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ABSTRACT

This report was a part of the Human Effectiveness Function Allocation Methodology (HEFAM) project, which is attempting to develop a workable cost-effectiveness methodology for man-machine function allocation. Researchers reviewed the cost-effectiveness and function allocation literature, and interviewed engineers, data analysts, programers, personnel researchers, and psychologists in the areas of cost-effectiveness, human factors, personnel research, and equipment design. Included in the report are analyses of: (1) the types of mathematical models required, (2) computer storage capacity, (3) five different possible sources of data, and (4) four possible methods of data collection. It was recommended that HEFAM should include future development of the concept of human effectiveness (as opposed to reliability), the data processing system, better data collection methods, computational formulas, and prediction methodology. (Author)

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NAVAL PERSONNEL AND TRAINING RESEARCH LABORATORY

SAN DIEGO, CALIFORNIA 92152

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THE DEVELOPMENT OF A HUMAN EFFECTIVENESS FUNCTION ALLOCATION METHODOLOGY (HEFAM)

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by

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SUMMARY AND CONCLUSIONS

Problem

The purpose of this project is to develop a workable cost/effectiveness methodology for man/machine function allocation. At the present time this effort is concentrated on developing human effectiveness indices suitable for use in function allocation.

Background and Requirements

Six end products related to Human Performance Effectiveness (HPE) have been published since the inception of the Cost/Systems Effectiveness project in December 1964: a bibliography of cost, effectiveness, and man/machine function allocation studies (58); a special progress report defining the problems of obtaining quantitative indices of Human Performance Effectiveness (65); an annotated bibliography of human performance quantification studies (67); a report confirming the feasibility of obtaining quantitative indices of Human Performance Effectiveness (63); a staff paper summarizing the overall conceptual development of HEFAM (64); and a special progress report on empirical data collection procedures (66).

Approach

During Fiscal Year 1969, cost/effectiveness and function allocation literature was reviewed. Numerous engineers, data analysts, programmers, personnel researchers, and psychologists working in the areas of cost/effectiveness, human factors, personnel research, and equipment design were interviewed.

Findings

There has been much effort devoted to the problem of improving human reliability and collecting human reliability data, however, there has been very little conceptualization of the overall problem of quantifying human effectiveness, especially in the case where prediction of human effectiveness in a developing system is desired. During Fiscal Years 1968 and 1969, an extensive literature search revealed no methods of quantifying Human Performance Effectiveness in a way suitable for use in Human Effectiveness Function Allocation Methodology (HEFAM) (67).

As the HEFAM problem was approached in depth during Fiscal Year 1969, new problems were revealed. Central to all of these problems is the lack of development of the state-of-the-art of quantifying Human Performance Effectiveness. It was discovered that there are many subproblems in the development of HEFAM which will require intense long lasting effort for solution.

The concept of HEFAM as a total data processing system was further developed during this year. The types of mathematical models required were determined, the computer storage capacity was estimated, and a data collection method was proposed. The type of data required and the manner in which it is to be stored in the system was also stated.

Five sources of data were found: the Man/Machine Systems Research Facility (MMSRF); COMFAIRWINGSLANT, Delta-Human Factors Group; COMASWFORLANT; Naval Safety Center, Behavioral Science Division; Submarine Medical Center, Submarine Base, New London, Connecticut.

Four methods of data collection and recording were proposed; one using Wilson's automated task analysis OSD (68, 69) was tested.

Formulae relating several pertinent variables were derived. They will form the basis for the computation and prediction of human performance effectiveness indices. A preliminary methodology for effectiveness prediction was also outlined.

Conclusions

1. Much more work effort and time will be needed to develop the HEFAM system.

2. The HEFAM system will consist of a methodology, computational formulae, and an automated data processing system.

3. More sources of data are needed in order to provide a large enough sample of human performance to form a data base for effectiveness predictions.

4. Simpler methods of data collection than the OSD method are needed in order to collect human performance data in a timely manner.

5. Computational and predictive formulae for HEFAM must be developed further in order to be used for actual computation or prediction.

Recommendations

1. It is recommended that the HEFAM system be developed as rapidly as possible. This will require more effort than is currently being expended. (page 16)

2. The future development of HEFAM should include: the further development of the conceptual bases of human effectiveness quantification; the further development of the HEFAM data processing system; the collection and utilization of HPE data; the development of better data collection methods; the further development and testing of computational and prediction formulae; and the development of the HEFAM prediction methodology. (page 16)

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I. INTRODUCTION

A. Purpose

The purpose of this report is to document FY 1969 developments in the Human Effectiveness Function Allocation Methodology (HEFAM), describing its present status and future goals. Included in this report is a discussion of the present conceptualization of HEFAM, results of the search for data collection methodologies and sources, and some preliminary human effectiveness formulae which will be used in deriving HPE indices.

B. Research Approach

During FY 1969 engineers, data analysts, programmers, personnel researchers, and psychologists working in the areas of cost/effectiveness, human factors, personnel research, and equipment design were interviewed, requirements were specified and analyzed and approaches were adapted for HEFAM. HEFAM research conclusions derived in the past were reanalyzed and from this a new overall concept of the HEFAM system was developed.

Many commands and activities were contacted to determine if they were collecting data which might be useful to the HEFAM system. Several potential sources of data were developed.

One possible method of collecting and recording data, Wilson's Task Analysis OSD, was tested on the ASWSC&C System at the Man/Machine Systems Research Facility. Performance on the system was observed, tasks were recorded, and an OSD was constructed.

A preliminary effectiveness formula was constructed from analyzed data, HEFAM assumptions, and logical deduction.

C. Historical Background

The HEFAM study grew out of a specific need within the Bureau of Naval Personnel for development of a cost/effectiveness methodology for use in decisions concerning the allocation of functions to men and machines early in the system development cycle. The Bureau of Naval Personnel has continued research in this problem area since FY 1965 with current work being conducted under two separate projects: HEFAM, now under development by Naval Personnel and Training Research Laboratory, and a personnel cost model now being developed by the Department of Defense.

Research on the cost formula has been reported elsewhere (14, 15).

Research on effectiveness measures was begun in FY 1967, six end products have been published: a bibliography of cost, effectiveness, and man/machine function allocation studies (58), a special progress report defining the problems of obtaining quantitative indices of Human Performance Effectiveness (65), an annotated bibliography of human performance quantification studies (67), a report confirming the feasibility of obtaining quantitative indices of Human Performance Effectiveness (63), a staff paper summarizing the overall conceptual development of HEFAM (64), and a special progress report on empirical data collection procedures (66).

D. Conceptual Background

1. Project Goals.

This study was conducted in an attempt to meet the Navy's need for improved methods of assigning functions to men, machines, or man/machine combinations in new systems under development. Rapid development of Navy technology has increased the opportunity to automate functions and tasks traditionally performed by humans. Although system reliability is often increased by automation, the cost is frequently also increased. Faced with definite mission requirements and limited financial resources, the Navy must select those function allocation alternatives which optimize cost/effectiveness during the lifetime of the system.

Currently there is no single methodology for man/machine function allocation which allows for quantification and optimization of the four major variables: equipment effectiveness, human effectiveness, equipment cost, and human cost. Methods have been developed to predict the cost and effectiveness of automated functions (19, 20) and to predict the cost of personnel (14, 15) in Navy weapon and support systems. However, suitable human performance effectiveness indices have not been developed.

The purpose of this project is to develop the needed workable cost/effectiveness methodology for man/machine function allocation. Therefore, research has been directed toward shaping the overall function allocation methodology while developing subsystems which will provide for quantification of the major variables. At the present time this effort is concentrated on developing human effectiveness indices suitable for use in the function allocation methodology.

During the development and operation of the HEFAM system, empirical observations of human performance in systems will be used as a basis for quantifying human performance effectiveness. These effectiveness measures, originally designed for use in function allocation, will find auxiliary uses in meeting other Navy needs for indices of Human Performance Effectiveness such as have been suggested in recent publications by BUPERS (8) and by NMC (26), as well as in recent Military Specifications (MIL-H-46855, February 1968; MIL-H-46855, Amend. 1, March 1968). By providing quantified effectiveness data, HEFAM can be used most effectively by the Navy in contracting for new systems where human effectiveness constraints on system design can be stated in the original work specifications included in the Request for Proposal (RFP).

In developing systems where man's working environment has not been finalized, HEFAM may be used by engineers to enhance system effectiveness. Personnel researchers will be able to use HEFAM data in the establishment of manning and training requirements for new systems. HEFAM will also provide inputs to other data bank systems, such as NSPRDS (9, 10, 30), a computerized personnel requirements information system, currently under development at Naval Personnel and Training Research Laboratory.

2. Conceptual Evolution.

Early in conceptual development, Human Performance Effectiveness (HPE) was defined as "the relative ability of the human component of systems to perform operator or maintenance functions adequately and in such a way that performance will, as intended by system planners, lead always toward mission accomplishment" (63). Researchers then began deriving a methodology to quantify Human Performance Effectiveness in a way that the quantities derived would be congruent with the above definition (66).

Most research reported in the literature on this area was concerned with the "reliability" of humans, and the data was usually reported in terms of numbers of errors which the human makes and/or the amount of time the human takes to perform a given function. However, HEFAM researchers were also interested in incorporating the effect of the unscheduled but beneficial positive actions which humans can add to upgrade system effectiveness and mission accomplishment. If only errors and time are focused upon, these beneficial innovations are ignored. For this reason the term human performance effectiveness was not limited to the "reliability" meaning, even though the majority of work done by others was under the reliability banner (63).

The Human Effectiveness Function Allocation Methodology (HEFAM) was conceived as an automated data storage and processing system to be used many times during the development cycle of new weapon and support systems. There would be subsystems for data flow in and out of the system and subsystems for calculating human effectiveness indexes.

No bank of comprehensive quantitative evidence about the performance effectiveness of humans in operational systems was extant, so the first step was to make observations and start collecting data to be used as a basis for predictions. Samples which would generalize to entire classes and populations were sought in order to form a statistical data base capable of reliable human effectiveness prediction.

The overall research plan for the project emphasized the development of aspects of the HEFAM system: data base, data storage and retrieval system, preparation of data for use, communication process, and feedback procedure. The ramifications of each problem area were explored (64).

During Fiscal Year 1969 there were four developmental goals in the HEFAM project: to evolve the HEFAM concept to the point where the system plan could be firmly stated; to develop data collection methodologies; to develop sources where data could be collected; and to derive preliminary computational formulae for human effectiveness quantification.

In the process of meeting these developmental goals, new problems were discovered and new possibilities for development of the system were uncovered. Analogous to getting close enough to the forest to see the individual trees, we knew trees (the problems) were there all the time, but as we approached the forest (HEFAM development) we could see them clearly and specifically. These new problems were analyzed and are presented here as part of the conceptual development of HEFAM.

3. HEFAM Developmental Problems.

One of the foremost problems in the development of HEFAM is the lack of development in the state-of-the-art of quantifying human performance effectiveness. Although interest in quantification of human effectiveness is growing, very few people are working in the field and these few are working in widely diverse areas. Thus research applicable to HEFAM is scarce. HEFAM researchers, themselves, must accomplish much of the advancement of the state-of-the-art.

In the development of the HEFAM system there are several highly complex problems which must be solved. Each of these problems is complex enough to be a project in its own right. Some of these are:

Defining all the parameters of human effectiveness.

Quantifying human effectiveness.

Predicting human effectiveness in systems which have not yet been developed.

Providing human effectiveness guidelines suitable for work specification.

Developing data collection methodologies for human effectiveness data.

Searching out and adapting sources of human effectiveness data.

Developing a language for recording human effectiveness information.

Developing a data store of human effectiveness data.

Working out storage and retrieval methods for human effectiveness data.

These problems are very complex, and it will take time to solve them and to complete the development of HEFAM.

The problems presented above were analyzed and broken down into smaller subproblems. Figure 1 reflects these areas as it summarizes the major subproblem areas, the progress which has been made and the projected rate of progress for Fiscal Years 1970, 1971 and beyond. It thus delineates the scope and complexity of the HEFAM project.

	A HEFAM CONCEPT	B HUMAN EFFECTIVENESS QUANTIFICATION	C DATA BASE	D DATA STORAGE & RETRIEVAL SYSTEM	E PREPARATION OF DATA FOR USE	F COMMUNICATION PROCESS	G FEEDBACK PROCEDURE
Before FY 69	1. Feasibility study. 2. Problem definition research plan. 3. What constitutes human effectiveness?						
Partially Accomplished During FY 69	4. What is the relationship between human effectiveness & system effectiveness? 5. How can HPE be quantified? 6. What are the relevant variables? 7. What levels within a sys. should be considered? 8. Derive a formula relating variables.		1. Determine most significant data to be collected. 2. Determine most significant independent variables. 3. Determine data sources. 4. Develop data collection methodologies.		1. Establish list of users. 2. Determine various types of needs.		
FY 70 +	9. Derive prediction methodology procedures.	1. Derive computational formulae. 2. Determine data needs. 3. Derive predictive methodologies and formulae.	5. Coordinate data collection.	1. Basis for storage (consistent language). 2. Model development to handle data in different metrics (e.g. ordinal and interval).			
FY 71 +			6. Continue data collection.	3. Provide for processing new data & feedback to derive updated statistics (M, σ, etc.) for various functions. 4. New data must be evaluated for validity & reliability. 5. Classified material & proprietary rights related to HPE data must be protected. 6. Program computational formulae.	3. Develop communication loops with users. 4. Compare/match the independent variables of past & current sys. with those of proposed system. 5. Use appropriate prediction techniques for particular needs.	1. Mathematical indices (Mean, σ, mode, error rate, etc.). 2. Periodic publication of HPE tables for certain general functions. 3. Cross references to facilitate users' best choice of independent variables.	1. Provide for automatic feedback loop. 2. Allow for overcoming a long time gap.

Figure 1. HEFAM Development Schedule Showing Subproject Interrelationships

II. RESEARCH METHODS AND RESULTS

The HEFAM research during Fiscal Year 1969 has been directed toward three major areas of system development: A. Initial data collection, including the development of data sources and the development of data collection techniques; B. Effectiveness quantification, including the development of a conceptual basis for human effectiveness quantification, the development of formulae for human effectiveness quantification, and the development of a preliminary methodology for human effectiveness prediction; C. Overall conceptualization of the HEFAM system, including details of the data bank system, the HEFAM-User interface, and the relationships between the HEFAM data bank system and other data banks.

A. Initial Data Collection

1. Development of Data Sources.

Data for the HEFAM data base must be collected from a wide variety of sources in order to cover many human activities and to acquire a large enough sample in each function for statistical reliability. Therefore, many commands and activities were contacted to determine if they were collecting data which might be useful to the HEFAM system.

Attempts were made to determine if data has been, is being, or will be collected from which Human Performance Effectiveness data could be taken directly or derived. The possibility of collecting data from the activities and commands by their staff, by some automated recording system or by HEFAM researchers was investigated.

Investigations of various "leads" that promised a possibility of providing quantitative data on human performance revealed the following sources:

a. Man/Machine Systems Research Facility (MMSRF). As part of a system evaluation program, quantitative data on the effectiveness of detector/tracker performance on the ASWSC&C System have been collected during the past year, and more data collection is planned. All of the data thus far collected will make useful additions to the HEFAM data base. The parameters with which the MMSRF personnel have been concerned thus far are: number of simultaneous targets, number of targets by type, ASWSC&CS vs. conventional CIC, and the value of TV observation vs. on-site human observations of the variables from "real" course, speed and distance as determined post facto by analysis of videotape recordings (43, 44, 45).

b. COMFAIRWINGSLANT, Delta-Human Factors Group. Personnel in this group have done some evaluation of personnel performance aboard aircraft, and plans are being made for collecting more. However, since this data was not collected specifically for quantifying human effectiveness, and since many details have been left out of the reported data it cannot be used by HEFAM without additional information and conversion.

c. COMASWFORLANT. The Fleet ASW Data Analysis Program (FADAP) is an operational data collection procedure. It does not collect human performance effectiveness data at present, but there exists a future possibility, and FADAP documents will be evaluated for such possible use.

d. Naval Safety Center, Behavioral Science Division. The Life Sciences Department has collected some quantitative data on human performance in a simulator, and there is a possibility of collecting more. The report containing the data is not yet available, so the usefulness of the data has not been evaluated.

e. Submarine Medical Center, Submarine Base, New London, Connecticut. The Center has collected a small amount of quantitative data on human performance effectiveness and is currently collecting more. The report containing the data is not yet available, so the usefulness of the data has not been evaluated.

2. Development of Data Collection Techniques.

Four procedures for collecting and recording Human Performance Effectiveness were investigated:

a. The use of existing shipboard personnel for recording human performance in operational systems was investigated by queries and interviews with personnel in command of shipboard activities. Strong possibilities for use of shipboard personnel exist.

b. The use of audiotape recorders and videotape recorders as instruments for recording observations of human performance was considered and the details for equipment acquisition were investigated.

c. The use of computerized recording techniques to automatically record system performance from which human performance could be derived was suggested and a preliminary design was considered for a shipboard data collection methodology. Computer based Man/Machine (M/M) systems, both simulated and operational, are a potential source of extensive HPE data. If appropriately programmed, all systems of this type can record their own operations over any selected time period and make these data accessible via programmed computer printouts. All state changes of the machine part of the system, along with the associated real times, are recordable, limited only by available computer storage. These changes of state can be matched with operator actions, either immediate or previous, to obtain a cause and effect tabulation of the recorded history. Converting these raw data into HPE parameters can be optimally affected by the system software and/or post-operation analysis by researchers.

d. The use of Wilson's Automated Operational Sequence Diagrams (OSDs) (68, 69) was tested as a device for recording expected performance in a system or empirical observations of a system in operation. An actual OSD was prepared for one function in a developmental system.

The Antisubmarine Warfare Ship Command and Control (ASWSC&C) System (43, 44, 45) was chosen as a starting point for evaluation of data collection techniques for several reasons:

(1) It has a complete and well conceived simulation installation in a convenient location. The ASWSC&C System is located in the Advanced Ship Development Evaluation Center (ASDEC) area of Naval Electronics Laboratory Center (NELC) with closed circuit TV cameras installed in locations appropriate to observe operator actions. Closed circuit TV monitors and video recorders are located in a large trailer facility adjacent to the ASDEC area, the "Man/Machine System Research Facility" (MMSRF).

(2) ASWSC&CS is a system which utilizes more automated functions than its predecessor NTDS, which in turn, involved the automation of many functions originally performed by humans. Analysis of ASWSC&CS (combined with analyses of NTDS and conventional CIC) will thus allow determination of the relative effectiveness of systems as more and more functions are allocated to equipment. Such comparisions should prove invaluable in trying to obtain optimum man/machine mixes for future systems which will probably be evolutionary-type changes in the present ASWSC&C System.

(3) ASWSC&CS is in a stage of the system development cycle where measurements of human (operator) effectiveness are possible, but still not so well established that such measurement will be superfluous; i.e., diagrams of operator functions can be useful for training purpose, and feedback from evaluations can be useful for system modifications and for training curriculum changes.

Through the cooperation of the personnel of MMSRF, the information for the OSDs was collected by observation of the system in operation and review of documentation. Many valuable suggestions about the utilization of the task analysis OSD technique were adopted, and many ideas for the further refinement of the task analysis OSD were provided.

A task analysis OSD was developed for one position in the ASWSC&C System. Figure 2 shows part of this OSD which was prepared in a modified version of Wilson's original format--the difference being the addition of a category listing the information displayed by the machine. This OSD reflects the procedures a surface detector tracker would follow were he presented with a radar contact. Slight changes have been made in the content of the OSD printout in order to avoid security classification requirements which would otherwise be necessary because of the actual system used for its development.

The purpose of testing Wilson's automated task analysis OSD procedure was to determine if it could be used as a means for describing expected (criterion) human performance in systems under study and if it could be used as a reference to be used by data collectors so that actions could

HUMAN EFFECTIVENESS FUNCTION ALLOCATION METHODOLOGY (HEFAM) 00 1
DATA COLLECTION METHODOLOGY - FUNCTION DESCRIPTION 2
SYSTEM - ASWTDS 3
MODE - SURFACE DETECTOR TRACKER 0 A0000
TASK - ENTERING NEW CONTACT INTO SYSTEM 01A0000
STATUS - OPERATOR HAS ASSIGNED RADAR RANGE DISPLAYED ON CRT 01A0001

SYSTEM RESPONSE	BEHAV. CODE	BEHAV. CODE	OPERATION SEQUENCE	FEEDBACK DISPLAY	FAULT DISP. + RESPONSE	0000101 / 0000102 / 0000103 / 0000104
RADAR RECEIVES	MRE					01A0101
SIGNAL						01A0102
COMPUTER PRO-	MAE					01A0103
CESSES + SENDS	MTE					01A0104
VIDEO TO CON-						01A0105
SOLE	MRED			VIDEO IS		01A0106
				DISPLAYED		01A0107
				VIA CRT		01A0108
		HRV	OPERATOR SEES VIDEO			01A0201
		HD	OP MUST DECIDE IF			01A0202
			VIDEO IS A CONTACT			02A0203
		HA	OP ASSUMES VIDEO IS			01A0204
			A CONTACT			02A0205
		HATD	DEPRESSES BALL TAB	BALL TAB	IF SYMBOL	01A0206
			ENABLE BUTTON	SYMBOL	DOES NOT AP	01A0207
				APPEARS	PEAR, OP	01A0208
					MUST DEPRES	02A0209
					BALL TAB	01A0210
					CENTER QAB	01A0211
		HATD	POSITIONS BALL TAB	BALL TAB		01A0301
			SYMBOL OVER VIDEO BY	SYMBOL		01A0302
			MOVING TRACK BALL	MOVES TO		01A0303
				VIDEO		01A0304

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Figure 2. Sample Partial Task Analysis OSD

be scored innovative, erroneous, or expected. In addition the ease of using the OSD procedure, the adequacy of the behavior codes, the adequacy of the updating methodology, and the adequacy of the task sequence codes were evaluated.

Constructing the OSD was a difficult, time consuming task. A complete task analysis of the system was required before the automated OSD could be constructed and the data for the task analysis was difficult to obtain. Actually putting the OSD on keypunching blanks was a clerical task which had to be accomplished by the analyst since order of events and time of occurrence of events was very critical to the total OSD and analytical judgements were required for their placement. Updating the OSD often required the rewriting of large portions of the OSD so that the new event could be placed in the correct part of the sequence. The task sequence codes had to be expanded to match the complexity of the ASWSC&CS task.

It was discovered that the existing task analysis OSD behavior codes needed to be developed further and modified to meet the specific needs of the HEFAM data collection system. New behavior codes are being evolved concurrently with the development of a new more detailed task analysis OSD.

It was concluded that the automated task analysis OSD is a useful tool for stating the expected human performance in a system, and as a reference for use by the observer of human performance in a system.

The ultimate usefulness of any techniques developed will be dependent upon their applicability to many different types of systems. Thus, while any and all data on HPE collected as a part of data collection methodology development will be retained for future use, the principle goal of this aspect of the HEFAM project remains the development of basic general data collection techniques.

B. Effectiveness Quantification

1. Conceptual Bases of the Formulae.

This section delineates the basic concepts incorporated into the preliminary HEFAM formulae presented in this report. The final formulae will incorporate many of these concepts but will not be necessarily limited to these concepts alone.

At the present time HEFAM is conceptualized as relating to systems at three basic levels of integration: the task element level, the task level, and the function level. These levels of integration and the way they interrelate are depicted in Figure 3. Levels of integration are considered from simpler levels (incorporating fewer interactions) through the function

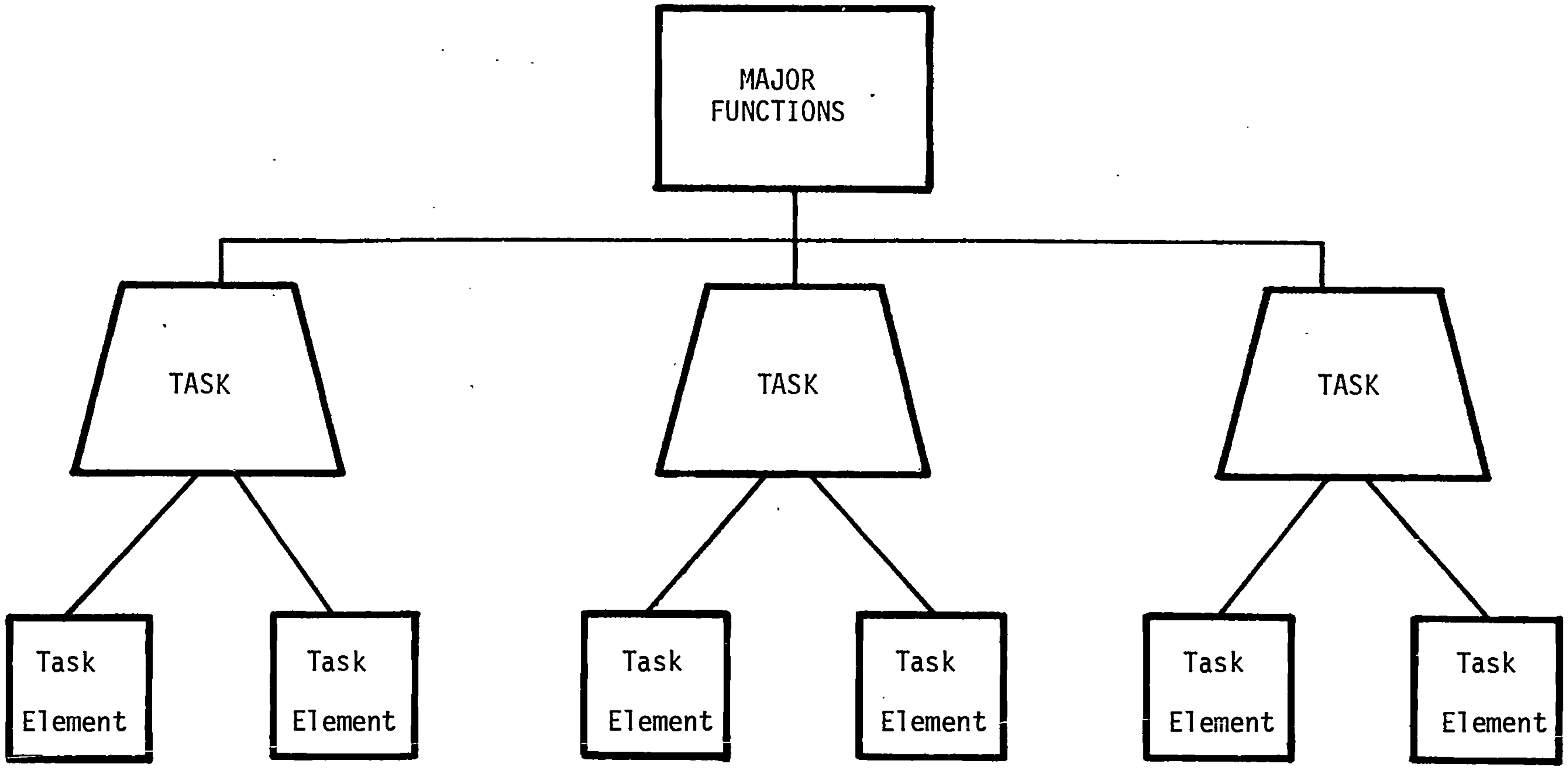

Figure 3. Levels of Integration

The basic work unit is the task element (e.g., the task element is "depress button" or "roll ball" or "flip switch"). Task elements are discrete simple units of work involving a single physical action directed to a single simple work goal. The task, a sequence of task elements directed to the accomplishment of a specific unit of work, is the next work unit (e.g., the task "hook target" is a sequence of task elements involving "press button", "roll ball", "flip switch"). The function is a sequence of tasks (e.g., the function "update track" is a sequence of tasks involving "hook target", "track trace", "record data"). These relationships which are incorporated into the HEFAM formula, are depicted in Figure 4.

HEFAM task analyses will be constructed from the simplest task elements up through the more complex functions. This direction of the analysis differs from many systems of task analysis which start with complex systems, breaking them down into functions, tasks and task elements. However, this complex-to-simple approach frequently doesn't reach the basic simple level of integration of the task elements. For HEFAM data recording, statistical derivation and eventual effectiveness prediction, data on the simplest levels of task elements are needed. HEFAM data will be recorded for the simple task elements and will be taken from many widely differing systems. These data will be recorded and statistics will be derived from them. Then these task elements and the related statistics may be recombined by a prediction formula into any variety of task sequences and any variety of functional sequences that are predicted for the system under analysis. This gives enormous flexibility for constructing hypothetical tasks and functions and for making predictions based on a statistical data base derived from empirical data.

HEFAM classifies the performance of task elements into three mutually exclusive categories: (a) planned action, the execution of an operation in the manner stipulated by the system's designer and which promotes the accomplishment of the mission; (b) innovative action, the execution of an operation in a manner not stipulated by the system's designer but which promotes the accomplishment of the mission; (c) erroneous action, the execution of an operation in a manner which fails to promote or inhibits the accomplishment of the mission.

Task elements have associated probabilities of effective performance which can be calculated. There also is a probability for their occurrence, and a probability for the occurrence of the operational sequences (tasks) of which they are a part. Probability statements for these individual events (effective performance and occurrence) are available so the human performance effectiveness for a given operational sequence can be predicted based on a combination of these probabilities. Time is accounted for in HEFAM to the extent that it affects the effectiveness of the performance of a unit of work. If a maximum time limit is exceeded then the action is scored as an "error". If the action takes no more than the expected amount of time it is scored as a planned action.

Some behaviors have more influence on the outcome of the next level of work complexity than others (e.g., some task elements influence the

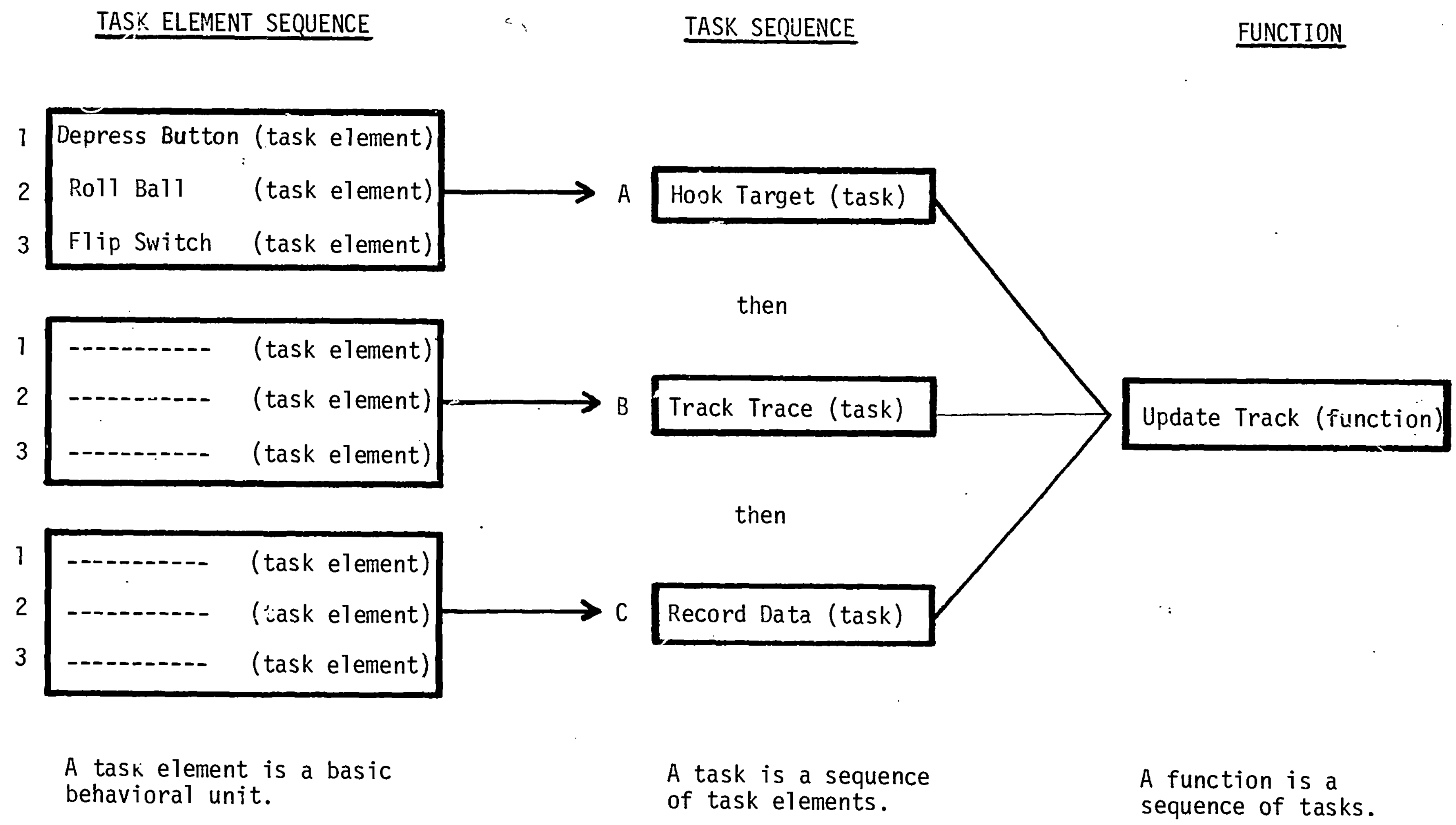

Figure 4. The Interrelationships Between Work Units and Work Unit Sequences

task performance more than others). This degree of criticality of a work unit is incorporated into the HEFAM concept and appears in the formula as the "criticality weighting factor". This factor will be determined by analysts in each individual function analysis.

The definition of human effectiveness as "the probability of the accomplishment of a unit of work", is central to the HEFAM concept and is expressed in the formulae. As a statement of probability, the theoretical maximum of human effectiveness would then be 1.0.

Functional analyses for effectiveness purposes can be made at all levels of system integration, and should incorporate the effects of the man, machine, and the man/machine components which interact within the system. The formulae account for effectiveness measurement at any level and reflect the mission requirements related to work at that level as discussed in the next section.

2. Human Effectiveness Formulae.

The formulae below present symbolic relationships in a preliminary attempt to model the quantitative relationships among the components of human effectiveness. They are at present only developmental models and therefore subject to change, modification, and revision. They are not meant to be used for effectiveness computation at this stage of their derivation.

It can be noted that the formulae are presented at three levels of integration within a system. This will allow the user to approach effectiveness analysis at the same level of integration as the allocation decision he is making.

At the task element level of integration, basic observations of performance of individual task elements are made. From these data a measure of effectiveness is derived for the task element being considered.

Thus:

$$E_{TE} = \frac{n_{PR} + n_{IR} - n_{ER}}{N_R}$$

Where:

E_{TE}	=	task element effectiveness
n_{PR}	=	number of planned responses
n_{IR}	=	number of innovative responses
n_{ER}	=	number of erroneous responses
N_R	=	number of responses

A task is a sequence of task elements. Therefore, at the task level of integration, the measures of effectiveness for the task elements whose sequence forms the task, are combined to determine the effectiveness of the task, represented by the formula:

$$E_T = \prod_{i=1}^{n} \left(E_{TE}\right)_i \left(C_{TE}\right)_i$$

Where:

E_T = task effectiveness

E_{TE} = task element effectiveness

C_{TE} = criticality of the task element to total task effectiveness in the specific system

A function is the next higher level of integration and consists of a sequence of tasks. At the function level the following symbolic relationships exist:

$$E_F = \prod_{i=1}^{n} \left(E_T\right)_i \left(C_T\right)_i$$

Where:

E_F = function effectiveness

E_T = task effectiveness

C_T = criticality of the specific task to total function effectiveness in the specific system

3. Human Effectiveness Prediction.

Human effectiveness predictions will be based on an evolved and refined version of the above formula. Data for many types of task elements will be stored and "average" values for each type of task element will be derived and stored. For each type of task and function, a probable sequence of task elements will be established and an effectiveness measure computed. Generalized statements of effectiveness for classes of functions may also be computed and stored. Users of HEFAM who know only the function to be evaluated, or the general type of function to be used in a system, may obtain estimates of effectiveness at that (function) level. As more information is available from the user, more specific information may be used in the formula, fewer estimates and generalities will be required and the reliability of the prediction will be enhanced accordingly.

C. General HEFAM System Conceptualization

One of the HEFAM research goals during Fiscal Year 1969 was to further develop the overall conceptualization of the HEFAM system. This was done by an analysis of HEFAM user needs, the situations in which HEFAM would be used, and the probable requirements of the HEFAM computational system.

1. The HEFAM Data Bank System.

The proposed basic system model will be based on an evolved version of the preliminary effectiveness formula which was presented previously in this report and on a prediction methodology and formula which will be developed during Fiscal Year 1970 (see Figure 1, page 6). This model will mathematically combine empirical data associated with task elements into effectiveness indices which will then be stored and later used with a prediction model to predict human effectiveness in developmental systems.

Data will be stored separately for each individual task element. This will allow greater flexibility of computation. New effectiveness models may then be applied with minimum modifications of the data store. At the present time data from task elements will be combined by the model into effectiveness indices. The branching diagram in Figure 5 shows this structure.

Content of the data bank may be structured into four classes: "input data", "stored data", "computed and stored data", and "reported data". "Input data" is composed of those data which will be supplied by the user with each problem he presents. They will be specific to the problem and must be supplied for each problem and alternative being evaluated for effectiveness. These inputs will be based on the requirements of the prediction model and will be defined in future HEFAM research. "Stored data" consists of data from empirical observations, and hypothetical work units. They will be stored in the simplest form possible in order to allow later combinations in a wide variety of ways. "Computed and stored data" will include major factors which have been computed from stored data and are being stored for additional future computation or for direct output on request of a user. These will be periodically updated as the data upon which they are based is updated or embellished. "Reported data" are completely computed effectiveness indices which are reported to consumers of HEFAM data. Table 1 identifies the storage classification of some of the types of data to be stored.

A very large storage capacity will be required by the HEFAM data bank system. Eventually data will be stored on at least 10,000 task elements with about 200 observation samples each, including frequencies of innovative, error, and planned actions, and computed effectiveness indices for each observation sample. Equal amounts of data will be stored for tasks, hypothetical tasks, functions, hypothetical functions, and criticality weighting factors. Experience with the system and further development of it, however, may reveal means of reducing active storage requirements.

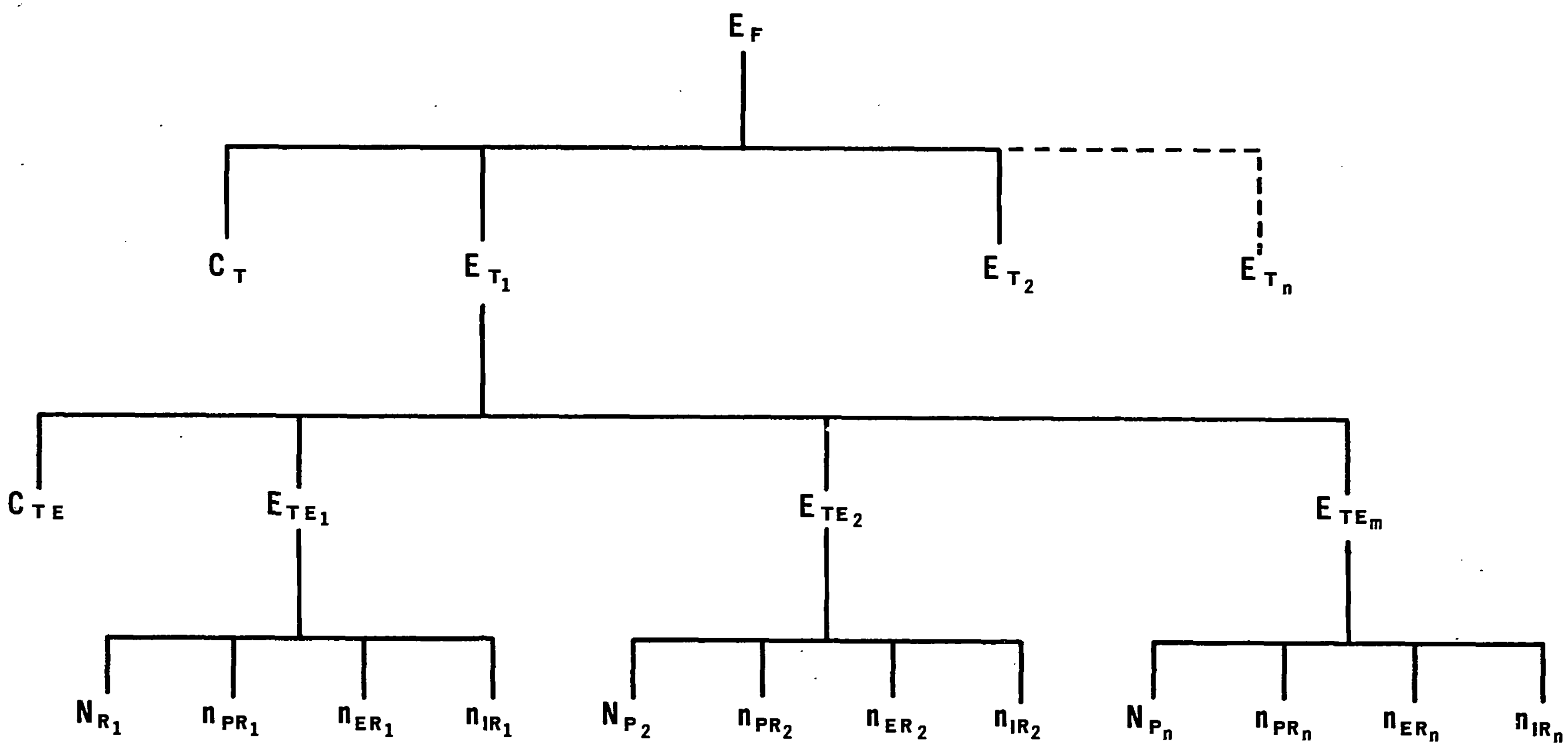

Figure 5. A Branching Model of the Effectiveness Formula

TABLE 1

DATA STORAGE CLASSIFICATION

Data Item	Input By User	Stored Elements	Computed And Stored Elements	Reported Elements
Effectiveness Criteria	X			
Function OSD	X			
Task Analysis OSD	X			
Frequency of Innovative Action		X		
Frequency of Planned Action		X		
Frequency of Erroneous Action		X		
Task Element Effectiveness Value			X	X
General Classes of Task Elements		X		
Effectiveness Values for General Classes of Task Element			X	X
Tasks (Task Element Sequence)		X		
Effectiveness Values for Tasks			X	X
Hypothetical Tasks		X		
Effectiveness Values for Hypothetical Tasks			X	X
Functions (Task Sequences)		X		
Effectiveness Values for Functions			X	X
Hypothetical Functions		X		
Effectiveness Values for Hypothetical Functions			X	X
General Classes of Tasks		X		

TABLE 1 (Cont'd)

DATA STORAGE CLASSIFICATION

Data Item	Input By User	Stored Elements	Computed And Stored Elements	Reported Elements
Effectiveness Values for General Classes of Tasks			X	X
General Classes of Function		X		
Effectiveness Values for General Classes of Function			X	X
Criticality Weighting Factors		X		
Effectiveness Values for Specific Systems			X	X

The data collection system which will provide data to support the data bank system will be extensive also. Many sources of data will be needed and data will have to be reported through some type of system so that the data bank is constantly growing with numbers of observations. Thus a data base with a large sample size will evolve.

Data, mostly in the form of observations on the performance of task elements, will flow into the data bank, be computed, and be sent to users upon request. Feedback from those systems in which HEFAM data was used in the design or upon which HEFAM predictions were made will also flow back into the system for validation of the predictions. Figure 6 depicts the generalized structure of the HEFAM data bank system.

2. HEFAM-User Interface.

HEFAM is conceived as being used at several stages of development of a weapon or support system: first, during early stages of weapon or support system design when only the general type of function will be known; again when the tasks have been defined and later when the task elements are defined; and finally when the system reaches the operational test and evaluation stage of development.

The HEFAM system can be used by either contractors or in-house system design engineers. It can be used to determine the human effectiveness requirements stated in the work order accompaning a Request for Proposal issued to contractors. This will occur at a very early stage of

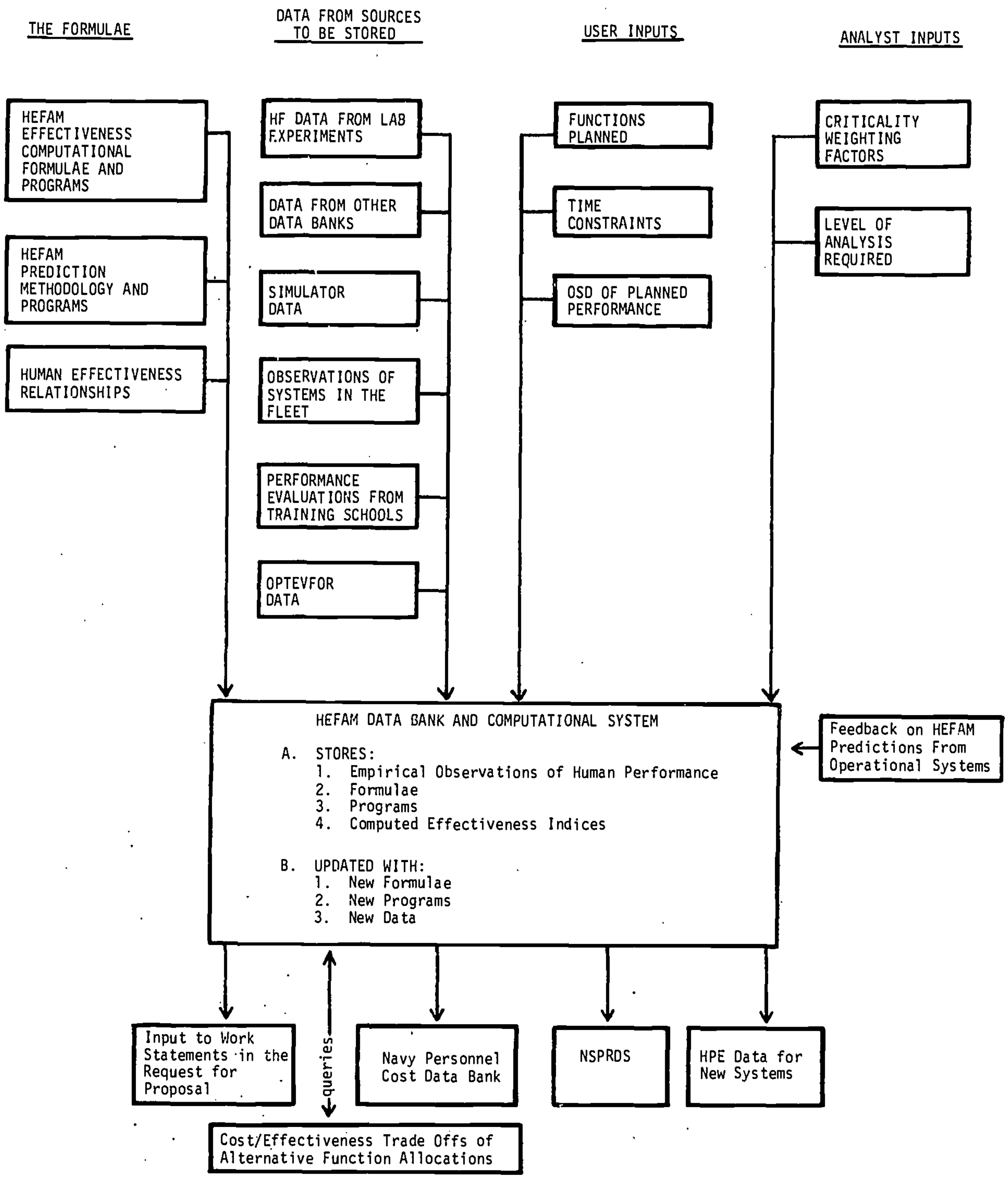

Figure 6. The Generalized Structure of the HEFAM Data Bank System

weapon or support system conceptual development. Thus, HEFAM data can form a basis for human factors requirements placed upon contractors, and will establish specified criteria in the RFP which will allow contract monitors to regulate, accept, or reject systems on the basis of human effectiveness considerations.

During each use of the HEFAM system, the design engineer can query the data bank for predictions of human effectiveness for each individual function allocation alternative. He can do this via a request form on which he supplies the required data about his particular system. The HEFAM request form will stipulate the necessary parameters for which the designer must supply information from which human effectiveness can be predicted. The request form will be processed by the HEFAM center and if enough data is available, a prediction of human effectiveness will be printed out by the computer along with a statement of prediction reliability.

An engineer using the HEFAM system should be able to query the data bank whenever it becomes necessary in his work (i.e., whenever he reaches a function allocation choice point). If he were limited to querying the data bank only a limited number of times during the system development, function allocations would probably be made without the use of HEFAM and thus without valuable pertinent data.

There will also be a feedback provision designed into the HEFAM system. Users will be required to supply certain information to the HEFAM center after they have used and evaluated the data which the center has provided for them. A user questionnaire will contain such questions as: Is this the right kind of data for your needs? Did you use the data we provided? Did you have to convert the data to meet your needs? Would it help you if we converted the data in some way? If so, what type of conversion do you need? Would you suggest changes in the format or in access of the data? Do you have confidence in the data we have provided for you? These questions, and the answers received by the HEFAM center, will be used in a continuing reevaluation of the HEFAM system and changes will be constantly made to keep the system up to date to meet the needs of the users of the HEFAM data. This continuing reevaluation is extremely important in producing a reliable function allocation system which will be of use (and used) in Navy system design.

3. Relationships with Other Data Banks.

The proposed HEFAM data bank system will be an independently operating system. However, it will exchange information with other systems and supplement information in the solution of problems. One of its major associations in this respect will be with New Systems Personnel Requirements Data System (NSPRDS) which is now being developed at the Naval Personnel and Training Research Laboratory at San Diego (9, 10, 30). Another data bank with which data will eventually be exchanged will be the Navy Personnel Cost Data Bank which is currently under development. Figure 7 depicts these data banks, their interactions, and the types of information they will store and exchange. Data exchanges with other

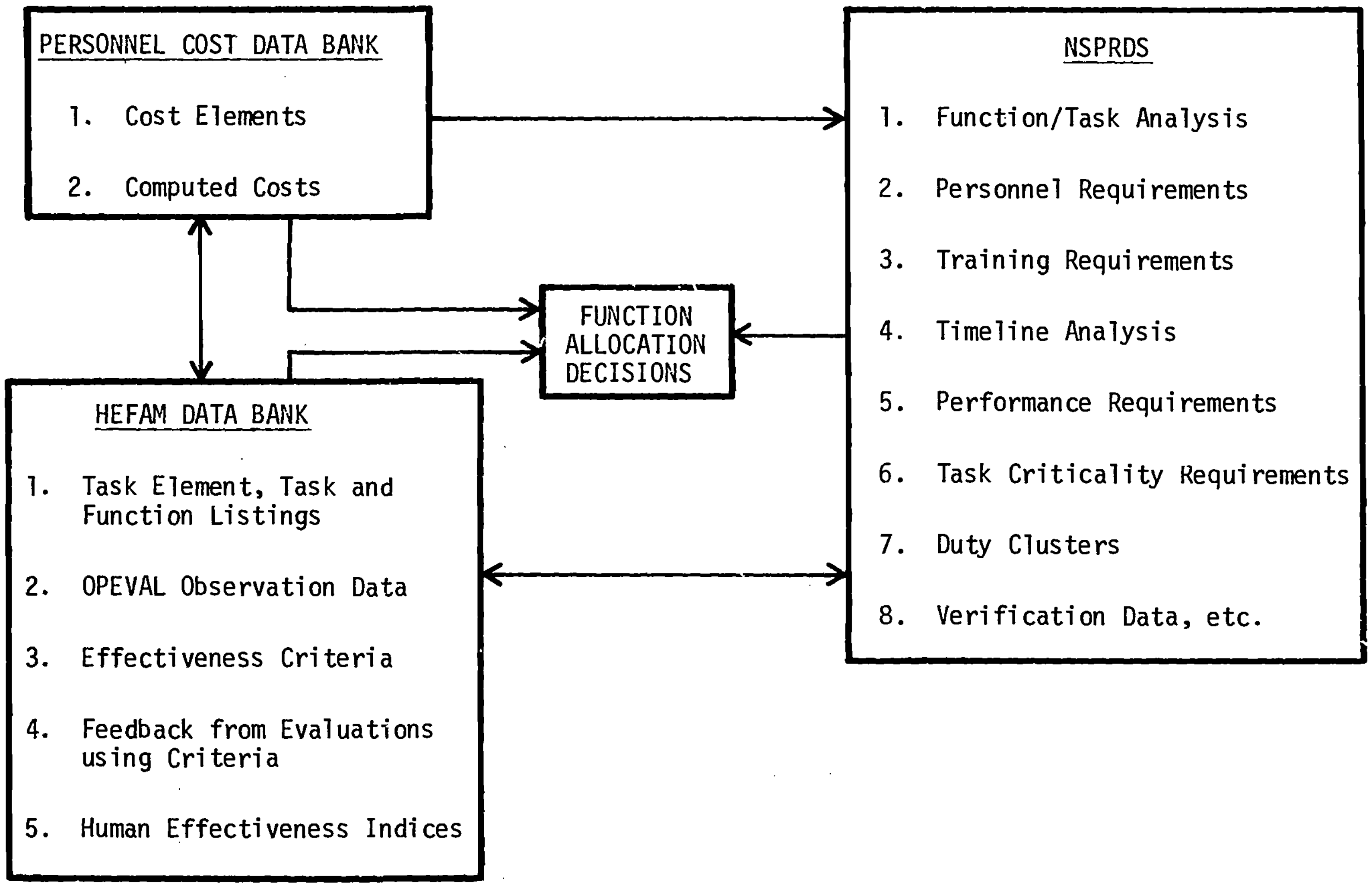

Figure 7. Interaction of HEFAM with the NSPRDS and the Navy Personnel Cost Data Bank.

computerized systems are possible and probable, especially with those systems which store human factors and human performance data. These systems are not listed here however, since they have not been committed to the information exchange at this time.

III. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. Much more work effort and time will be needed to develop the HEFAM system.

2. The HEFAM system will consist of a methodology, computational formulae, and an automated data processing system.

3. More sources of data are needed in order to provide a large enough sample of human performance to form a data base for effectiveness predictions.

4. Simpler methods of data collection than the OSD method are needed in order to collect human performance data in a timely manner.

5. Computational and predictive formulae for HEFAM must be developed further in order to be used for actual computation or prediction.

B. Recommendations

1. It is recommended that the HEFAM system be developed as rapidly as possible. This will require more effort than is currently being expended.

2. The future development of HEFAM should include: the further development of the conceptual bases of human effectiveness quantification; the further development of the HEFAM data processing system; the collection and utilization of HPE data; the development of better data collection methods; the further development and testing of computational and prediction formulae; and the development of the HEFAM prediction methodology.

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