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Function Allocation: Policy, Practice, Procedures, & Process

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Abstract

Allocation of functions is known by human systems integration professionals as encompassing both a process and a product. As a process, function allocation refers to the sequence of steps involved in establishing the alternate roles, responsibilities, and requirements for humans and machines in a complex human-machine system. As a product, function allocation refers to the end state of the application of the process, the optimal distribution of roles, responsibilities and tasks between humans and machines.

When the system development objective is to downsize emerging systems as compared with existing systems, the focus of the allocation of function effort changes from an emphasis on optimizing human roles to minimizing human involvement in system functions. In addressing the issue of performing system functions with fewer humans as compared with existing systems, the function allocation strategy is not simply to assign functions to automated or manual performance on the basis of differential capabilities and capacities of the two, as exemplified in the Fitts' List approach. Rather, the strategy is to automate functions to the extent needed to enable the required reduction in workload and manning, with attendant provisions for decision aiding, task simplification, and design in conformity with human engineering standards to ensure adequate levels of human performance and personnel safety.

Another change in emphasis when allocating functions for a reduced manning system is the focus on interaction between human and machine. In the reduced manning environment humans and machines are not viewed as competing resources to which responsibilities are assigned on the basis of their unique and individual capabilities but rather as cooperative elements of a system interacting and collaborating in synergy to achieve the system objectives.

Introduction

Function allocation, the determination of how to allocate responsibilities for the conduct of system functions to human performance or to automation, has been a mainstay in the arsenal of methods in the field of human factors engineering (HFE) almost from its inception. One of the founders of the human engineering profession, Alphonse Chapanis, called it "one of the first and most important problems in man-machine systems design" (1965).

In attempting to determine how humans should fit into complex weapon systems, aerospace systems, and industrial systems, HFE practitioners traded off system functions to human or machine following the "Fitts List." This list, named for Paul Fitts, an early leader in the field, attempted to differentiate the activities for which human performance would be preferred against those for which the machine would be preferred. The original Fitts List is reproduced in **Table 1**.

A number of workshops and conferences have been held in the recent past to inquire into the methods of conducting function allocation. The first of these was a NATO sponsored workshop on improving function allocation for integrated systems design (Beevis et al. 1995). The primary conclusion of that workshop was that function allocation is the key process for solving problems associated with human error, system unreliability, and human-machine mismatch, because it seeks to

Table 1

Original Fitts' List

HUMANS ARE BETTER AT:	MACHINES ARE BETTER AT:
1. detecting small amounts of visual or acoustic energy	2. responding quickly to control signals and applying great force smoothly and precisely
3. perceiving patterns of light or sound	4. repetitive, routine tasks
5. improvising and using flexible procedures	6. storing information briefly and erasing it completely
7. storing very large amounts of information	8. deductive reasoning including making computations
and recalling relevant facts at the appropriate time	9. inductive reasoning
10. handling complex operations, i.e. things at once	
11. exercising judgement	

integrate and balance functional requirements specifications with human possibilities and technological opportunities. Another key conclusion of this workshop was that function allocation is not an isolated, stand-alone activity but rather is one that must be included in the analysis-design-evaluation process (Beevis et al. 1995).

Another symposium convened to address the issues of function allocation was conducted in Galway, Ireland in 1997. This symposium entitled Revisiting the Allocation of Function Issue: New Perspectives (Fallon 1997) included 56 papers on a variety of issues and application areas for function allocation.

This paper presents an orientation and approach to function allocation that is predicated on the need to allocate functions for a reduced manning system. When the system development objective is to downsize emerging systems as compared with existing systems, the focus of the allocation of function effort changes from an emphasis on optimizing human roles to minimizing human involvement in system functions. In addressing the issue of performing system functions with fewer humans as compared with existing systems, the function allocation strategy is not simply to assign functions to automated or manual performance on the basis of differential capabilities and capacities of the two as exemplified in the Fitts' List approach. Rather, the strategy is to automate functions to the extent needed to enable the required reduction in workload and manning with attendant provisions for decision aiding, task simplification, and design in conformity with human engineering standards to ensure adequate levels of human performance and personnel safety. The allocation of functions for highly automated, optimized manning systems is a constituent element of the Ship-SHAPE methodology, developed for NAVSEA.

Ship-SHAPE is a set of automated processes, tools, and databases developed specifically to enable HSI analysts in the Navy meet the requirements of the DoD 5000 series documents as well as Naval Sea Systems Command Instruction 3900.8 and SECNAVINST 5000.2B. The guiding principle behind the design of the Ship-SHAPE software is that the HSI analyst should have at his or her fingertips all of the requirements, guidance, instructions, processes, procedures, methods, tools, and data needed to conduct a timely and complete HSI effort.

In the Ship-SHAPE methodology the candidate roles of the human are developed through application of an automated tool designated the "Role of Man and Automation" (ROMAN) tool. This tool provides the analyst with the capability to import a set of functions and to assign roles to human performance and automation for each function. As each function is presented to the analyst, a decision is required as to the extent to which the function can be automated. In each case where an assignment of function performance has been made, the analyst is asked to identify the role of the human and the role of the machine in the performance of the function.

FUNCTION ALLOCATION: THE POLICY

MIL-STD 1472F (1999), in its description of general requirements for applying human engineering in the design of systems, identified allocation of functions as a major requirement. According to this DoD design criteria standard, the design of systems should reflect the allocation of functions to personnel, equipment, and personnel-equipment combinations to achieve: (a) required sensitivity, precision, time, and safety; (b) required reliability of system performance; (c) minimum number and levels of skills of personnel required to operate and maintain the system; and (d) required performance in a cost-effective manner.

The DoD Regulation 5000.2R, in the section on systems engineering, requires that iterative functional analyses/allocations shall define successively lower level functional and performance requirements, including functional interfaces and architecture to achieve open systems. System requirements are to be allocated and defined in sufficient detail to provide design and verification criteria to support the integrated system design.

In the section on human factors engineering (HFE), the DoD regulation requires that the program manager (PM) shall employ HFE during systems engineering (to include function allocation) to provide for effective human-machine interfaces. Where practicable and cost effective, design efforts are to seek to reduce manpower and training requirements. Design efforts are to minimize or eliminate system characteristics that require excessive cognitive, physical, or sensory skills; require extensive training or workload-intensive tasks; result in mission-critical errors; or produce safety or health hazards.

Finally, the DoD Deskbook presents guidance on conducting function allocation within an HSI application to system design. The Deskbook states that human factors engineers (HFE) play a major role in this process by working with MPT, health and safety, and acquisition communities to translate broad constraints into more refined requirements. An important step in this process is the review of performance requirements and clarification of the role and tasks the human will perform as part of the "total system." Functional analysis is to be performed iteratively to define successively lower functional and performance requirements, to identify functional interfaces, and to allocate functions to components of the total system. Functional allocations are made to the hardware, software, data, people, and facilities, as appropriate. Requirements analysis is to be conducted iteratively with functional analysis to develop and refine system level functional and performance requirements, external interfaces, and provide traceability among user requirements and design requirements. Human-machine interfaces are identified as an outgrowth of the functional allocation process. Early identification of human-machine interfaces ensures compatibility, interoperability, and integration of all functional and physical interfaces and ensures that system definition and design reflect the requirements for all (hardware, software, and people) system elements.

FUNCTION ALLOCATION: THE PRACTICE

There are several requirements associated with the application of function allocation for highly automated systems such as DD 21. These include the following considerations:

- allocation of functions must be an integral element of an overall design process;
- allocation of functions must itself comprise a process;
- in the allocation of functions for automated systems, the emphasis must be on deter-

mination of the roles of the human in performance of system functions;

- the allocation of functions for highly automated systems must depend on a multidisciplinary understanding of operational constraints, technology availability, and human performance limitations;
- the allocation of functions must contribute to the design of the system, specifically in terms of human-centered automation;
- the allocation of functions model developed for the automated system must be capable of being verified and validated;
- allocation of functions can be inherent in the design, or it can be dynamic, changing in the operational setting as a function of mission conditions and human workload.

Allocation of functions is part of a larger process. Allocation of functions must be considered to be an important step in the broader human systems integration (HSI) process, and this importance increases with the need to significantly reduce system manning and incorporate a high degree of automation.

Allocation of function is itself a process. Since the design of ships in the future, such as the DD 21, begins with an assumption of zero manning, function allocation can be represented by a formalized process wherein the thrust is to maximize the role of automation and minimize roles of the human which address the actual performance of system functions.

On the roles of humans in the determination of function allocation strategies for a reduced manning environment, the issue is not so much defining the allocation of system functions or subfunctions to human or machine performance as establishing the *role of the human* in the system. In highly automated systems where both human and machine are equally competent to perform individual functions, the design issue is to determine the role of the human vs. automation in the performance of each function. The emphasis on the role of the human in the system acknowledges the fact that the human has some role in every system function. In some cases that role may encompass actual performance of the function, while in others it may involve monitoring machine performance (Malone 1997).

The allocation of functions proceeds in three major steps: (1) identifying areas where human performance is mandatory and/or where automation is proscribed. Alternative strategies are then identified for allocation of system functions and subfunctions to human, machine, or a combination of both. The requirement is to decide that a function (or subfunction) should be completely performed by the human (manual function), completely performed by machine (automated function), or performed by some combination of human and automated performance (semi-automated); (2) identifying the role of the human in automated or semi-automated functions; (3) identifying requirements associated with human roles and responsibilities in all functions, including manual, semi-automated, and automated. It is important to keep in mind that automating a function does not logically mean that the human does not have a role, that he or she has effectively been designed out of the system for that specific function. Rather, in an automated function or task, the role of the human is that of a manager, monitor, decision-maker, system integrator, or backup performer.

Multidisciplinary-nature function allocation must be conducted by an integrated design team comprising systems engineers, operational specialists, and HSI practitioners. Each of these specialists brings a unique perspective to the task of determining how much of a function to automate, and what should be the role of the human.

Allocation of function must contribute to design function allocation. It must support the design of the human in the system, specifically in terms of human collaboration, cooperation, coordination, and interaction with automation, as described in the human-centered automation aspects of HSI.

As ship systems become more and more automated, complex, and sophisticated, increased attention must be given to the issue of how to effectively integrate human performance into system performance. As automation of ship systems increases, it becomes more imperative for the human commander, evaluator, and decision maker to understand not only the tactical situation but also the automated machine itself - what it knows, what it concludes, what it anticipates, and what it recommends. It can be agreed that we have not yet arrived at the juncture where the human is ready to turn over all decision making, systems management, and action execution authority and responsibility to the machine. The requirement is to acquire ship systems under a strategy wherein the human is integrated into the system, enabling cooperation and collaboration between human and machine, which depends on the unique capabilities of each. Integration in this sense extends to integration of the human with system hardware, software, firmware, information, procedures, environments, organizations, and other humans. To be successful, this integration must begin with a systems engineering orientation that considers the human as a critical component of the system, rather than as merely a user of the system and system products.

Problems with humans interacting with automation have been identified. The major problem is that the human doesn't always have a valid conceptual model of what the system is doing. According to the International Maritime Organization, The U.S. Coast Guard, and the U.S. Navy Safety Center, 80% of ship accidents result from human error. A major cause for human error is the fact that the human is operating on the bases of erroneous cognitive expectancies concerning what is the problem, what the system is doing, and how it will respond. In attempting to diagnose a problem event, an operator relies on expectancies developed on the basis of information presented, procedures, training, past experience, design conventions, and intuition. Expectancies will support the diagnosis when the cognitive model that the operator has of the system is in close agreement with what is actually happening, i.e., has high conceptual fidelity (Malone et al. 1997).

The requirements associated with specific function allocation/role of human concepts must be identified including task requirements (information, performance capabilities, decision and support requirements, task sequencing, and time dimensions of tasks), human knowledge/skill requirements, and requirements for reducing the incidence of human errors and/or making systems error tolerant. These requirements are generated for specific mission scenarios that represent configurations of mission objectives, threat and own force deployment, system conditions of readiness, and special conditions (environmental, operational, and tactical).

The role of automation in the reduction of system manpower is to reduce human workloads associated with performance of functions, thereby reducing the number of crewmembers required to perform the functions. In system engineering circles there is an increasingly prevalent attitude that automation leads naturally to manning reduction, and that required magnitudes of manpower reduction will be achieved in a straightforward manner by simply increasing the level of automation.

The commercial aviation industry has been intensely involved for a number of years in determining the role of automation in reducing pilot workload. According to Wiener (1988) cockpit automation refers to the situation where tasks performed by the human crew can be assigned, by choice of the crew, to machinery. Wiener also lists advantages and disadvantages of automating human-machine systems and cites as one disadvantage a concomitant increase in mental workload. It is noted as questionable as to whether or not automation reduces overall crew workload. The conclusion was that cockpit automation as currently implemented generally does not result in reduced crew workload since, while manual tasks may be declining, demands for monitoring and subsequent mental workload have increased (Wiener 1988).

Specific problems with human interaction with automation have been identified by Funk et al. (1996) for commercial aircraft flight decks. The majority of these problems center around the design and implementation of automation, including the design of interfaces between the automated system element and the human operator, and the use of the automation. Design problems for human interaction with automation identified by Funk et al. (1996) in a comprehensive survey of commercial aviation crewmembers include the following:

- Automation lacks the functionality or performance desired by operators;
- Automation designs do not take into account the operational knowledge of operators leading to designs that are counterintuitive and resulting in increased workload and potential for error.
- Although automation does what it was designed to do, design specifications do not take into account possible conditions, leading to unsafe automation behavior.
- Automation fails to perform according to operator expectations and in ways that are unexpected and unexplainable, causing confusion and degraded performance.
- Failure modes are unanticipated by automation designers.
- Automation employs different control strategies than operators.
- Automation is too complex;
- Automation is not standardized;
- Automation is poorly integrated;
- Automation usurps operator authority;
- Interfaces between operators and automation are poorly designed;
- Automation obscures situation information from the operator;
- Automation provides too much information;
- Automation is not compatible with other systems;
- Automation degrades operator performance;
- Operators have difficulty assuming control from automation;
- Operators have difficulty recovering from automation failures;
- Operators are out of the control loop when using automation;
- Operators place too much or too little confidence in automation;
- Operators fail to develop skills needed in case of automation failure;
- Automation increases operator requirements for planning;
- Automation leads to mode selection errors;
- Automation interferes with operator situation awareness;
- Automation interferes with crew coordination;
- Automation increases operator workload.

From this list it is apparent that there are significant problems with the manner in which automation is being implemented on the flight deck of commercial airliners. The majority of these classes of problems revolve around the inadequacy of the provisions for human interaction with automation. It is important for the Navy ship community to learn from these aviation lessons in designing automated systems to reduce ship crew workloads. The major lesson learned is for the need for human-centered automation.

Validation of Function Allocation

Function allocation models must be validated through simulation, including task network simulation to assess workloads and performance capabilities, human-in-the-loop simulation to assess human performance with human-machine interface concepts appropriate for the function allocation strategy, and geometric simulation for visualizing workspace and arrangements requirements attendant to a function allocation strategy.

DYNAMIC FUNCTION ALLOCATION

The process by which functions/tasks that are candidates for automation can be identified is through the determination of the required role of the human in the system. The classical method for determining the role of the human in a complex system involves allocation of functions or tasks to human or machine (automated) performance. Mosier (1996) defined the characteristics of human expertise that surpass the capabilities of automation to include the human capacity for creativity, adaptability, and the facility to incorporate experience, a broad focus, logical reasoning, and common-sense knowledge.

Function/task allocations can be either inherent in the design or dynamic. Inherent allocations identify which functions or tasks should be allocated to human performance vs. machine performance based on an assessment of the requirements associated with the function/task and the unique capabilities and limitations of the human and machine. Inherent allocations are usually made on the basis of lists (Fitts' Lists) which compare the relative capabilities and limitations of human and machine performance in specific dimensions.

Dynamic allocations make the assumption that the optimum allocation strategy can change with operational conditions, workloads, and mission priorities. According to Rouse (1977) a dynamic approach allocates a particular task to the decision-maker (human or machine) which has the resources available at the moment for performing the task. Rouse (1981) identified the advantages of a dynamic approach as compared with a static approach such as improved utilization of system resources; less variability of the human's workload; and providing the human with improved knowledge of the overall system. Revesman and Greenstein (1983) recommended an approach wherein the human and computer work on tasks in parallel with the computer selecting actions so as to minimize interference with the human. Here the human is not forced to change planned actions and he or she retains the primary role in the system. This implementation requires that the computer must make predictions about the human's actions and must, therefore, have a model of the human in terms of the actions he/she will take at a point in time and under certain circumstances. The computer would use this model of human decision making to predict the human's actions and to select other actions that do not replicate or interfere with the human's actions.

FUNCTION ALLOCATION: THE PROCEDURE

The Ship-SHAPE tool to support the collaborative allocation of function and determination of the roles of humans and automation is designated Roles of Man/Automation (ROMAN) tool. The NATO conference on Function Allocation (Beevis et al. 1995) addressed the requirements for tools to support function allocation. The major recommendation of that conference was that a tool be developed to support allocations of functions to human and machine performance which incorporates the differential expertise of the HSI analyst, the subject matter expert (operational expert), and the systems engineer. The procedures required of each of these specialists in making function allocation decisions are presented below:

HSI/Manning Specialist

- present for each function the allocation options — role of human options
- allocate functions and identify role of human
- identify workload reduction potential based on high drivers and simulation results
- identify crew positions/workstations associated with workload reduction potential

- identify role of humans in automated and semi-automated functions
- identify functions which are amenable to consolidation
- identify functions which are amenable to elimination
- identify functions which are amenable to simplification
- identify technology requirements
- assess technologies
- track characteristics of each concept
- identify crew positions for each concept
- identify reduced manning/HSI design concept

Subject Matter Expert

- identify allocation strategy in legacy systems and define the rationale for that decision
- identify workload reduction potential based on experience
- identify constraints on function automation
- identify functions and task sequences which are amenable to consolidation, and operational consequences
- identify functions and task sequences which are amenable to elimination, and operational consequences
- identify functions and task sequences which are amenable to simplification, and operational consequences
- identify operational constraints on concept development

Systems Engineer

- identify potential automation approaches
- identify role of automation
- identify workload reduction potential based on engineering and technology requirements
- identify how recommended automation can be implemented
- identify role of machines in automated and semi-automated functions
- identify functions and task sequences

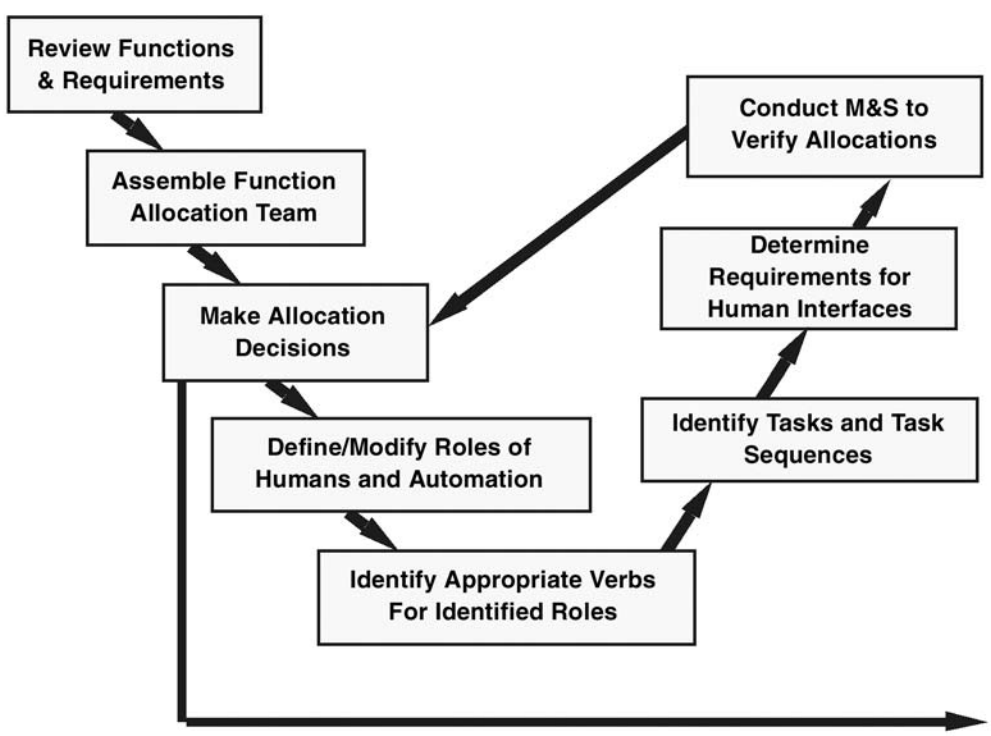

FIGURE 1: *The HSI Function Allocation of Function Process*

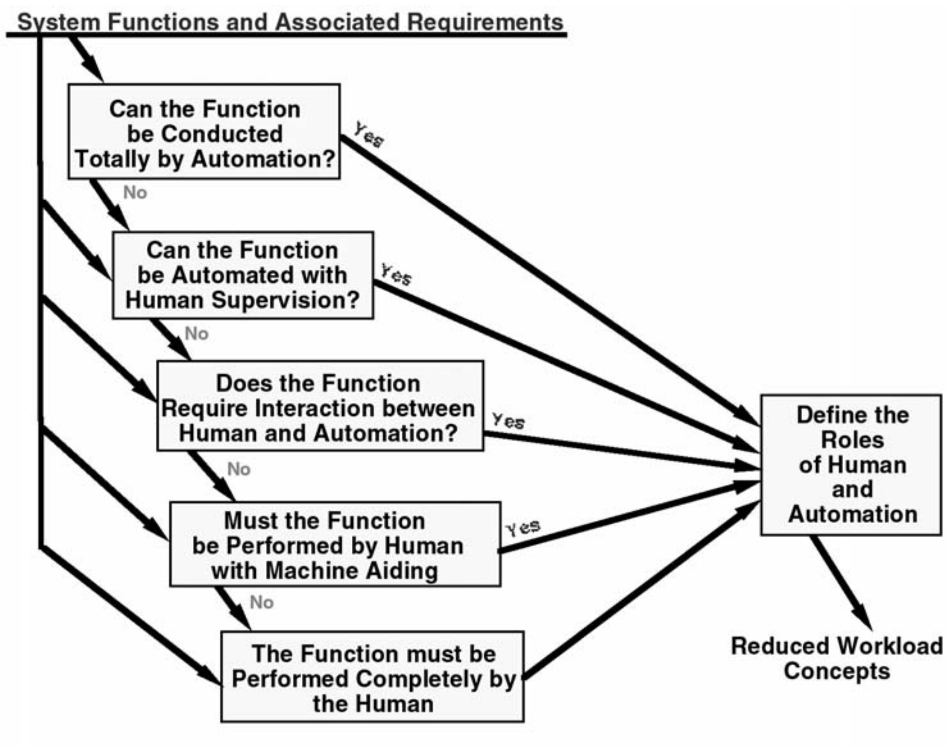

FIGURE 2:
The HSI Function Allocation Decision Process

which are amenable to consolidation, and engineering consequences

- identify functions and task sequences which are amenable to elimination, and engineering consequences
- identify functions and task sequences which are amenable to simplification, and engineering consequences
- identify engineering constraints on concept development

FUNCTION ALLOCATION: THE PROCESS

The process for conducting function allocations in the context of an HSI process is depicted in **Figure 1**. The process begins with a review of functions and associated requirements, which will be considered in the allocation of these functions.

The next step is to assemble the function allocation team, consisting of an HSI specialist, an operational specialist, and a systems engineer.

The third step actually involves the actual allocation of functions. The sequence involved in making allocation decisions is presented in **Figure 2**. The steps in this decision process are as follows:

- *Determine if the function can be fully automated*

  If it can, the roles of the human and automation are determined.

  If the decision is that the function in question cannot be performed totally by automation, continue the decision process:

- *Determine if the function can be automated with human supervision*

  If yes, the roles of the human and automation are identified.

  If no, continue the decision process:

- *Determine if the function can be performed by human/automation interaction*

If yes, the roles of humans and automation are identified.

In this allocation each element has some responsibility for some facet of function performance, and the allocation of these functions may vary in the operational setting due to workload, safety, or uncertainty considerations (dynamic function allocation).

If this allocation is not viable, continue the decision process.

- *Determine if the function can be performed by humans with machine aiding.*

  If so, the roles of humans and automation are defined.

The classes of machine aiding include:

- on-line help;
- memory aids (with intelligence for anticipating operator action requirements and providing prompts and cues concerning when and how to accomplish the action;
- planning aid;
- intelligent tutoring system which provides real-time tutoring based on an understanding of the user, and what the user is attempting to accomplish;
- situation awareness aid which characterizes a model of what is happening in the external world, what to expect, what actions are required, what additional information is needed, what's important, and how much time is available;
- real-time simulation for investigating the potential outcome of planned activities, assessing alternate diagnoses, and rehearsing action strategies prior to implementation;
- cooperative, collaborative decision support, wherein humans interact with other humans and with intelligent machines, which serve to enhance or augment the operator's decision-making capabilities;
- integration of data fusion with decision support;
- operator's associate (or pilot, commander, evaluator, or maintainer), which incorporates many of the features of categories described above to enable the intelligent machine act as an aide to the human in the performance of missions, functions, and tasks.

If this allocation is not viable, perform the function manually. ⚓

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Expiration Date: ____________________

Signature: ____________________

CANCELLATIONS, TRANSFERS, AND REFUNDS: *Cancellations must be in writing and cannot be accepted after 6 June 2003. A $50 administrative fee will be applied to all refunds, $25 to any transfers.*