine the probability that the reliability of the man-machine combination will lie within a fixed interval with a known degree of certainty.

The horns of the dilemma are evident: more and more, an increasing amount of information must be extracted from a decreasing supply of information. Methods of analyses must be developed to accommodate these changes. Though current analyses have provided valuable information throughout all phases of design, production and usage in the field, these techniques must be expanded to satisfy the needs and demands of newer systems.

The Need for Data

The computer is useful because it can store and retrieve data, and because it can manipulate data in accordance with required analytical techniques. It can cut down response time from an intolerable span to useful practicality. This appears reasonable. A question, which arises, however, again and again, concerns dependence upon the data. Analysis depends upon data. What good is the best computer system in the world in the absence of data? What good is the computer then?

Fortunately, though life is seemingly a lot nicer and a lot easier with all data, a computer system is still useful in the absence of data. This should be rephrased. In the absence of data, there is no alternative to more sophisticated analysis, there is no alternative to the power of the computer. This does not mean that we can barge into all areas in complete ignorance. This is neither indicated nor suggested. But this is not the case. We suffer not so much from complete ignorance, but more from gaps in interesting but inconvenient areas. The problem is how to bridge these gaps. If a computer system is important when all data is at hand, it is even more important in the face cf missing data.

As the state-of-the-art is pushed, making decisions in absence of a complete data set becomes more and more commonplace. And this is the situation prevalent in human factors considerations concerning aerospace systems and extension of the frontiers of space. To continue exploration under these circumstances, it becomes more and more necessary to use more sophisticated analytical tools such as decision theory and game theory.

Future Analyses

Projection into the future is at best hazardous. We are not sure of the aims and economies of our country, and we are not sure of what data and what tools will be made available. We do know, however, that tools have been developed and are being developed, in all areas of computer technology, which will be at the disposal of the human factors analyst. There is no question that he must use them, and that he will use them.

The human factors specialist, tomorrow, will have a communications network available to him to facilitate data interchange which will dwarf the telephonic network which exists today. It will be possible to couple computers and to couple their contents. The pace of technology is so rapid that we must ready ourselves now if we are not to be behind tomorrow.

Demands for human factors information stem from different sources with varying degrees of urgency. The human factors group if it is to actively participate in these considerations must be able to respond. Questions which cannot be answered by means of analytical considerations will be answered by means of "rule of thumb" and "best guess" techniques.

By the very nature of the size and numbers of calculations involved in human factors calculations, the computation is a large one. Unless provision is specifically made to provide the expeditious calculation, the likelihood is that desired answers will be long in forthcoming and that the answers obtained will be only of historical interest rather than of operational utility. There is no alternate to the use of the computer in human factors task analysis.

APPENDIX

Data Processing Equipment - State-Of-The-Art

Much of what can be considered state-of-the-art in electronic data processing can be gleaned from manufacturers' brochures. In many major respects, some equipments are so competitive as to appear almost identical. In other respects, differences do occur. Importance of these differences, and whether the differences are beneficial can only be determined from specific application.

To provide an indication of the state-of-the-art, a number of systems are described. These descriptions are in terms of the products produced by different manufacturers. Mention of a particular equipment is not to be considered as endorsement of the product, but only as the means for describing a given type of real existing equipment.

Equipment described are grouped in the following categories:

- Computers
- Micro-Reduction Equipment
- Auxiliary Storage Devices
- Transmission Devices

Computers

The storage, retrieval, and manipulation of refined data can be achieved through use of a digital computer. At the present time, manufacturers of computers are introducing the third generation of computers. The trend is toward a "family of computers." A "family" consists of different models from the same manufacturer capable of execution of the same programs and capable of using the same input/output devices. The main differences between models stem from differences in speed and in size. Two basic computer systems are described: (1) IBM System 360 and (2) RCA Spectra 70 System.

System 360

The models within this system are identical in concept and compatible in programming but are matched in size, speed, and cost to the various new applications and data rate demands. In the range of models (30, 40, 50, 60, 62 and 70), Model 70 has about 15 times the internal performance of Model 30 when used for commercial tasks, or approximately 50 times for scientific problems, with the other models performing at intermediate points. These differences in speed and simultaneity greatly affect overall performance, none affects the appearance of the design to the programmer, nor does it affect the results of any program that does not depend on time.

The System/360 is a general-purpose system designed to meet the needs of the commercial, scientific, communications, and control system users. It obviates the choice between a "commercial" system with its decimal arithmetic, variable length fields, editing capabilities, etc., and a "scientific" system with its high storage utilization (because of binary format), high-speed arithmetic, etc. The System/360 combines all such features.

This means that applications presently assigned to various systems can be done by a single universal system; this is true whether the application is large or small and regardless of the type - commercial, communications, scientific, control or mixed. Universality has a side benefit: once the user's systems personnel have been trained in the operation of one of the System/360 models, they understand all models of the system.

System compatibility ensures the easy growth to a larger model, whenever the user finds that necessary, with continued utility of his programs. The facility exists at any time to use small models to back up large ones - within the limits of compatibility. These models of the IBM System/360 are fully instruction set compatible with one another. This means that any program that operates on one model will operate on any other model that has the required configuration of equipment. Compatibility may be lost where execution of a program depends on internal timings or the relationship between internal times and input/output speed.

The System/360 was designed to operate almost entirely under control programs. Concepts such as multi-programming and program relocation are basic in the System/360. Capacity of main core storage varies from 8,192 to 524,288 bytes, depending on the system model. A byte consists of eight bits plus a parity (check) bit, and is the smallest addressable unit in the IBM System/360. Storage capacities are always given in bytes.

The history of data processing shows that the main barrier to expanding the work that can be done on a computer has been that the amount of core storage that can be addressed by a system rapidly becomes much too small as the jobs grow bigger. The System/360, however, has in its design the logical capability of addressing up to 16,777,216 bytes.

Storage protection prevents the contents of specified 2,048-byte blocks of storage from being altered by either errors in programs or input from I/O devices. As many as 15 different programs, each existing in any number of such storage blocks (which may be non-contiguous), can be protected at any one time. The number of programs and blocks depends on the capacity of main storage.

All input operations are monitored for violations of storage protection, and the control program is alerted and takes appropriate action when any such error occurs. This protection of storage, particularly vital for applications in communications, causes no loss of performance.

Presently available for Model 50, the shared storage feature permits the main storage of two Model 50's to be shared and addressed by each as a single main storage. To share storage, the feature must be installed on both systems. The processing power of Models 50-70 can be expanded by adding large-capacity storage in blocks of either 1,048,576 or 2,097,152 bytes, to a maximum of 8,388,608 bytes. This storage is addressed contiguously with main storage. Speed of large-capacity storage is 8 microseconds. The number of bytes obtained per storage access, and all other features of large-capacity storage except cycle time, are the same as those of the main storage of the system.

The System/360 performs decimal arithmetic on signed decimal data packed two digits (or one digit and sign) per byte. Decimal operations are performed storage-to-storage, with the lengths of the variable fields being specified in the instruction. The maximum field size is 31 digits and sign.

The System/360 has 16 general registers that can be used for binary addition, subtraction, multiplication, and division; their primary use is in computing and modifying addresses within the program. The registers are all four bytes long, though two registers are sometimes coupled; for example, to preserve precision of the products and quotients in multiplication and division.

When floating-point instructions are added to or included in the instruction set, four additional registers are provided with the system; all are eight bytes long; all floating-point arithmetic is done in them. The floating-point operations use the 16 general registers for indexing and address arithmetic.

The floating-point, which is basically a mathematical shorthand that reduces numbers to a fraction and a characteristic (exponent), can express decimal values ranging from about 2.4×10^{-78} to about 7.2×10^{75}. The use of floating-point greatly increases the speed and efficiency of computations.

The system/360 floating-point feature includes both short precision (four bytes) and long precision (eight bytes), for the use of either at the programmer's discretion. Short precision is used to minimize execution times and maximize the number of factors in storage. Long precision is used when maximum precision is desired; all models have both precisions and operate identically.

Most instructions in the IBM System/360 have two data addresses; either address may be a register address or a storage address. Depending on the operation to be performed, instructions are two, four, or six bytes long.

The standard set of instructions provides the basic processing and logical instructions of the system. The addition of decimal arithmetic and editing facilities - important in commercial applications - forms the commercial set. The addition of floating-point instructions to the standard set forms the scientific set. Two instructions are provided to control storage protection. The universal instruction set, a standard facility on Models 50-70 and optional on models 30 and 40, includes the standard set, the decimal, the floating-point, and the two instructions for storage protection.

One of the chief lessons of the last decade of data processing is the desirability of open-ended design. The System/360 was designed in this way, and, therefore, lends itself to taking maximum advantage of new technology, new I/O devices, etc. A simple example of open-ended design is the capability of addressing more than 16,000,000 bytes of storage, thereby anticipating larger storage needs; another is judicious reservation for many new blocks of operation codes.

To make maximum use of a modern data processing system, some automatic procedure must be made available to alert the system to an exceptional condition, the end of an I/O operation, program errors, machine errors, etc., and send the system to the appropriate routine following the detection of such an event. The system must have, in effect, the ability to pause to answer the telephone and then to resume the interrupted work. This automatic procedure is called an interruption system.

Also, a main requirement for systems attempting to handle communications is the ability to be interrupted in any task in order to take on a task of higher priority.

The efficiency of any interruption system is based on the amount of time it takes to safekeep the reminders of where it was at the time of interruption, switch to the interruptive work, and then switch back to the interrupted work. This is done in the System/360 by one of the most advanced and efficient interruption systems ever conceived, suitable for the most rigorous demands of communication systems.

All data and instructions are monitored for invalid information by parity-checking throughout the system. Also, reliability is an inherent advantage of solid logic technology.

Programs are checked as they are executed. Because any interruptions caused by machine or program errors are at once classified by the interruption system and are treated differently, program errors cannot create machine errors; in this way, the causes of malfunctions can be and are clearly separated.

The compatible design of the System/360 makes it easy to couple together, either permanently or temporarily, a special system containing redundant I/O, storage, and processing units; thus, the expanded system can be made capable of operating even when components fail.

The use of eight information bits for each character means that the System/360 can accept most character codes now in use or planned. The system provides defined operations for processing either the extension to the widely used BCD interchange code or the recently adopted American Standard Code for Information Interchange X3.4 - 1963 (ASCII).

An additional advantage of the eight bit character for alphameric data is the ability to pack two decimal digits in each byte, providing high data-packing efficiency in storage and on tapes and disks. Such packing is possible because decimal digits require only four information bits each, and is implemented because decimal data occur in business records more than twice as frequently as alphameric data.

Each System/360 channel directs the flow of information between main storage and those input/output devices the channel controls. The channel relieves the processing unit of the tasks of communicating directly with I/O and permits data processing to proceed concurrently with input/output operations. The channels are of two general types: multiplexor channel and selector channels.

The multiplexor channel, a completely new concept in data channels, separates the operations of high-speed devices from those of lower-speed devices. Operations on the channel are in two modes: a "multiplex" mode for lower data rates, and a "burst" mode for the higher.

In the multiplex mode, the single data path of the channel can be time-shared by a large number of low-speed I/O devices operating simultaneously; the channel receives and sends data to them on demand. When operating in the burst mode, however, a single I/O device captures the multiplexor channel and does not relinquish it from the time it is selected until the last byte is serviced.

Examples of low-speed devices that can operate simultaneously on the multiplexor channels are:

Printers

Card Punches

Card Readers

Terminals

The 2702 Transmission Control can transmit messages to the System/360 from many remote 1050 terminals, for instance, all of which may be operating intermittently or even simultaneously, but at relatively low data rates.

Examples of I/O devices that operate in the burst mode are tape units and disk, drum, or data cell storage.

The multiplexor channel has the effect of subdividing the data path into many subchannels (as many as 256). To the programmer, each such subchannel is a separate channel, and can be programmed as such. A different device may be started on each subchannel, and controlled by its own list of channel commands.

The multiplexor channel attaches up to eight I/O control units and addresses as many as 256 I/O devices, of which the number that can run simultaneously depends on the system model. Model 30 can operate 32 simultaneously, or, with an optional feature, 96. Model 40 can operate 128 devices simultaneously. Model 50 can operate 128 simultaneously, or optionally, all 256.

In the multiples mode, data processing takes place while data are being transferred, thus increasing throughput by overlapping channel operations with processing. In the burst mode, processing is not overlapped in Models 30 and 40 but is overlapped in Model 50. (The multiplexor channel is available only for Models 30-50.)

Selector channels transmit data to or from a single I/O device at a time and are capable of handling high-speed I/O devices. Each selector channel attaches up to eight I/O control units and can address as many as 256 I/O devices. One I/O device per selector channel can be transmitting data at any given time; no other I/O device on the channel can transmit data until all data are handled for the selected device. With two or more channels, read/write/compute is possible. All selector channels might be reading or writing, or some reading and others writing, with or without simultaneous operation of the Models 30-50 multiplexor channel, while processing also takes place.

In general, I/O operations on a selector channel are overlapped with processing, and all channels can operate simultaneously, provided only that the processing unit's data rate capabilities are not exceeded. Nominal data rates for the selector channels range from 250 thousand bytes to 1.3 million bytes per second, depending on the system model and the channel options selected.

The only exception to the foregoing is a special high-speed selector channel available for Model 50, which operates in non-overlap mode.

One selector channel is required on Models 60-70; all others are optional. The number of selector channels on a given model thus ranges from none to two for the Models 30 and 40, none to four for the Model 50 (one of the four being the high-speed channel) and one to six for the Models 60-70.

Available for every channel (on Models 60-70) or just one of the channels (on Models 30/50) a channel connector provides a variety of uses that magnify the flexibility of the system. One use for the channel connector is to connect a selector channel on one system to a selector channel on another system, thereby providing intersystem communication. When this is done, each system appears like I/O equipment to the other.

NOTE: More than one channel connection may be made for a particular Model 30, 40, or 50, but the additional channel connector(s) must be physically installed on the other system(s); only one channel connector can be physically installed per Models 30-50.

The variations in system models, core storage capacity, optional features, and I/O configuration provide a flexibility that permits the system to be tailored to suit the individual user's exact requirements - with the added advantage of system growth without reprogramming.

Magnetic tape units and disk storage units can be employed in various combinations as high-speed I/O and for storing vast amounts of data in tape and/or disk libraries.

Input/output also includes data communications services, magnetic character readers, visual displays, many choices in rate and type of card input and card or printer output, voice output, and the numerous other I/O capabilities.

The physical connection between I/O devices and the channels is called the "I/O interface." All devices, regardless of their differences, can be connected to the system without adding new instructions to the processing unit or new channel commands. Basic control of devices of the future will be via the interface; consequently, I/O interface also represents an instance of open-ended design.

Several systems, of the same or different models, may be combined into a multi-system. Three levels of communication among processing units are available. The largest in capacity and slowest in speed is communication via a shared I/O device; for example, a shared disk or drum storage. Faster transmissions are obtained by the direct connection between channels afforded by the channel connector previously discussed. Finally, storage may be shared between two Model 50 processing units.

Direct control provides a means of exchanging control signals between two System/360 processing units, or between a System/360 and some specialized I/O device such as an analog-digital converter. Direct control bypasses the channel.

Operator errors are reduced by minimizing the active manual controls. The system panel containing the controls is attached to the processing unit and functionally divided into three sections: operator control, operator intervention, and Customer Engineering maintenance. The operator control section is physically and functionally identical for all models; the operator intervention section is functionally similar for all models; the CE maintenance section for each model is unique.

Control over the system is concentrated at the system panel. The controls include stop, start, and selection of the unit for initial program loading. The operator control portion can be duplicated at a console elsewhere in the computer area.

RCA Spectra 70 System

The RCA Spectra 70 System constitutes the next generation of computers embracing the spectrum of electronic data processing operations within a single computer family. The completely new line of full-scale RCA systems offers four different processors with progressively faster, more powerful and broader capabilities to cover the spectrum of EDP applications. It includes an extensive array of "family-standardized" input/output terminals and peripherals, a hierarchy of mass storage, and extensive facilities for integrated data communications. Third generation technology features use of monolithic integrated electronics in the central processing units for increased reliability, economy and performance in the nanosecond speed range.

Through program compatibility, common language, and universal input/output devices, the user can expand his data processing capabilities without costly program rewriting or file conversion as his data volumes increase or his application base expands. The RCA Spectra 70 provides an open-ended family of compatible data processing systems. With its wide range of system configurations and all-purpose design Spectra 70 meets the requirements of the user in all areas of commercial, scientific, multi-system, control, and communications applications. Through the use of the RCA Standard Interface (standard input/output packaging), new devices for general or special applications can be added without undergoing major redesign costs. In addition, the RCA Standard Interface permits the extension of possible system configurations at an extremely favorable cost-performance basis.

Spectra 70 is a multi-lingual system capable of accepting and processing a wide variety of industry accepted codes and programming languages. The high-order models feature micro-magnetic memories for nanosecond processing power and extensive instruction complements. Internal circuitry consists of the latest developments in the state-of-the-art. Design has been left open-ended to permit the addition of subsequent advanced concepts as they become available.

Presently there are four processors offered within the Spectra 70 series - Models 70/15, 70/25, 70/45, and 70/55. The common code structure is based on the Extended Binary Coded Decimal Interchange Code (EBCDIC) of eight bits plus parity. The standard memory unit is termed a byte. Memory access ranges from two microseconds down to 0.84 microseconds. Transfer at these access speeds varies from one to four bytes, depending upon the particular processor used.

Memory storage capacities start at 4,096 bytes and extend to 524,288 bytes. The user is provided with extensive memory overlap between models; thus, system growth can be directed towards increased processing power.

In the area of system throughput, simultaneous input/output processing is provided by the use of input/output channels. A selector channel is capable of addressing up to 256 devices, one at a time. The number of selector channels depends upon the processor. In addition, a multiplexor channel capable of simultaneously addressing 115 or 256 input/output devices is available on the 70/25, 70/45 and 70/55 Processors. The multiplexor provides simultaneously operation of devices by time-sharing the channel.

The 70/15 is a small-scale processor that allows the user to handle a variety of applications. It can stand alone as a data processor, function as satellite support for larger systems, or operate as a remote communication terminal.

Memory is available in either 4,096 bytes or 8,192 bytes. Memory cycle time is 2 microseconds to access one byte of information.

The 70/25 is a small-to-medium size processor that accommodates a wide range of applications. It may be used as a free standing data processor or as a subsystem of a multi-system complex.

High throughput rate is facilitated by fast memory cycle time and a high degree of input/output simultaneity. The 70/25, equipped with selector channels and a multiplexor channel, concurrently operates up to eight slow-speed devices in addition to eight high-speed devices.

Core storage is expandable from 16,384 bytes to 32,768 bytes or 65,536 bytes. Memory cycle time is 1.5 microseconds per byte of information. Four-byte internal operations speed throughput.

The 70/45 is a medium-scale processor with a high performance capability for business, scientific, communications, and real-time applications. A complete and powerful instruction complement with floating-point operation as an option is available to the 70/45 user.

The 70/45 equipped with a communication multiplexor, addresses up to 256 communications lines or intermix of a full range of peripherals.

Thus, it is an ideal system central for a multi-system operation and/or a powerful communication switching system with up to 11-way simultaneity.

Memory storage is expandable from 16,384 bytes to 32,768 bytes to 65,535 bytes to 131,072 bytes to 262,144 bytes. Memory cycle time is 1.44 microseconds for two bytes of information.

The 70/55 is a medium-to-large scale processor with excellent performance characteristics. Though capable of the most demanding scientific applications, the 70/55 maintains a high throughput capability with up to 14-way simultaneity, thereby offering a total solution to all data processing requirements.

Core storage is expandable from 65,536 bytes to 131,072 bytes to 262,144 bytes to 524,288 bytes. Memory cycle time is .084 microseconds for four bytes of information.

Spectra 70 input/output devices are systems-oriented towards the processing task to be performed:

- Card punches are fully buffered and punch at either 100 or 300 cards per minute.
- Two printers are offered - a medium-speed printer which prints at a rate of up to 600 lines per minute, and a high-speed printer which prints at a rate of up to 1,250 lines per minute. Both printers contain a 132 print-position drum. A bill-feed printer is also available which prints at a rated speed of up to 600 lines per minute on continuous forms and up to 800 cards per minute on card documents. A read-compare feature is optional. To ensure maximum system capability, all printers are fully buffered.
- Card reading up to 1,435 cards per minute is performed photo-electrically. Optional mark reading is available.
- Paper tape capability of 5, 6, 7 or 8-channel operation is offered at a reading rate of up to 200 characters per second and a punching rate of up to 100 characters per second.
- Three versions of magnetic tape units are available. Tape speeds are 30, 60, or 120 kilobytes per second. In a numeric mode, tape reading and writing are performed up to 240,000 digits per second. All units are optionally industry-compatible and contain extensive accuracy control features. Either 7 or 9-channel tape code can be read in either the forward or reverse direction.

- Within the Spectra 70 family, a complete complement of auxiliary storage devices capable of use on either a random or serial basis is available including:

  (1) High-speed drum with an average access time of 8.6 milliseconds and a capacity of up to one-million bytes.

  (2) Interchangeable disc storage units storing up to 7.25 million bytes with a transfer rate of 156 kilobytes per second.

  (3) Mass storage units capable of accessing multi-billion bytes of information in the millisecond range.

- The growing importance of optical character reading is recognized in Spectra 70 by the inclusion of the Videoscan Document Reader capable of reading up to 1,300 documents per minute on demand. Optional features allow the Videoscan to function as a slow-speed card reader, and as a fast mark reader.

Micro-Reduction Equipment

The storage and retrieval of large amounts of raw data can be handled by a number of different types of equipment such as microfilm and video tape. Included in this section are descriptions of: (1) NCR - Photochromic Micro Image, (2) Magnavue, (3) Ampex Videofile, and (4) FMA FileSearch.

NCR - Photochromic Micro Image

Development of the photochromic micro-image (PCMI) process by the National Cash Register Company provides, for the first time, the practical means for the recórding and dissemination in quantity of a plurality of micro-images with very high packing density. Linear reductions from 100-to-1 to greater than 200-to-1 (representing area reductions from 10,000-to-1 to greater than 40,000-to-1) have been successfully demonstrated by using a variety of image formats, such as printed materials, photographs, drawings, and finger-prints. Key factors in the success of the PCMI process are the following capabilities: a) inspection and error-correction at the micro-image level; b) high-resolution contact printing of micro-images on a mass production basis; and c) simple, effective retrieval and utilization of micro-images by means of specially designed viewers.

A basic PCMI system, consisting of a camera-recorder, automatic contact printer, and a micro-image viewer, has been completed and is operational. Development studies are underway with this equipment to accumulate data for system application studies. Some of the potential application areas for PCMI techniques are information storage, retrieval and dissemination, micro-form publishing, and specialized library uses.

Mechanization of the NCR PCMI storage technique is simple in principle. The original document is first recorded on high-quality microfilm. Properly filtered, near-ultraviolet radiation is directed through the transparent microfilm and into the micro-image optics forming a miniature image on the photochromic coating. By a step and repeat process, multi-image matrices of these miniature images are formed.

When all micro-images are formed, and properly inspected to insure that no errors occurred during exposure, the complete contents of the photochromic plate are then transferred in one step as micro-images to a high-resolution photographic emulsion by contact printing. The photographic emulsion is then developed under controlled conditions, and the result is, for example a 3 by 5 inch photographic micro-image master. Many such silver halide masters can be produced from a single photochromic micro-image matrix.

The 3 by 5 inch photographic micro-image master can then be used to publish a great number of duplicate 3 by 5 inch micro-image cards upon photographic film by using a contact printing process. Photographic film provides image permanency and permits file dissemination at small cost.

The final element of the micro-image system is the PCMI file. The basic PCMI card is 3 by 5 inches. One million document pages can be stored in micro-image form at 200-to-1 reduction on less than 400 cards: a stack of PCMI cards less than 6 inches high. For so few cards, fully automatic retrieval equipment is technically possible but difficult to justify.

A file of this size could be housed in an ordinary file drawer. For a small or large file, however, card handling equipment can automatically drop cards which satisfy specific search parameters. With a 40,000 - to-1 area reduction, a tremendous reduction in storage space and ease of handling can be realized.

Depending on application, micro-image viewers can range from manually-operated, desk-top models to semi-automatic consoles. The complexity of the specific micro-image system involved and the particular user requirements or needs determine the degree of automation. The ability to produce hard copy printout of enlarged micro-images can be accomplished by combining viewing and printing into a dual-purpose, micro-image Viewer-Printer.

Magnavue

Magnavue - a computer-controlled system which combines the automatic storage and retrieval of information in the form of microfilm images with a unit record magnetic storage medium. The Magnavue concept combines microfilm techniques for storing graphic information along with machine-readable codes on a single unit document storage medium - the Magnavue film chip.

The Magnavue film chip is 35mm wide by 3 inches long and has a mylar base. The film chip has a high-resolution image portion for the permanent storage of 80 alphanumeric characters which identify the associated microfilm image. In addition, where more information is desired to describe a given image, this data may be recorded on magnetic chips which are stored along with the film chips. The magnetic chips are completely compatible with the film chips; each magnetic chip can store 1,000 alphanumeric characters of eraseable data.

The U.S. Army Missile Command DARE (Documentation Automated Retrieval Equipment)program utilizes the Magnavue system for the processing of a large file of engineering drawings and associated documentation. The DARE System provides automatic compilation, storage, retrieval, and preparation of punched Diazo copy card outputs from a rapid-access file with a capacity of 900,000 microfilm images. The equipment provides an average access to any image in the file in 30 seconds, and offers the capability for sequential processing of a file of 725,000 microfilm images in approximately 7 hours. The daily sequential processing includes the output of 5,000 Diazo copy cards, the input of 2,000 new Magnavue film chips to the system, and the removal of 2,000 Magnavue film chips from the system. With the simple addition of a second rapid-access file, the system may be expanded to a total storage and retrieval capacity of 1.8 million microfilm images and a total file processing time of 9 hours.

The image portion of the film chip can contain data sheets, specifications, engineering drawings, standards, technical reports, etc. The digital portion of the film chip will contain the identifying data and other information necessary for determining whether or not the image portion is to be included in a given Technical Data Package. The 80 characters of digital information provide sufficient indexing data for retrieval of scientific and technical information required to support research, engineering, and other technical effort.

The addition of magnetic storage by means of Magnavue magnetic chips or conventional tape and disks provides Magnavue with full general-purpose digital capability to supplement its use as a document processor. The range of potential applications covers any requirement calling for both digital and graphic data.

The storage and retrieval system consists of the following elements: a coder/exposer for making the Magnavue chips; a rapid-access file for the storage of 900,000 Magnavue chips; a four-drum chip transport unit for automatically sorting, merging, selecting, and purging Magnavue film chips; an associated copy and punch station for making a Diazo copy of the image contained on a film chip and for punching the identifying digital data into each copy card; a data processor for making the logical decisions required in the control of the Magnavue equipment; and magnetic tape units for storing detailed breakdowns for the major items. The data processor in the Magnavue system may have associated input and output equipment, such as paper tape reader or paper tape punch, card reader or card punch, line printer, and input/output type-writer.

The chip storage in the rapid-access file may be proportioned as necessary to solve a specific problem. For instance, if it is desired to store 600,000 microfilm images, there would be capacity in the rapid-access file for the storage of 300,000 magnetic chips. These 300,000 magnetic chips would provide 300 million alphanumeric characters of eraseable data. In addition, the described system may be expanded by the attachment of a second rapid-access file to store a total of 1.8 million chips.

Ampex Videofile

A complete Videofile Filing System consists of 6 units: television, camera, Ampex Videotape recorder and tape, temporary memory storage unit (buffer), coder, desk top television set and printout device (as many as needed). It requires one or two non-technical people to guide the operation and one room to house both system and files. Tape images are immediately ready to view without processing. One 8-1/2 x 11 document fills 1/3 inch in a 7200 foot reel and costs about 1/16 cent in tape.

With the Videofile System, each paper, photo, graph or document is recorded through a camera scanner on video tape into a segment set aside for it, and is indexed by keypunch. To retrieve a document, the requestor dials its index into a desk top control unit. A reel of tape is mounted and is electronically searched until a frame with matching index is found. It is then copied into the temporary memory (buffer) and the recorder is free to answer other requests. Time for the whole operation is under 1 minute. If hard copies are desired, a printer tied into the system will deliver them in seconds.

An 8-1/2" x 11" system can read out or read in documents at the rate of approximately 13 per second and can search for an address at a high speed equivalent to over 900 documents per second.

Tape is available in various reel sizes up to a maximum of 7,200 feet on a reel 14 inches in diameter. This size reel would hold over 250,000 document images with a resolution of 100 lines per inch.

Like any magnetic tape recording, document images are stored in a form which facilitates erasing and reuse. The recording process, which can be conducted in daylight conditions, is instantaneous and available for use immediately after recording.

The average cost of a 20 operation standard filing system over one year could support a Videofile Filing System for five years. It is in the areas where costs are highest (labor and floor space charges consume 95% of conventional filing systems) that Videofile Filing System saves money.

FMA FileSearch

FileSearch is a microfilm system of automatic storage and retrieval of documents. It consists of three items of equipment: 1) a Recording Unit which photographs documents and their indexing information adjacent to one another on reels of photographic film; 2) a Retrieval Unit which searches the film and selectively retrieves documents; 3) an electric typewriter/card punch which codes indexing and request information into the machine language on which the system operates.

The first step in storing is indexing. The prepared indexing information is typed out on the electric typewriter/card punch. The typewriter produces a human-readable copy of the information and simultaneously a punched card.

Documents and their binary-coded indexes are recorded simultaneously on the Recording Unit. The document to be recorded is placed on the Recording Unit Table. The punched index card (or cards) associated with the document is inserted into a slot in the Unit's control panel. Insertion of the card automatically triggers the Recording Unit camera. Two strobe lights over the table illuminate the document, an image of which is conveyed by a mirror into the camera. At the same time, a light source in the control panel, immediately beneath the inserted card, flashes. The punched holes are converted within the camera to a series of square bits and recorded immediately adjacent to the document image. The Unit then automatically advances the film one frame.

If a document contains several pages, the pages appear as a sequence of frames on the film. Sometimes the entire document can be indexed in the code areas for the first page or two. Occasionally, the index to a document contains too much information to put into the code areas beside its pages. When this happens, the index is continued in the coded areas of succeeding frames. The portions of these frames which normally contain photographs of document pages are left blank.

Stored documents can be rapidly retrieved by the Retrieval Unit which automatically scans and processes the binary indexing information on the film at the rate of 6400 pages per minute. The general nature of the search operation is as follows: A request of information is typed on the electric typewriter/card punch, producing an edge-punched card. The card is inserted in a slot in the Retrieval Unit where a reader converts the holes in the card to a series of pulses. A reel of film is placed in the Retrieval Unit's transport and the film is moved past an optical scanning station which converts the indexing information on the film to a series of pulses. The pulses from the film and those from the card reader are brought together in sets of comparison circuits or registers where they are compared with one another. When the information on the film corresponds to information in the request, the transport stops, and the Retrieval Unit retrieves the document as an image on a screen, a hard copy, or a 1:1 film copy.

The registers in which the two sets of pulses are compared are six in number and bear the alphabetical labels A through F. These registers may be associated with one another by logical connectors AND, OR, and NOT, and may be required to function in three different ways: (1) to match exactly the code on the film with that on the request card (normal comparison); (2) to accept code on the film which falls between limits established by the request card (e. g., all documents after 1 June 1961 and before 1 June 1963); (3) to function in continuity with one another so that a descriptor which begins in one register can be continued into the next (used for index terms more than 7 characters in length).

The number of subject matter categories used in a file is dependent primarily on two file characteristics - the volume of documents associated with a given subject matter, and the frequency with which requests are made for this subject matter. Whenever either of these characteristics increases to the point at which it is convenient to have a subject-oriented reel, the Retrieval Unit can automatically make one.

File expansion is accomplished so rapidly (search time plus 0.4 second per page) that it is frequently advantageous to store a single document on several subject-oriented reels - i. e., to crossfile the document several times. Thus a typical piece of business correspondence might be stored on several reels - one organized by accession number (chronological file), one organized by document type (e. g., contracts), and one by the subject of its contents (e. g., servoamplifiers).

A comparison of the main features of the Ampex Video File, the FMA FileSearch, and the Magnavue system are shown in Figure 27.

Auxiliary Storage Devices

A number of auxiliary storage devices are of such importance that they are worthy of mention. Devices treated include: (1) Magnetic Tape, (2) Drum Storage, (3) Disk Storage and (4) Magnetic Cards.

AMPEX VIDEO FILE	FMA FILESEARCH	MAGNAVOX MAGNAVUE
Identifiers		
25-30 alphanumeric characters/document	56 alphanumeric characters/ document. Identifiers can be logically combined	80 alphanumeric characters/ document
Input		
Can insert into system 780 documents/min. Keypunched cards used to initiate search	Typewriter produced keypunch cards are used to initiate search	Requires a computer for control such as a Control Data Corp. 160A which can have its own input/output equipment
Search		
54, 000 documents/min.	6400 documents/min.	13600 documents/min.
Storage		
250, 000 documents on 7200 ft. tape. Tape is erasable and reusable	32 documents/foot 28000 documents/reel 1, 500, 000 documents/filing cabinet	900, 000 Magnavue chip/file Can have 2 files in system = 1.8 million chips, chip = 35mm 3" film, 4 8 1/2" x 11" documents. Also can store digital info from computer on chips = 1000 alphanumeric per chip
Output		
TV type screen & hard copy. Long distance transmission under development	Hard copy in 7 sec Film copy .4 sec/document	Diazo copy card = copy of original input = microfilm + punched identifiers

Figure 27 -- Pictorial Processors Comparison

Magnetic Tape

Magnetic tape is the principal input/output medium for data processing systems. The tape is also used for storing intermediate results of computations and for permanent storage of large files of data.

The 10 1/2 inch diameter plastic reels can hold 2400 feet of tape. Shorter lengths - as short as 50 feet - may be used. A full reel weighs about four pounds and can contain data equivalent to that in 200,000 fully punched IBM cards.

Magnetic tape possesses a characteristic unique among data processing records - that of automatic erasure. Although recording is permanent, affecting the magnetic state of the tape surface, any previous recording is destroyed by the writing operation. This means that tape can be used again and again, with significant savings in recording costs.

Records on tape are not restricted to a fixed length of characters, fields, or words. Records may be of any practical size within the limits of capacity of the area assigned to the storage of data in the computer. This feature allows writing all information pertinent to an item in a single continuous data record. The need for repeating the identification in multiple records is eliminated. As much information as is needed can be conveniently included in its most compact form.

The major differences in magnetic tape units are the density of the recorded information on tape and the speed at which tape is moved past the read-write head.

Density is the number of columns of data recorded on a unit length of tape. Densities presently used are 200, 556 and 800 columns per inch of tape.

Tape unit speed is stated as the length of tape that is transported past the read-write head in a unit of time. Three recording speeds are currently used: 36 inches per second, 75 inches per second, and 112.5 inches per second.

The faster the tape speed and the greater the density of recording, the higher is the rate at which information is recorded on or read from tape. The number of lateral columns of data read or written in a unit of time constitutes the information rate for a tape unit.

Character Rate

Tape Speed (inches/sec)	Density (char/inch)	Character Time (microseconds)	Character Rate (char/inch)
36	200	139	7,200
	556	50	20,016
	800	34	28,800
75	200	67	15,000
	556	24	41,667
	800	17	60,000
112.5	200	44	22,500
	556	16	62,500
	800	11	90,000

Drum Storage - Example UNIVAC FASTRAND I

1. Capacity

   Each FASTRAND I unit provides a random access storage capacity of 66,060,288 six bit characters. This is made possible by the combination of several innovations in magnetic drum design; for example, a recording density of 1000 bits per inch. This is achieved in part through the use of aerodynamically supported read/write heads (called flying heads) rather than the conventional fixed head. This flying head permits the use of drums of large diameter. Also, the flying head automatically adjusts to eccentricities in the recording surface of the drum. This reduces the space required between the head and the drum which means that less current is required to record data and that each bit recorded requires less space.

2. Modularity

   From one to eight FASTRAND I drum units may be installed as a subsystem on a UNIVAC 1050 general purpose channel. An installation may, at the beginning, employ a single unit and others may be added as circumstances require. The additional units may be installed with minor field modifications of the system. No extensive shutdown of operation is involved.

3. Speed

   The average access time of a UNIVAC FASTRAND I subsystem is approximately 93 milliseconds. Moreover, file search operations may be conducted in the offline mode: that is, once the necessary instruction is issued, the central processor is free to continue other work until the find is made.

There are two drums in a FASTRAND I unit, one mounted above the other. There are 64 read/write heads, 32 per drum. All of the heads may be positioned with one movement of this mechanism in an average time of 58 milliseconds. Maximum positioning time is 86 milliseconds; minimum time is 30 milliseconds. The drum rotates at 870 rpm. Maximum latency time is 70 milliseconds and minimum is zero. Average latency is 35 milliseconds.

In a multi-unit subsystem, the heads in each drum may be prepositioned so that only latency and circuit activation time delay the central processor. Also, as in other random access systems, data may often be so arranged as to reduce substantially the number of positioning operations required.

If the heads are prepositioned, special features of the read/write function eliminate activation of the positioning mechanism saving five milliseconds. If these features are not used, five milliseconds are added to latency time. (When the heads are not prepositioned, these five milliseconds are included in the positioning times stated above.)

The combination of large capacity plus the great speed resulting from short access times, prepositioning, and offline search provides random access storage of extreme efficiency.

Disk Storage

The IBM 2311 Disk Storage Drive provides random-access storage for 7.25 million 8-bit bytes in each disk pack. In the Packed Decimal mode, the capacity is 14.5 million numeric characters. Eight disk storage drives can be attached to each storage control unit.

In addition to this on-line capacity of 58 million alphameric or 116 million numeric characters, virtually unlimited data storage capacity is possible because the disk pack on each drive can be easily removed and replaced with another pack in less than one minute.

The 2300 data rate is 156,000 bytes per second.

The IBM 2311 Disk Storage Drive is self-contained in a compact cabinet and consists of two main components: the disk assembly and the access mechanism.

The disk assembly is a light, compact disk pack that weighs only ten pounds. Each removable disk pack is composed of six disks, 14 inches in diameter, mounted one-half inch apart on a vertical shaft. Circular protective plates are mounted above the top disk and under the bottom disk to protect the assembly. The six disks provide ten surfaces on which data can be recorded; the upper surface of the top disk and the lower surface of the bottom disk are not available because of the protective plates. The entire assembly of disks, vertical shaft, and protective plates rotates at a speed of 2,400 revolutions per minute.

The access mechanism of the 2311 has ten horizontal access arms mounted in pairs on a vertical assembly, with each pair positioned between two disks. One read/write head is mounted at the extremity of each arm; each head is positioned to read or write on the corresponding upper or lower disk surface. The entire assembly moves horizontally between points near the periphery and the center of the disks so that the heads have access to the entire recording area with no vertical movements.

The use of a comb-like access assembly greatly reduces access time of a record in disk storage. The track-to-track access time, of great importance in sequential processing, is 30 milliseconds (ms). The maximum seek time is 145 ms, and the average time is 85 ms. In addition, at 2,400 revolutions per minute, rotation time is 25 ms; the average rotational delay time, therefore, is 12.5 ms.

As the access mechanism moves horizontally, it can be stopped at any one of 203 positions. This provides 203 tracks of data on each disk surface. Since all of the ten read/write heads operate in the same vertical plane, ten tracks are available without movement of the access mechanism. These ten tracks, numbered vertically from zero to nine, top to bottom, can be considered a cylinder of data.

Because each record has certain non-data characters, such as disk address, etc., the net data storage capacity of tracks may vary. Based on one record per track, each track has a data capacity of 3.625 bytes. Each byte consists of 8 bits and can store one alphabetic, numeric, or special character.

Magnetic Card

Of the truly large capacity mass storage devices, particularly of the magnetic card type, RCA has the only one installed and in operation. This is the Model 3488 Random Access Computer Equipment, a significant accessory for RCA's 301 and 3301 computer systems.

Probably the single outstanding feature of the 3488 is its enormous capacity. A single unit holds 340.7 million characters in eight magazines, 681.5 million when combined with an expansion assembly which brings the magazines up to 16. As many as eight such combinations can be added to a system making capacity 5.4 billion characters.

The basic component making up this capacity is the magazine which houses magnetic cards. Each magazine holds up to 42.6 million characters. Magazines are removable and interchangeable, having open ended capacity and high flexibility.

Each magazine houses 256 magnetic cards on which data are recorded. Each card contains up to 166,400 characters, totaling over 42 million per magazine. Data are organized on each card by 650 characters per block, 4 blocks per band, 64 bands per card. The card is 16 inches long and 4.5 inches wide. Data are called for by computer command specifying the magazine, card, band, and block.

Data are recorded bit serial longitudinally (along the length) of the card at a density of 700 bits per inch. Transfer rate is 80,000 characters per second, after the data have been brought to the read/write heads, of course.

A 3488 has a magazine storage section of 8 to 16 magazines. It has a rotating drum with a read/write head assembly located at the head of the unit. Behind this station are the magazines; alongside the magazines are two card transport mechanisms (called raceways), one to feed cards to the drum and read/write heads and the other to return the card to its magazine. Associated with the read/write station is a gate which, when closed, causes the card at the station to be read more than once, and when open, allows the card to enter the return transport back in its magazine.

The entire operation, except the reading and writing, is mechanical from the selection and extraction of cards, movement through the raceway to the read/write station, wrapping around the drum, and returning to the magazine via the return raceway. Obviously access times will be in relation to this high degree of mechanical motion. In addition, the access times are necessarily variable because magazine #1 is physically closer to the read/write station than is magazine #8 or #16. With this in mind, the average access time for #1 is 290 milliseconds, for #2 300, for #8 360, and 465 milliseconds for #16. Some improvement in these times is accomplished with a card preselect technique which allows overlap of the selection of the card with the feeding, drum revolution, and/or return of a previously selected card.

The 3488 is hung on its 301 or 3301 by special channels, two of which can be used in each system. Each channel can control up to four 3488 units of 8 to 16 magazines each.

Transmission Devices

The transmission of information to remote locations is accomplished either by telephone lines or microwave transmission. Computers can be linked by these methods. Another development of interest is long distance Xerography. Described are: (1) Western Union Transmission System, (2) Xerox LDX and (3) IBM's QUIKTRAN.

Western Union Transmission System

Western Union developed the Broadband Exchange Service. This is a system which automatically links two subscribers over transmission channels which they choose as best suited to their communications needs.

On a call-up basis by Western Union's pushbutton voice-data instrument, users can select the broadband width that will furnish optimum, economical data transmission. For example, different broadband widths can be chosen to transmit punched card data, or allow remote computers to communicate with each other.

Since this system is designed primarily to handle data, all channels interconnecting exchanges have been conditioned to minimize delay distortion, a vital factor in high speed data transmission. As a result, an 8 1/2 x 11 inch page of copy transmitted via facsimile over a Western Union 4 kc band will take three minutes to send. This is half the time previously needed using available voice band facilities.

Type of transmission may vary. It may be voice, alone. It may be digital data as contained in punched cards and paper tape, or magnetic tape and electronic storage devices. Whatever the medium, the data communication link can be economically tailored to a user's needs. For example, it costs only 65 cents for a one-minute, two-kilocycle connection between New York and San Francisco. A 4 kc hookup between Chicago and Washington, D. C. can be completed for 45 cents.

Subscribers are furnished with voice-data instruments and Datasets. Unlike the telephone it resembles, the voice-data instrument contains 10 pushbuttons used to transmit the number of the party being called to the switching center. The pushbutton method is faster than dialing and reduces the chance of error.

Connections are made through switching centers in seven cities and concentrators in 13 other locations. At the outset, these facilities will serve subscriber needs throughout the country. Concentrators can switch up to 16 kc bandwidths. Generally, concentrators are limited to terminating nine subscriber lines. As volume grows, concentrators and/or switching centers will be added to the system.

Most long distance transmission paths will be over Western Union's 7,500 mile microwave radio network. Two separate radio paths, each of a different frequency, are assigned to each transmission direction. The transmitted signal is sent simultaneously over both paths. Electrical combiners join the signals at the terminals to virtually eliminate frequency fading.

If during transmission either terminal wants to return to voice mode, a "ring" button is depressed. Transmission is interrupted and, when the handsets are picked up, the two parties can begin conversation.

Billing information is automatically recorded. Charges are set on a toll basis, depending on bandwidth, time on the line, and distance. There is a one-minute minimum.

Xerox LDX

LDX (Long Distance Xerography) is based on the rapid and permanent copying method known as Xerography, the same method used in the well-known Xerox 914 and 813 office copiers. Xerography is an electrostatic process which utilizes light, electricity and heat to form permanent images on nearly every type of paper, and even on plastics, metal or glass. Xerographic copying uses a dry powder to form the images and does not require chemical solutions, darkrooms, film negatives or special paper. No exposure adjustment is necessary. Copies produced by the LDX printer are ready for immediate use and the image will last as long as the paper.

A basic LDX system consists of three parts: a Scanner (or transmitter), the Transmission Link and the Printer Receiver.

In the scanner a narrow yet intense spot of light is projected by a Cathode Ray Tube (CRT) on to the document to be transmitted. This spot of light rapidly sweeps across and successively "views" narrow segments of the document as it moves under the tube. The speed at which the document moves under the tube plus the rate at which the scanning sweeps are made determine the number of sweeps per inch and, as a result, the quality level of the copy produced by the printer. As the spot of light from the CRT sweeps across the original, the lighter portions of the document reflect back into a light pipe. This reflected light is fed into a photo-multiplier and into the scanner electronics where it is amplified and converted into electrical impulses. The impulses are then transmitted via the transmission Link using either wires or microwave signals to the printer where the impulses are converted back into light by the printer electronics and a Cathode Ray Tube which projects the light impulses onto a Xerographic drum where, by conventional xerographic methods, the finished document is produced. The total time lapse from the viewing in the scanner to an image in the printer is a fraction of a second - 3 milliseconds. The printer produces an accurate, permanent image as quickly as the scanner generates the electrical impulses and transmits them. The scanning rate of the CRT is normally factory-set at 135 or 190 lines per inch (LPI).

IBM QUIKTRAN

This is a method of linking remote locations with a central data facility on a time sharing basis. Developed on the 7090, it may also be used on the 7044. The configuration used during development linked 40 remote locations with the central facility, where a 7090-32K, a 1301 disk, and a 7740-16K computer were available. The disk was used for storing queries while awaiting processing. A 7340 drum was used for the intermediate storage necessitated by the time sharing technique. The 7740 was used to receive the information and act as a buffer between the 7090 and the remote location. The telephone lines were used for transmission.

At each remote location was a 1051-1052 keyboard control, by means of which requests to the central agency were made and responses received. A card reader and punch, as well as a tape reader and punch, could be tied in with this keyboard. The same configuration for remote locations is now available at a cost of $200 to $300 a month, depending on the components chosen. Purchase price is approximately $10,000 to $12,000. Although this system was developed for Fortran statements, the problem-oriented language proposed for handling human factors data can be used, provided the preprocessor is adapted to accept its statements.

IBM also provides the ability to copy tapes at remote locations. A 1401 is used at each end. Transmission is via telephone lines.

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Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Computer Concepts, Incorporated 10889 Wilshire Boulevard Los Angeles, California 90024	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

THE ROLE OF COMPUTERS IN HANDLING AEROSPACE SYSTEMS HUMAN FACTORS TASK DATA

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final report, 3 June 1964 - 3 June 1965

5. AUTHOR(S) (Last name, first name, initial)

Whiteman, Irvin R., PhD

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1965	182	8

8a. CONTRACT OR GRANT NO. AF 33(615)-1557	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 1710	
c. Task No. 171006	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	AMRL-TR-65-206

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
This report contains a Bibliography section of 186 citations.	Aerospace Medical Research Laboratories Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, Ohio

13. ABSTRACT

The characteristics of a computer based data system for handling human factors task information generated in support of advanced system development are described. On the basis of information gathered from users and generators of data at representative Government and contractor installations, the current and potential uses of computers were assessed to determine the desirable characteristics for a computerized human factors task data handling system. The proposed data handling system will assist the human factors specialist and system design engineers in the design and development of systems by providing them with means for: (1) drawing them closer to the data through a user-oriented system, (2) comparing data generated throughout the life-cycle of an advanced system and across systems, (3) analyzing data and conducting man-machine simulations, and (4) insuring that data are made available on a selective query and a timely basis. These objectives are met within the framework of a data system concept referred to as CENTRAL. The functions of CENTRAL are: (1) data storage and retrieval, (2) data processing, (3) computer program maintenance, and (4) system operational manual maintenance. The forms of data to be housed within CENTRAL, the methods for storage, processing and retrieval, and the nature and configuration of the data handling are discussed. Recommendations are made for a follow-on prototype data handling system to be developed and exercised with actual advanced system data. The prototype system would be responsive to data which are best stored within the computer, and data which do not lend themselves to storage within a digital computer, such as data of a pictorial nature.

DD FORM 1 JAN 64 1473

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Personnel Subsystem Data						
Task Analysis Data						
Information Storage						
Information Retrieval						
Data Processing						
User-Oriented Language						

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GPO 886-551

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