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LICENSING TOPICAL REPORT

ESBWR ALLOCATION OF FUNCTIONS IMPLEMENTATION PLAN

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1 Introduction

The Man-Machine Interface System Human Factors Engineering (MMIS HFE) Design Implementation Plan [2.1(2)] includes the following three steps to conduct a system/operations analysis, which are the core activities for establishing design requirements for a Human System Interface (HSI):

- System Functional Requirements Analysis (SFRA)
- Allocation of Functions (AOF)
- Task Analysis (TA)

This plan document covers the second of these steps, Allocation of Functions.

Function allocation is based on an analysis of the functional requirements for plant control and then providing an assignment of control functions to either (1) personnel (e.g., manual control), (2) system elements (e.g., automatic control and passive, self-controlling phenomena), or (3) combinations of personnel and system elements (e.g., shared control and automatic systems with manual backup). Future HFE tasks refine adjust and reallocate the initial assignment to take advantage of human machine capabilities, existing practice, operational experience, regulatory requirements, technical feasibility and cost. Plant safety and reliability are enhanced by exploiting the strengths of personnel and system elements, including improvements that can be achieved through the assignment of control to these elements with overlapping and redundant responsibilities. In addition to technological and economic considerations, function allocation will use a structured and well-documented methodology that seeks to provide personnel with logical, coherent, and meaningful tasks based on HFE principles.

This plan meets the requirements of the ESBWR DCD and the ESBWR MMIS HFE Design Implementation Plan [2.1(2)]. Figure 1 shows where this plan fits into the overall HSI design implementation process.

A comprehensive literature review on function allocation was published 15 years ago (NUREG/CR-2623 [2.3(2)]). A detailed methodology for allocating functions in nuclear power plants was published a year later (NUREG/CR-3331 [2.3(1)]). Further work based on this methodology attempted to make the process of allocating functions more practical, human-centered (i.e., task sharing), and cost-effective for application to large nuclear design projects (IAEA-TECDOC-668 [2.5(1)]). These methodologies, like those used in other industries (e.g., aviation, aerospace, military, medical, commercial), concern *static* function allocation. Static function allocation does not account well for the dynamic (changing) nature of plant operations (e.g., due to component aging, plant modifications, and changes in the operating points) and human performance (e.g., due to procedures, training, cultural factors, attitude, boredom, fatigue, learning, adapting, etc.). Nevertheless, this plan document began with the work reported in NUREG/CR-3331 and IAEA-TECDOC-668 which was applied to previous BWR designs, and has been upgraded from the experience of applying this process to the ABWR designs and incorporating new HFE elements found in NUREG 0711r2.

1.1 Purpose

The purpose of this implementation plan is to establish methods, criteria and guidance for allocating functions to human, software, or machine during the HSI design implementation process. This plan document describes a methodology for static function allocation to be performed by the Design Team and the Control Room Design Team (CRDT) as specified in the MMIS HFE Design Implementation Plan [2.1(2)].

1.2 Scope

This plan document establishes an AOF process in conformance with ESBWR MMIS HFE Design Implementation Plan [2.1(2)], and NUREG-0711r2, Human Factors Engineering Program Review Model [2.3(4)]. The scope of this plan includes the following:

- Defining bases and criteria for function allocation analysis and the selection of the preferred method of control for each requirement identified in the specification of functional requirements. The function allocation can follow the same allocation from proven previous designs when the interface and information is unchanged. Thus, in many cases the HFE work performed for the previous ABWR designs applies directly to the ESBWR.

- Establishing a framework for AOF so that a multi-disciplinary team can analyze functions and their allocations in a consistent, uniform and thorough manner. The framework includes models of the human and the machine.

- Detailing the steps of the AOF process for both new systems and changes to existing systems.

The AOF will be an evaluation of every function from the SFRA that can be allocated to a human, software, machine, or a combination (i.e., shared). The AOF will provide additional bases for the degree of automation of each function. Due consideration will be given to the system designs as specified in ESBWR Project documents (e.g., SDSs [2.1(7)]), automation issues (operator workload, equipment reliability, etc.), and potential issues (performance, logistics) concerning allocation between control room personnel and personnel outside the control room. During the design of the system, the responsible engineer (RE) will make allocations based upon criteria of allocation (See Figure 8).

The AOF will be developed as a delta process to the ABWR plant designs. The Baseline Review Record established as precursor to these activities will form the bases from which a gap analysis will document the level of application of the technologies described herein. The systems will undergo execution of the described AOF activities, either because they are new systems or the design and/or regulatory basis is sufficiently changed to warrant reevaluation/reengineering.

1.3 Definition of Terms

Several terms are defined to provide a common basis for subsequent paragraphs.

1. System/Operations Analysis

   A methodological study and evaluation of system goals performed to identify a hierarchy of functions for operations, and the optimal means by which these functions can be accomplished.

2. Function

   An activity or role performed by a human, structure, or automated system to fulfill an objective. (System Functional Requirements Analysis Implementation Plan [2.1(3)]).

3. Control Function

   "Keeping measured functional parameters within bounds though a process of manipulating low level functions to satisfy a higher level function" (NUREG-0711, Rev. 2, page 96, [2.3(4)]).

4. Allocation of Functions (or Function Allocation)

   "The analysis of the requirements for plant control and the assignment of control functions to (1) personnel (e.g., manual control), (2) system elements (e.g., automatic control and passive, self-controlling phenomena), and (3) combinations of personnel and system elements (e.g., shared control and automatic systems with manual backup)." (NUREG-0711, Rev. 2, page 19, [2.3(4)]).

5. Human Performance

   The activity of a human required to accomplish a function. For example the human user conserves, reduces, or adds information, and supplies or controls energy.

6. Machine Performance

   The activity of a machine in accomplishing a function by supplying whatever information or energy is required. The machine includes both hardware and software.

7. Human-System Interface (HSI)

   The organization of inputs and outputs used by personnel to interact with the plant, including the alarms, displays, controls, and job performance aids. Generically, this includes maintenance, test, and inspection interfaces as well.

8. Local Control Station (LCS)

   An operator interface related to nuclear power plant (NPP) process control that is not located in the main control room. This includes multifunction panels, as well as single-function LCSs such as controls (e.g., valves, switches, and breakers) and displays (e.g., meters) that are operated or consulted during normal, abnormal, or emergency operations.

9. MMIS HFE Design Team

   MMIS are those systems that perform the monitoring, control and protection functions. The MMIS HFE Design Team (Design Team) is a team of engineers, as defined in the MMIS HFE Design Implementation Plan, responsible for the design of the MMIS.

10. Control Room Design Team

    The Control Room Design team (CRDT) is a subset of the Design Team. The CRDT is responsible for the overall coordination of the design of the Main Control Room (MCR), Remote Shutdown System (RSD) Panels, and applicable Local Control Stations.

1.4 Activities Not Within the Scope of AOF

The following activities are not within the scope of AOF in this plan:

1. Human-System Interface Design

   The design of control and displays depends on clearly specified operator task requirements. Because these requirements derive from the allocation of functions, task requirements are greatly assisted by a clearly documented allocation. However, the actual interface design is a separate set of decisions.

2. Human Factors Engineering (HFE)

   AOF is based on HFE principles and part of the MMIS HFE process but HFE is a separate discipline and is ongoing activity throughout the design and implementation process.

3. Job Design

   Job design allocates human tasks to particular job positions. It is part of the human subsystem design.

4. Component Selection

   It is necessary to ensure that allocation will not be used as a means for selection of components based on the referenced limitations and capacities of an identified user. For this reason, it is advisable not to be very specific related to the selection of components.

2 Reference Documents

2.1 Supporting Documents

1. ESBWR Design Control Document Tier 2 Chapter 18 Human Factors Engineering

2. ESBWR Man-Machine Interface Systems (MMIS HFE) Design Implementation Plan NEDO-33217,

3. ESBWR System Functional Requirements Analysis Implementation Plan NEDO 33219,

4. GE Advanced Boiling Water Reactor Standard Safety Analysis Report (SSAR),

5. ESBWR Task Analysis Implementation Plan,

6. ESBWR Human Factors Verification and Validation Implementation Plan,

7. ESBWR System Design Specifications (SDSs), (design description documents)

2.2 Codes and Standards

1. IEEE-1023, IEEE Guide to the Application of Human Factors Engineering to Systems, Equipments and Facilities of Nuclear Power Generating Stations, 1988, (IEEE)

2. IEEE-1023, IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities, 2004, (IEEE)

2.3 Regulatory Requirements and Guidelines

1. NUREG/CR-3331, A Methodology for Allocating Nuclear Power Plant Control Functions to Human or Automatic Control, 1983, (U.S. Nuclear Regulatory Commission).

2. NUREG/CR-2623, The Allocation of Functions in Man-Machine Systems: A Perspective and Literature Review, 1982, (U.S. Nuclear Regulatory Commission).

3. NUREG-0700, Human System Interface Design Review Guideline, Rev. 2, 2002, (U.S. Nuclear Regulatory Commission)

4. NUREG-0711r2, Human Factors Engineering Program Review Model, 2004, (U.S. Nuclear Regulatory Commission)

2.4 Department of Defense and Energy

1. AD/A223 168, System Engineering Management Guide, (Department of Defense, Defense System Management College, Kockler, F., et al.).

2.5 Industry and Other Documents

1. IAEA-TECDOC-668, The role of automation and humans in nuclear power plants, International Atomic Energy Agency, 1992.

2. IEC 964, Design for Control Rooms of Nuclear Power Plants, (Bureau Central de la Commission Electrotechnique Internationale).

3. Information processing and human-machine interaction, an approach to cognitive engineering, J. Rasmussen, Elsevier Science publishing Company, New York, 1986.

4. Decision with multiple objectives: Preferences and Value Tradeoffs, Keeney, Ralph and Raiffa, 1992, Cambridge University Press, 2nd.

5. Decision Analysis and Behavioral Research, D. Winterfeld and W. Edwards. Cambridge: Cambridge University Press.

6. Handbook of Human Factors, edited by Gavriel Salvendy, John Wiley and Sons, 1987.

3 Basis and Criteria for Allocation

Allocation of functions is a required part of the ESBWR HFE design process as noted in the MMIS HFE Design Implementation Plan.

3.1 Allocation of Functions Philosophy

Most methodologies for structured, top-down system design prescribe alternating steps of hypothesis and test. Allocation is an inventive process that uses iterations of hypothesis and test. Successful allocations of functions are realized when the human and machine are given balanced consideration. The AOF process is based on a number of underlying ergonomics principles as follows:

1. Human cognitive strengths should be fully exploited by the designer. There are some things that a human does better than machines. The three disciplines of engineering, ergonomics, and psychology, must work in harmony to exploit these strengths. Humans can successfully perform many very complex tasks or processes that are difficult and costly to automate.

2. Automation should start with the most prescriptive procedural functions first. Those manual functions that are memorized or performed prescriptively by detailed procedures should be automated whenever possible. This will reduce the burden on operators for performing many routine control loop actions and shift the human function to monitoring.

3. Automation should be used to reduce human cognitive overload. Humans can suffer from information overload and consequent mental overload. This can occur from high information rates, multiple tasks competing for operator attention or task complexity. An example is trying to manually control xenon oscillations and power level in a large reactor core at the same time. Whenever the designer can predict this problem, or whenever operating experience demonstrates it to be so, automation should be used to relieve the human of the function that causes the problem. If possible, tasks that have been assigned to automation should not be returned to a human when the automation fails. In general, humans do not act effectively as a back up for a machine, when the timing for a recovery action involving multiple control function actions is very short. For example, if automated systems for turbine speed control are lost, it is unlikely that the operator could control the power production for very long without a generator trip. Thus, this control circuit is a candidate for automation with no expectation of human backup.

4. A reason for using automation is when system requirements exceed the capacity for human control (e.g., processors can evaluate multiple inputs simultaneously, make a comparison, and initiate a function). Consequently, human back up for the same control function is unlikely to be appropriate. In this case human actions should address a backup plan such as power reduction or plant trip to achieve protection from safety barriers in a new defense-in-depth configuration, which is within human response capability.

5. Automation can be considered for actions that occur infrequently, if it is expected that human performance on control of the task will diminish over time based on the level of planned training or actual experiences.

6. During a system failure automated systems should be designed to clearly indicate the system status and minimize the need for operator intervention. This can be accomplished by achieving required functions by redundant or diverse active systems or passive systems. Operators can perform some simple valve alignments if sufficient cues, procedures and time are available.

7. Automation and feedback information can be used to protect society from the fallibility and variability of humans. This requires an analysis of the control function requirements for proposed human tasks to identify possible errors, the HSI cues for making corrections and the consequences of an uncorrected error.

8. Particular attention should be paid to risk sensitive functions. The tasks should be automated if it is practical, feasible and cost-effective. Otherwise special simulator training and validated procedures should be used to enhance the success of the human action.

9. The correct process for balancing human and machine actions should become an institutionalized part of system design. The right balance will not emerge until there are processes in common use by designers, operators, and management, which reflect the correct principles and embody proven practices.

10. The evaluation should include consideration of the professional motivation and psychological well-being of the operator.

11. Ultimate control should remain with a human, in that the human can set objectives for starting or stopping a process. In the ESBWR design, the control room operator maintains control.

12. Override capability should be given to a human to correct automatic control if necessary. The ESBWR design allows the main control room operator to intervene in the automatic process.

13. Information should be provided to a human concerning the actions of automatic control and its objectives. Using break-point logic, the ESBWR operator monitors and controls the automated process, allowing it to continue at predefined steps.

14. Control logic of machines should be designed for the intended manual operating strategies and associated manual control actions.

15. The information system to the operator (computer generated displays and controls) should be behaviorally suitable.

16. Adequate cognitive support should be available to the operator, so that the operator will have an adequate mental model when assuming control.

3.2 Allocation of Function in the ESBWR Plant Design Process

The allocation of functions to humans and machines takes place as a part of the system design. The RE utilizes the System Design Specifications (descriptions SDS) to allocate those functions required by regulatory or system requirements. Those RE allocations are first implemented as part of the system logic diagrams. The HFE group preparing the HF documents (e.g., SFRA, AOF, etc.) reviews the engineering documents and then may question the allocations and overall HSI design implementation process. The AOF will be performed in accordance with Section 4.4 of the ESBWR MMIS HFE Design Implementation Plan [2.1(2)]. The depth and breadth of AOF will be consistent with the depth and breadth of analysis for SFRA augmented by the Baseline Review Record Gap Analysis.

NUREG-0711r2 [2.3(4)] allows that SFRA and AOF be performed for functions that have been allocated differently than their predecessor designs. However, for ESBWR, the SFRA and AOF will also be performed for unchanged allocated functions to ensure that Task Analysis documentation is consistent in format and to ensure that allocated functions of predecessor designs are consistent with the requirements of the ESBWR Project. Operating Experience Review (OER) data collected during the design of the U.S. ESBWR will be reviewed during the performance of the SFRA and AOF for both modified and unmodified systems. The OER issues will be reviewed for their effect on the system functions and the function allocations for each system.

Specific guidelines from Section 4.4 of NUREG-0711r2 [2.3(4)] will be followed. The guidelines are paraphrased herein for clarification and convenience purposes.

1. Functions identified as "unchanged" shall be reviewed to determine (a) instances where the allocation between human and machine is unchanged, and (b) instances where the allocation has changed (through increased automation for example). Changed allocations shall be noted as having "modified" function allocations (see NUREG-0711). The level of automation shall be noted (e.g., fully automatic; fully manual, automatic with manual backup) for each "unchanged" function having an "unchanged" allocation.

2. Unchanged functions with "modified" allocations shall be analyzed in terms of resulting human performance requirements based on the expected plant operator population. The rationale for the resulting allocation shall be documented. The

AOF shall address (a) safety-related requirements and estimated execution time; (b) required reliability; and (c) the number of personnel and the necessary skill levels needed to operate the system (NUREG-0711).

3. "Modified" safety functions and processes from the SFRA shall be analyzed in the same manner as that prescribed in the previous paragraph.

4. Any allocation criteria, rationale, or rule applied for the AOF and differing from those in this AOF Implementation Plan, shall be documented in a Design Record File (DRF) (NUREG-0711).

5. The allocation process shall take into account the ESBWR projected operator crew size and configuration. The allocation criteria shall include taking maximum advantage of the capabilities of humans and machines without imposing unfavorable requirements on either (NUREG-0711).

   Note: The projected operator crew is as follows pending the outcome of the Staffing and Qualifications Plan and analysis:
   a) One person with a senior reactor operator (SRO) license provides overall supervision of control room operations
   b) Two persons with reactor operator (RO) licenses to operate controls in the MCR
   c) One person qualified to serve as a shift technical advisor (STA)
   d) Auxiliary person qualified to operate plant equipment at locations outside the MCR (number pending)

6. Allocation criteria for "modified" safety functions and processes shall include applicable results of the OER (shown in Figure 4.1 in NUREG-0711).

7. Applicable results of the OER that justify unchanged allocations for unchanged functions shall be identified (NUREG-0711). Unchanged allocations will be justified as part of the OER if the OER identifies HFE-related safety issues.

8. The impact of new allocations on unchanged allocations shall be evaluated (NUREG-0711).

Figure 1 shows the relationship of the AOF to the overall HSI design process. In Figure 1 it can be seen that, relative to the function allocation process, there are:

- Precursor Activities (Note: These are part of the ESBWR design process. For example, establishing the Baseline Review Record (MMIS HFE Implementation Plan).

- Phases of Function Allocation

  - Defining and Evaluating the Functions

  - Allocating the Functions
  - Evaluating the Function Allocations
- Feedback from other phases of the design process
  - Task Analysis
  - Human Factors Verification and Validation

These items are discussed in the following sections.

3.2.1 Precursors to Function Allocation

For allocating functions, the following precursor activities must take place:

1. Defining the Roles for Human tasks in the control and monitoring of plant functions
2. Linking the overall design functions to systems and subsystems to define Functional Requirements Analysis elements for control option selection.
3. Organization and Composition of Design Team (e.g., the CRDT)
4. Organization of Documentation

In the ESBWR design process, these precursor activities are accounted for in the GE ESBWR DCD [2.1(4)]), predecessor phases of the HSI design implementation process (Chapter 18.0 of the ESBWR DCD), and the MMIS HFE Design Implementation Plan [2.1(2)].

3.2.2 Phases of Function Allocation

The AOF process has the following phases:

1. Defining and Evaluating the Functions
2. Allocating the Functions
3. Evaluating the Function Allocation

3.2.2.1 Defining and Evaluating the Functions

For the allocation process to work, an operational definition of the function is necessary. This operational definition comes from the functional requirements analysis that precedes AOF. The team, in concert with system designers, should decide at which level of the hierarchical structure of plant functions they would begin working for function allocation. This decision may be redefined or identified by the CRDT. The system designers should be able to determine when a function should be redefined through repartition, to a lower level in the hierarchical function structure, until an operational definition can be made.

The SFRA Implementation Plan [2.1(3)] describes a nine level hierarchical structure that establishes functional relationships among plant functions and system functions. This structure is shown in the following table. Using the ESBWR Design Control Document (DCD)[2.1(4)] as a basis, it is appropriate that allocation of functions begin at Level 5 - System Goals (SFL-1) of the hierarchical structure.

Plant and System Functional Analysis Assignment

Level 1	Plant General Goals (PFL-1)	Plant Functional Analysis Level
Level 2	Plant Subgoals (PFL-2)	
Level 3	Plant Critical Functions (PFL-3)	
Level 4	Plant Performance Requirements (PFL-4) (the interface between the plant functional structure and the system functions and design basis)	
Level 5	Systems Goals (SFL-1)	System Functional Analysis Level
Level 6	Systems Subgoals (SFL-2)	
Level 7	Systems Critical Functions (SFL-3)	
Level 8	Systems Performance Requirements (SFL-4)	
Level 9	Systems Support Requirements (SFL-5)	

PFL: Plant Functional Level
SFL: System Functional Level

Following function definition, the function should be reviewed to identify system characteristics or requirements such as load, accuracy, time factors, complexity of action logic, etc.

3.2.2.2 Initial (Hypothetical) Allocation (from NUREG/CR-3331, [2.3(1)]

The objective of the initial stage of the allocation phase is to quickly reach an allocation that is nearly optimal for the intended application. The allocation is hypothetical only. It will be tested during an evaluation phase and the procedure may be repeated before a final allocation is achieved. The process for the initial stages of allocation is described in Section 4.2.

If necessary, the design team can return to SFRA, divide the functions into a larger number of smaller functions and repeat the function allocation. This iterative process should cycle rapidly among the design team and the system designers. Design decisions should be recorded as design documentation in a database.

3.2.2.3 *Evaluating the Function Allocation*

The evaluation phase is deductive because, at this stage of the design, empirical tests usually are not possible. The evaluation depends principally on deductive analysis based on methods such those described in NUREG/CR-3331 [2.3(1)]. When the allocations pass the evaluation tests, the function allocation process is complete, and the results obtained (functions and tasks allocated to humans) should provide the inputs needed for task analysis.

3.2.3 Feedback from Other Phases of the Design Process

There is feedback from other design phases. If the results obtained under the Task Analysis Implementation Plan [2.1(5)] and Human Factors Verification and Validation Plan [2.1(6)] show either that some tasks exceed human capabilities or that a machine could perform better than a human, there will be a feedback to the function allocation phase to re-allocate the function. This feedback might result in changing the HSI, the system design (e.g., automation), or staffing, for example. The ESBWR design process will incorporate changes within the controls of the ESBWR QA Program.

3.3 A Framework for Function Allocation

A framework for AOF is needed so that a multi-disciplinary team can analyze functions and their allocations in a consistent, uniform and thorough manner. This section describes such a framework that includes a systematic process for using models of the operator (the human) and the control system (the machine) to evaluate control allocation strategies. The framework is adapted from NUREG/CR-3331 [2.3(1)]. The technical approaches proposed for the framework can be updated and improved to address new issues as needed by the multi-disciplinary team.

3.3.1 Psychomotor and Cognitive Behaviors

Two categories of human tasks can be defined as follows based on NUREG/CR-3331 [2.3(1)]:

1. Observable Psychomotor Behaviors

The human reacts to situational stimuli, using overtly visible psychomotor responses that can be described and measured (e.g., piloting an aircraft or word processing on a personal computer). These psychomotor behaviors are part of mental information processing tasks, yet, unlike cognitive behaviors; they can be measured from overt responses and the results and outcomes of the tasks.

2. Cognitive Behaviors

The human observes equipment, monitors instruments, compares, evaluates, etc. The human typically acts by way of spoken communication (e.g., an instruction to another person) or by operating a control device (e.g., a touch screen or the electronic mouse for a personal computer). These actions do not reveal to an observer what the human did in reaching a decision to act. The cognitive behaviors behind such information processing tasks have become a larger portion of operator tasks in process control industries. For this reason, researchers and analysts have proposed a number of different models of information processing.

The AOF process described in Section 4 was developed for handling cognitive behaviors, which are a predominant part of the nuclear power plant operator's tasks (Ref: Section 2.6 of NUREG/CR-3331). Specific analysis tools are identified for dealing with such tasks, and a formal cognitive model is used (Section 3.3.2). The AOF process is heavily dependent on expert judgment rather than on quantified analysis for two reasons noted in NUREG/CR-3331:

- Past methodologies for allocating functions were unsatisfactory due to lack of quantified data on cognitive tasks and the data could not be credibly extrapolated. Data for psychomotor tasks was more prevalent.
- Even with the data available, the number of operating variables and the complexity of their interaction are so great that no algorithm for their analysis would be feasible, even though many attempts have been made.

Plant functions that require cognitive tasks in control can be evaluated using formal models of the information processing sequence. Three categories of possible models are shown in Figure 2.

1. Models of the control requirement. Block 1 of Figure 2 represents possible models of the control requirement for a task or function. Given a general future engineering design, one might ask what control actions will be required to configure and control the plant in all its normal and failure conditions. Given those requirements, it is possible to model the actions that must be taken to acquire information, formulate control decisions, and actuate controls. It is known that for each feasible control task there is an underlying sequence of information processing steps that can convert sensor data into control signals.
2. Models of the automation requirement. For any control requirement that is to be met by automation, there must be a sequence of automation steps that lead from input data to control signals. Block 2 of Figure 2 represents possible models of this requirement.
3. Models of the human performance requirement. Block 3 of Figure 2 represents possible models of human psychomotor and cognitive performance that the human must exercise to perform the control requirement (Block 1), or in other

words, actions paralleling the automated control process (Block 2). It is important that these three models be mutually consistent and valid as representations of the control requirements. The analysis method begins with a model of the human (Block 3) and uses the same language to describe the control and automation requirements (Blocks 1 and 2).

3.3.2 Recommended Model

The recommended model of system performance is shown in Figure 3. It is a combination of the model recommended in Section 4.1.6 of NUREG/CR-3331 [2.3(1)] and the operator decision-making model developed by Rasmussen and modified by Woods [2.5(3)]. Figure 3 shows three control loops: a closed control loop between human and machine, and open loops from and to the external system or environment. The "Human" block represents the control room crew, and the "Machine" block represents the NPP and its links to the electrical grid.

3.3.3 Core Performance Areas

The model described in Section 3.3.2 identifies four core performance areas. These core performance areas are the working taxonomy for describing the steps to process data from sensors to control signals, whether these steps are performed by a human or machine. These core performance areas are the following:

- Detection
- Monitoring
- Planning and Decision Making
- Control

Definitions from the Berliner Taxonomy [2.5(6)] are as follows:

- *Detection* - To become aware of the presence or absence of a physical stimulus.
- *Monitoring* - To track over time.
- *Planning* - To devise or formulate a program of future or contingent activity.
- *Decision Making* - To come to a conclusion based on available information.
- *Control.* To execute an intervention in the system.

3.4 The Allocation Decision Space

In determining whether a certain function should be performed by human or by machine, it has often been assumed that if human performance of a task is inadequate, a machine will necessarily perform it well. The assumption reflects the bias of the designer towards automation. However, there are tasks such as low-speed sorting of objects by size that both humans and machines perform very well. There are other tasks such as multivariate value weighting that neither humans nor machines alone are well suited. Each allocation decision actually requires two separate assessments, the effectiveness of human and the effectiveness of machine.

The relationship between these two assessments is described by a two-dimensional decision space where a given task or function is associated with a particular point or region within that decision space (Ref: Section 2.7 of NUREG/CR-3331 [2.3(1)]).

Figure 4 illustrates the decision space. The horizontal (X) dimension (the abscissa) represents the relative effectiveness of the human, scaled from "unsatisfactory" at the left to "excellent" at the right, and the vertical (Y) dimension (the ordinate) scale bottom to top represents the corresponding effectiveness of a machine. The X and Y values of a point in that space represent the estimated probable effectiveness with which humans or machines, respectively, can perform a specified function or set of tasks. Locating points in the decision space is intended as a visual aid for analysts to decide how the function should be allocated.

This decision space can be defined as having two basic regions as differentiated by the diagonal line U-E where Y=X. Any point above U-E represents a function best suited to a machine, and any point below U-E represents a function best suited to a human. This distinction alone is not a basis for an allocation decision, since special conditions exist at several points. At the lower left, for instance, in the area marked (U), are tasks that are not performed well by either human or machine. Such tasks may not be feasible, or they may be very difficult to achieve safely in a practical manner. By contrast, the area in the upper right corner near (E) is where the functions are performed equally well by either human or machine so that the allocation decision becomes a matter of choice. Any function defined by a point close to the diagonal line U-E is one for which human and machine are equally well suited (or equally poorly suited). Allocation of such functions can be based principally on criteria other than the relative suitability of humans and machines.

The decision space of Figure 4 can be redrawn as a decision matrix (Figure 5) containing five regions. The appropriate decision strategy for allocating one function or some segments of this is different for each region.

The matrix includes two regions shown shaded in Figure 5. One region is labeled Ua and the other region is labeled Uh. Functions associated with region Ua are too low on the "machine performance" scale to be considered for automation; they can presumably be allocated to human by default. Conversely, functions associated with region Uh will presumably be allocated to machine by default. However, at the intersection of region Ua and region Uh is the region Uah where both humans and machines perform unacceptably. This corresponds to the area U in Figure 4. Any function that falls in this region should be considered for redesign or included in a system only as a final resort.

The regions not shaded in the matrix represent functions that might be acceptably performed by either human or machine, with varying degrees of advantage. In the region Ph, a human is expected to be substantially superior as a control component. Functions in this region will be allocated to a human in the absence of other overriding considerations. Conversely, in the region Pa, allocation will ordinarily be to machine.

Finally, there is the region Pha, bounded by regions Pa, Ph, Ua, and Uh, and by the lines U-E and U′-E′. The difference between the expected performance of the human and the expected performance of the machine is insignificant for all points in this region. Pha is a region of less certain choice so far as the relative control performance of human and machine is concerned.

It must be recognized that the matrix concerns only the question of which allocation is preferred from the analytic point of view. The decision rules suggested by the matrix (of relative effectiveness of human versus machine) may be overruled based on other criteria such as cost, legal restrictions, worker preferences, or because of a technological inability to construct a system using the ideal allocation.

3.5 Precursors to Function Allocation

The following precursors of AOF establish requirements and constraints governing the allocation decisions. The following sections discuss these precursors:

1. Defining the Role of the Human
2. Functional Requirements Analysis
3. Organization and Composition of Design Team (e.g., the CRDT)
4. Organization of Documentation

3.5.1 Defining the Role of the Human

General expected roles of the human, an initial allocation of functions, and an operator crew organization have been determined for the ESBWR in the DCD Chapter 18. These elements of the GE ESBWR design have evolved from a five year (1986-1991) research program which covered allocation of functions and validation testing (Chapter 18.4 of ABWR DCD]) and subsequent ABWR deliveries.

3.5.2 Functional Requirements Analysis

The operational requirements and constraints for the accomplishment of each function are obtained by the SFRA that precedes AOF in the HSI design implementation process. Refer to the SFRA Implementation Plan [2.1(3)] for details.

3.5.3 Organization and Composition of Design Team

The team members specified in the MMIS HFE Design Implementation Plan [2.1(2)] assure that function allocation is performed by personnel whose combined expertise meets or exceeds the expertise identified in NUREG/CR-3331 [2.3(1)] and NUREG-0711r2 [2.3(4)]. Supporting experts, consultants, or subcontractors with applicable expertise may also participate with the MMIS HFE Design in performing the allocation of functions. GE system engineers, as a part of the MMIS Design Team, will have oversight of work performed by subcontractors.

3.5.4 Organization of Documentation

Adequate documentation will be necessary to provide the basis for allocation of functions if design changes are proposed. Without documentation, lessons learned during each system development are lost, if the cumulative experience cannot be shared by a body of professionals who assume responsibility for, and develop a special competency in, making allocation decisions. This suggests that the implementation of criteria and methods described in this implementation plan will not by itself solve the problem of allocating control functions.

The documentation should serve the following purposes:

- Ease of communication. The HSI design process requires effective communication among differing disciplines and traceability of information. Formal documentation is essential and it should be written so that it is reasonably standard and understood among disciplines.
- Permit access to data by other disciplines. Each discipline should have continuous access to the current level of design.
- Provide a durable historical record to retrieve past decisions within any discipline. The rationale for decisions should be recorded.
- Provide continuity of effort and direction as people and design teams change.
- Assist redesign by providing a record of what is to change and a record of alternatives that were considered but not selected.
- Permit a design to be tested by deductive analysis, even though there might not yet be any hardware to test empirically.

Documentation should consist of at least:

- Drawings and flow charts
- Records of the decision process, including alternatives considered and the basis for choice.
- The expected engineering-quantified parameters and input/output characteristic of each function.
- Resource documents describing the characteristics of any prior technology to be applied or modified.

Documentation is stored and accessed through the design database. HFE issues will be tracked through an HFE Issues Tracking System for identification, tracking, and closure of issues raised during the design process.

One example suggested by NUREG/CR-3331 [2.3(1)] related to the contents of an allocation-of-function document is shown in Figure 6.

If applicable, it is recommended that an electronic database be used to store and prepare necessary documents (reports, tables, etc.) to implement the plans. An electronic database would allow for manipulation (sorting) of data and possible transfer of data from one report to another. Data collected could be electronically imported into one or more reports as necessary.

4 Phases of Function Allocation

The AOF process has the following phases and it is depicted in Figure 7:

- Defining and Evaluating the Functions
- Allocating the Functions
- Evaluating the Function Allocation

4.1 Defining and Evaluating the Functions

This phase consists of the following steps:

- Defining the functions
- Evaluating the functions

4.1.1 Defining the Functions

The SFRA Implementation Plan [2.1(3)] calls for the functional analysis to begin at the system level. Therefore, the allocation of functions will also begin at the system level. All functions can be broken or divided into more detailed functions. The SFRA Implementation Plan identifies five levels of decomposition for the system functional analysis. This allows the designers to judge when a function should be redefined through repartitioning among lower levels in the hierarchical function structure.

4.1.2 Evaluating the Allocated Functions

After defining the function in the functional requirements analysis, it is necessary to evaluate the function through performance of a task analysis. The purpose of task analysis is to identify the detailed components of a function and its characteristic measures (IEC 964 [2.5(2)]). The task analysis shall be performed in accordance with the guidelines of the Task Analysis Implementation Plan [2.1(5)]. The methodology described in Section 4.1.2 is consistent with that plan.

The first source from which to obtain the information needed will be the results obtained by the System Functional Requirements Analysis:

- Logical requirements for its accomplishment (Why its accomplishment is required)
- Control actions necessary for its accomplishment (How it can be accomplished)
- Parameters necessary for control actions
- Criteria for evaluating the result of control action
- Parameters necessary for the evaluation
- Evaluation criteria
- Hazardous requirements
- Facility requirements imposed by the performance and design requirements (i.e., controlled and natural environmental requirements such as temperature, atmospheric pressure, etc.)

Next, the analyst has to break down the function into the main information processing steps. These are the steps that must be taken to process data from sensors to control signals. These main information processing steps are called Core Performance Areas in this implementation plan. Core Performance Areas consist of the following:

- Detection
- Monitoring

- Planning and Decision Making
- Control

The analyst has to identify which Core Performance Areas are involved for carrying out the function, and understand the requirements and constraints for the Core Performance Areas. The analysts proceed to identify characteristic measurements of the function and define several classes for each measurement. The characteristic measurements should be objective (e.g., time, rate) but they may include subjectively scaled measurements as well. The measurements should also include qualitative measurements to assist decision-making. The analysts should consider the following characteristics:

- Load
- Accuracy
- Time factors (e.g., rate, time margin/constraint)*
- Complexity of action logic
- Types and complexities of decision making
- Impacts resulted from the loss of function and associated time factors (criticality-for safety, and/or for plant availability)
- Frequency of required intervention
- Hostility of the environment

The analyst must then evaluate each function against these characteristic measurements without undue bias or regard to the function being allocated to human or to machine. This evaluation is important in order to set the input for allocation of a function in the next phase.

Criteria for allocations should be consistent with these characteristic measurements. A relative measure of human and machine performance with respect to these criteria and characteristic measurements is tabulated below (Ref: IEC 964, Table A.3 [2.5(2)]).

* If time is detected as a critical factor, it is recommended to do a timeline analysis. This is a method of identifying the density of actions to be performed at the same period time to accomplish a function. It graphically represents the relative timing of different actions and the duration of individual operation, and hence identifies where actions are required to be performed.

Allocation Criteria Consistent with Characteristic Measurements	Human Performance	Machine Performance
Load	Moderate	High, very low
Time margins	Large	Small, very large
Rate	Moderate	High, very low
Complexity of action logic	Simple	Complicated
Types and complexities of decision-making	Ill-structured	Well-structured

4.2 Function Allocation

The AOF process criteria are illustrated in Figure 8.

The objective at this stage is to assign each function to one or more of the regions within the decision matrix shown in Figure 9. Some functions could pertain totally to one region within the decision matrix shown in Figure 9. Other functions could have some segment in region Pa, other segments in region Ua, and the rest in region Pha. The functions are allocated using the following decision guidelines:

- It may be that the function studied partially fulfills the criteria of a region. In this case, allocate to this region the part of the function affected, and follow the process with the rest of the function until the whole function has been allocated.
- The goal is to quickly converge on a nearly optimal allocation and to critique it. The allocation will be tested under a global test and evaluation phase, and the procedure may have to be repeated many times before a final solution is achieved.

Furthermore, within a whole system design it will be necessary to accept some allocations that are less than optimal. Therefore, a permissive criterion should be exercised: each decision is made based on best first judgments, and will not be delayed by critical reexamination. This rule is reversed in the evaluation phase when a conservative critique is made.

If necessary, analysts should return to definition of function, partition the function into a larger number of smaller functions, and repeat the allocation. This process of iterative correction may cycle rapidly within a small design group. Design decisions are documented for traceability.

In general, the analysts will deal with initial (tentative) functions one at a time. Later in the evaluation phase the simultaneous effects of all functions will be examined, but here the goal is to achieve a nearly optimum allocation for each function individually. This does not mean that the analyst disregards what is known about functions already allocated. They will not make decisions that are highly inconsistent with prior decisions, or decisions that are unacceptable due to conflicting interactions among functions. There will be many functions that have already been allocated due to design evolution. However, it is prudent to examine the premises upon which prior allocations have been made.

4.2.1 Functional Allocation to Human or Machine for Mandatory Reasons

The first criteria to be applied to a function will be those belonging to Group A: Mandatory. The process to be followed is represented in Figure 10. The criteria to be applied are represented in Figure 11.

4.2.1.1 Automation is Mandatory

The function or function segments to be identified by this step are those to be automated. They will be under automatic control, although some of them may require some residual role of a human at the task level for guaranteeing awareness of the situation. This aspect has to be considered in this step and may be revised in the evaluation phase. The function or segments of the function for which the automation is mandatory will fall in region Uh as shown shaded in Figure 12. The criteria to be applied are represented under the box labeled "Machine" in Figure 11.

The procedural step used to decide if the automation is mandatory in the function studied or in segments of this function is the following:

1. Intrinsic Criteria Fulfilled

   Use the information obtained in previous phases (control requirements and constraints, core performance areas, and characteristic measurements of a function) to determine if the function or segments of this function meet one or more of the following intrinsic criteria:

   a. Regulation or policy. A function must be automated when regulation or policy so dictate. This assumes that automation can be accomplished with available resources and known technology.

   b. Hostile environmental factors. A function or function segments must be automated when any form of human participation is precluded because the system or its environment either will not support human life or will create products or conditions that would endanger it. This assumes that an adequate life support system cannot be developed and that humans cannot be located in a safer environment to perform essential system functions.

   c. Human limitations. A function or function segments must be automated when its performance requirements exceed or fall outside the range of human capabilities.

Examples:

- Processing large quantities of data
- Tasks requiring high accuracy
- Tasks requiring high repeatability
- Tasks requiring fast performance
- Situations in which unrecovered errors lead to significant consequences.
- Situations in which error cannot be corrected

For determining if performance requirements exceed human capabilities it is necessary to consider:

- long-term demands of the resulting task
- required performance under the worst possible conditions
- the variability of human operator

2. Technical Feasibility

Confirm that automation of the functions or function segments is technically feasible. If the use of the previous criteria indicates that the function or function segments must be automated, it is necessary to confirm that the automation of function or function segments is feasible because in some cases automation would be required but it is not technologically feasible. Such cases fall in region Uah shown shaded in Figure 13. This decision is made principally on the advice of the engineering members of the allocation team.

Assess the technical feasibility of automation. A function or function segments can be automated if the following criteria can be satisfied:

a. Component availability. Are the necessary hardware and software components required by the function available off-the-shelf?

b. Development time. If components are not readily available off-the-shelf, can the needed components be developed within the scheduled life-cycle development limit for the system or can that limit be revised to permit development and testing?

c. Predictability. Can all function events (that is, function failure modes) be predicted and handled by automation?

d. Reliability. Is the expected reliability of the proposed function configuration adequate to meet system performance requirements?

e. Failure. Can the consequences of expected system failures be compensated for by automatic back up or otherwise prevented from exceeding acceptable limits?

f. Safety. Can adequate safeguards against dangers to public health be fully automated?

3. Economic Feasibility

Assess the economic feasibility of automation.

A system can be automated within economic constraints if it meets the following criteria:

a. Funding. Can known financial resources cover all necessary cost of development, design, testing, installation, and automation?

Allocate to automation the entire function or segments of this function if the automation is mandatory and feasible technically and economically. If these criteria do not apply to the function or function segments, continue to the next step: Human Performance is Mandatory (see Figure 10 and Subsection 4.2.1.2).

If the entire function or segments of the function are mandatory but are not feasible, the entire function or segments of the function that do not fulfill these criteria are returned to system functional requirements analysis for an alternative solution.

4.2.1.2 Human Performance is Mandatory

This step reverses the logic of the previous step (Subsection 4.2.1.1) to identify whether direct human participation is mandatory and the function or function segments must be manual. This function or function segment will fall in region Ua shown shaded in Figure 14.

The functions or function segments to be identified by this procedural step are those to be manual. That is, all tasks included here must be under human control, although some may require automated support at the task level (residual automation support). This aspect must be taken into account to enhance the operator's potential capabilities and to obtain an adequate level of workload. The criteria to be applied are represented under the box labeled "Human" in Figure 11.

Mandatory manual control is required for any of the following conditions:

1. When human performance is required by law or regulation
2. When human performance is required by labor agreement
3. Functions that maintain policy-level or on/off control. Human users must be able to make the basic policy and economic decisions which cause the plant to produce economically desired products and keep it within statutory safety standards
4. Functions which require heuristic or inferential knowledge, and flexibility
5. Functions which occur in extreme abnormal or accident situations, where human flexibility and high-level skills are essential and the unexpected nature of the tasks makes specifying automation difficult or impossible
6. If allocation to machine is not technically feasible

If the outcome of previous steps is affirmative, it is necessary to confirm that performance requirements are within human capability. These cases fall in area Uah of Figure 15. This decision is made primarily on the technical advice of the human factors members of the team. The criteria to be used are those previously cited.

Allocate to a human the entire function or segments of this function, for which human performance is mandatory and feasible, although some automated support may be required at the task level. This aspect has to be considered for enhancement of operator capabilities in decision-making etc., and obtaining an adequate workload. This aspect may be revised in the global test and evaluation phase.

If the entire function or segments of this function are mandatory but are not feasible, the entire function or segments of the function that do not fulfill these criteria should be returned to system functional requirements analysis to look for a new solution.

4.2.2 Functional Allocation to Human or Machine for Technical Reasons

This step covers the following cases:

- Automation is not Mandatory, but is Technically Preferred (Region Pa)
- Human Performance is not Mandatory, but is Technically Preferred (Region Ph)

The process of allocating Group B functions (Figure 8) is illustrated in Figure 16. The criteria to be applied in this step are represented in Figure 17.

4.2.2.1 Automation is not Mandatory, but is Technically Preferred

There are some functions or function segments that, although lying within the capability of humans to perform, may be better assigned to machines. These cases lie within region Pa shown shaded in Figure 18.

The following criteria may be used in allocation of functions or function segments to automation:

- Human performance presents technical challenges and automation technology is highly acceptable

- OR -

- Automation is marginally effective or costly, but the human is not expected to perform as well.

4.2.2.1.1 A human imposes some problems and automation technology is highly acceptable related to the following criteria:

1. Technical aspects

    a. Component availability. Are the necessary hardware and software components required by the function available off-the-shelf?

    b. Development time. If components are not readily available off- the-shelf, can the needed components be developed within the scheduled life-cycle development limit for the system or can that limit be revised to permit development and testing?

    c. Predictability. Can all function events (i.e., function failure modes) be predicted and handled by automation?

    d. Reliability. Is the expected reliability of the proposed function configuration adequate to meet system performance requirements?

    e. Failure. Can the consequences of expected system failures be compensated for by automatic back up or otherwise prevented from exceeding acceptable limits?

    f. Safety. Can adequate safeguards against dangers to public health be fully automated?

2. Economic aspects

   a. Cost effectiveness. Will automation of the function be more cost- effective than the use of a human operator*? This assumes that inclusion of the operator is not precluded for reasons of life support or human performance limitations.

   b. Funding. Can known financial resources cover all necessary costs of development, design, testing, installation, and automation?

4.2.2.1.2 Automation is marginally effective or expensive, but humans are not expected to perform as well:

1. Functions which are lengthy

2. Functions which require high consistency

3. Functions which require high accuracy

4. Functions which involve boredom or monotony for the operator

5. Functions which imply risk to the operator

If one or more of the mentioned criteria do not apply to the entire function, allocate the function segments that fulfill these criteria and continue the process for the rest of the function.

4.2.2.2 Human Performance is not mandatory, but is Technically Preferred

This step is the reverse of previous step. It identifies functions or sub functions for which human performance is preferred, because they can be performed more reliably by a human than by automation. These cases lie within region Ph shown shaded in Figure 19.

There are functions or function segments that are better performed by a human. These include all functions that require heuristic or inferential knowledge and flexibility. A particular set of functions or function segments that must currently be left with the human operator are those which occur in extreme fault or accident situations, where human flexibility and high-level skills are essential and the unexpected nature of the task makes automation difficult or impossible.

* Total cost includes the cost of acquiring, automatic surveillance tests, and operating a fully automatic function (i.e., the cost of including one or more human operator or maintainers entails the aggregate cost of personnel selection, training, life support, staffing and management, and the provision of supporting documents, manuals, job aids, and training services). The cost of additional software maintenance should also be considered.

Functions or function segments identified in this step are those in which all included control tasks should be manually controlled, although some tasks may profit from automated support (residual automation support) for enhancement of operator's abilities and for obtaining an adequate workload. This aspect will be revised in the global test and evaluation phase.

4.2.3 Function Allocation to Human or Machine by Other Criteria

The remaining functions and function segments that were not allocated in the previous steps must be accounted for. The functions represent cases in which allocation to either a human or automation is completely acceptable from the point of view of both engineering and human factors design. These functions or function segments may therefore be allocated based on any other criteria of interest to management or the design team. All of these functions and function segments should lie in region Pha shown shaded in Figure 20 and they belong to box C of Figure 8.

The criteria that can be used include the following (Ref: Section 4.1.15 of NUREG/CR-3331, [2.3(1)]:

1. Relative cost of human or automated design
2. Consistency with earlier allocation and design practices
3. Available technologies
4. Crew preferences
5. Management preferences
6. Designer preferences

4.2.4 Global Test

A global test related to the allocation can be carried out before evaluating the function allocation. The design team should have the freedom to decide to undertake this global test or proceed directly to evaluation of function allocation. The global test is described in the following sections.

4.2.4.1 Verify Adequate Residual Automation Support in Functions Allocated to Humans

This step is a global check of functions or function segments allocated to human, and it ensures that the conditions of allocation provide for appropriate automated support of the functions or parts of them allocated to human. This step is the recognition that human tasks are usually carried out with some level of mechanical support.

Therefore, at this step, the design team will examine each function or function segment allocated to the human to ensure that no unnecessary burden is being placed on the operator, that multiple levels of access are specified where appropriate, and that automated support provides the maximum possible degree of plant stability without human control action. This evaluation should consider the following criteria as a minimum (Ref: Section 4.1.16 of NUREG/CR-3331, [2.3(1)]):

1. Automated Data Display. Examine each function and function segment and specify points where automated display will simplify the core performance requirements for detecting, monitoring, planning or executing.

2. Set-Point and Sequence Controllers. Examine each function and function segment allocated to a human and search for all points where unnecessary manipulation of analog control can be avoided by using set-point controllers. Also search for all common switch-and-valve sequencing that can be simplified by automatic switching. (Note: These aspects have been considered in the standard ESBWR).

3. "Dead Man" Controls. Examine each function and function segment allocated to a human. What happens if the operator fails to perform them? Can appropriate automation make the plant stable under these conditions?

4. Multiple Levels of Control Access. A hierarchy of control functions is established by the implementation of System Functional Requirements Analysis. Operator access to each level or layer in the hierarchy may provide additional backup capability to accommodate degradation of upper level function and provide for emergency reconfiguration. The further up the hierarchy that operator control is exercised, the more integrated the control action becomes. Thus at high levels, a single action can engage, disengage, or modify many subsystems. Examine each level and function within that level to determine the most effective access points.

5. Consistent level of automation. The control room should present to the operating crew a consistent level of automated support.

4.2.4.2 Verify Adequate Cognitive Support in Functions Allocated to Automation

Cognitive support should ensure a continuous awareness of the status and trend of each engineering subsystem during each plant state. Safety-critical and time-critical subsystems require a more precise awareness. The design team should particularly examine those functions or function segments allocated to automation and answer the following questions (Ref: Section 4.2.6 of NUREG/CR-3331 [2.3(1)]:

- Does automation deprive the operator of important information?
- Is there adequate remaining task activity to provide sufficient cognitive support regarding plant status?

The team should selectively reconsider past allocation to automation, to ensure a pattern of operator activity that promotes an adequate mental model of the plant. If the answer to the above questions is affirmative, consideration should be given to reallocate the functions or function segments to the human.

4.2.4.3 Verify Adequate Residual Role of Humans in Functions Allocated to Automation

This step is a final check of functions or function segments allocated to automation and assures that the conditions of allocation are specified so as not preclude necessary human access to control. This step recognizes that while automation of many of the control requirements is desirable, it is very rarely intended to exclude the human altogether. Ultimate authority ("policy control") must remain with the human. Therefore at this step each function and function segment allocated to automation will be examined to ensure the following (Ref: Section 4.1.18 of NUREG/CR-3331 [2.3(1)]:

- The human retains necessary emergency control
- There is reasonable consistency from function to function
- Multiple levels of access are specified where appropriate
- The human retains appropriate, discretionary control

1. Retaining Emergency Control by Humans

   Examine each function in relation to each plant state, and in relation to the abnormal conditions that can originate from that state. Compare these data with the defined human role.

   a. Does the degree of automation interfere with a human's necessary emergency role?

   b. Will humans receive enough information to make the required diagnostic judgments?

   c. Will control capabilities permit a human to intervene as required?

      The human role should be expanded if these conditions do not exist.

2. Consistent Level of Automation

   Ensure that a reasonably consistent level of automation across plant systems is planned, except when there is a clear reason to specify otherwise.

3. Multiple Levels of Control Access

   Examine each function consistent with Item d. in Subsection 4.2.4.1. Furthermore, examine each function in a manner consistent with the previous paragraph and verify that any required multiple levels of control access are provided.

4. Policy-Level Control

   Ultimate control should remain with human, in that he can set objectives for starting or stopping the process. In the ESBWR design, the control room operator maintains control. However, it is an item to be tested in this phase.

If any of the aspects considered above are not adequate, it should be convenient to reallocate the functions or function segments that could improve the situation.

4.2.5 Record Function Allocation

Once these reallocations have been made, the final results and the rationale for them should be documented (see Section 3.5.4).

4.2.6 Record Automation Requirements

Each time an allocation is made to automation, that allocation includes and implies requirements for engineering development of automatic controls. At this step those requirements have to be identified and documented. Preferably, the allocation of functions will be documented in such a way that it is easy to retrieve and manipulate the information, particularly by other discipline groups.

The CRDT shall review the allocations, identifying cases where an allocation requires development of automated control, and ensuring agreement concerning what has to be automated and the level of technology to be achieved.

Individual system designers are responsible for documenting and preparing the functional specifications necessary to meet these requirements. These functional specifications may be (a) performance statements, which describe (in general terms) what automation will be required to do, or (b) descriptions in terms of analogous technology. (It is not yet time to specify hardware or software solutions). The engineering staff needs to question the proposed design by asking: "Is the required control automation achievable?" If so, these automation requirements are documented, and they become part of the engineering requirements to be developed during future iterations of the design cycle.

4.3 Evaluation of Function Allocation

The allocations must be consistent with a viable plant/system design. Deductive testing and evaluations of function allocations are one approach for assuring the viability of the allocations (Ref: Section 4.2 of NUREG/CR-3331 [2.3(1)]).

4.3.1 General Method

The recommended evaluation procedure exercises the six test steps shown in Figure 20. In each step, a small interdisciplinary evaluation team, from the HFE team with experience in observing the use of or using similar HSI, follows an ordered evaluation procedure using the documented allocation data. Allocations and design hypotheses that are found faulty are returned for reallocation. The following general principles should be applied to all six decision steps. These principles are essentially the same as those in the allocation phase, except where noted below.

1. Expert Judgment

   When tools such as simulation or similar HSIs are not yet available expert judgment can be to anticipate (1) potential psychological demands on humans by a plant under design, (2) needed skills and knowledge, and psychological response limitations, of an operating crew of a future plant design, and (3) the multivariate characteristics of the human operator, including his or her limitations. Lessons learned from the previous ABWR designs reduce reliance on expert judgment in the case of the ESBWR when establishing similar functional HSI features.

2. Comparable Technology

   Lessons learned and insight from previous experience with comparable technology in previous ABWR provides a way to foresee the human performance requirements that a given function will impose.

3. The Data Base

   The evaluation of allocations makes use of data that includes the functions and their allocations, and OER documentation in a database format.

4. Conservative Criterion

   The criterion for decisions will be conservative. Allocations should not be accepted unless it is reasonably certain that (a) the allocation is practical and without undue risk for the intended application; (b) the basis for the allocation includes human-centered considerations; and (c) assumptions regarding human factors and human performance are reasonable for the intended application and they will not preclude meeting the requirements of the allocation.

5. Series and Simultaneous Analysis

   In each test, the allocated functions and their associated design hypotheses are evaluated, first one function at a time and then simultaneously, to determine their impact on compatibility and implementation of each function.

6. Decision Procedure

   The team discusses the functions to ensure that they are fully understood with respect to the test in progress. Available quantified and empirical data are examined. Each unquantifiable variable of human capability and of unknown future technology is identified and its impact on the design is evaluated.

The team members can individually judge whether the function (or whole system) passes the test and a consensus can be attempted. Reasons for failing the test should be recorded.

The following paragraphs describe in detail the evaluation of function allocation.

4.3.2 Phases to Evaluate Function Allocation

The phases to evaluate function allocation are represented graphically in Figure 21. In the case of recent ABWR designs these function allocation phases were performed independently using a team of subject matter experts.

4.3.2.1 Phase 1: Can the Human Meet the Core Performance Requirements?

This phase examines the allocation of functions and asks whether the operator will be able to perform the allocated functions or function segments, considering the engineering and human factors subsystems.

In this phase, the human is viewed as an engineering component, one that senses plant conditions from instrumentation, makes control decisions, and executes control actions, just as an automated device might do. Human physical support requirements and vulnerabilities, emotional state, fatigue, and competing interests are considered in the next phase.

1. Analyze the Required Core Performances

   The total set of performance demands on the human can best be estimated with the assistance of a human-machine model with which the successive requirements for detecting, monitoring, planning, decision making, and executing of a task can be recognized and classified. Figure 3 models operator performance in terms of four core performance areas (which was explained in detail in Section 3.3).

In preparation for this evaluation, a human factors expert or psychologist evaluates each function as it is hypothetically allocated, and estimates the load which control tasks will place on each of the core performance functions. This analysis can examine prior allocations that have been documented.

2. Perform Series and Simultaneous Analysis

   Allocated functions are first evaluated individually and in series, on their own merits, against the question, "Can a human perform the control requirements of this function as allocated?" Then all functions are evaluated in their collective demands on the operator, asking, "Can a human perform all the functions required during each operating sequence scenario?" During scenarios, a set of functions is performed so these functions should be evaluated as combined functions. The scenarios to be considered should be large enough to cover adequately all the functions studied. As an example, the following scenarios will be considered:

   a. Safety related

      i) Loss of coolant accident

      ii) Main steamline break

      iii) Loss of all AC power

      iv) Anticipated transient without scram (ATWS)

   b. Availability-related

      i) Failure of control system sensor

3. Test Procedure

   The team discusses each function serially to ensure that the engineering and human factors solutions are fully understood. The allocation of functions is examined for its effect on each core performance area. The system is evaluated based upon functional requirements. The evaluation of allocation must be evaluated following the development of the HSI. The functions allocated will be further evaluated during the part-task and the simulator evaluation.

   Team members, including the engineering and human factors design representatives, make individual judgments concerning whether humans can perform the function as it is designed, taking core performance areas one at a time. They state their conclusions and attempt to reach a consensus position. The chairperson resolves any undecided case.

4. Evaluation Results

Failed: If any allocation of function or function segments fails this evaluation serially or simultaneously, one or more functions or function segments must be returned for reallocation. After the reallocation has been made, repeat this phase.

Passed: Functions that pass this phase may continue to Phase 2.

4.3.2.2 Phase 2: Can Operators Meet the Human Performance Requirements?

This phase continues to evaluate the ability of human operators to meet the demands and constraints of the system as allocated and designed. It widens the question by examining human (the operator) more broadly. Here, humans are viewed in reference to their physical, emotional, and social requirements, and the job is viewed collectively rather than in terms of single human-machine transactions.

1. General Method

The general method of evaluation in this phase is similar to that used in phase 1, and the principles are detailed in Section 4.3.1.

2. Scope

This phase is required to consider all demands upon human except: (a) simple perceptual, cognitive, and motor information processing requirements (the core performance areas treated earlier in Phase 1), and (b) the long-term question of job satisfaction, which will be treated in Phase 6.

This step is therefore very inclusive, and must consider all demands made on humans that are predictable using the current disciplines in physiology, engineering psychology, and human factors science. A checklist of issues to consider will be offered below, but it is not meant to limit the range of inquiry. The evaluation team should seek to identify any excessive demand or constraint imposed by the allocation that is detectable based on either applied experience or scientific analysis.

3. Checklist

The following issues should be considered:

a. Psychological/physiological environment: shift length, job coherence, learning/performance requirements, and stress levels.

b. Physical environment: heat, lighting, noise, glare, etc.

c. Social structure: inter/intra-group characteristics, work team structure, and interpersonal interaction and support.

d. Organizational policy and structure: channels of communication, supervisory structure, and operator autonomy/responsibility.

4. Test Result

Failed: If an allocation of function or function segments fail this evaluation serially or simultaneously, one or more functions or function segments must be returned for reallocation. After the reallocation has been made, repeat this phase.

Passed: Functions that pass this test proceed to Phase 3.

4.3.2.3 Phase 3: Is the Cost Trade-off Acceptable?

This phase evaluates whether the allocation makes an optimum balance of cost between engineering and human factors development. In particular, it asks whether the engineering and human factors solutions can be achieved at an acceptable cost.

1. Evaluation Method

a. General Method. The general method of evaluation is parallel to that used in Phase 1, and the principles are detailed in Section 4.3.1.

b. Specific Method. The specific method includes the following procedural steps:

i) Re-examine the engineering and human factors solutions.

ii) Estimate the levels of development effort imposed by these solutions.

iii) Anticipate development problems.

iv) Detect cases of gross imbalance.

v) Detect cases where solutions may not be achievable.

vi) Detect cases where the cost of development may be unacceptably high.

c. Team Orientation. The engineering and human factors design representatives are responsible for assuring that team members understand the following matters:

i) The engineering and human factors design solutions.

ii) The degree to which those solutions are tested designs, departures from prior designs, or designs requiring new development.

iii) The implications of cost of acquisition cost of development, and development time (in general or comparative terms – not necessarily dollars).

iv) Actual dollar costs for analogous past developments (if available).

v) Technological hazard. What chance is there that the proposed solution will encounter development problems? Include the human factors solution: Can you really achieve the training or procedures capability proposed? Will it really perform as described?

vi) Consider full life cycle costs, as well as immediate development and procurement costs.

2. Items to be considered

   a. Identify Overlooked Tradeoffs. Consider each function in sequence. Are there any obvious improvements in engineering design that would reduce human factors cost (for example, automate to reduce crew size and reduce training cost)? Are there technology costs that could be reduced by allocation to human? Consider only major and obvious cases – do not pick the design.

   b. Is There Any Gross Imbalance of Cost? Examine each function to see if the designers have increased system cost by overemphasizing technology. Conversely, have they increased human cost by under exploiting technology? Refer to the level of technology guidance provided by the engineering concept.

   c. Has Technology Been Overestimated? Examine each function to see if there is a chance that the solutions may not be achievable, or may encounter unacceptable development problems.

   d. Can Technology Be Developed in Time? Can each hypothesized engineering or human factors solution be developed, debugged, and delivered in time?

   e. Are Costs Acceptable? Is there a chance that the development or procurement costs of hypothetical engineering or human factors technology will be unacceptably high? Consider each function individually, and then consider the design as a whole.

f. Special attention should be given to training costs, because when unrealistic costs have been hypothesized, the usual outcome is as follows: (1) At some point in development, either management raises an objection or a period of project economy forces retrenchment. (2) When this happens, management looks first to human factors items, such as training and simulators, to cut costs. Prime system hardware is less likely to be affected. (3) As a result, high-cost items, especially training programs, are replaced with less costly ones of more limited effectiveness. (4) The consequence is an imbalance of man and machine: the human factors design may depend on instrument, control, or automation technology which was not provided, or the engineering design may assume a training/crew/procedure capability which was not achieved.

g. Is Technology Consistent? Costs may not be defensible if one function demands a level of technology inconsistent with that of the system as a whole. Examine the design for functions that are treated at an obviously inconsistent level of technology, or at a level other than that supported by the engineering concept (step 2).

3. Test Result

Failed: A function or function segments fails this phase if there is a gross imbalance of technology between human and machine, if the balance selected causes unnecessary system cost, if the technical expectations will be hard to achieve, or if technology costs may not be acceptable. If the evaluation is Failed, the function or function segment should be returned for reallocation. The team chairperson makes the pass/fail decision after he has heard the opinions of the team members. When the function or function segment has been reallocated, repeat this phase.

Passed: Functions that pass this phase may continue to Phase 4.

4.3.2.4 Phase 4: Is the Human Factors Structure Adequate?

This phase inquires whether the human factors solution will actually meet the system demand for human performance. The allocation of functions up to this point was based on certain assumptions concerning the organization, numbers, ability, skill, and training of operating and supervisory personnel defined in the design basis. The design basis describes a human factors solution, requiring a supporting human subsystem design that would assure the availability of an adequate organization, numbers, ability, skill, and training of personnel. This phase evaluates whether the allocation of functions is adequate to the needs determined by the human factors solution of the design basis.

1. Method and Content

   a. General Method. The general method of evaluation is parallel to that used in Phase 1, and the principles applied are detailed in Section 4.3.1.

   b. Special Considerations. This test will determine whether the human subsystem design can be reasonably assumed to meet its objectives in the following areas:

      i) Can the organization be expected to provide personnel at the times and places required?

      ii) Is supervisory and consultative support adequate?

      iii) Is the division of roles between plant and control room suitable to enable implementation of functions that may be anticipated for future use but are not currently planned?

      iv) Is crew size adequate at all times?

      v) Are specified individual abilities equal to anticipated demand?

      vi) Are specified skill and experience levels of the operators consistent with the operational demands of the HSI?

      vii) Are specified training levels equal to anticipated demand?

      viii) Are specified documentation and procedures equal to the crews' anticipated needs?

   The answers to the foregoing questions will depend on all features of the HSI design.

2. Test Result

   Failed: If the function or function segment fails this evaluation, return them for reallocation.

   Passed: If this evaluation is passed, proceed to Phase 5.

4.3.2.5 Phase 5: Is Cognitive Support Adequate?

This phase determines whether the design provides the control room operator with sufficient information to maintain a continuous and adequate mental model of the plant and systems. At any time operators may be required to make judgments or take control actions based on knowledge of the plant and its structure, status, and behavior. This knowledge constitutes a mental model which operators will use continuously to predict how plant processes will proceed, as well as to predict the effect of any control actions taken. In emergencies, those mental models provide a means to detect abnormal conditions, to diagnose their cause, and to intervene to minimize the consequences.

How well these mental models are maintained depends on the operator's training and, more particularly, on recent operating experience. That experience must be adequate to provide frequent reminders of the plant's structure and continuous information about its important process variables. "Cognitive support" is that part of the operator's job that is deliberately designed to supply to him the information necessary for maintaining an adequate mental model.

1. General Method

   The general method of evaluation used in this step is also parallel to that used in Phase 1 and the principles are detailed in Section 4.3.1.

2. Test Result

   Failed: If the function or functions fails this evaluation, return for reallocation.

   Passed: If passed, proceed to Phase 6.

4.3.2.6 Phase 6: Is Job Satisfaction Optimum?

Previous phases have evaluated whether the human/machine solution is an acceptable allocation and is not precluded by human factors limitations. This step asks whether the human, on a continuing basis, will be satisfied in performing the job as designed. Moreover, it asks whether tasks have been allocated to human or machine in such a way as to optimize the human's satisfaction.

1. General Method

   Again the general method of evaluation used is parallel to that used in Phase 1, and all except Item (2) of the principles detailed in Subsection 4.3.2.1 are applied. In this case, analysis considers functions simultaneously only – not individually in series.

2. Test Result

   Failed: If the function or functions fail this evaluation, they are returned for reallocation.

   Passed: If this evaluation is passed, evaluation of functions is completed.

4.3.3 Tradeoff Studies

For deciding between different function allocations in the framework of function evaluations, it should be very convenient to carry out analysis and trade-off studies to determine adequate configurations of personnel and system-performed functions. Tradeoff studies are performed throughout development as an essential part of the development process. As a formal decision analysis method, tradeoff studies are used to solve any complex problem where there is more than one selection criterion and to document the rationale for the decision (AD/A223 168 [2.4(1)]).

The CRDT should develop a measurement of goodness of allocation that could supplement the categorical measures provided earlier by deductive evaluation phase and which also might permit scalar comparison between different alternative allocations. This method of quantification is recommended as an adjunct to deductive evaluation for supporting results and also for deciding between different functional allocation strategies in the framework of function evaluation.

The Multi-Attribute Utility Technique (MAUT) is recommended [2.5(4 and 5)]. Listed below are reasons for recommending MAUT:

1. Systems under evaluation normally have multiple goals, not all equally important, and frequently competing.
2. Judgments are inevitably a part of any evaluation.
3. Judgments of magnitude are best when made numerically.
4. Evaluations typically are, or at least should be, relevant to decisions.

An important advantage of this technique is that it can use subjective judgments, when no other data is available, although when experimental or other 'hard' data are available, they can easily be incorporated. It makes coexistence of judgment and objective measurement within the same evaluation easy and natural, and opens the door to easy combination of complex concatenations of values. Use of subjective inputs can also greatly shorten the time needed to perform an evaluation. The process for carrying out a tradeoff analysis is represented in Figure 22.

4.3.3.1 Definition of Objectives and Requirements

The first step is to define the objectives and requirements of the trade-off study.

4.3.3.2 Identify Alternatives

Candidate alternatives should reflect the widest possible range of distinctly different solutions if the overall goal of optimized system design is to be achieved.

Next, candidate alternatives identified through brainstorming may be screened based on attainability and affordability: That is, are the candidate alternative solutions achievable within time and budgetary constraints? This ensures that the analysis effort does not waste time.

Remaining candidate alternatives become the decision alternatives. These alternatives are described fully and carefully. Sufficient detail must be available to judge the relative worth of each workable, attainable alternative.

4.3.3.3 Formulate Selection Criteria

Selection criteria or decision attributes are standards for judging different allocations of the functions studied. The criteria may include quantitative goals (the desired value of the attribute) where possible, and thresholds beyond which the characteristic is unsatisfactory. The CRDT may decide to use criteria that are based on personal experience. The decision criteria used by the CRDT should:

1. Differentiate meaningfully between alternatives without bias.
2. Relate directly to the purpose of the tradeoff analysis, including established requirements and high-interest concerns.
3. Be stated in broad terms
4. Be able to be measured or estimated at reasonable cost.
5. Be independent of each other at all levels.
6. Be universally understood by evaluators.

Selection criteria could include both objective and subjective measures. The team should formulate these criteria. The design team may use the criteria applied in deductive evaluation or additional criteria. Possible criteria include:

- Safety
- Availability
- Producibility
- Reliability
  - Load
  - Accuracy
  - Time

  - Frequency
  - Complexity
- Feasibility
- Maintainability
- Staffing
- Existing practices and procedures
- Operational experience
- Regulation
- Policy
- Situation awareness
- Training needs
- Job satisfaction
- Cost*

NUREG/CR-3331 [2.3(1)] presents different methods for weighting the criteria, preparing a utility function, evaluating alternatives and performing sensitivity checks. Each methodology must be reviewed to determine if the data collected using qualitative methodologies can be evaluated quantitatively. Many of the allocation decisions for ESBWR are expected to be based on operating experience and expert judgment.

4.3.3.4 Weight the Criteria

The purpose of this step is to assess the relative importance of each of the criteria previously identified. Weighting is a subjective process for quantifying value ("goodness") judgments. However, weighting helps make potential decision biases apparent to persons other than the designer or the analyst, and this is consistent with a team-oriented HFE approach. There are three weighting schemes as follows:

* An important attribute in all evaluations is cost. There are two approaches to evaluating cost. One approach is to treat cost as another attribute. This is often done, especially for informal or quick evaluations. Disadvantages of this practice are that some evaluations may not involve cost in any significant way, or they are desired to be cost-independent. Judgments required to trade off cost against utility points are usually considered the least secure and most uncomfortable to make of all those that go into MAUT [Edwards and Newman, 1982]. The other approach is to consider cost in a final benefit-cost analysis with final aggregated utilities, the numeric result of MAUT.

1. Equal or Unit Weighting

   NUREG/CR-3331 [2.3(1)] follows this scheme, in which all criteria are considered as equally important. However, on the design basis of expert judgment, this scheme is not recommended, since it does not capture all the possible differences in criteria.

2. Weights from Rank Ordering

   This is the simplest way of assessing differential weights. The procedure is to rank order each criterion from most important to least important. A numerical weight is assigned to each criterion according to its rank. The most important criteria is given the highest weight, the second most important the next highest weight, and so forth. Some (but not all) of the criteria may be equally important in which case they should be given the same weight. These numeric "importance weights" are called *inverse ranks*. Normalized weights are obtained by dividing each weight by the sum of the weights. These normalized weights are called *rank sum weightings*. An example is given below:

Criteria	Importance Weight (or Inverse Rank)	Normalized Importance Weight (w_i)
Safety	10	0.36
Cost	8	0.29
Reliability	6	0.21
Job Satisfaction	4	0.14
	$\Sigma = 28$	$\Sigma = 1.00$

3. Ratio Weighting

   This scheme is more demanding and requires preliminary training and practice. Techniques 1 and 2 are sufficient. Ratio Weighting involves the elicitation of numerical quantities for importance of each criterion, in an interval scale (e.g., from 1 to 10). The final weights are computed using eigenvector analysis to determine the relative weightings of all criteria.

4.3.3.5 Prepare a Utility Function

Utility functions are useful techniques for translating diverse criteria to a common numeric scale. Utility functions assume that changes in the performance associated with a particular criterion can be translated into a utility score called a *utility measure*. Utility measures (also called single-criterion utilities or single-attribute utilities) are assessments of how favorable or desirable each function allocation is with respect to each of the criteria. These measures are subjective and they may be either simple arithmetic transformations or objective measures. The team determines where each function allocation lies within a respective criteria scale.

Normalized utility measures can be calculated using the following transformation:

$$u_{iA} = (u_a - u_{min})/(u_{max} - u_{min})$$

where u_{iA} is the normalized utility measure for Alternative Allocation "A" for the i^{th} criteria, u_a is the position of Alternative Allocation "A" in the criteria scale, u_{min} is the minimum desirability of the criteria, and u_{max} is the maximum desirability of the criteria.

A common scaling from 0 (zero) to 1 (one) can be defined for each selection criterion. Zero would correspond to the least favorable condition regarding the criterion (e.g., lowest reliability) and 1 would correspond to the most favorable condition regarding the criterion (e.g., highest reliability). An example is given below:

Utility Measures (u_{ij})

Alternative Allocations	Safety (scale: 0 to 1)	Cost (scale: 0 to 1)	Reliability (scale: 0 to 1)	Job Satisfaction (scale: 0 to 1)
"A"	0.5 (= u_{1A})	0.7 (= u_{2A})	0.5 (= u_{3A})	0.5 (= u_{4A})
"B"	0.9 (= u_{1B})	0.4 (= u_{2B})	0.6 (= u_{3B})	0.3 (= u_{4B})

4.3.3.6 Evaluate Alternatives

Two sets of numbers are available at this stage; namely, the importance weights (w_i) for each criteria and the utility measures (u_{ij}) for each alternative allocation on each criteria. The next step is to combine these two sets of numbers into composite utility measures using the following relationship:

$$U_j = \sum_{i=1}^{n} w_i u_{ij}$$

where U_j is the composite utility measure for the j^{th} alternative allocation, which is computed as the weighted sum of the criteria weights and the individual utility measures. This is the numeric output of MAUT. A larger value of U_j indicates a more favorable or desirable allocation.

4.3.3.7 Perform Sensitivity Check

When the total weighted scores of several alternative allocations are approximately equivalent, a small change in the estimated performance of any alternative allocation against any criterion can change the outcome regarding which allocation is most favorable. In these instances, it may be useful to indicate a range of estimated performance values having a known confidence level that can be transferred to the weighted scores. If objective data are used, knowledge about the frequency distribution of measures will be of great value, since accurate confidence intervals can be computed.

Sensitivity analysis consists of changing some of the numbers that went into the initial analysis, and doing it again to see if the composite utility measure for each alternative allocation changes. Probably the most important kind of sensitivity to look at is sensitivity to weights, since they are the essence of the technique and because they are purely subjective numbers about which people usually disagree. Sensitivity analysis consists of a series of steps. The first step involves varying the importance weights. The second step consists of changing the utility measure. Then the overall utility measure for each allocation is computed again, and differences with respect to previous results can be seen.

Often, the final choice (that is, the alternative with the highest composite utility measure) is not changed. However, when the final choice is changed, there are several options:

1. Delay the decision until additional information is available.
2. Acquire additional data or refine analysis to reduce uncertainty.
3. Review criteria and weights for modification.

The tradeoff study is completed when the team selects the preferred alternative.

5 Allocation of Functions Report

An allocation of functions report shall be prepared for each system subjected to functional requirements analysis. The report shall document those functions that have been allocated to the human and/or the machine. The bases for the allocation shall be clearly stated. Design requirements provided in the SDS (e.g. regulatory, design, etc.), previous studies, design record files, or operating experience shall be referenced if it has been used as a basis. Functions allocated to automation shall also be clearly identified. The report shall identify, by function, the monitoring and control functions that have been allocated.

The criteria provided in Appendix A provide guidelines that may be used as a decision bases. As necessary, the CRDT may elect to perform static and/or dynamic evaluation to verify the allocation of functions before the formal V&V.

The CRDT shall review the report to insure that the allocation clearly identifies the bases for allocation, including any HFE criteria that are applicable. If the system has been automated in the past and continued automation is required due to operating experience, etc., this should be clearly noted. The report should attempt to capture the results in an electronic database to facilitate quick review and revision.

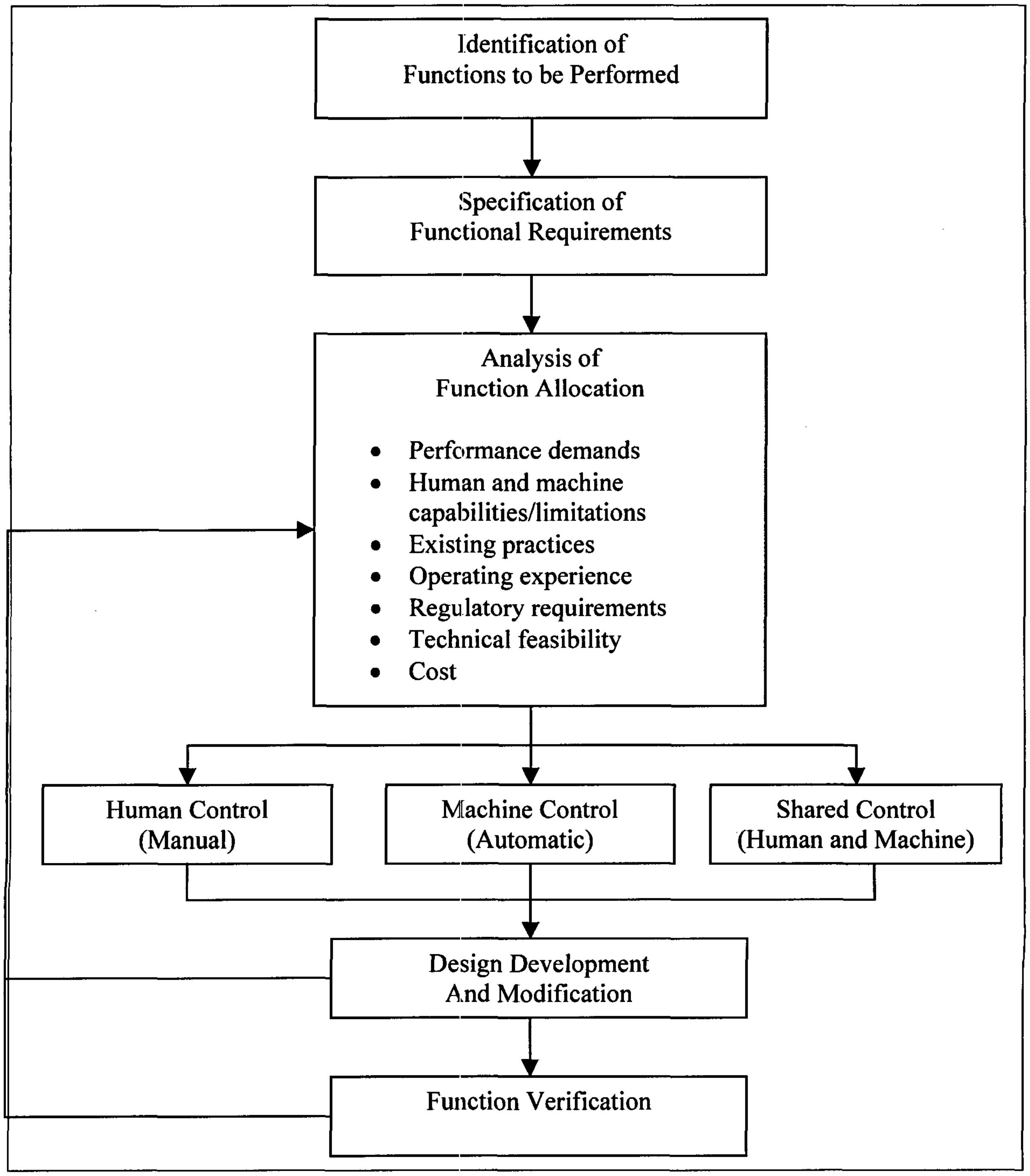


Figure 1 Human-System Interface Design Implementation Process

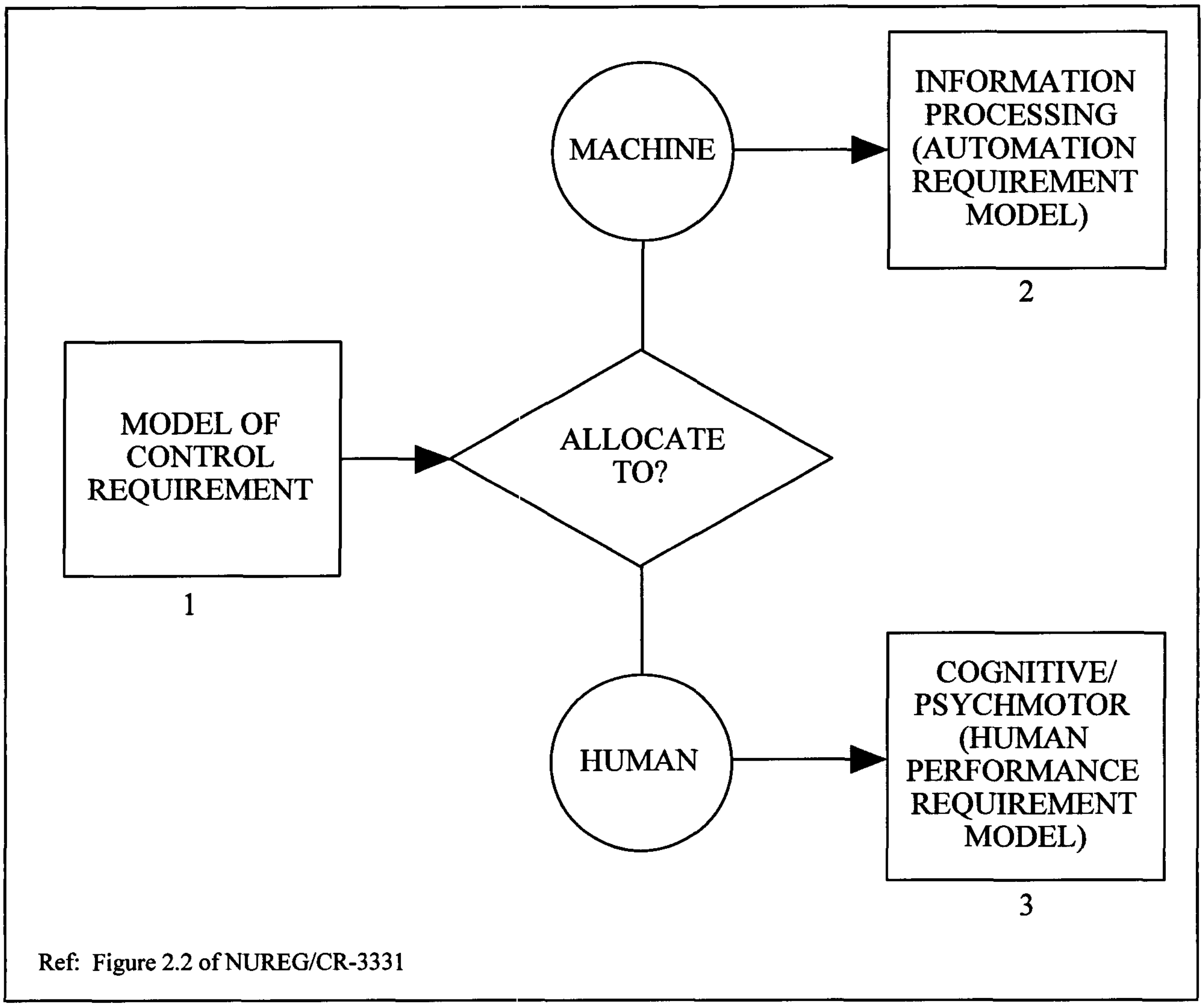


Figure 2 Models Involved in Analysis of Functions

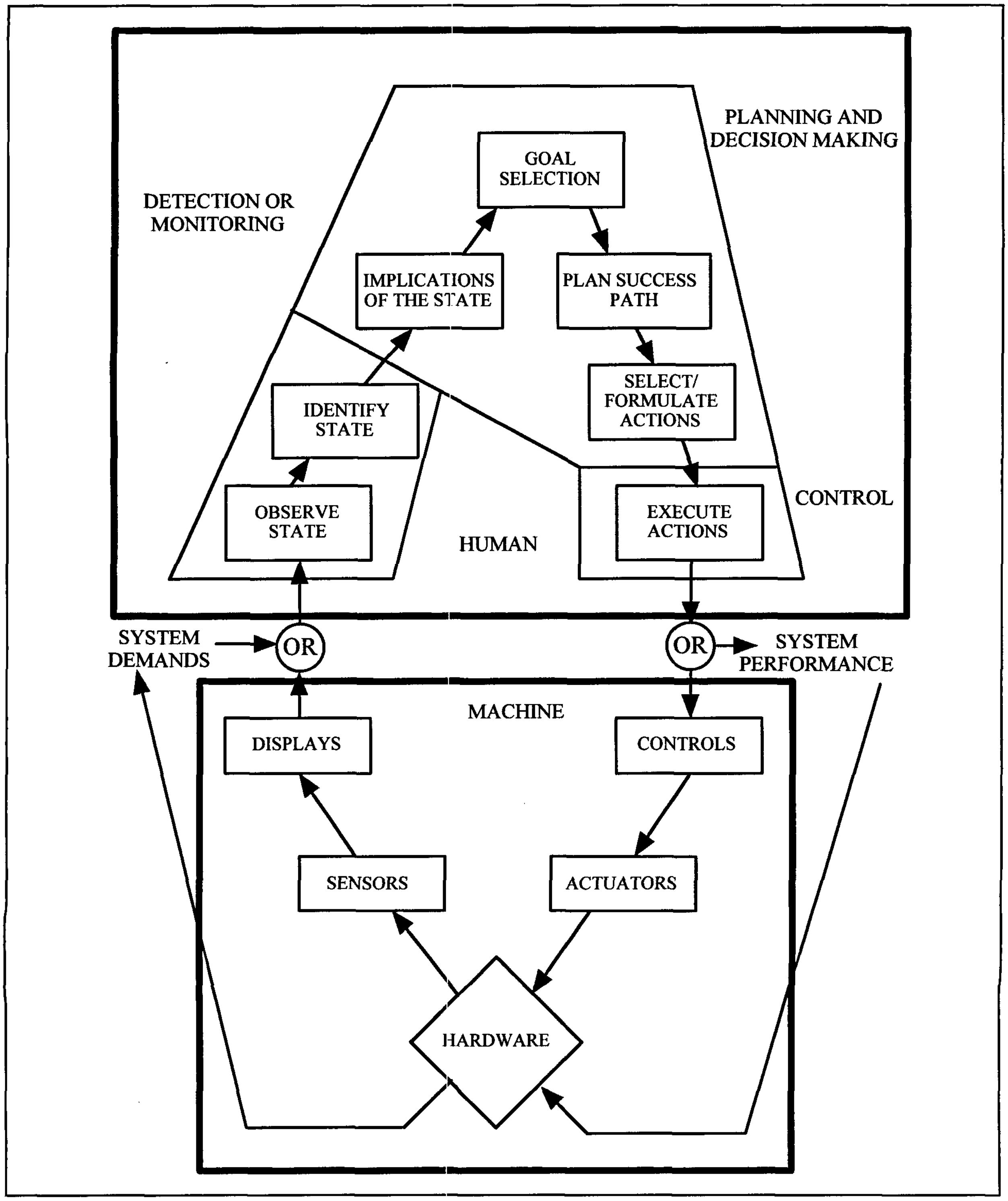


Figure 3 Model of Control Requirements

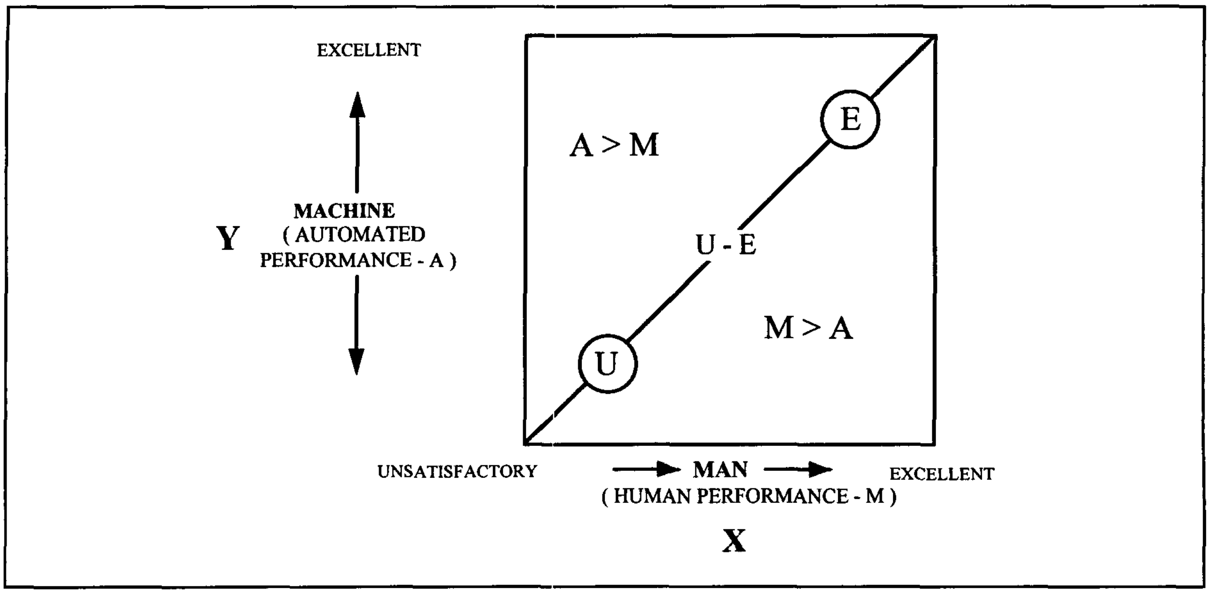


Figure 4 Decision Space for Relative Control Performance of Human and Machine (From NUREG/CR-3331, [2.3(1)])

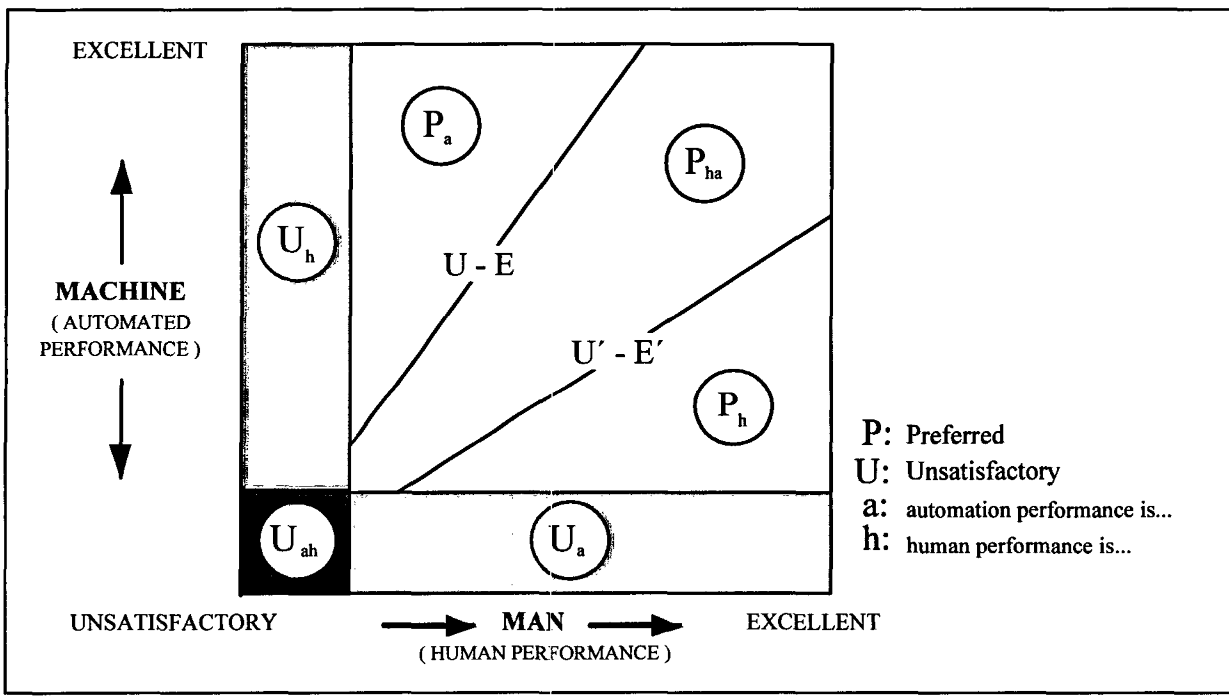


Figure 5 Decision Matrix for Allocation of Functions (From NUREG/CR-3331, [2.3(1)])

1. Function	Code 1.5.2.3: Heat, cool, vent areas of RAB with filtered air at specified temperatures. Maintain human habitability. Cool RAB equipment. Control radiation leakage.
2. Subsystems	HVAC RAB subsystems. RAB equipment. On/off site power. Pumped river cooling water system. Ambient air. Heating steam supply system.
3. Plant States	(1) Normal operation. (2) Equipment fire (3) Equipment radiation leak (4) Radiation leak external to RAB (5) HVAC component failure/maintenance. (6) Transition to/from (2) (3) (4) (5)

4. Control Requirements	5. Equipment Function	6. Operator Function
Maintain normal cooling level Maintain normal heat level Maintain required rate of air flow • • • Start backup fans Filter radiation from exhaust air Reconfigure dampers for radiation containment • • • Etc.	Activate fans, refrigeration, heating coils, using setpoint thermostat Display temperature and flow data Display predicted data from trend forecasts Provide abnormal parameter alarms Provide equipment failure alarms Control dampers (normal) using program logic • • • Etc.	Recognize abnormality Set thermostats seasonally by phone to Plant Equipment operator Make periodic log entries per procedure Start emergency fans • • • Reconfigure dampers to contain radiation Reconfigure dampers to control fire • • • Etc.

Figure 6 Examples of Contents of an Allocation of Function Document (From NUREG/CR-3331, [2.3(1)])

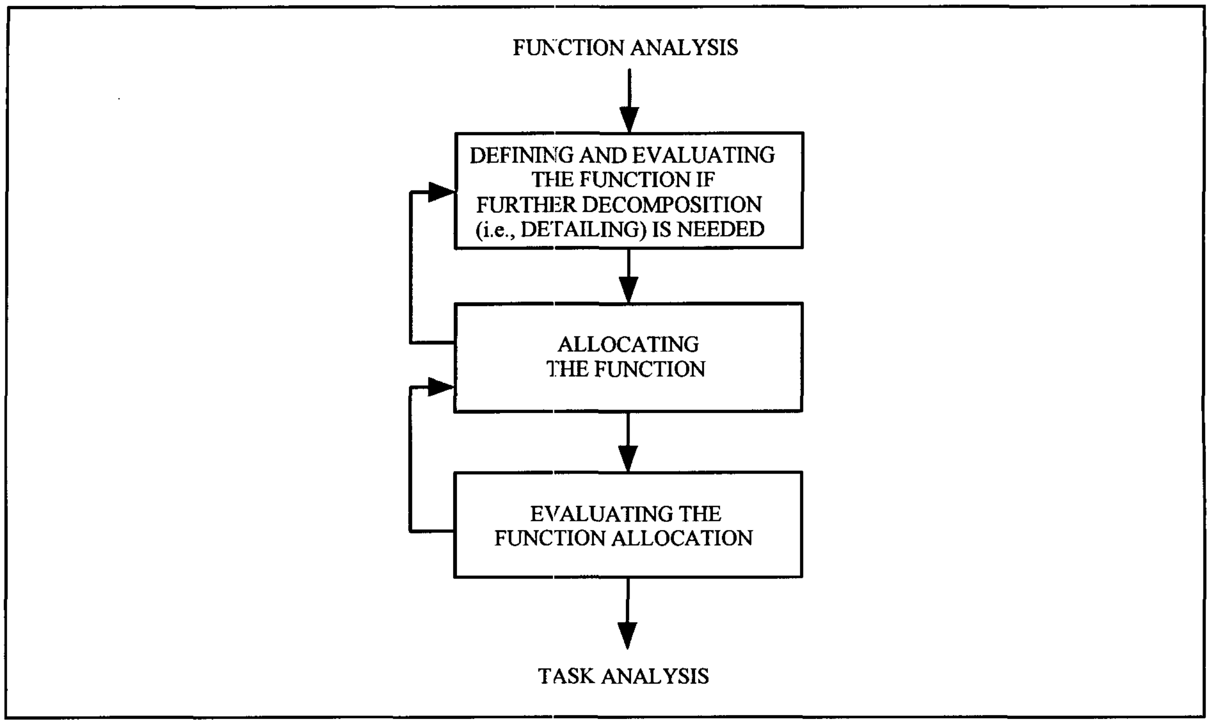
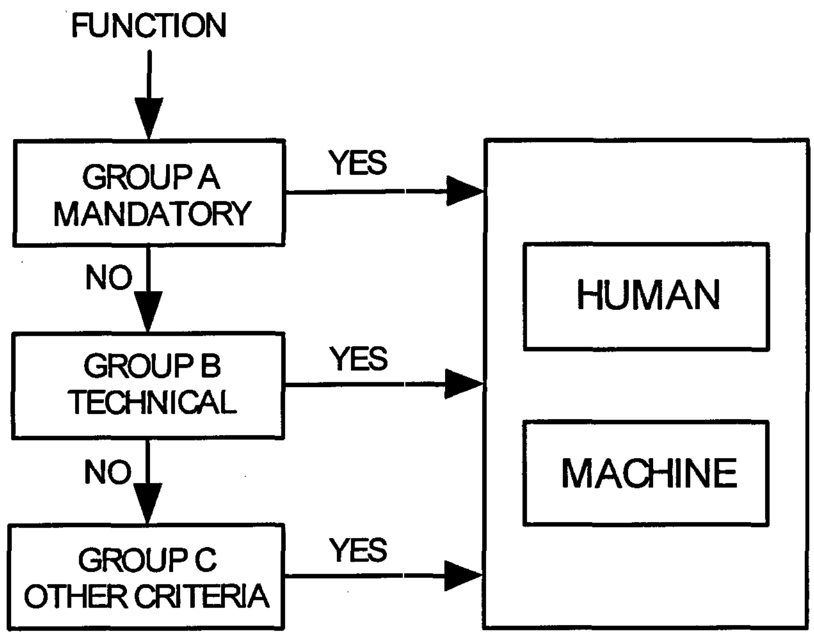


Figure 7 Phases of Function Allocation



Groups A, B and C above correspond to regions of the decision matrix as shown in Figure 9.

Figure 8 Processes to Carry Out a Function Allocation

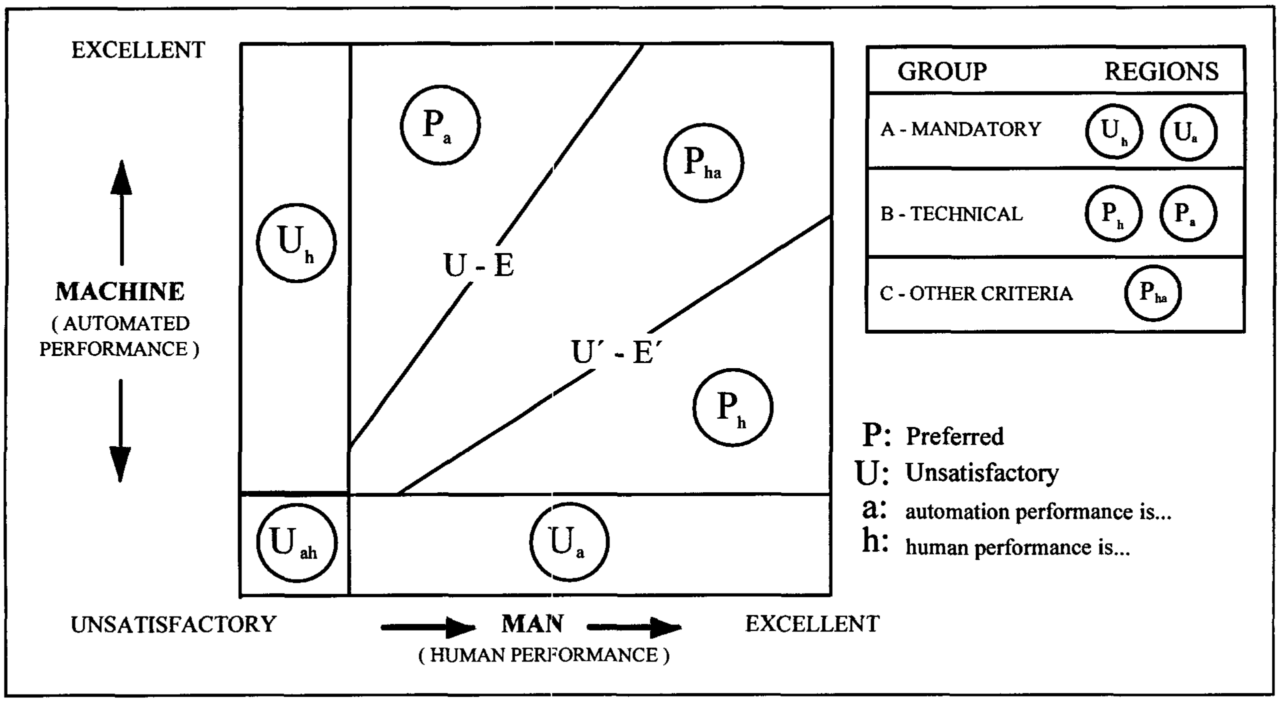


Figure 9 Decision Matrix for Allocation of Functions

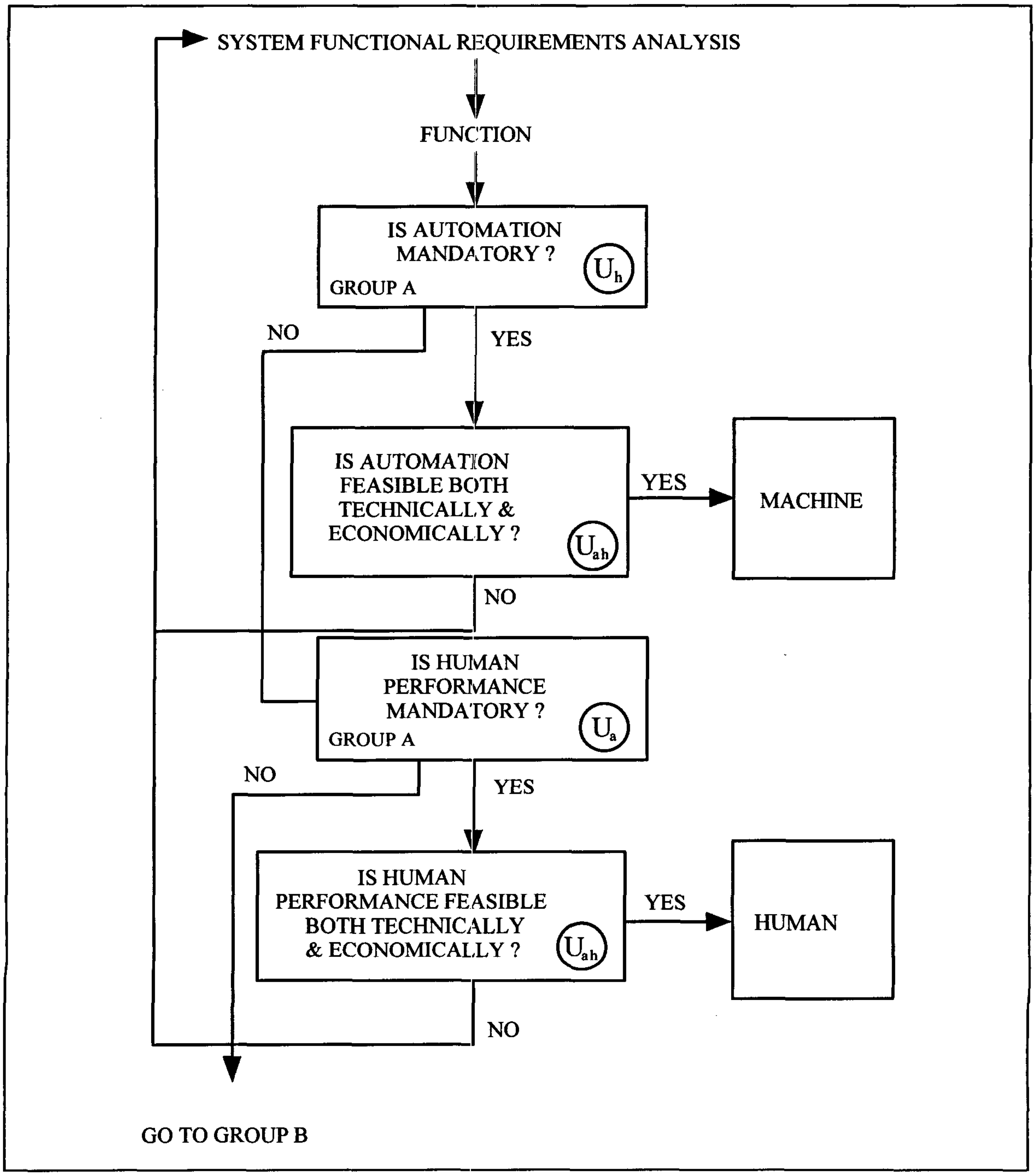


Figure 10 Process for Allocating a Function for Mandatory Reasons

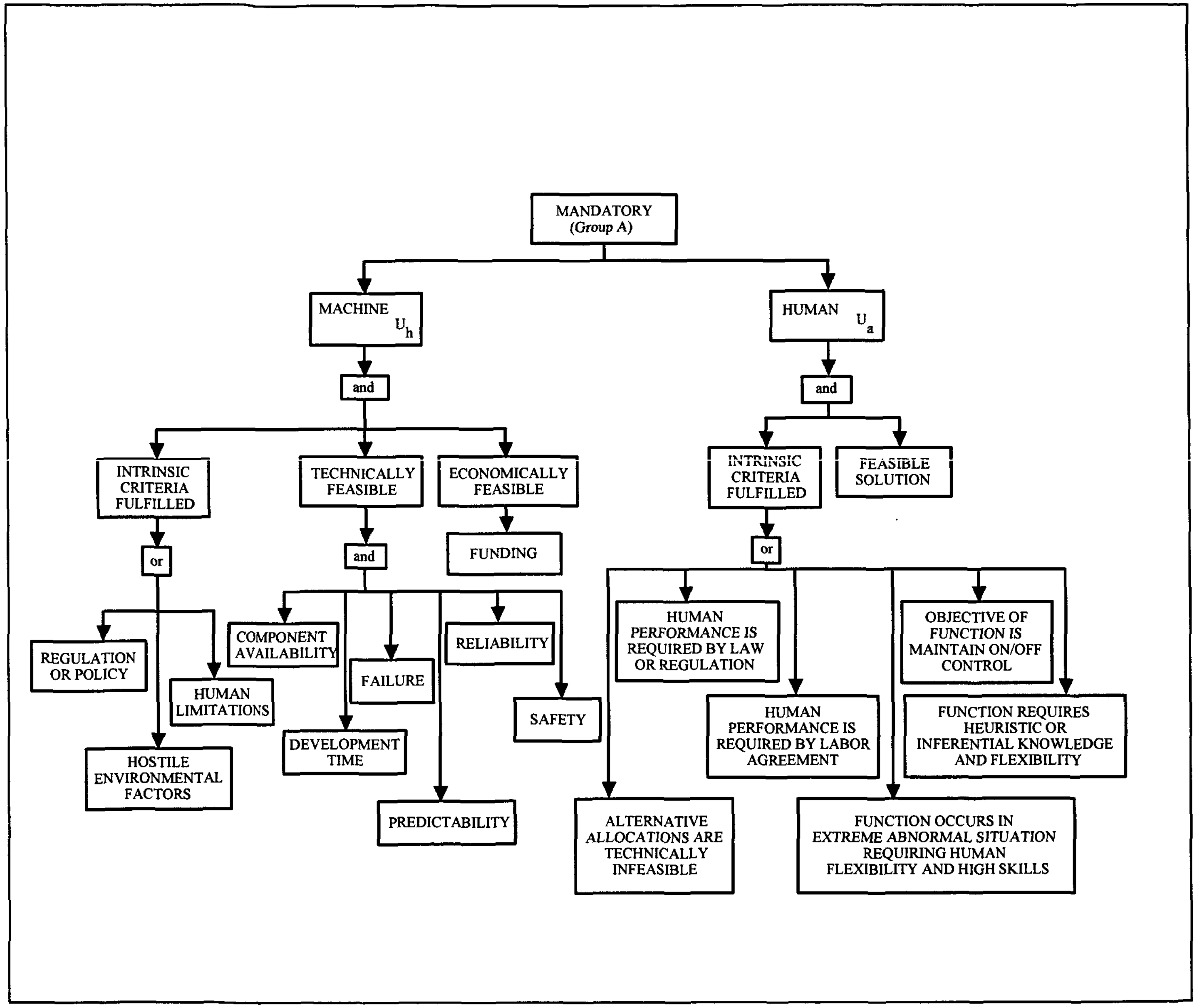


Figure 11 Criteria for Allocating a Function to Human or Machine for Mandatory Reasons

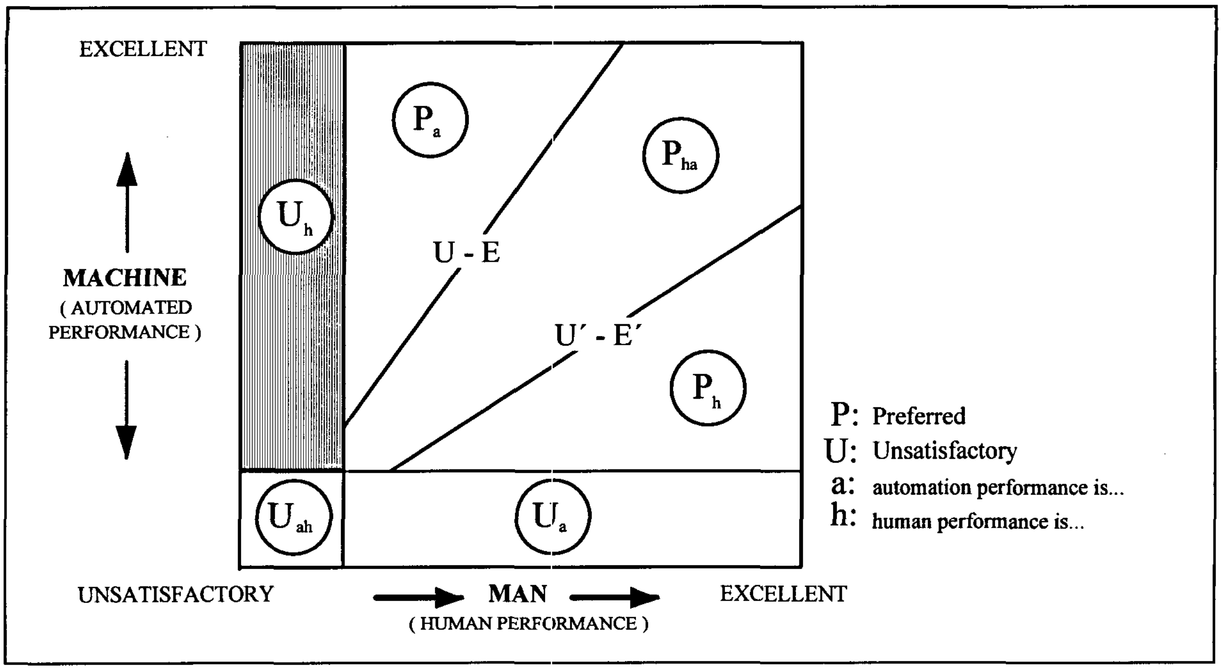


Figure 12 Decision Matrix for Allocation of Functions – Automation is Mandatory

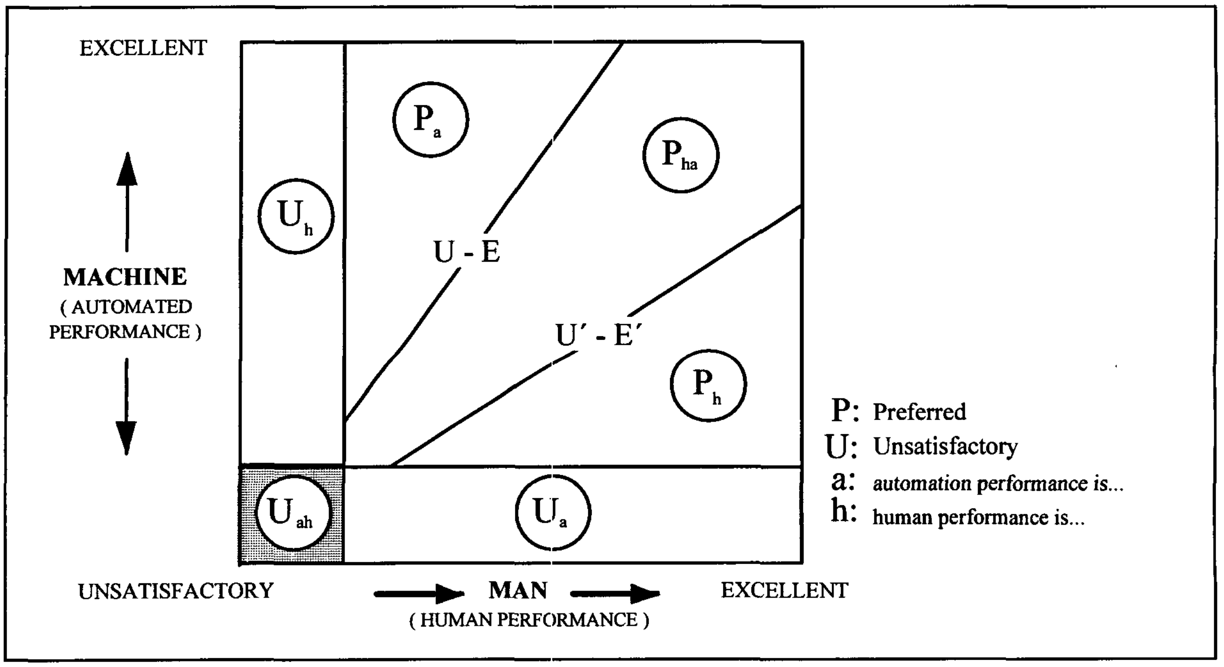


Figure 13 Decision Matrix for Allocation of Functions – Automation is Not Technologically Feasible

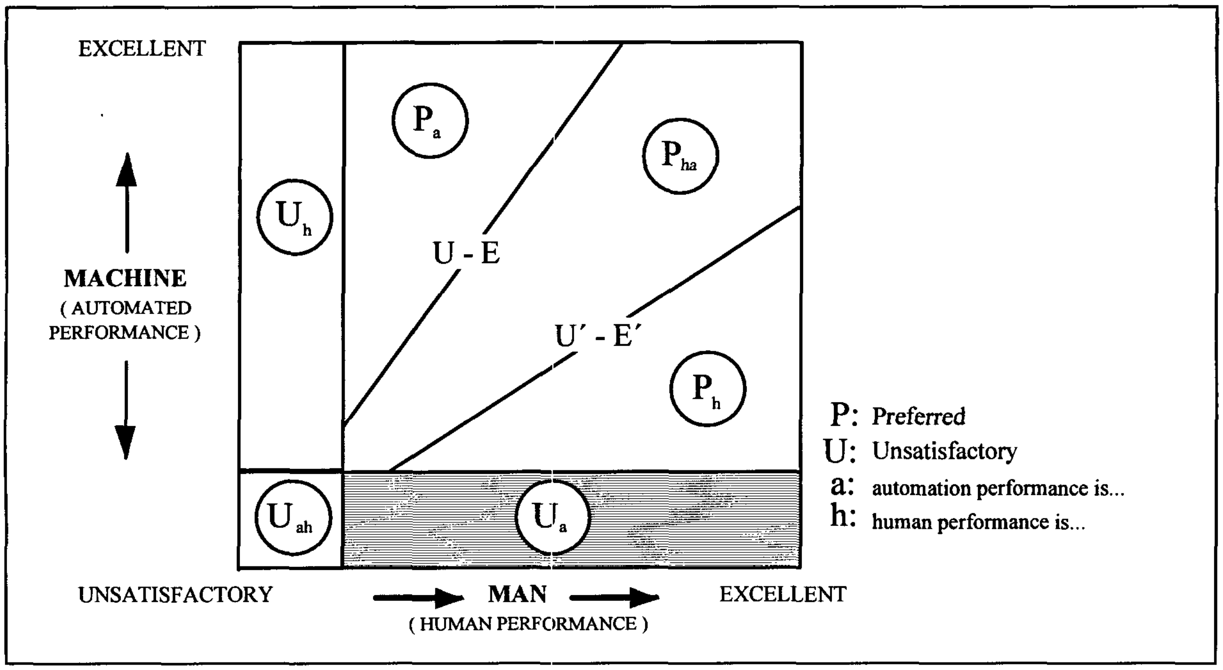


Figure 14 Decision Matrix for Allocation of Functions – Manual Control is Mandatory

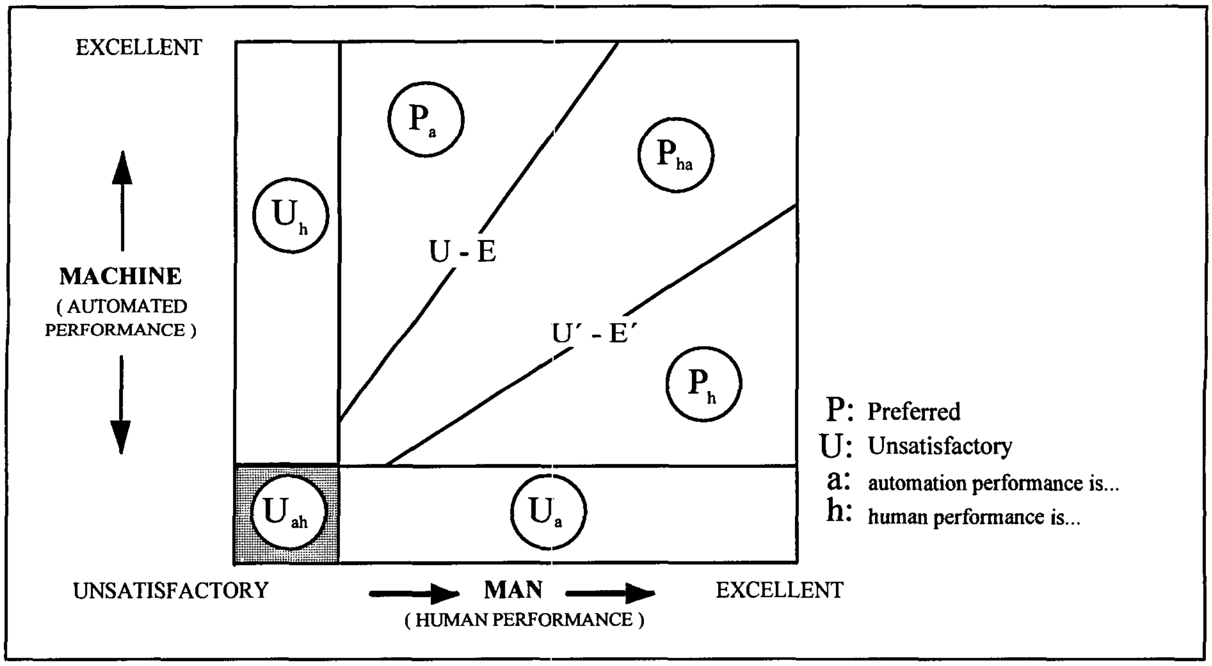


Figure 15 Decision Matrix for Allocation of Functions – Manual Control is Mandatory but not Feasible

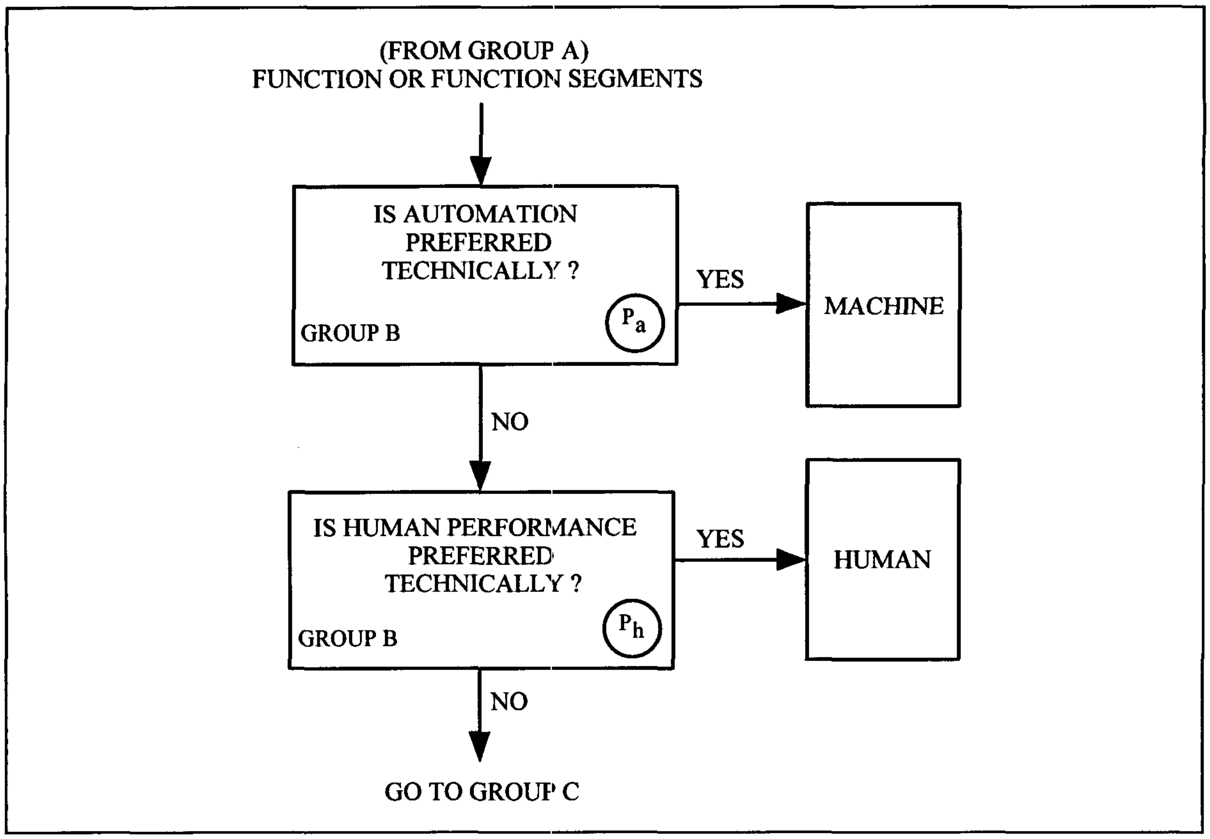


Figure 16 Process for Allocating a Function to Human or Machine for Technical Reasons

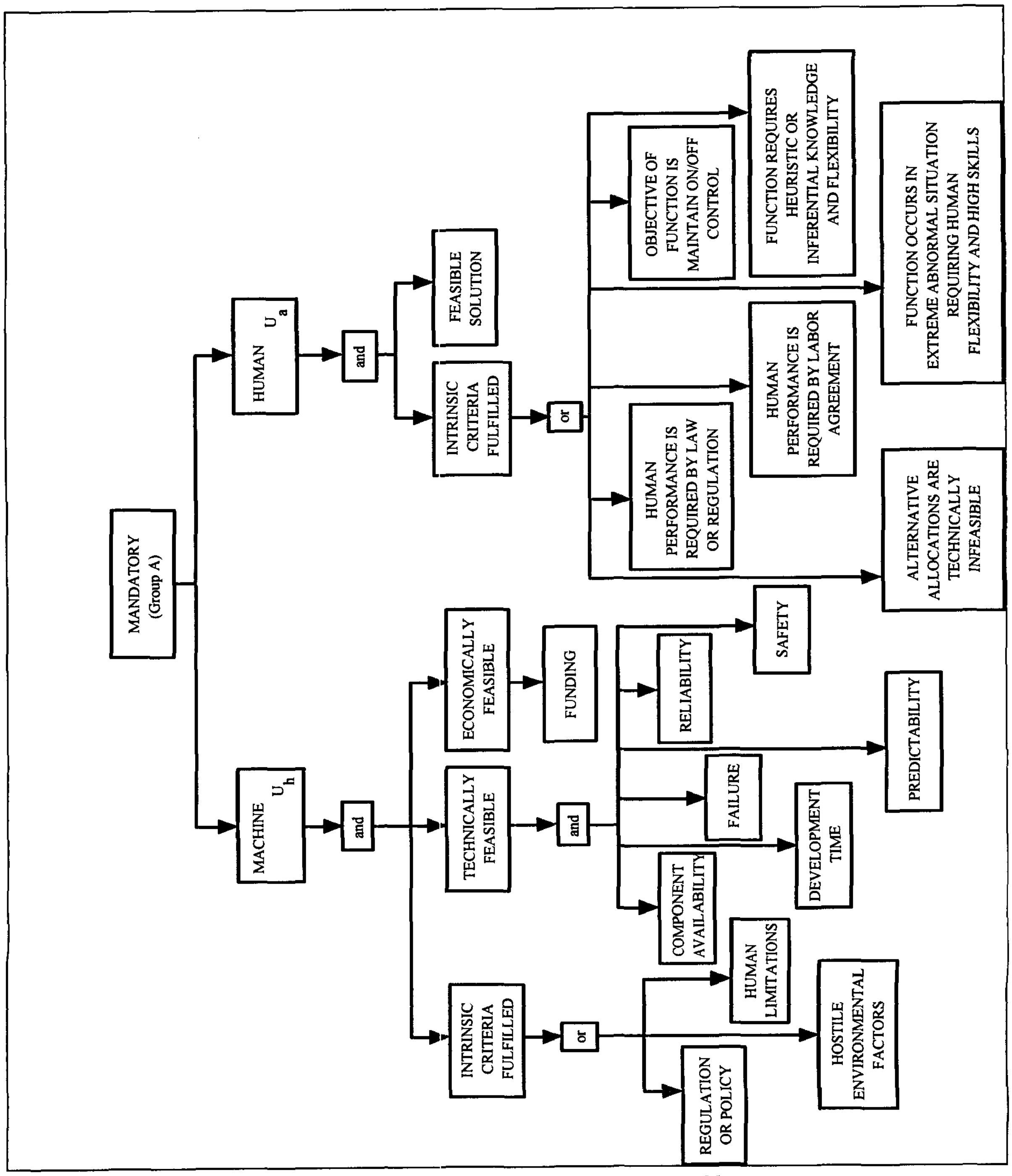


Figure 17 Criteria for Allocating a Function to Human or Machine for Technical Reasons

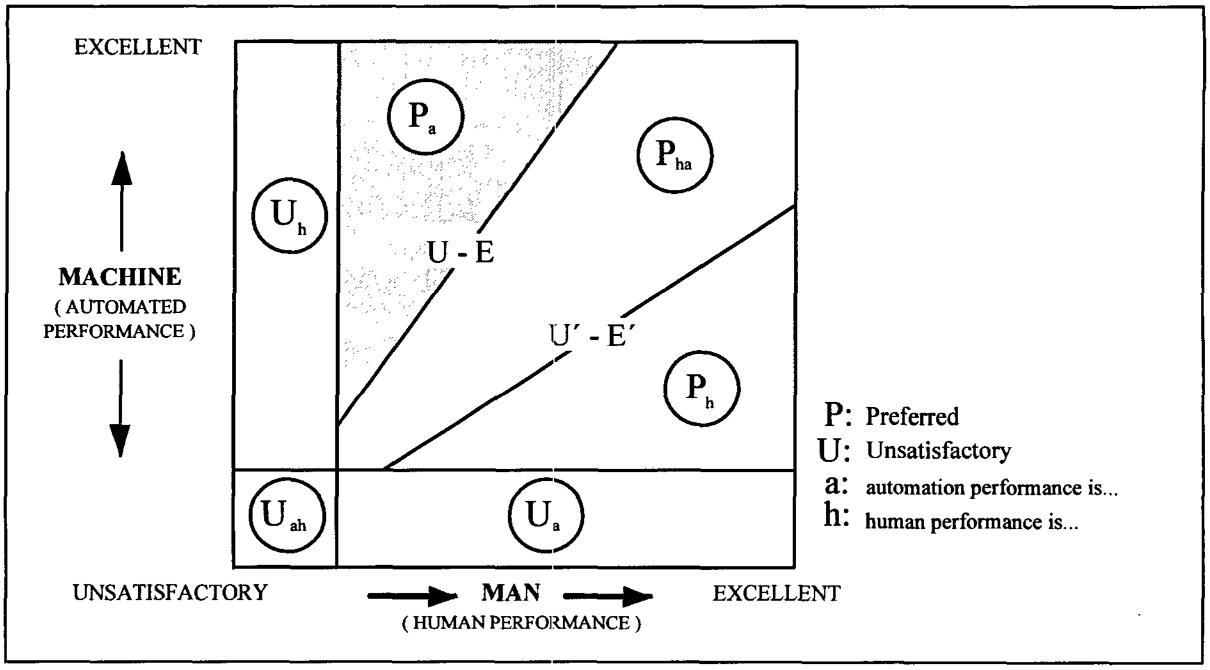


Figure 18 Decision Matrix for Allocation of Functions – Automation is Not Mandatory but Technically Preferred

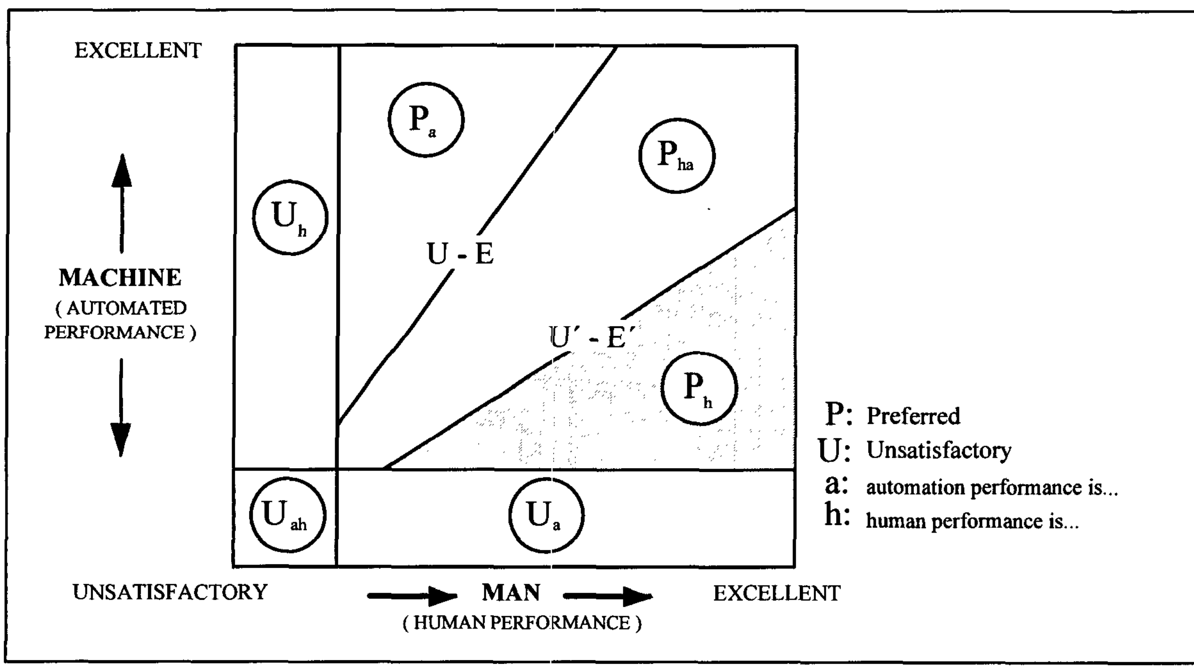


Figure 19 Decision Matrix for Allocation of Functions – Manual Control is Not Mandatory but Technically Preferred

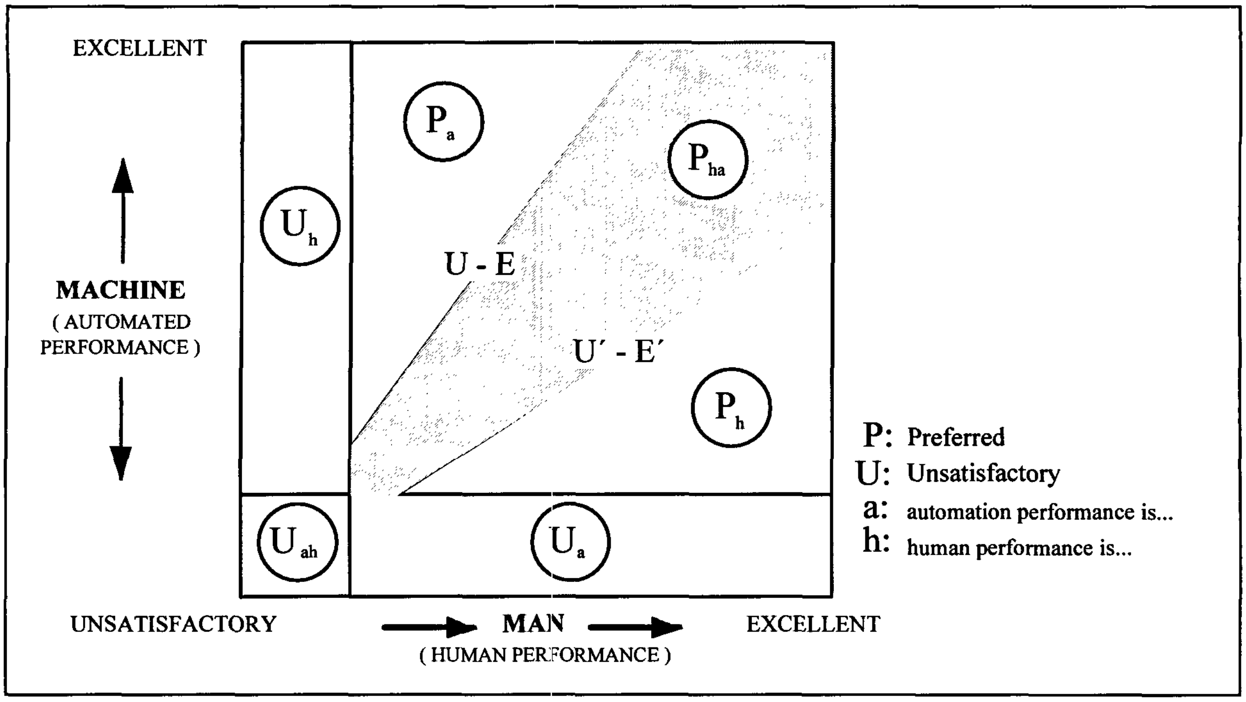


Figure 20 Decision Matrix for Allocation of Functions – Function to be Allocated by Other Criteria

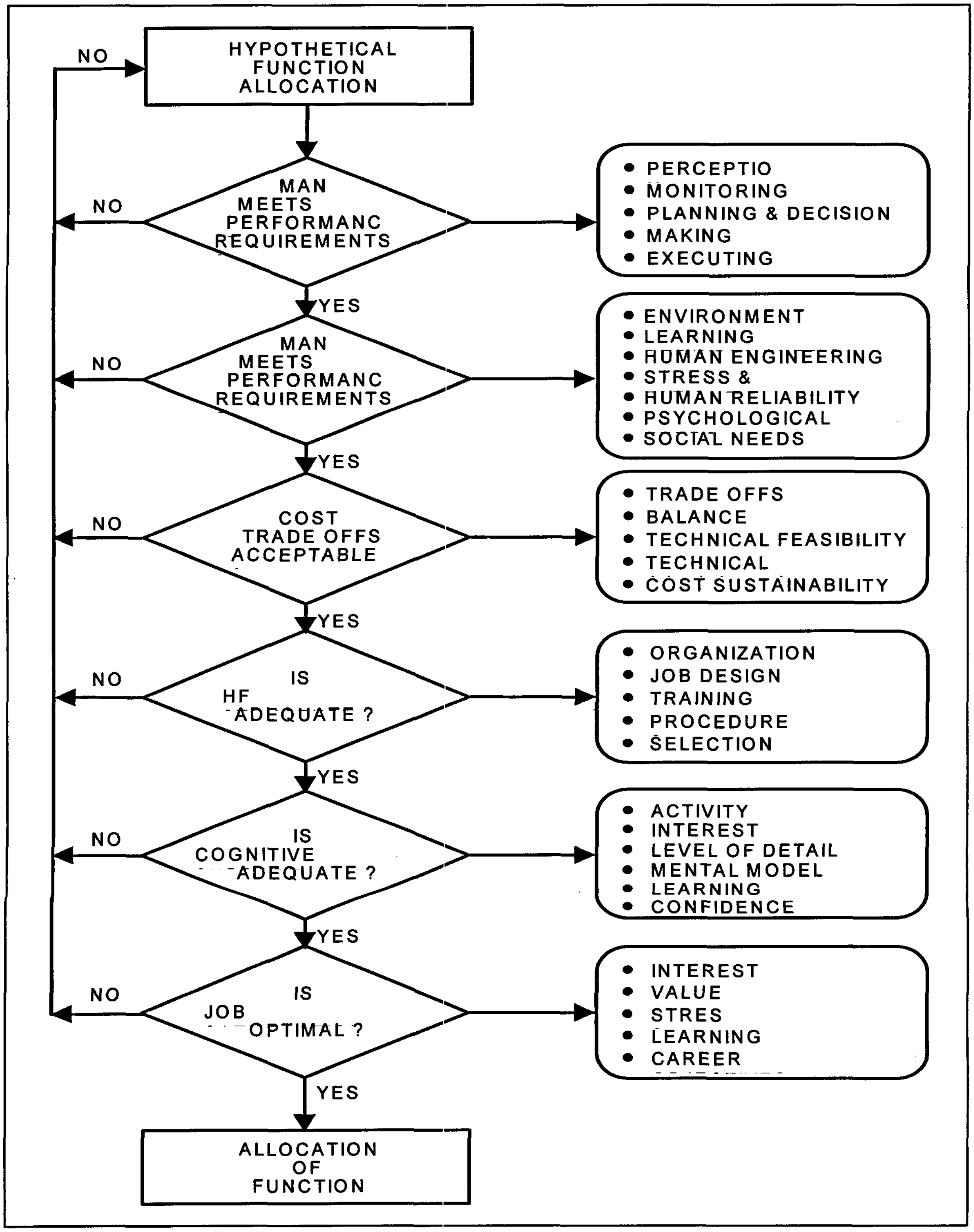


Figure 21 Evaluate Allocation of Functions Deductively

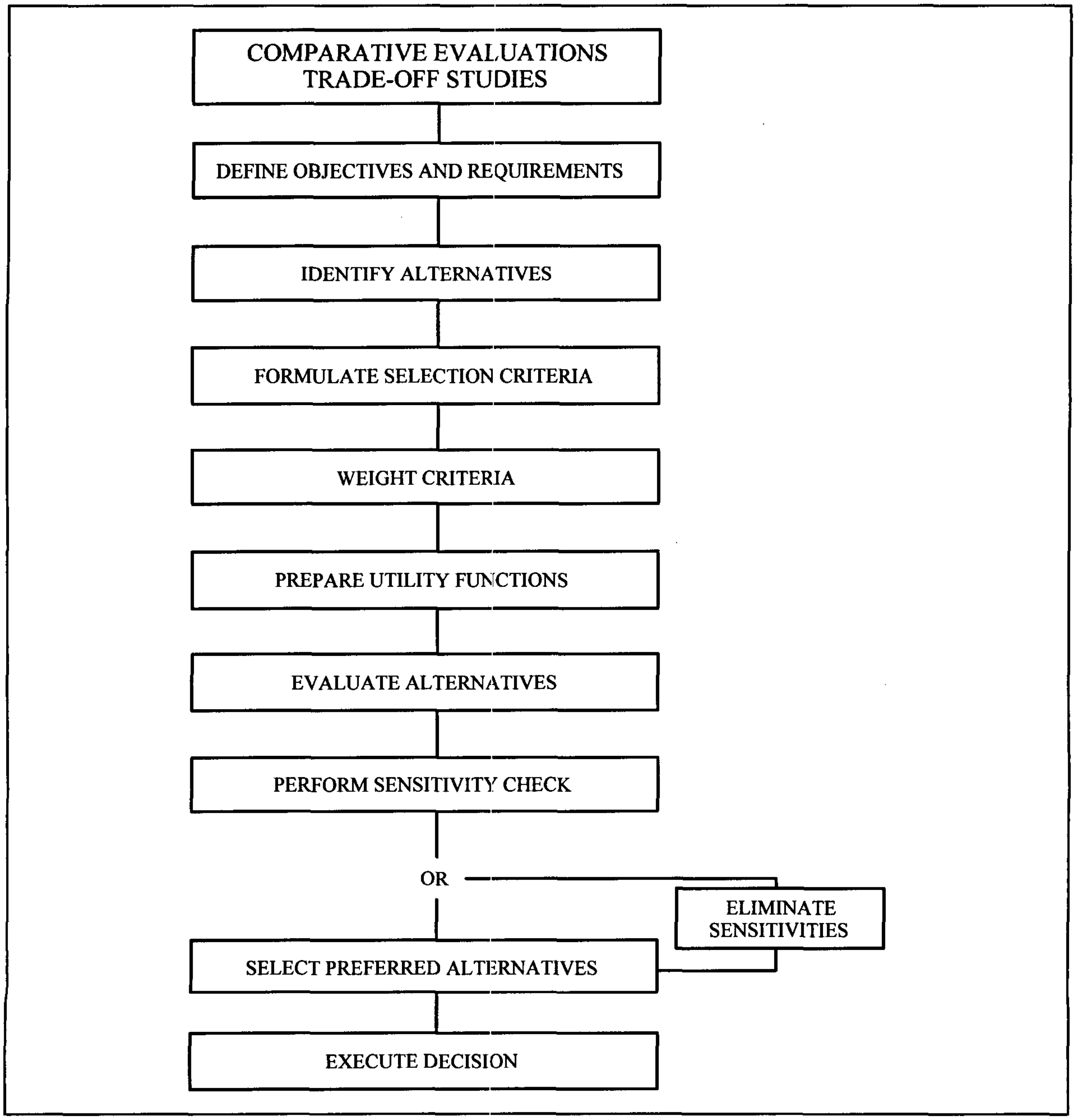


Figure 22 Process to Carry Out a Tradeoff Analysis

Appendix A: Human Capabilities and Limitations

A1 Criteria that Limit or Preclude Human Participation in a System Function

Consideration should be given to the exclusion of the human in performing a function when one or more of the criteria below apply [Ref: 2.3(2)]:

Application of Force	Large, precise, or extended applications of force preclude the human. Human instantaneous peak force is limited to a mean force of 50 Newton.
Response to Stimuli/Signals	The human operator experiences a finite lag between the onset of a stimulus and the ability to make a response to it. This lag varies from a mean of 100 msec for auditory stimuli and approximately 120 msec for visual stimuli, to lags in excess of 1 second for responses involving a choice among alternatives.
Precise Calibration and Measurement	Humans are incapable of making precise measurements and calibrations mentally.
Reliable Response	Because of the variability of human response, humans should be precluded from performing functions which require the unvarying repetition of one or more responses.
Time Sharing	Under most circumstances, humans act as a single-channel information processor and should ordinarily be precluded from performing multiple time-shared tasks.
Continuous Performance	Humans should be precluded from performing functions which cannot be interrupted or which require sustained attention for long periods of time (e.g., in excess of 20 minutes).
Detection of Infrequent Events	Humans should be precluded from performing functions that require detecting rarely occurring stimuli, events, or conditions.

A2 Criteria that Define Unique Human Capabilities

Human participation in the performance of a function is mandatory when the function requires one or more of the following capabilities [Ref: 2.3(2)]:

Develop a Strategy	Human involvement is mandatory when • Operations cannot be reduced to preset procedures • The form and content of all inputs and outputs cannot be specified or predicted • The relationship between inputs and outputs may require restructuring during task performance.
Integrate a Large Amount of Information	Humans must be included in the accomplishment of a function when: • Signals must be detected against a noisy background • Patterns of information and trends must be extracted from several sources.
Make and Report Unique Observations	Humans must be included when a function requires that observation be made of: • The performance of others; • The performance of the individual; • Ephemeral (continuous, endless events, etc.)
Assign Meaning and Value to Events	Humans must be included when performance of a system or function requires that meaning and relative values be assigned to events.