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# DEPARTMENT OF DEFENSE HANDBOOK

## HUMAN ENGINEERING PROGRAM PROCESS AND PROCEDURES

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# FOREWORD

1. This handbook is approved for use by all Departments and Agencies of the Department of Defense.

2. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply.

3. The individual services require the application of human engineering (HE) to military system design to achieve required performance by operator and maintenance personnel and to minimize personnel skills and training requirements. Department of Defense (DoD) and service policies require that HE be applied within the limits of time, cost, and performance tradeoffs. Although such service policies and regulations may change, there will continue to be a need for HE in the development of systems, equipment, and facilities and in product improvement and modification. This handbook provides HE program task guidance (Section 4), describes the significance of the analysis, design, and test aspects of the HE program (Section 5), outlines procedures found effective in implementing such guidance (Sections 6 - 7), and provides summaries of methods (Section 8).

4. Section 4 of this handbook (previously MIL-HDBK-46855) is the primary source used by the services to specify HE efforts during system acquisition and is now considered to be a set of guidelines or preferred practices, rather than rigid requirements. Section 4 is designed to support the human factors engineering discipline independently or as a part of Human Systems Integration (HSI) initiatives. Its guidelines and preferred practices serve as a baseline for obtaining HE program information to be provided by offerors during the solicitation process.

5. Section 4 expresses analysis, design, test, and related preferred practices, and strives to accommodate all service HSI initiatives, all acquisition phases, and a wide range of products, including small equipment items as well as major systems. To accomplish these ends, Section 4 is written as general, nonrestrictive, program task guidance that also provides latitude for contractors to apply technical/program judgment and innovation consistent with specific procurements. As a result, Section 4 is expressed as general guidelines or preferred practices. A collateral result, however, is lack of detail. Accordingly, Sections 5 - 7 provide background, procedures, task options, and rationale to assist military customer (or requiring organization) and contractor (or performing organization) program managers and HE practitioners to understand and apply HE in the system acquisition process. Finally, Section 8 summarizes HE methods that can be considered for application to the HE effort. Sections 5 - 8 of this handbook provide guidelines in the following areas:

- HE documentation and requirements applicable to the program
- Source data supporting definition of the HE effort
- Planning and scheduling needed to accomplish the program

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- Coordination of HE with other disciplines and with the program manager
- Possible allocation of effort to laboratories, consultants, or subcontractors
- Tailoring
- Preparation by the government of the HE portion of the request for proposal
- Preparation of the proposal by the contractor
- Evaluation of the proposal by the government
- Contractor task accomplishment, including details of several analysis, design, and test and evaluation (T&E) methods
- Government monitoring of and interaction with the contractor

6. Beneficial comments (recommendations, additions, deletions) and any pertinent data that may be of use in improving this document should be addressed to Commander, U.S. Army Aviation and Missile Command, ATTN: AMSAM-RD-SE-TD-ST, Redstone Arsenal, AL 35898-5270, by using the Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

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# 1. SCOPE

1.1 General. This handbook provides human engineering (HE) (a) program tasks, (b) procedures and preferred practices, and (c) methods for application to system acquisition. The program tasks outline the work to be accomplished by a contractor or subcontractor in conducting an HE effort integrated with the total system engineering and development effort. They serve as a basis for offerors to provide HE program information during the solicitation process.

1.2 Applicability. This handbook applies to acquisition of military systems, equipment, and facilities; however, all guidelines and practices contained herein apply to every program or program phase.

1.3 Application guidance. Section 4 of this handbook should be tailored to specific programs and the milestone phase of the program within the overall life cycle. This tailoring by requiring or performing organizations—contractual or otherwise—focus on attaining essential human performance requirements, consistent with avoiding unnecessary program costs. Guidance for the procuring activity's selection of this handbook for contract use and, when invoked, the partial and incremental application of section 4, are contained in Appendix A. The tailoring process normally focuses on ensuring that *requirements* are necessary and contribute to mission performance; however, tailoring of the section 4 *guidelines* is also felt to be advisable since implementing unnecessary guidelines can drive costs just as surely as implementing unnecessary requirements. The coverage of tailoring in Appendix A and elsewhere herein, also identifies for lesser experienced readers the acquisition life cycle phases that human engineering processes are best applied.

# 2. APPLICABLE DOCUMENTS

2.1 General. The documents listed below are not necessarily all the documents referenced herein, but they are the ones needed to fully understand the information provided by this handbook.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks. The following standards and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the latest issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto.

STANDARDS

DEPARTMENT OF DEFENSE

| | |
|---|---|
| MIL-STD-961 | DoD Standard Practice, Defense Specifications |
| MIL-STD-1472 | Human Engineering Design Criteria for Military Systems, |

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Equipment, and Facilities.

HANDBOOKS

DEPARTMENT OF DEFENSE

| | |
|---|---|
| MIL-HDBK-248 | Guide for Application and Tailoring of Requirements for Materiel Acquisition |
| MIL-HDBK-759 | Human Engineering Design Guidelines |
| MIL-HDBK-881 | Work Breakdown Structure for Defense Material Items |
| MIL-HDBK-1908 | Definitions of Human Factors Terms |

(Unless otherwise indicated copies of the above specifications, standards, and handbooks are available from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094).

2.2.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this handbook to the extent specified herein.

| | |
|---|---|
| DoDD 5000.1 | Defense Acquisitions |
| DoD 5000.2-R | Mandatory Procedures for Major Defense Acquisition Programs and Major Automated Information Systems Programs |
| DoDD 5010.12-L | Acquisition Management Systems and Data Requirements Control List |
| DoDI 6055.1 | DoD Safety and Occupational Health (SOH) Program |
| DoD TAFIM, Vol. 8 | Technical Architecture Framework for Information Management, Volume 8: DoD Human Computer Interface Style Guide |
| AR 602-1 | Human Factors Engineering Program |
| AR 602-2 | Manpower & Personnel Integration (MANPRINT) in the Materiel Acquisition Process |
| SECNAVINST 50000.2B | Implementation of Mandatory Procedures for Major and Non-Major Defense Acquisition Programs and Major and Non-Major Information Technology Acquisition Programs |
| DI-HFAC-80741B | Human Engineering Progress Report |
| DI-HFAC-80742B | Human Engineering Dynamic Simulation Concept |
| DI-HFAC-80743B | Human Engineering Test Plan |
| DI-HFAC-80744B | Human Engineering Test Report |
| DI-HFAC-80745B | Human Engineering System Analysis Report |
| DI-HFAC-80746B | Human Engineering Design Approach Document - Operator |
| DI-HFAC-80747B | Human Engineering Design Approach Document - Maintainer |
| DI-HFAC-81399A | Critical Task Analysis Report |

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(Copies of the above documents required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

## 3. DEFINITIONS

3.1 General. Terms are defined in accordance with MIL-HDBK-1908.

3.2 Acronyms used in this handbook. The acronyms listed in this handbook are defined as follows:

| | |
|---|---|
| 3D | 3 Dimension |
| ACTD | Advanced Concept Technology Demonstration |
| ADI | Attitude Directional Indicator |
| AF | Air Force |
| AFI | Air Force Instruction |
| ARL-HRED | Army Research Laboratory's Human Research and Engineering Directorate |
| AFMC | Air Force Materiel Command |
| AMC | Army Materiel Command |
| AMSDL | Acquisition Management System and Data Requirements Control List |
| ANSI | American National Standards Institute |
| ASA | Assistant Secretary of the Navy |
| ASME | American Society of Mechanical Engineers |
| ASP | Acquisition Strategy Panel |
| ASVAB | Armed Services Vocational Aptitude Battery |
| AWACS | Airborne Warning and Control System |
| $C^4I$ | Command, Control, Communications, Computers, and Intelligence |
| CAD | Computer Aided Design |
| CAM | Computer Aided Manufacturing |
| CDR | Critical Design Review |
| CDRL | Contract Data Requirements List |
| CGA | Conceptual Graph Analysis |
| CIC | Combat Information Center |
| CID | Commercial Item Description |
| CJCS | Chairman of the Joint Chiefs of Staff |
| CL | Control List |
| CM | Configuration Management |
| CNO | Chief of Naval Operations |
| COEA | Cost and Operational Effectiveness Analysis |
| COI | Critical Operational Issues |
| COMBIMAN | Computerized Biomechanical Man-Model |
| CONOPS | Concept of Operations |
| COTS | Commercial Off The Shelf |
| CPAT | Critical Process Assessment Tool |

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| | |
|---|---|
| CRT | Cathode Ray Tube |
| CSERIAC | Crew System ERgonomics Information Analysis Center |
| CTA | Cognitive Task Analysis |
| CTAR | Critical Task Analysis Report |
| CUBITS | Criticality/Utilization/Bits of Information |
| CWG | Cockpit Working Group |
| DAD | Design Approach Document or Deployable Aerodynamic Deceleration |
| DCL | Digital Control Language |
| DCP | Decision Coordinating Paper |
| DCS | Data Collection System |
| DDSM | Directory of Design Support Methods |
| DEP | Design Eye Point |
| DID | Data Item Description |
| DoD | Department of Defense |
| DoDD | Department of Defense Directive |
| DODISS | Department of Defense Index of Specifications and Standards |
| DR | Deficiency Report |
| DRS | Data Reduction System |
| DSARC | Defense System Acquisition Review Council |
| DSN | Defense Switching Network |
| DT&E | Development Test and Evaluation |
| DTIC | Defense Technical Information Center |
| ECA | Early Comparability Analysis |
| ECP | Engineering Change Proposal |
| EEG | Electroencephalogram |
| EKG | Electrocardiogram |
| EMD | Engineering and Manufacturing Development |
| ERP | Eye Reference Point |
| FAA | Federal Aviation Administration |
| FIPS | Federal Information Processing Standards |
| FPC | Flow Process Chart |
| FSD | Functional Sequence Diagram |
| GSR | Galvanic Skin Response |
| HDBK | Handbook |
| HE | Human Engineering |
| HEDAD-M | Human Engineering Design Approach Document-Maintainer |
| HEDAD-O | Human Engineering Design Approach Document-Operator |
| HEDGE | Human Factors Engineering Data Guide for Evaluation |
| HESAR | Analysis Report Human Engineering System |
| HESC | Human Engineering Simulation Concept |
| HETP | Human Engineering Test Plan |
| HETR | Human Engineering Test Report |
| HF | Human Factors |
| HFE TAG | Human Factors Engineering Technical Advisory Group |
| HFE | Human Factors Engineering |

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| | |
|---|---|
| HODAC | Human Operator Data Analyzer/Collector |
| HOS | Human Operator Simulator |
| HP | Human Performance |
| HQ | Headquarters |
| HPRA | Human Performance Reliability Analysis |
| HSD | Human Systems Division |
| HIS | Human Systems Integration |
| HUD | Head Up Display |
| ICD | Interface Control Drawing |
| ICOM | Input, Controls, Output, and Mechanisms |
| IDEF | Integrated computer-aided manufacturing DEFinition |
| IMS | Integrated Management (or Master) Schedule |
| IMP | Integrated Master Plan |
| INS | Inertial Navigation System |
| IOT&E | Initial Operational Test and Evaluation |
| IPS | Integrated Program Summary |
| IPT | Integrated Product Team |
| IRAD | Independent Research And Development |
| ISD | Instructional Systems Development |
| JSSG | Joint Service Specification Guide |
| LCC | Life Cycle Costs |
| LED | Light Emitting Diode |
| LFT&E | Live-Fire Test and Evaluation |
| LMI | Logistics Management Information |
| LOS | Line-of-Sight |
| LRIP | Low Rate Initial Production |
| MAIS | Major Automated Information System |
| MAJCOM | Major Air Command |
| MAPPS | Maintenance Personnel Performance Simulation |
| MANPRINT | MANpower and PeRsonnel INTegration |
| MATRIS | Manpower and Training Research Information System |
| MDAP | Major Defense Acquisition Program |
| ME | Manpower Estimate |
| MIC | Methyl IsoCyanate |
| MNS | Mission Needs Statement |
| MODAPTS | Modular Arrangement of Predetermined Time Standards |
| MOE | Measures of Effectiveness |
| MOP | Measures of Performance |
| MOPP | Mission Oriented Protective Posture |
| MOST | Maynard Operation Sequence Technique |
| MPT | Manpower, Personnel and Training |
| MTM | Methods Time Measurement |
| NAVAIR | Naval Air Systems Command |
| NAVSEA | Naval Sea Systems Command |
| NBC | Nuclear, Biological, Chemical |

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| | |
|---|---|
| NDI | Nondevelopmental Item |
| NGS | Nongovernmental Standards |
| NIST | National Institute of Standards and Technology |
| NSSN | National Standards System Network |
| NTSB | National Transportation Safety Board |
| OMB | Office of Management and Budget |
| OPR | Office of Primary Responsibility |
| ORD | Operational Requirements Document |
| OSD | Operational Sequence Diagram |
| OSHA | Occupational Safety and Health Administration |
| OT&E | Operational Test and Evaluation |
| OWLES | Operator Workload System |
| PARI | Precursor Action Result and Interpretation method |
| PDR | Preliminary Design Review |
| P-HSIP | Preliminary Human Systems Integration Plan |
| PLSS | Precision Location and Strike System |
| PMD | Program Management Directive |
| PMP | Program Management Plan |
| POC | Point-of-Contact |
| PTS | Predetermined Time Standard |
| R&D | Research and Development |
| RAM | Reliability, Availability, and Maintainability |
| RCM | Requirements Correlation Matrix |
| RD&E | Research, Development, and Engineering |
| RFP | Request For Proposal |
| REHMS-D | Reliable Human-Machine System Developer |
| S&WM | Sustenance and Waste Management |
| SA | Situation Analysis |
| SAGAT | Situation Awareness Global Assessment Technique |
| SARS | Situational Awareness Rating Scales |
| SART | Situational Awareness Rating Technique |
| SA-SWORD | Situation Awareness Subjective Workload Dominance |
| SDR | System Design Review |
| SECNAV | Secretary of the Navy |
| SLIM-MAUD | Success Likelihood Index Method using Multi-Attribute Utility Decomposition |
| SMMP | System MANPRINT Management Plan |
| SOH | Safety and Occupational Health |
| SON | Statement Of Need |
| SOO | Statement Of Operational Objectives |
| SOSD | Spatial Operational Sequence Diagram |
| SOW | Statement Of Work |
| SPO | System Program Office |
| SRP | Seat Reference Point |
| SSAR | Survival, Search And Rescue |

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| | |
|---|---|
| STAR | System Threat Assessment Report |
| STS | Space Transportation System |
| SWAT | Subjective Workload Assessment Technique |
| T&E | Test and Evaluation |
| TAFIM | Technical Architecture Framework for Information Management |
| TEMP | Test and Evaluation Master Plan |
| THERP | Technique for Human Error Rate Prediction |
| TI | Technical Interchange |
| TIC | Tactical Information Coordinator |
| TIR | Test Incident Report |
| TLA-1 | Time Line Analysis program model |
| TM | Technical Manual |
| TMU | Time Measurement Unit |
| VCR | Video Cassette Recorder |
| W/CS | Windshield/Canopy System |
| WBS | Work Breakdown Structure |
| WIPT | Working IPT |

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# 4. PROGRAM TASKS

## 4.1 General guidelines.

4.1.1 Scope and nature of work. Human engineering (HE) should be applied during development and acquisition of military systems, equipment, and facilities to integrate personnel effectively into the design of the system. An HE effort should be provided to (a) develop or improve all human interfaces of the system; (b) achieve required effectiveness of human performance during system operation, maintenance, support, control, and transport; and (c) make economical demands upon personnel resources, skills, training, and costs. The HE effort should include, but not necessarily be limited to, active participation in the following three major interrelated areas of system development.

4.1.1.1 Analysis. Starting with a mission analysis developed from a baseline scenario, the functions that must be performed by the system in achieving its mission objectives should be identified and described. These functions should be analyzed to determine their best allocation to personnel, equipment, software, or combinations thereof. Allocated functions should be further dissected to define the specific tasks that must be performed to accomplish the functions. Each task should be analyzed to determine the human performance parameters; the system, equipment, and software capabilities; and the tactical/environmental conditions under which the tasks will be conducted. Task parameters should be quantified where possible, and should be expressed in a form that permits effectiveness studies of the human-system interfaces in relation to the total system operation. HE high-risk areas should be identified as part of the analysis. Analyses should be updated as required to remain current with the design effort.

4.1.1.2 Design and development. HE should be applied to the design and development of the system equipment, software, procedures, work environments, and facilities associated with the system functions requiring personnel interaction. This HE effort should convert the mission, system, and task analysis data into (a) detail design and (b) development plans to create a human-system interface that will operate within human performance capabilities, meet system functional requirements, and accomplish mission objectives.

4.1.1.3 Test and evaluation (T&E). T&E should be conducted to verify that military systems, equipment, and facilities can be operated and maintained within the intended users' performance capabilities and meet HE design criteria.

4.1.2 HE program planning. HE program planning, in accordance with the provisions of this section and the equipment specification, should include the following elements as part of an integrated effort within the total project: the tasks to be performed, HE milestones, level of effort, methods to be used, design concepts to be utilized, and the T&E program.

4.1.3 Risk management. Risk management procedures should be planned and implemented for the entire life cycle of the system. Human performance and HE design criteria issues that involve potential technical, cost, or schedule risks should be identified, analyzed, and prioritized as early as possible to establish provisions for eliminating the associated risks or

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reducing them to acceptable levels. Such provisions should be implemented and monitored during the HE program. Risk management should

- identify potential cost, schedule, design, and performance risks that result from design aspects of human-system integration;
- quantify such risks and their impacts on cost, schedule, and performance;
- evaluate and define the sensitivity of such risks to HE design;
- identify alternative solutions to moderate- and high-risk HE problems and define their risks;
- take actions to avoid, minimize, control, or accept each HE risk; and
- ensure that human performance/design risk is an element of specification requirements.

4.1.4 Reviews.

4.1.4.1 Major technical reviews. HE practitioners should participate in the major technical reviews, as applicable to the acquisition phases indicated and in keeping with the guidelines herein:

- Alternative System Review (Concept Exploration phase )
- System Requirements Review (Program definition and risk reduction phase)
- System Functional Review (as appropriate to the acquisition)
- Preliminary Design Review (as appropriate to the acquisition)
- Critical Design Review (as appropriate to the acquisition)
- System Verification Review (as appropriate to the acquisition)

4.1.4.2 Subsystem reviews. HE practitioners should also participate in subsystem reviews, including, where applicable, software specification, test readiness, and functional reviews (e.g., support, training, systems engineering, test, and manufacturing reviews).

4.1.5 Cognizance and coordination. The HE program should be integrated into the total system program. In particular, HE should be coordinated with RAM (reliability, availability, and maintainability), system safety survivability/vulnerability, facilities engineering, Acquisition Logistics and Logistics Support Analysis (LSA) and other human factors (HF) functions, including biomedical, life support, personnel survivability, habitability, and personnel and training functions, and should be integrated into the total system program. HE data should be provided for incorporation into Logistic Management Information (LMI). The HE effort should utilize the LMI reports as source data where possible. The HE portion of any analysis, design, or T&E program should be conducted under the direct cognizance of personnel assigned HE responsibility by the contractor.

4.1.6 Data

4.1.6.1 Traceability. Contractor documentation should provide traceability from initial identification of HE requirements during analysis or system engineering, through implementation

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of such requirements during design and development, to verification that these requirements have been met during T&E of approved design, software, and procedures.

4.6.1.2 Access. All data, such as plans, analyses, design review results, drawings, checklists, design and test notes, and other supporting background documents reflecting HE actions and decision rationale, should be maintained at the contractor's facilities and made available to the procuring activity for meetings, reviews, audits, demonstrations, T&E, and related functions.

4.1.7 Subcontractors and suppliers. The prime contractor should ensure that tasks and products obtained from subcontractors and suppliers conform to relevant HE guidelines herein.

4.1.8 Nonduplication. The efforts performed to apply the HE guidelines specified herein should be coordinated with, but should not duplicate, efforts performed pursuant to other contractual program tasks. (Necessary extensions or transformations of the results of other efforts for use in the HE program will not be considered duplication.)

4.2 Detailed guidelines.

4.2.1 Analysis. Requirements analysis should be developed from a baseline mission scenario. Analysis should include application of HE methods as follows.

4.2.1.1 Definition and allocation of system functions. The functions that must be performed by the system in achieving its objective(s) within specified mission environments should be analyzed. HE principles and criteria should be applied to specify human-system performance requirements for system operation, maintenance, and control functions, and to allocate system functions to (1) automated operation/maintenance, (2) manual operation/ maintenance, or (3) some combination thereof. Function allocation is an iterative process achieving the level of detail appropriate for the level of system definition.

4.2.1.1.1 Information flow and processing analysis. Analyses should be performed to determine the basic information flow and processing required to accomplish the system objective. These analyses should include decisions and operations without reference to any specific machine implementation or level of human involvement.

4.2.1.1.2 Estimates of potential operator/maintainer processing capabilities. Plausible human roles in the system (e.g., operator, maintainer, programmer, decision-maker, communicator, monitor) should be identified. Estimates of processing capability in terms of workload, accuracy, rate, and time delay should be prepared for each potential operator/maintainer information-processing function. Comparable estimates of equipment capability should also be made. These estimates should be used initially in determining the allocation of functions and should later be refined at appropriate times for use in defining operator/maintainer information requirements and control, display, and communication requirements. In addition, estimates should be made of how implementation or

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nonimplementation of HE design recommendations is likely to affect these capabilities. Results from studies in accordance with 4.2.2.1 may be used as supportive inputs for these estimates.

4.2.1.1.3 Allocation of functions. From projected operator/maintainer performance data, estimated cost data, and known constraints, analyses and tradeoff studies should be conducted to determine which system functions should be machine implemented or software controlled and which should be reserved for the human operator/maintainer. Allocation of functions should consider the risks of making an incorrect decision for each alternative being evaluated. Designs should be simplified or enhanced to prevent or minimize situations where human decisions are made under conditions of uncertainty, time stress, or workload stress. The possibility of influencing human or equipment capabilities through personnel selection and training as well as through equipment and procedure design should be considered, and the costs of such action should be considered in tradeoff and cost-benefit studies.

4.2.1.2 Equipment selection. HE principles and criteria should be applied along with all other design requirements to identify and select the particular equipment to be operated, maintained, or controlled by personnel. The selected design configuration should reflect HE inputs expressed in "best estimate" terms, to satisfy the functional and technical design requirements and to ensure that the equipment will meet applicable HE design criteria, such as MIL-STD-1472.

4.2.1.3 Analysis of tasks and workload. HE principles and criteria should be applied to analyses of tasks and workload. These analyses should also be provided as basic information for developing preliminary manning levels, equipment procedures, and skill, training, and communication requirements, and as inputs to Logistic Support Analysis, as applicable. All analyses of tasks should utilize the task taxonomy expressed in MIL-HDBK-1908. An approach for conducting a task analysis is given in Appendix B.

4.2.1.3.1 Analysis of tasks. An analysis of tasks should be conducted and should provide one of the bases for making design conceptual decisions. For example, the task analyses should be considered in determining, to the extent practicable, before hardware fabrication, whether system performance and maintenance requirements can be met by combinations of anticipated equipment, software, and personnel, and in ensuring that human performance requirements do not exceed human capabilities. Time requirements for tasks should be evaluated with respect to task duration versus time availability, task sequencing, and task simultaneity. Task requirements should be evaluated, as applicable, with respect to accuracy, precision, completeness, and the effects of task feedback and error tolerance/error recovery on performance. These analyses should also consider effects of sustained/continuous operations on human performance. Those human-system tasks identified during HE analysis which require performance of critical tasks, reflect possible unsafe practices, or show the potential for improvements in operating efficiency should be further analyzed.

4.2.l.3.2 Analysis of critical tasks. Further analysis of critical tasks should identify the

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- information available to operator/maintainer;
- evaluation process;
- decision reached after evaluation;
- action taken;
- body movements required by the action taken;
- workspace envelope required by the action taken;
- workspace available;
- location and condition of the work environment;
- frequency and tolerances of action;
- time base;
- feedback informing the operator/maintainer of the adequacy of the action taken;
- tools and equipment required;
- number of personnel required, their specialties, and their experience;
- job aids, training, or references required;
- communications required, including type of communication;
- special hazards involved;
- operator interaction when more than one crewmember is involved;
- performance limits of personnel; and
- operational limits of machine and software.

The analysis should be performed for all affected missions and phases, including degraded modes of operation. Each critical task should be analyzed to a level sufficient to identify operator/maintainer problem areas that can adversely affect mission accomplishment and to evaluate proposed corrective action.

4.2.1.3.3 Workload analysis. Operator (individual and crew) and maintainer (individual and team) workload analyses should be performed and compared with performance criteria. To avoid overloading or underloading, the degree to which demands of any task or group of tasks tax the attention, capacities, and capabilities of system personnel (individually and as a crew) and thus affect performance should be evaluated. Sensory, cognitive, and physiological limitations should be considered, as applicable. The workload analyses should define operational sequences and task times. Preliminary workload estimates should correlate mission segments with crew tasks for each task component (visual, auditory, motor, cognitive) specified in terms of time, workload, mental effort, and psychological stress. A workload estimate for each crewmember should be defined in a fashion permitting crew workload to be related to mission segment(s).

4.2.1.3.4 Corrective action. Human-system interface design incompatibilities and excessive skill/physical requirements identified by analysis of tasks, analysis of critical tasks, or workload analysis should be corrected by changing the design or restructuring the tasks to preclude degraded human performance.

4.2.1.3.5 Timeliness and availability. Analyses of tasks should be modified as required to remain current with the design effort and should be available to the procuring activity.

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4.2.1.4 Preliminary system and subsystem design. HE principles and criteria should be applied to system and subsystem designs and should be reflected in design criteria documents, specifications, functional flow diagrams, system and subsystem schematic block diagrams, interface control drawings, overall layout drawings, and related applicable drawings provided in compliance with contract data requirements. The preliminary system and subsystem configuration and arrangements should satisfy human-system performance requirements and comply with applicable HE design criteria, such as MIL-STD-1472.

4.2.2 HE in design and development. During design and development, the HE inputs made as a result of implementing the analysis guidelines of 4.2.1, as well as other appropriate HE inputs, should be converted into detail engineering design features. Design of the equipment should satisfy human-system performance requirements and meet applicable HE design criteria such as MIL-STD-1472. HE testing of the system or equipment should be considered during design and should include such factors as verifying proper operation, defining need for maintenance, and allocating adequate space for test personnel to perform their tasks. HE provisions in the equipment should be evaluated for adequacy during design reviews. Personnel assigned HE responsibilities by the contractor should participate in design reviews and engineering change proposal reviews of all equipment end items involving the human-system interface.

4.2.2.1 Experiments, tests, and studies. The contractor should conduct experiments, tests (including dynamic simulation), and studies to resolve HE and life support problems specific to the system. Experiments, tests, and studies should be performed with actual users in the actual user environment (or in a realistic simulation thereof) to validate design goals and system performance. These experiments, tests, and studies should be accomplished in a timely manner so that their results may be incorporated in equipment design and, if necessary, used to revise initial function allocations. Any significant HE or life support problem deemed resolvable only by a major experiment, test, or study effort should be brought to the attention of the procuring activity; this notification should include the estimated effect on the system if the problem is not resolved. To ensure that these experiments, tests, and studies do not duplicate current or previously conducted efforts that may be germane to resolving HE problems, the applicability and utility of existing HE and other relevant data bases (e.g., general literature, research reports, study reports) should be determined before initiating major efforts.

4.2.2.1.1 Computer models, three-dimensional mockups, and scale models.

4.2.2.1.1.1 Computer models. When it is cost effective, three-dimensional computer models, rapid prototyping, and computer-aided design/computer-aided manufacturing (CAD/CAM) methods should be used to develop the design of equipment for which human performance will be a determinant of operational performance and maintenance effectiveness. Computer models should be able to provide a suitable range of body sizes, clothing, and postures for evaluating proposed designs and design changes in terms of compatibility with whole-body fit and access; finger, hand, arm, foot, leg, and other access and reach; visual field; and strength. Computer models should not be used for compliance testing of human performance and HE design. When used for predictive purposes, such models should produce accurate and empirically repeatable, valid outputs. Computer models, simulations, rapid prototyping outputs, and

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CAD/CAM designs and analyses should be accessible to the procuring activity and should, as applicable, be available during IPT meetings and design reviews to facilitate concurrent engineering.

4.2.2.1.1.2 Three-dimensional mockups. At the earliest practical point in the development program and well before fabrication of system prototypes, full-scale three-dimensional mockups of equipment involving critical human performance should be constructed. The mockups should be constructed sufficiently early to ensure that results of HE evaluations can influence design. The mockups should be no more elaborate or expensive than is essential to represent those aspects of the human-system interface to be evaluated. These mockups should provide a basis for resolving operational and maintenance access, workspace, and related HE problems, and for incorporating solutions into system design. In those design areas that involve critical human performance and for which human performance measurements are necessary, development of functional mockups should be considered. (Disposition of mockups after they have served the purposes of the contract will be stipulated by the procuring activity.)

4.2.2.1.1.3 Scale models. Scale models may be used to supplement three-dimensional computer models, rapid prototyping, CAD/CAM, or mockup methods, but should not be substituted for mockups unless such substitution provides equivalent, valid, repeatable, and accurate information in a cost-effective and timely manner.

4.2.2.1.2 Dynamic mockups. Dynamic mockups, also known as engineering simulators (full-scale physical models that simulate functions), may be used when static three-dimensional mockups are inadequate for assessing human performance in the design of complex systems. These mockups may be used to (a) evaluate operator procedures and equipment/operator interfaces, and identify any potentially unsafe procedures and unacceptable workload demands; (b) evaluate the nonmechanical aspects of a design, such as control dynamics, communications, information, electronic displays, and display formats; (c) emulate user-system performance to derive estimates of performance for alternate design configurations and cost-effectiveness evaluations of variable manpower, personnel, and training parameters, and (d) evaluate biomedical and environmental considerations. While the simulation equipment is intended for use as a design tool, its design should consider the opportunity to transition the technology to subsequent training simulators.

4.2.2.2 Engineering drawings. HE principles and criteria should be reflected by the engineering drawings and CAD representations to ensure that the final product can be used and maintained effectively, efficiently, economically, reliably, and safely. The following drawings are included: system layout, panel layout, control, communication system, individual equipment design drawings, and other drawings depicting equipment important to system operation and maintenance by human operators. The design, as reflected by such drawings, should comply with applicable HE design criteria such as MIL-STD-1472. Personnel assigned HE responsibility by the contractor should review layouts and drawings for all designs with potential impact on human performance or the human-system interface and should identify for corrective action those designs that may induce human error or be unsafe.

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4.2.2.3 Work environment, crew station, and facilities design. HE principles and criteria should be applied to detail design of work environments, crew stations, and facilities to be used by system personnel. Drawings, specifications, and other documentation of work environments, crew stations, and facilities should reflect compliance with human performance requirements and with applicable Human Performance design criteria such as MIL-STD-1472. The design of work environments, crew stations, and facilities that affect human performance under normal, unusual, and emergency conditions should incorporate at least the following, where applicable:

- Provisions for addressing the effects of atmospheric conditions, such as composition, volume, pressure and control for decompression, temperature, humidity, and air flow
- Provisions for minimizing the effects of weather and climate, such as rain, hail, snow, and mud; and arctic, desert, and tropic conditions
- Provisions for minimizing the effects of positive and negative acceleration forces, including linear, angular, and radial
- Protection from physical and performance effects of acoustic noise (steady state and impulse), vibration, and impact forces
- Provisions for maintaining human performance during weightlessness
- Provisions for minimizing disorientation
- Adequate space for personnel, their movement, and their equipment
- Adequate physical, visual, and auditory interfaces between personnel and their equipment, including provision for proper eye position in relation to display surfaces, controls, and external visual areas
- Safe and efficient walkways, stairways, platforms, and inclines
- Provisions for minimizing physiological stresses
- Provisions for minimizing physical fatigue
- Allowance for the effects of clothing and personal equipment, such as full and partial pressure suits, fuel handler suits, body armor, chemical/biological clothing and equipment, cold weather clothing, and temperature-regulated clothing
- Equipment handling provisions, including remote handling provisions and tools when materiel and environment require them
- Provisions for safe and error-proof equipment installations
- Protection from chemical, biological, toxicological, radiological, thermal, mechanical, electrical, and electromagnetic hazards
- Optimum illumination commensurate with anticipated visual tasks
- Appropriate sustenance and storage equipment (i.e., oxygen, water, and food), and provision for refuse management
- Crew safety protective restraints (shoulder, lap, and leg restraint systems; inertia reels; and similar items) appropriate to mission phase and compatible with control and display utilization
- Adequate space, clearance, and layout for normal ingress/egress and emergency escape from crew workstations and aircraft crew stations

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4.2.2.4 HE in performance and design specifications. The provisions of performance, design, and procurement specifications prepared by the contractor should invoke applicable HE design criteria such as MIL-STD-1472.

4.2.2.5 Procedure development. Based upon the human performance functions and tasks identified by HE analyses (4.2.1 herein), the contractor should apply HE principles and criteria to the development of procedures for operating, maintaining, or otherwise using the system equipment. This effort should be accomplished to ensure that the human functions and tasks identified through HE analysis are organized and sequenced for efficiency, safety, and reliability; to provide inputs to the Logistic Support Analysis where required; and to ensure that the results of this effort are reflected in the development of operational, training, and technical publications.

4.2.2.6 Software development. The contractor should apply HE principles to software design in those systems where software determines part of the human interface. Software that affects controls and displays should be evaluated for its impact on the human-system interface. Automated system functions requiring human monitoring or intervention should be considered part of the human-system interface. Multifunction controls and displays that vary in function depending on system software should also be considered part of the human-system interface.

4.2.2.7 Manuals. HE should be applied to the development of maintenance and training manuals (electronic or hard-copy) to ensure thoroughness, technical accuracy, suitable format of information presentation, appropriate reading level, appropriate level of technical sophistication, clarity, and suitable quality of illustrations.

4.2.3 HE in test and evaluation. The contractor should establish and conduct a T&E program to (1) demonstrate conformance of system, equipment, and facility design to HE design criteria; (2) confirm compliance with system performance requirements where personnel performance is a system performance determinant; (3) secure quantitative measures of system performance that are a function of the human interaction with equipment; and (4) determine whether undesirable design or procedural features have been introduced. Maximum use should be made of the data collected from experiments, tests, and studies (see 4.2.2.1). The fact that these functions may occur at various stages in system, subsystem, or equipment development should not preclude final HE verification of the complete system. Both operator and maintainer tasks should be performed as described in approved test plans during the final system test.

4.2.3.1 Planning. HE testing should be incorporated into the system T&E program and should be integrated into engineering design and development tests, contractor demonstrations, flight tests, acceptance tests, and other development tests. Compliance with HE requirements should be tested as early as possible. HE findings from design reviews, mockup inspections, demonstrations, and other early engineering tests should be used in planning and conducting later tests. HE test planning should be directed toward verifying that the system can be operated, maintained, supported, and controlled by user personnel in its intended operational environment. HE test planning should also consider data needed from or to be provided by operational T&E. Test planning should include methods of testing (e.g., use of checklists, data sheets, test

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participant descriptors, questionnaires, operating procedures, and test procedures), schedules, quantitative measures, test criteria, and reporting processes.

4.2.3.2 Implementation. Planned HE T&E should be implemented upon approval by the procuring activity. Test documentation (e.g., checklists, data sheets, test participant descriptors, questionnaires, operating procedures, and test procedures) should be available at the test site. HE portions of all tests should include the following:

- Performance of mission or work, or a simulation thereof if actual performance is not possible
- Critical tasks
- A representative sample of noncritical scheduled and unscheduled maintenance tasks that do not duplicate the tasks selected for the maintainability demonstration
- Proposed job aids, new equipment training programs, training equipment, and special support equipment
- Use of personnel who are (1) representative of the range of the intended military user populations in terms of skills, size, and strength; (2) wearing suitable military garments and equipment appropriate to the tasks; and (3) approved by the procuring activity (use of military personnel from the intended user population is preferred)
- Collection of task performance data in actual operational environments, or in simulated environments if collection in the actual operating environment is not possible
- Identification of discrepancies between required and obtained task performance
- Criteria for acceptable performance of the test

4.2.3.3 Failure and error analysis. All failures occurring during T&E should be subjected to an HE review to differentiate between (a) failures of equipment alone, (b) failures resulting from human-system incompatibilities, and (c) failures due to human error. Human errors occurring in the performance of critical tasks during T&E should be analyzed to determine the reason for their occurrence. The contractor should identify to the procuring activity those design characteristics or procedures that may contribute substantially to human error and should propose corrective action.

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# 5. THE SIGNIFICANCE OF HE FOR PROGRAM ACQUISITION

This section is prepared primarily for program managers who are responsible for HE and who are familiar with the contemporary acquisition process as stipulated by DoDD 5000.1 and DoD 5000.2-R and implementing policies. A number of HE activities are described in general terms to provide an indication of the range and scope of HE responsibilities and actions that may be encountered during the system acquisition process. In accordance with DoD 5000.2-R, the need for timely and extensive communication and coordination among organizations with related responsibilities is emphasized. The use of Integrated Product Teams (IPTs) to promote concurrent engineering, the principal means mandated in DoD 5000.2-R for formally accomplishing the required coordination, is discussed. The significance of providing HE support to the three system development areas identified by the program tasks of Section 4, (1) analysis, (2) design and development, and (3) test and evaluation (T&E) is addressed in broad terms. Various HE program management relationships are suggested. The practical value of HE is discussed, and lessons learned and success stories are presented that demonstrate the importance of sound and timely HE efforts.

5.1 HE support in system acquisition. HE activities are required throughout the system acquisition process. HE-related factors and considerations are pervasive in a system, occurring at each point where the user interacts with the system. HE issues, considerations, and needs are identified and acted upon throughout analysis, design and development, and T&E activities in system acquisition. For good reason, DoD 5000.2-R mandates that "Human factors engineering requirements shall be established to develop effective human-machine interfaces, and minimize or eliminate system characteristics that require extensive cognitive, physical, or sensory skills; require excessive training or workload for intensive tasks; or result in frequent or critical errors or safety/health hazards. The capabilities and limitations of the operator, maintainer, trainer, and other support personnel shall be identified prior to program initiation (usually Milestone I), and refined during the development process. Human-machine interfaces shall comply with the mandatory guidelines for all Command, Control, Communications, Computers, and Intelligence ($C^4I$) systems, automated information systems, and weapons systems that must interface with $C^4I$ systems or automated information systems."

This regulation also mandates the establishment of (a) broad cognitive, physical, and sensory requirements for the operators, maintainers, and support personnel that contribute to, or constrain, total system performance; and (b) requirements for human performance that will achieve effective human-system interfaces.

5.1.1 Total system approach. DoD acquisition policy stresses the importance of optimizing system performance and minimizing the cost of ownership through a "total system" approach. The total system includes not just the prime mission equipment and software, but also the people who operate, maintain, and support the system; the training and training devices; job aids; and the operational and support infrastructure. HE, a design-oriented discipline, assists in fully integrating the human into the total system by:

- Defining human components of total system operational performance, support, or life cycle cost objectives and thresholds;

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- Specifying human performance (in terms of critical human functions or tasks, standards of performance, and operational/environmental conditions) to meet operational, support, and life cycle cost goals;
- Ensuring that engineering processes provide for the effective utilization of personnel by accommodating the human cognitive, physical, and sensory characteristics that directly enhance or constrain system performance;
- Ensuring that these human-related concerns are addressed and are represented adequately in the systems engineering process throughout system acquisition; and
- Ensuring that system design requirements related to human factors and human-system integration performance requirements are established, reviewed, and considered in the systems engineering tradeoff process.

5.1.2 HE and Human Systems Integration (HSI). HSI is a comprehensive management and technical strategy to ensure that human performance, the burden design imposes on manpower, personnel, and training (MPT), and safety and health aspects are considered throughout system design and development. HSI assists with the total system approach by focusing attention on the human part of the total system equation and by ensuring that human-related considerations are integrated into the system acquisition process. DoD Regulation 5000.2-R mandates that a strong HSI strategy be initiated early in the acquisition process. The regulation also stipulates that "reports, plans, and program decisions made by the HSI communities outside the acquisition infrastructure (such as manning documents and personnel occupational specialty decisions) must reflect and, to every extent possible, be reflected in program design decisions, trade-offs, risk assessments, and test results."

5.1.2.1 HSI elements. HSI encompasses seven elements or constituencies: human (factors) engineering, manpower, personnel, training, safety, health hazards, human survivability. The primary concerns of each of these elements are shown in Table I. As suggested by this table, optimizing total system performance entails tradeoff studies between the seven HSI elements to determine the most effective, efficient, and affordable design. Of these seven elements, HE is the one with primary responsibility for drafting HSI human performance objectives and thresholds.

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TABLE I. HSI elements and the areas of concern for each.

| HUMAN (FACTORS) ENGINEERING | MANPOWER | PERSONNEL | TRAINING | SAFETY | HEALTH HAZARDS | HUMAN SURVIV-ABILITY |
|---|---|---|---|---|---|---|
| Unnecessarily stringent selection criteria for physical & mental capabilities<br><br>Compatibility of design with anthropometric & biomedical criteria<br><br>Workload situational awareness, and human performance reliability<br><br>Human – system interface<br><br>Implications of mission and system performance require-ments on the human operator, maintainer, supporter<br><br>Effects of design on skill, knowledge, & aptitudes require-ments<br><br>Design-driven human performance, reliability, effectiveness, efficiency, and safety performance requirements<br><br>Simplicity of operation, maintenance, and support<br><br>Costs of design-driven human error, inefficiency, or ineffectiveness | Wartime / peacetime manpower requirements<br><br>Deployment considerations<br><br>Force & organizational structure<br><br>Operating strength<br><br>Manning concepts<br><br>Manpower policies | Personnel selection & classification<br><br>Demographics<br><br>Accession rates<br><br>Attrition rates<br><br>Career progression & retention rates<br><br>Promotion flow<br><br>Personnel & Training pipeline flow<br><br>Qualified personnel where and when needed<br><br>Projected user population/ recruiting<br><br>Cognitive, physical, educational profiles | Training concepts & strategy<br><br>Training tasks and training development methods<br><br>Media, equipment, and facilities<br><br>Simulation<br><br>Operational tempo<br><br>Training system suitability, effectiveness, efficiency, and costs<br><br>Concurrency of system with trainers | Safety of design and procedures under deployed conditions<br><br>Human error<br><br>Total System reliability & fault reduction<br><br>Total system risk reduction | Health hazards induced by systems, environment , or task requirements<br><br>Areas of special interest include (but not limited to):<br><br>Acoustics,<br><br>Biological & chemical substances,<br><br>Radiation,<br><br>Oxygen deficiency & air pressure,<br><br>Temperature extremes,<br><br>Shock & vibration,<br><br>Laser protection | Threat environment<br><br>Fratricide Identification friend/foe (IFF)<br><br>Potential damage to crew compartment & personnel<br><br>Camouflage / Concealment<br><br>Protective equipment<br><br>Medical injury<br><br>Fatigue & stress |

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These requirements must ensure total system operational performance goals are met while also achieving manpower, personnel, training, safety, and health hazard requirements. and ensuring that these requirements are incorporated into the appropriate acquisition program documents, such as the Mission Need Statement (MNS), the Cost and Operational Effectiveness Analysis (COEA), the Operational Requirements Document (ORD), and the Test and Evaluation Master Plan (TEMP). The HSI process can serve to sensitize users of defense systems to the need to identify human performance constraints, thresholds, and issues in acquisition program documents; the HE practitioner can then place these in the Request For Proposals (RFP) and Statement Of Work (SOW) as requirements or study subjects.

5.1.2.2 Mutually supportive roles. HSI has the same goals as HE: to ensure that systems, equipment, and facilities

- incorporate effective human-system interfaces;
- achieve the required levels of human performance;
- make economical demands upon personnel resources, skills, and training;
- minimize life-cycle costs; and
- manage risk of loss or injury to personnel, equipment, or environment

HSI programs can support HE efforts; thus HE practitioners should form cooperative alliances with HSI proponents and HSI constituents to ensure that human-related goals, constraints, and issues are identified early in acquisition, that requirements are clearly stated, and that human outcomes are tested.

5.1.3 Coordination requirements. Both the provisions of DoD 5000.2-R and the realities of having to address the increasingly divergent HE issues that arise with the emergence of highly sophisticated and complex systems impose substantial requirements for frequent formal and informal coordination among organizations, agencies, and individuals with concerns related to HE. To achieve the goals of a concurrent engineering environment where design issues can be considered at virtually the same time by all interested parties (e.g., design specialties, user, program management), coordination among specialty areas is essential. The computer aided design (CAD) environment and the use of integrated product teams (IPTs) enables the goals of concurrent engineering to be more easily reached.

5.1.3.1 Concurrent engineering approach. Concurrent engineering is a paradigm for systems or product development that attempts to integrate design-related decisions in a concurrent manner. This approach allows the developers to consider all elements of a project from the outset, and continuously throughout planning, testing, and design. With all aspects of the design considered from project initiation, the HE practitioner can ensure operator, maintainer, and supporter accommodation without last-minute system redesigns or Engineering Change Proposals (ECPs). Thus, concurrent engineering allows the proactive HE practitioner to provide inputs at the beginning and continuously throughout the project to influence the total design in a more timely manner, allowing for more efficient and effective design processes. For each system/subsystem in development, a team (e.g., IPT), to address all aspects of the system/subsystem, needs to be developed to facilitate this type of integrated process development.

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The team normally includes engineers, HE practitioners, program managers, users, designers, manufacturing representatives, etc. Concurrent engineering differs from traditional linear engineering by as far as possible, considering all facets of the project concurrently and continuously from project inception through completion. Final configuration later in the development process allows all foreseeable design questions to be addressed. In this type of engineering process the HE practitioner can have a greater impact by incorporating HE principles from the outset instead of making corrections after the system is already designed and when changes would be costly. The extensive use of computers has greatly facilitated concurrent engineering. The advent of computer-aided design (CAD) tools has allowed engineering teams to take advantage of rapid prototyping tools and electronic mock-ups. Many of the HE analyses that used to be manual can now be automated in the CAD environment for quick responses to the concurrent engineering team. Electronic engineering drawings and rapid prototypes can be viewed by design teams instantly across the country or world, enabling user, program manger, engineering specialties, contractors, and their subcontracts to see design proposals all at once. This concurrent engineering approach, facilitated by the CAD environment, enables coordination among members of the system development team, which in turn, can foster more effective design decisions. For further information on concurrent engineering concepts see Gorman (1990).

5.1.3.2 Coordination among specialty areas. The design of a system is typically an iterative, evolutionary process. The need to better accommodate one aspect of the design may require reconsideration of another. The results of T&E may indicate a need for further analyses and eventual redesign. Interactions such as these clearly point up the need for coordination among a variety of principals. For example, the design of systems to be deployed in an extreme environment such as severe cold requires the participation of individuals with expertise in human biomedicine and physiology to devise effective means of assessing and mitigating human response to this environmental stressor. In addition, the HE practitioner needs to identify issues relating to performance in severe cold, obtain needed information on the use of cold-weather gear (such as range of motion and manual dexterity) from the designers of protective clothing, and discuss such relevant needs with those responsible for the layout and design of operator and maintainer workstations. Finally, the HE practitioner must coordinate closely with the designers of controls or weaponry to be used. To meet the system-related performance criteria, the user working in a hostile or extreme operational environment must be able to perform all tasks satisfactorily. However, sound, intelligent tradeoffs may be required to ensure that the user's performance is optimized for a given operational environment. This example readily demonstrates the need to consider the implications of system design factors such as operational environment from a variety of HE and related perspectives and highlights the need for early coordination and communication among the specialists most knowledgeable in all relevant areas. Such coordination will help ensure effective interface by facilitating HE's influencing design in a comprehensive manner.

5.1.3.3 Demands on HE. Because of the wide range and variety of HE responsibilities, considerable demands are placed upon HE practitioners. HE practitioners need to be extensively involved in widespread coordination and communication efforts to ensure that HE considerations are appropriately defined, represented, and addressed throughout the system acquisition cycle. The approach mandated by DoD 5000.2-R to achieve such coordination is the use of IPTs.

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5.1.4 Integrated Product Teams (IPTs). The reality is that a single individual cannot be sufficiently knowledgeable—let alone expert—in all areas to ensure that every concern is identified, fully articulated, and addressed during the design and development process. Accordingly, DoD 5000.2-R calls for IPTs to be formed at the outset of major system acquisition programs to ensure that the necessary coordination occurs in a timely manner. At the time new system acquisition programs are approved and a program manager is identified, Working IPTs (WIPTs) are formed. Typically, it is within the context of these WIPTs that HE concerns and issues are formally addressed. While such groups provide the formally recognized means of coordination, frequent informal coordination to identify and address HE issues ultimately proves to be the most effective means of ensuring that concerns are properly dealt with during the formal WIPT meetings. This coordination is necessary to ensure that maximum use can be made of existing resources (for instance, that HE issues are fully represented in planned exercises, tests, evaluations, and simulations). Such coordination efforts also ensure that issues and actions being considered by non-HE groups are adequately reviewed so that HE-related factors can be identified and addressed appropriately before decisions are made. From an HE perspective, the goal of such efforts is to ensure that the proper information and source data are available in a timely manner to substantively support the design process, and that the results of these efforts improve the integration and design of the system. HE activities typically interact with other disciplines in all stages of development, particularly in a concurrent engineering environment. HE activities—whether related to analysis, design and development, or T&E—should emphasize close coordination between HE practitioners and other relevant groups, including individuals with programmatic responsibilities (such as program managers and members of IPTs); specialists in related technical disciplines (for instance, systems engineering, training, safety, health hazards, logistics, manpower—all apt to be represented in the IPTs); and operational personnel. Interactions between HE efforts and MPT are especially important because MPT is a significant life cycle cost driver and some MPT activities occur outside of the formal systems acquisition process. These interactions are discussed below.

5.1.5 Manpower, personnel, and training interactions and implications. With few exceptions, the MPT areas are predominant sources of life cycle cost of major systems. Since initial MPT constraints limit design, while equipment, software, and task design place demands on MPT resources, it is imperative that the HE and MPT communities harmonize their work from requirements-setting to total system design and evaluation. The increasing sophistication of the DoD acquisition process and methods of managing cost entails the need to characterize the aptitude and skill requirements, manpower requirements, and training implications of system design for projected users. Such factors have a direct impact on the affordability and life-cycle cost of the total system. They also have implications for HE evaluations of operator procedures and of the mental and physical demands associated with task performance. Early HE analyses provide the initial characterizations, which are based, in part, on an understanding of the aptitudes and capabilities of users of related or predecessor systems. With this baseline, HE practitioners may suggest or evaluate methods, designs, or technologies that would reduce sources of MPT costs. Later HE analyses and tests may indicate a need to reevaluate the range of aptitudes or capabilities to be required of the projected user population, a need to change the design to accommodate apparent deficiencies in the aptitudes of intended users, or both. In addition, the results of HE evaluations—particularly those involving task analyses and other procedural

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assessments—are apt to have direct implications for the training community with regard to both the creation of training manuals and the design of training equipment and simulators. The reduction of MPT requirements is critical to developing more cost-effective systems as the military strives to become a more lean and efficient fighting force. Effective use of HE can show its payoffs through decreased MPT requirements. Considerations such as these point up the need for HE practitioners to coordinate closely with representatives of the MPT community.

5.1.6 Scope of HE concerns. HE applies knowledge about human capabilities and limitations to system (including system software), equipment, and facility design and development to achieve efficient, effective, and safe system performance at least cost consistent with allocated manpower, skill, and training resources. HE ensures that design of hardware, software, human tasks, and induced work environment is compatible with the sensory, perceptual, cognitive, and physical attributes of the personnel who will operate, maintain, and support it. To accomplish these goals, HE draws upon knowledge and data from many different disciplines and integrates these data into system design and development. Figure 1 illustrates these relationships and shows how HE serves as the agent through which human factors information influences design. To provide a clearer understanding of the breadth of important HE responsibilities to ensure effective integration of the human element into design, Table II shows a detailed (though not exhaustive) listing of a number of significant HE concerns and some of their components. While the HE practitioner may not be responsible for each of these areas directly, the practitioner is charged with developing analyses, design criteria, contract requirements, and T&E plans which ensure that human-system performance goals in all these areas are achieved. The scope of HE concerns is shaped by the need to consider all personnel who must interact with the system, not just the operator, and to examine all aspects of the system, not just the hardware aspects.

5.1.6.1 Operators and maintainers. For every human-system interface, there is a user. When considered in the context of the design, development, and fielding of an entire system (or even a small item of equipment), the term *user* is meant to include not only the operator (such as the infantry soldier, the aviator, the sonar operator), but also individuals who are responsible for maintaining and transporting the system or equipment item. Hence, HE is concerned not only with the functions and tasks of those most directly and obviously associated with system operation and mission success, but also with the functions and tasks of those responsible for crucial behind-the-scenes maintenance to keep the system operational. When the term *user* is understood to include maintainers, and the important role played by such personnel is recognized, then the areas of HE concern are considerably broadened. Attention expands to include more and different types of procedures, and additional work areas and environments.

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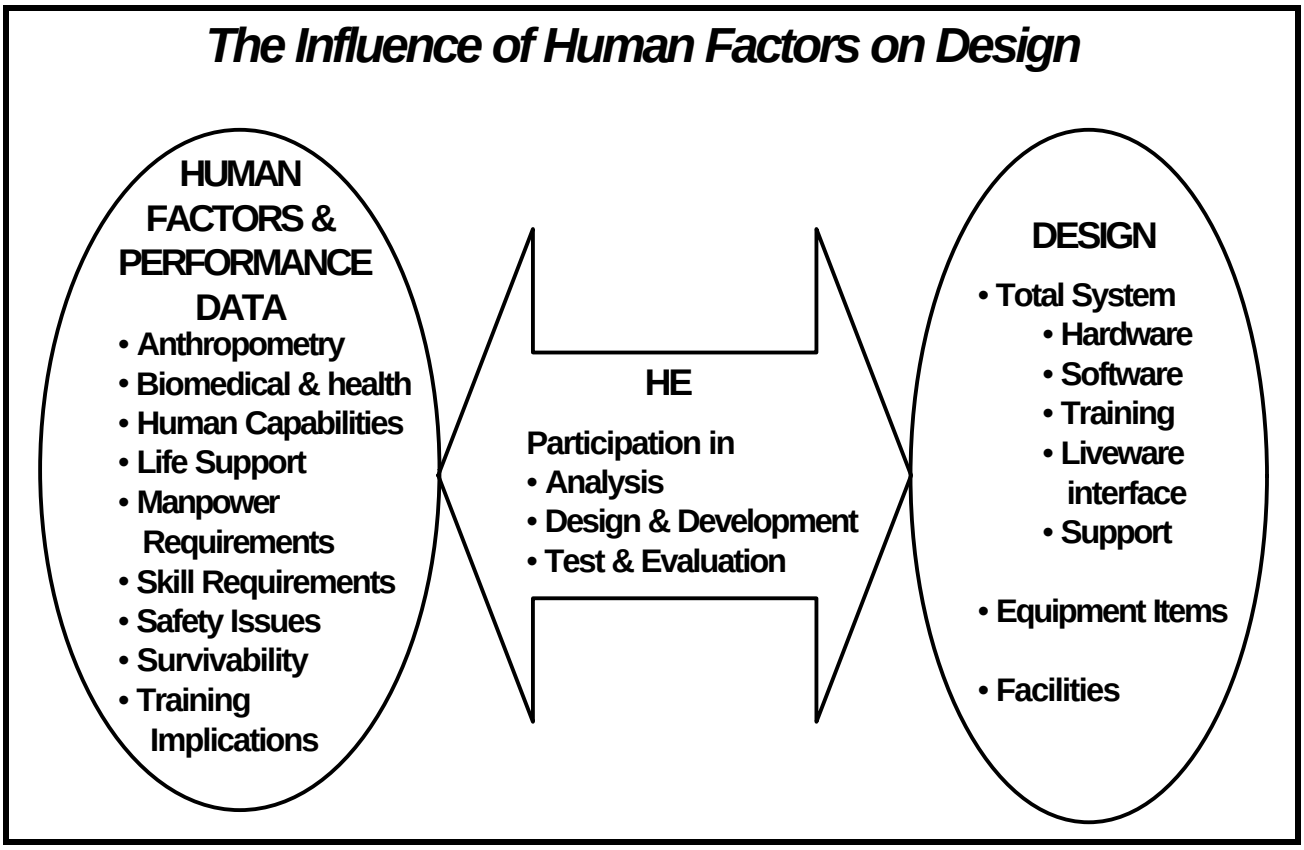


FIGURE 1. HE as a bridge between human-related data and design.

5.1.6.2 Nonhardware issues. It is important to recognize that HE design concerns are not constrained to or derived solely from the hardware aspects of the user-system interface. While admittedly a considerable portion of HE concerns are related to system hardware, many other equally important considerations warrant attention from an HE perspective. For example, software is an integral component of many present-day systems and raises important concerns regarding human-computer interfaces. Four nonhardware factors— (1) the cognitive demands of the system interface on the user, (2) software ergonomics, (3) technical procedural and training manuals, and (4) the conditions under which the system will be deployed—deserve special attention here because they strongly affect user-related design considerations, yet have sometimes been overlooked.

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TABLE II. Subjects of concern to HE.

1. Human Perceptual/Performance Characteristics
   - Anatomy and physiology
   - Anthropometry and biomechanics
   - Sensory processes in vision, hearing, and other senses
   - Spatial awareness and perceptual organization
   - Attention, workload, and situational awareness
   - Learning and memory
   - Decision-making and problem solving
   - Perceptual motor skills and motion analysis
   - Complex control processes
   - Performance speed and reliability
   - Language
   - Stress, fatigue, and other psychological and physiological states
   - Individual differences
2. Display and Control Design
   - Input devices and controls
   - Grouping and arrangement of controls
   - Process control and system operation
   - Control/display integration
   - Visual displays
   - Audio, tactile, motion, and mixed-modality displays
   - Information presentation and communication
   - Human-computer interfaces
3. Design of Equipment, Vehicles, and Other Systems
   - Portable systems and equipment
   - Remote handling equipment
   - Command and control systems
   - Equipment labeling
   - Ground vehicles
   - Marine craft
   - Aircraft and aerospace vehicles
   - Manpower and crew size requirements
5. Automation and Human-Machine Integration
   - Allocation of functions between human and machine
   - Automation of human tasks
   - Aiding of operators, maintainers, and teams
   - Artificial intelligence
   - Virtual environments
   - Robotics
6. Environmental Conditions
   - Illumination
   - Noise
   - Vibration
   - Acceleration/deceleration
   - Whole-body velocity (motion)
   - Temperature extremes and humidity
   - Microgravity
   - Underwater conditions
   - Restrictive environments
   - Time-zone shifts
7. Work Design
   - Task description, task analysis, and task allocation
   - Job skills, structure, and organization
   - Crew coordination and crew resource management
   - Work duration, shift work, and sustained and continuous operations
   - Job attitudes, job satisfaction, and morale
   - Personnel selection and evaluation
   - Training, instructional manuals, and job support
8. Health and Safety
   - Health hazard assessment
   - Risk perception and risk management
   - Biological, chemical, radiation, and other hazards
   - Occupational safety and health
   - Alarms, warnings, and alerts
   - Preventive education and training

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- Maintainability
- Reliability
- Usability

4. Workplace, Crew Station, and Facilities Design

- Console and workstation dimensions and layout
- General workplace and building design
- Design of nonwork (service) facilities
- Design of multi-building environments
- Design of self-contained working/living environments
- Protective clothing and personal equipment
- Life support, ejection, escape, survival equipment

9. System Evaluation

- Modeling and simulation
- Mock-ups, prototypes, models
- Mannequins and fitting trials
- Information flow and processing
- Systems analysis
- Reliability, failure, and error analysis
- Operational effectiveness testing
- Usability testing

5.1.6.2.1 Cognitive factors. As computer-based system components have become more and more common, as automation has increased, and as the overall complexity of emerging systems has risen, HE concerns have expanded and have focused increasingly on the cognitive aspects of the user-system interface. Computerized systems and subsystems have vastly increased both the amount of information available to the user and the rate at which it can be presented. Accordingly, there is increasing HE concern regarding the nature and extent of the cognitive demands (workload) imposed on the user. Greater emphasis is being given to assessing what information is required, and how and when it should be accessed and displayed as part of decision support considerations. The HE challenge and goals are to provide the HE-related data, information, and design criteria needed to develop a user-system interface that permits the user to remain situationally aware, optimally informed, and maximally responsive without imposing overload.

5.1.6.2.2 Human-software interface. The human interface with many systems, subsystems and items of equipment is now software driven. This interface is critical for system operation, maintenance, and support. If the interface is awkward, it invites errors and slows operations. For personal computer and larger computer-based systems, the *Technical Architecture Framework for Information Management (TAFIM)*, Section 8, presents recommendations for good interface design except for systems specifically excluded such as aeronautical systems that are covered under the *Joint Service Specification Guide (JSSG) for Aircrew Systems*. However, some smaller systems, maintenance interfaces, and items of equipment may not have sufficient computer capability to provide a TAFIM-style interface. In these cases, HE must apply sound ergonomic judgment to ensure that the interface facilitates efficient communication and understanding of the operation, maintenance, and support of the item. Usability principles that must be addressed include:

- *Use of effective display principles*, such as consistency, feedback, support of the natural task flow, standard fields, format, user conventions, display order, data grouping, logic, labeling, and spacing.

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- *Effective wording*, such as speaking the user's language, simple and natural dialogue, clear and consistent abbreviations, concise wording, temporal or alphabetical sequence.
- *Use of color* should be conservative, for emphasis or differentiation (with monochrome redundancy to compensate for color blindness sectors of the population), consistency with common color connotations, and allowing for a readable contrast.
- *Graphics* should mimic displays, clearly showing relationships and be used when they can communicate more clearly and efficiently than text, such as displaying trends, limits, or rapidly changing data.
- *Data entry* should be avoided when not necessary, be easy to locate and enter, and allow for minimizing keystrokes with facilities such as defaults, "duping," and truncating commands.
- *Control and display devices* should provide instant feedback, be available in modes appropriate for the operational environment, be consistent with user's common control and display devices, minimize keystrokes and free hands for other work when possible.
- *Error messages* should provide a response to every input, allow for recovery, clearly show error cause and solution while protecting the system and making it very difficult to destroy work.
- *On-line assistance* should be available linked to errors and inquiries in the user's terminology, well indexed, and with clear instructions.
- *User-centered considerations* that should be applied include providing a mental model that capitalizes on pre-existing user mental models and using an intuitive visual layout that follows the task flow or concept. In addition, allow for user customization and defaults, design around errors in a fail-safe manner, minimizing hidden modes, avoiding unnecessary detailed display information.

5.1.6.2 3 Technical manuals. The technical manuals or publications should be evaluated as to their usefulness and adequacy in three areas: (1) Job Instructions, (2) Training, and (3) Job Performance Aids. Job instructions tell how to accomplish a task by providing the step-by-step procedures along with the necessary illustrative drawings. These instructions may help the novice learn the job process or could confuse the learner. Job instructions can be useful for training (factory, classroom, or on-the-job). HE practitioners need to ensure that such manuals apply logical steps of learning, such as the following principles: known to unknown, simple to complex, and whole-part-whole (overview, detail, summary), and that they are well indexed by concepts the user will likely think of when operating or maintaining the system. Technical manuals require validation or verification. These manuals provide critical support for job performance and training. Since out-of-sync or nonconcurrent manuals may cause misunderstanding, wasted time, and possibly accidents, special attention must be paid to procedural manuals and job aids. Several major types of jobs performance aids are identified as follows: (a) *Job Guides* contain instructions for fixed-procedure tasks such as checkout, adjustment, removal, and replacement. (b) *Fully Proceduralized Troubleshooting Aids* spell out the steps to follow in isolating malfunctions to a replaceable or repairable unit. The steps start with observable symptoms of malfunction. (c) *Troubleshooting Decision Aids* provide diagrammatic and supporting textual information which will help the technician decide what steps to take in isolating malfunctions to a replaceable or repairable unit. For larger systems, many of these job aids have been computerized

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and technical manuals are becoming available on CD-ROM or on-line systems. In these cases, the content is still critical to ensure efficient and safe performance. In addition, the computerized technical manuals add the need to use effective human-computer interface principles that will allow the user to take advantage of this computerization so that such systems are not just page-turners. Hyperlinks, head-mounted displays, and voice-activated searching are just some of the possibilities for computer-based job aids. These job aids can serve the purpose of providing "just-in-time training" to personnel who have only performed similar tasks before. This can allow for generalist career fields allowing greater flexibility in work assignments and making for a more efficient work environment than overly specialized skill specialty codes.

5.1.6.2.4 Deployment conditions. The nature of the doctrine and the projected tactical use of a system have important implications for HE analysis.

5.1.6.2.4.1 Mission duration. Anticipated mission duration, especially the need to support sustained and continuous operations (SUS/CONOPS), influences the type of HE design issues raised. For example, in a crew-served system, the number of crewmembers required depends strongly on the anticipated duration of deployment of the system. Lengthy deployments—particularly in potentially bare base, hostile conditions, and contaminated areas, as discussed below—can markedly increase the number of crewmembers needed to operate, secure, and maintain the system. Determining the amount of space required to operate the system and accommodate the additional personnel is another related HE design concern that arises when extended missions are envisioned.

5.1.6.2.4.2 Operational environment. The anticipated operational environment for a given system also influences HE-related design considerations. If operations will be conducted in environments with nuclear, biological, or chemical (NBC) contaminants that require users to remain confined within a tactical vehicle or in mission-oriented protective posture (MOPP) gear for sustained periods, then important HE concerns arise. Factors relating to the maintenance of air quality; the need to accommodate waste elimination; the provision, integration, and stowage of personal protective clothing; and the provision of sleeping accommodations escalate in importance. When operations are anticipated in rough, off-road areas and in geographic locations where climatic extremes are apt to be encountered, HE attention expands to include physical impact and vibration hazards, physiological responses to heat and cold, and related issues of degraded manual dexterity and motor performance. The need to wear cold-weather clothing (and possibly also MOPP gear), including gloves and headgear, presents and highlights HE issues regarding the impact of such gear on a variety of user capabilities. For example, HE analysis must assess the extent to which the user's functional field of view, range of motion, sensitivity, and manual dexterity may be compromised by the use of personal protective headgear, clothing, and gloves.

5.2 HE activity areas. As cited above and in Section 4, there are three broad areas of system development to which HE efforts provide support: analysis, design and development, and T&E. The iterative nature of the overall system development process has been emphasized previously. Figure 2 depicts where in this process each type of HE activity is typically carried out.

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The following paragraphs provide general descriptions and describe significance of each HE activity area.

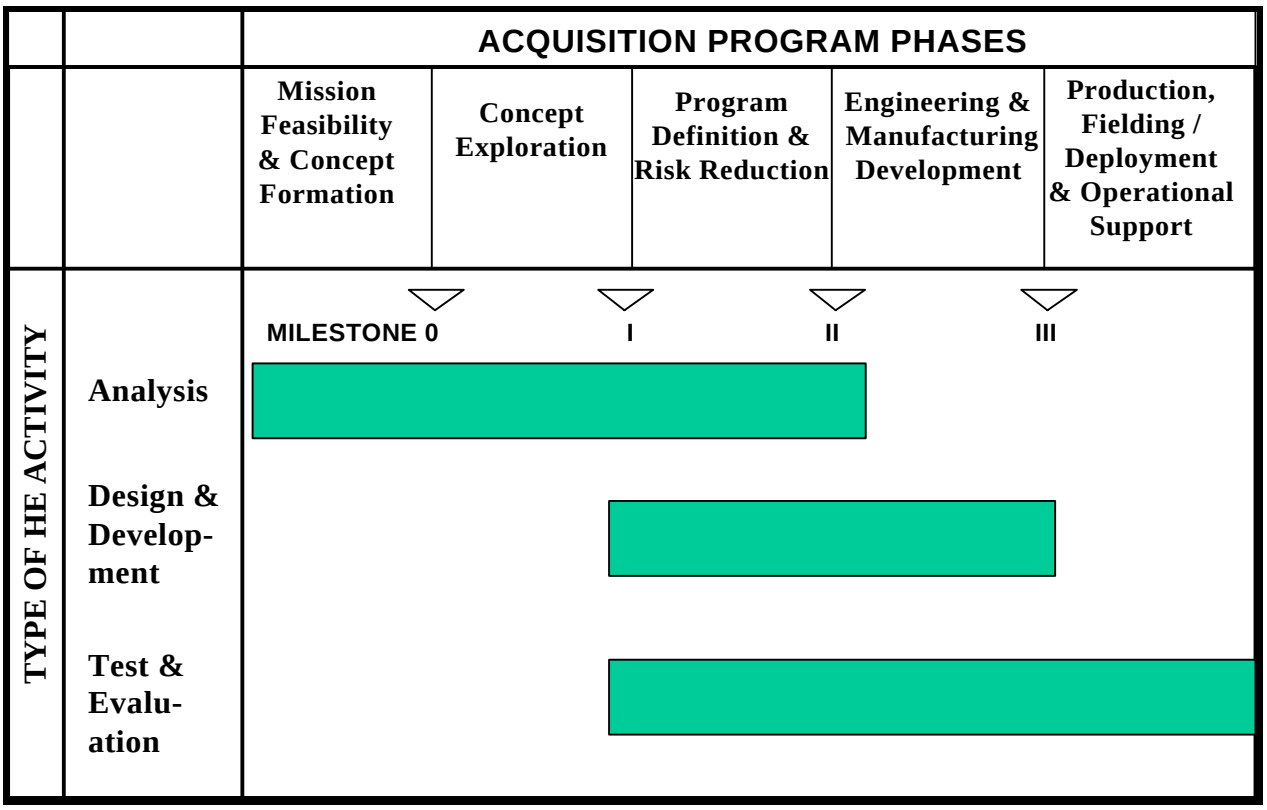


FIGURE 2. Typical program phases for HE activity areas during system development.

5.2.1 Analysis area. HE efforts face challenges and concerns brought about by the reforms to the DoD acquisition process. Early HE activities focus on analysis of the MNS, COEA, ORD, the contract RFP and SOW, the TEMP, and other formative, conceptual system definition documents to identify areas of potential HE concern and to ensure that HE-related goals, objectives, critical design issues, and metrics are addressed. The results of these efforts are used in the early analyses of alternatives to determine if nondevelopmental items (NDIs) and commercial off-the-shelf (COTS) items may be appropriate. To support this NDI/COTS assessment, the results of HE analyses are incorporated in any market research conducted to ensure that HE considerations are properly identified and represented. Some of the most important NDI/COTS HE analyses concern the use of the proposed NDI/COTS systems in unique military environments where protective gear is necessary. Such analyses must consider the unique military missions involved and whether the military population will be able to learn and use the proposed equipment efficiently. These sorts of conceptual analyses are critical to the early system definition efforts.

5.2.1.1 Approaches. Early analytical efforts to anticipate the nature of HE concerns and issues are undertaken without benefit of access to an actual system. Such analyses often focus on information pertaining to HE design issues encountered with similar predecessor systems. System

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development files, “lessons learned” data bases, and T&E findings for predecessor systems are examined to identify problems that occurred earlier, so that similar problems can be anticipated and eliminated (or at least minimized) during the development of the new system. Discussions are held with individuals involved in the design of the predecessor system to uncover further information regarding difficulties experienced with the earlier system. Mockups and computer models may be developed and analyzed, battlefield simulations run, function allocation and task analyses undertaken, and Computer-Aided Design/Computer-Aided Modeling (CAD/CAM) and virtual environment models exercised to provide needed information regarding the feasibility and merit of proposed approaches and designs. A considerable number of HE analysis tools, methods, and models can be meaningfully and inexpensively applied in support of HE analysis activities. Many methods are described in 8.3. HE analyses may identify HE issues to receive further consideration or lead to recommendations for achieving compatibility between the system hardware/software and human performance capabilities and limitations.

5.2.1.2 Interactions with other disciplines. The results of the HE analyses impact other disciplines as well. For example, technical publications relating to safety, maintenance, or training procedures usually reflect the results of task analysis data. Recommendations pertaining to manpower requirements and skill levels may grow out of these analyses as well. The design of training simulators or other training equipment is influenced by data generated by HE function allocation and task/workload analysis. Systems engineering and operations analyses frequently provide data that are relevant to the HE analyses. The results of HE workload analysis are often critical when addressing issues such as crew size or the design of crew stations.

5.2.2 Design and development. HE ensures that the human-system interface will facilitate achieving required human performance in an effective, efficient, and safe manner and reflect incorporation of applicable human engineering design criteria. If the human-system interface design activity is not performed directly by the HE practitioner, then it is the responsibility of the HE practitioner to supply appropriate design information and data. Approval of drawings indicates that the drawings or CAD models have been reviewed for compliance with appropriate HE design criteria.

5.2.2.1 Range of HE applications. HE influences the design of hardware, software, communications, screen display configurations; user and maintainer procedures, including those to be performed during both normal and emergency conditions; decision support information subsystems; work environments; and all facilities associated with system functions that require personnel interaction. Aspects of the design related to interoperability and integration with other systems are also considered from an HE perspective.

5.2.2.2 Approach and results. The results of the HE analyses are examined and compared to system performance specifications and any HE standards that may have been identified as applicable at the outset of the system acquisition process. Typically, such efforts are heavily dependent on the selection and tailoring of pertinent MIL-STD-1472 design criteria. A wide range of HE activities, methods, and tools may be used (see 8.3). These include the review of engineering drawings and specifications, the use of HE checklists, the review of vision plots and reach envelopes derived from CAD/CAM-based anthropometric and workstation modeling tools, and the examination of physical mockups. The product of these HE activities is a set of design

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recommendations yielding human-system interfaces that are compatible with human performance capabilities, that meet system functional requirements, and that contribute to the accomplishment of mission objectives consistent with allocated manpower, skill, and training resources. Where appropriate, the final design should incorporate human-system interface considerations associated with any preplanned product improvements. HE interacts with many other technical disciplines during the design and development effort. Systems engineering and maintainability are two; most maintainability design criteria are, in fact, HE design criteria.

5.2.3 Test and evaluation. The HE T&E effort is important to verify that the user-system interface and procedures are properly designed so that the system can be operated, maintained, supported, and controlled in its intended operational environment by typical users. HE practitioners must work closely with operational, maintenance, systems engineering, logistics, and training personnel prior to and during Developmental T&E (DT&E), Initial Operational Test and Evaluation (IOT&E), Operational Test and Evaluation (OT&E), and (when applicable) Live-Fire Test and Evaluation (LFT&E). HE activities prior to these events are to ensure that HE issues and concerns are incorporated into the TEMP and related documents. They also ensure that appropriate HE-oriented critical operational issues (COIs) are identified, and that measures of effectiveness (MOEs) and measures of performance (MOPs) for assessing these COIs are identified, and that means are provided for their collection. These COIs, MOEs, and MOPs must also relate to the concept of operations (CONOPS) and the System Threat Assessment Report (STAR). HE test items, COIs, MOEs, and MOPs must be traceable to items in the MNS and ORD, and be related upward, in the strategy-to-task framework, to ultimately support national security objectives (see Figure 3). This requirement illustrates how important it is that HE practitioners be involved in the development of these two documents, as well as in the development of the TEMP. HE activities during the tests include ensuring that representative users are involved as test participants and that intended data collection procedures are appropriately carried through. Because multiple tests increase costs and operator time is limited and expensive, HE tests must often hitchhike on other, higher-priority tests. The HE test practitioner must often be creative in obtaining the maximum amount of HE testing for the least cost. HE involvement after the tests centers on analysis of the data and findings to determine what, if any, human-system interface issues surfaced and warrant further consideration or redesign efforts. HE personnel may be invited to participate in or provide consultation regarding the analyses and interpretation of the HE-related data. In addition to providing information of interest to the immediate system, T&E activities also generate HE-related performance data and design criteria for use in the development of subsequent system upgrades and follow-on acquisitions. HE problems identified through T&E are usually presented in service reports that document each human interface issue and what would be necessary to correct the problem.

5.3 The value of HE. There are two major ways to illustrate the value of sound HE efforts. One is to demonstrate positive results of HE activities, and the other is to show the negative results from lack of appropriate HE involvement. The following paragraphs examine the value of the HE effort from both perspectives.

5.3.1 Benefits from HE. As with most worthwhile efforts, HE requires an investment of money and time to gain eventual savings, increased total system performance, safety, and user

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satisfaction. Typically, investment in HE is relatively small compared to that in other system creation activities, while the return is relatively high (see Table III).

TABLE III. Benefits from HE examples. (Booher, 1997).

| System Type | Investment | Total Savings | Time (Years) |
|---|---|---|---|
| Reconnaissance & Light Attack Helicopter | $74.9M | $3.29B | 20 |
| Attack Helicopter | $12.3M | $268.8M | 20 |
| Nuclear/Biological/ Chemical Reconnaissance Vehicle | $60K | $2-4M | 1 |

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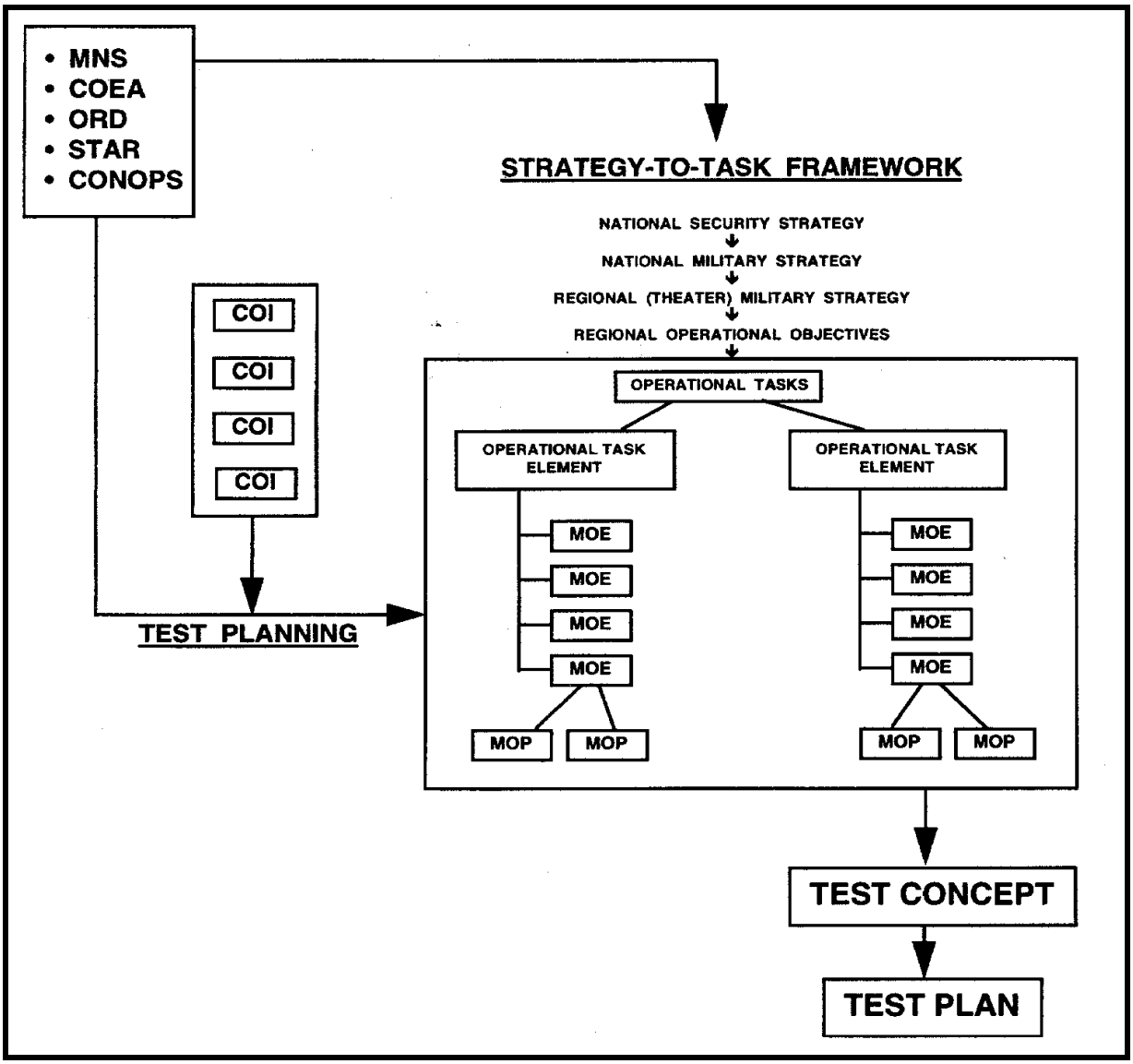


FIGURE 3. Test concept and test concept development.

HE efforts strive to optimize the system to (1) permit operator and maintenance personnel to achieve required performance levels; (2) minimize MPT requirements; (3) achieve required reliability and effectiveness of personnel-system combinations; and (4) provide safe operation by avoiding human error. These benefits can be seen in overall system and HE T&E reports. Success stories such as the following help illustrate the importance and value added of HE efforts.

- Nuclear/Biological/Chemical Reconnaissance Vehicle. Redesigning interfaces utilizing subjective workload assessment, this system, originally requiring a four-member crew, was successfully reduced to three members. As a part of crew risk reduction, HE design principles enabled incorporation of standoff detection capability, thereby

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reducing exposure risk to crewmembers. In addition, HE involvement in overall system design integration allowed for considerable reductions in maintainability costs. (Booher, 1997)

- Forward Area Artillery Resupply Vehicle. During the beginning stages of system development, subjective workload analysis and computer modeling were used to determine optimal vehicle crew size for maximum mission performance. During the T&E phase of the design process, task analysis, and field observation techniques were utilized to identify critical areas of interaction between warfighters, equipment and environment during battle scenarios. Throughout the course of the project, these HE principles targeted key issues that were subsequently resolved by the design team leading to a more effective product. (Booher, 1997)

- Transport aircraft redesign to accommodate parachutists. A joint Air Force-Army working group helped redesign the fuselage and door position of a large transport aircraft using HE principles to improve the airflow for parachutes. The vehicle is now considered the best aircraft for parachute jumping. (Air Force HSI Office, 1995)

- Screen display redesign. The CRT screen display used by the directory assistants at a regional telephone company was reconfigured in keeping with HE recommendations. After the redesign, the average time to process a call dropped by 600 milliseconds. This reduction saves the company $2.94 million a year across the five-state region served by the system. (Hendrick, 1996)

- Training system redesign. At the same telephone company, HE was applied in redesigning the systems used to train directory assistants. These revisions reduced the time needed to train an operator from five days to one and a half days. (Hendrick, 1996)

- Shoulder-launched missile system. A shoulder-launched missile system with challenging operational requirements received extensive human engineering during its concept, design, test, and fielding, closely following the tasking in Section 4. Not only did it meet operational requirements, but the design of the user-system interface and operational procedures enabled what might have otherwise been a complicated system, to facilitate effortless field use by third-world freedom fighters. Its original critics now praise the system for its simplicity. (Reed, 1988)

- Center high-mounted brake lights. In 1985, after extensive HE studies showing positive results, center high-mounted stop lamps became standard equipment on all new passenger cars in the U.S. Vehicles equipped with the new brake lights are involved in 50 percent fewer rear-end collisions, and when an accident does occur, the cost of repairs is 50 percent less. It has been estimated that 126,000 reported crashes will be avoided annually from 1997 on, for a savings of $910 million a year. These benefits stemmed from a $5 million investment in HE. (Hendrick, 1996)

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- Gunship aft-scanner workstation redesign. Because gunship aft-scanners (who look for missile launches and other threats from the tail of their aircraft) had to remain in an "unnatural" prone position for hours over hostile territory, they suffered back and neck pain. To remedy this problem, HE practitioners identified alternative design solutions for the aft-scanner workstation. The program office was able to fund several of these recommendations. As a result of the HE effort, weight distribution, body posture, positioning for mission tasks, functional reach, and external visibility were all improved, and neck and back pain complaints declined. (Gentner, Wourms, Hunn, & Farrell, 1996)

- Aircraft throttle module redesign. An oversensitivity problem (an unacceptably large output for a small input) was discovered in the use of the throttles of a large transport aircraft during aerial refueling. After engineers unsuccessfully redesigned the throttles without HE input, the HE group was asked to develop a solution. The HE practitioners collected and analyzed data and identified critical component failures. They worked with designers to modify the throttles by reducing the spring force, smoothing the cam action, and adding helper handles. The solution was greeted with overwhelming pilot acceptance. (Air Force HSI Office, 1995)

- Development of an efficient helicopter tool kit. A striking example of the benefits of HE involvement is the design of the tool kit for helicopter mechanics. Historically, aircraft maintenance tool kits have been large, awkward, and heavy to transport on deployments. Based on HE recommendations, the organizational tool kit for one helicopter was reduced from 134 tools to only 6 tools. This redesign reduced what is usually a trunk-sized kit to a canvas pouch that is approximately half the size of a rolled-up newspaper. (Skelton, 1997)

- Modification of a manufacturing facility. Following an HE evaluation and modification of a manufacturing facility, worker's compensation losses dropped more than 75 percent, from $400,000 to $94,000, in the first year. The changes that resulted from this HE evaluation saved the manufacturer $1.48 million in the period 1990-1994. (Hendrick, 1996)

- Transceiver Operator Panel. Many times sound HFE involvement goes unnoticed because of the flawless way a system operates. A transceiver operator panel for the control of an airborne computerized communications sending and receiving processor was designed using HFE principles. A task analysis fleshed out six major system requirements, as well as fit it into an existing slot on the flight deck. The panel's design was integrated into the operator's concept of operation so well that upon first questioning during T&E, the field test engineers could not recall using the system at all. (Shafer, 1976).

- Antisubmarine Warfare System. Using mission task and function analysis methods the HE practitioner shaped the design process of this system. The designers were able to meet mission objectives while incorporating many off-the-shelf components, lowering

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overall system cost. During T&E, the system substantially exceeded customer expectations, and subsequently the design lead to a highly successful deployment. (J. B. Shafer, personal communication, May 7, 1998)

- Experimental Helicopter Technological Integration. During mid-nineteen eighties studies were conducted to determine if a single pilot could perform a scout/attack mission using advanced flight deck technology that previously required two aviators. Function analysis was used to determine which mission segments had the greatest workload, and pilots were interviewed regarding flight deck automation and workloads. Next, pilots were assessed using fixed based simulators installed with a prototype flight deck design. The tests and interviews led to two conclusions: (1) a highly effective pilot orientated flight deck was designed, and (2) although an exceptional single pilot could perform the scout/attack mission, under battle stress the pilot would become overloaded and, consequently, the mission performance would be sacrificed. Due to early HE involvement, the military had the opportunity to discontinue a project before any further investment was required. (J. B. Shafer, personal communication, May 7, 1998)

5.3.2 Problems from lack of HE. Lack of appropriate HE involvement in design can result in system shortcomings that require costly redesign, produce substandard system performance, or, in extreme cases, precipitate system failures endangering life and equipment. Many problems found during T&E are evidence of the lack of a good HE effort during the design and development phase. Some of the problems are resolvable, but it costs more to do so during this phase. Problems found during the operational phase are still more costly to resolve. Sometimes problems are identified only after a critical incident. Two sets of examples are provided below to illustrate the problems that can occur when insufficient attention is paid to the HE aspects of design. The first set describes several well-known disasters that, though they have multiple causes, are considered to be due at least partly to lack of adequate HE. The second set provides a sampling of specific lessons learned in a variety of HE-related areas. These examples are provided in the hope that future system design will benefit from previous system design failures.

5.3.2.1 *Catastrophic accidents*. The failure to adequately consider human capabilities and limitations in system design can sometimes have disastrous consequences, as illustrated by the following well-known incidents.

5.3.2.1.1 Downing of Korean Air Lines Flight-007 (KAL-007). KAL-007 was shot down by Soviet air-to-air missiles on September 1, 1983, when it strayed into Soviet air space. A navigational error led the aircraft approximately 365 miles off course, placing it over Soviet military installations at Sakhalin Island. All 269 people on board perished after a 90-second descent into the Pacific Ocean. The most likely cause of the navigational error concerns the inertial navigation system (INS) installed in this large passenger aircraft. The aircraft had three INS systems: one primary system and two backups. Each INS could be programmed separately, or a “remote” mode could be chosen in which the crew programmed only the primary INS and the information was then automatically passed to the two backup units. To ensure that the proper coordinates have been placed in the system, the INS checks the primary INS coordinates against

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the coordinates entered into the two backup units. It is hypothesized that the crew, to save time and energy, chose the "remote" mode when programming the INS units and incorrectly entered the flight path coordinates. This error would not have been detected when in this mode because a copy of the incorrect coordinates would have been used to check the original incorrect coordinates. This INS system was designed to reduce workload and stress to the aircrew. Unfortunately, the system was so automated that it caused inactivity, boredom, and complacency. Due to the defective interface of its INS system, KAL-007 found itself off course and in unfriendly airspace, which led to tragedy. (Based on Stein, 1983; Malone, 1990; Time, 1992)

5.3.2.1.2 Three Mile Island Incident. On March 28, 1979, operators at Three Mile Island, a nuclear power plant in Pennsylvania, made a series of mistakes that led to a near meltdown of the plant's reactor core. This accident was caused by a series of equipment failures and operator errors. The result of the accident was a release of approximately 1200 millirem/hour of radiation into the environment, forcing the evacuation of several thousand residents of the surrounding area. Fortunately, there were no deaths as a direct result of the incident. The near meltdown of the reactor occurred when a pilot-operated relief valve at the top of the pressurizer failed to close, resulting in a loss of the pressurizer steam bubble and a loss of reactor control system pressure and quantity. The indicator lights on which the operators were relying to determine the position of the relief valve led them to believe that the valve was closed. However, the indicator light was not displaying the actual system state—rather, it was showing the presence of a signal commanding the valve to close. In other words, the operators believed the relief valve was closed when in reality the valve was open, though it had been commanded to close. This led the system operators to conclude falsely that a leak had occurred, and they began to act accordingly. However, they continued to make errors that increased the volatility of the system, such as confusing reactor B with reactor A (a problem directly attributable to the control panel layout). Not until two hours into the accident, when an operator who had recently arrived finally realized that the relief valve was at fault, did the proper actions begin to be taken to correct the problem. In the end, the investigation by the Nuclear Regulatory Commission into the human factors (HF) aspects of the accident determined that "the human errors which occurred during the incident were not due to operator deficiencies but rather to inadequacies in equipment design, information presentation, emergency procedures, and training" (Malone, 1990). (Based on Malone, 1990)

5.3.2.1.3 Downing of Iranian Air Lines Flight 655 (IAL-655). On July 3, 1988, the *U.S.S. Vincennes* shot down a commercial airliner over the Persian Gulf, believing the aircraft to be an Iranian F-14. This tragedy led to the loss of 290 lives. The accident occurred in part because a tactical information coordinator (TIC) mistakenly reported the aircraft as *descending* over the ship, based on the seaman's perception of the information gathered from his display, when in actuality the aircraft was *ascending*. Two other crew concurred with the TIC's assessment of the situation. To understand why this error was committed, the events leading up to this incident must be examined. The accident is a classic example of the influence of expectancy in causing human error. Already in a stressful environment, Naval personnel in the Gulf had been told to expect an attack from the Iranians on Independence Day. In addition, specific warnings had been issued concerning possible attacks from Iranian F-14 Tomcats. From June 2 - July 2, 1988, there were 150 challenges issued by warships to aircraft. Of these, 83 percent were to Iranian military aircraft (7 of which were F-14s), while only 1.3 percent were

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issued to commercial aircraft. Moreover, Iranian F-14s had previously been observed flying commercial traffic routes for cover, emitting radar squawk signals of commercial aircraft in tandem with their military squawk. These circumstances, combined with the fact that an Iranian F-14 had been observed taking off from an Iranian military base in the same general location and at approximately the same time as the commercial airliner, led to the accident. With such intense expectations of an attack, and given previous observations allowing for the possibility of an F-14 cloaking itself as a commercial airliner, the crew was falsely led to believe they were under attack. The official investigation of the incident by Admiral Fogarty used the phrase "scenario fulfillment" to describe the TIC's distortion of the situation. The investigation states, "Stress, task fixation, and unconscious distortion of data may have played a major role in this incident." (Based on Malone, 1990)

5.3.2.1.4 Industrial Accident at Union Carbide. On December 2, 1984, the accidental release of a toxic chemical from a Union Carbide subsidiary in Bhopal, India, killed at least 2,500 people (official count) and quite possibly as many as 10,000. In addition, over 150,000 people (out of a population of 672,000 in this urban area) sought medical attention due to the accident. The incident occurred at night when the pressure relief valve blew on a tank containing 45 tons of methyl isocyanate (MIC), releasing its contents and bathing the city of Bhopal in suffocating fumes. MIC is a highly volatile, unstable, flammable chemical that becomes a gas at approximately 100 degrees F and is highly reactive with water at any temperature. In this accident, the MIC in the tank became contaminated with water when the connecting lines were flushed during a routine maintenance operation. Within a period of less than two hours, the pressure in the tank had risen from its normal acceptable level of between 2 and 25 psig to well in excess of 55 psig, and the temperature had soared to at least 392 degrees F, causing the relief valve to open. The accident was attributed to human error caused by carelessness, poor training, and improper maintenance, as well as design shortcomings in the control room. Control room instrumentation supplied no record of previous valves for important system parameters such as tank pressure to supply a historical trace for an operator who was taking over a shift from another (the accident occurred within a few hours of shift change). The upper limit on the displays for the tank temperature and pressure gauges was too low to adequately reflect the conditions in the tank (for example, the pressure gauge topped out at 55 psig). The tank temperature display was not even located in the control room. In Bhopal after the accident, Union Carbide's chairman, Warren M. Anderson, expressed his concern for the loss of life, but maintained that the "safety standards in the U.S. are identical to those in India…. Same equipment, same design, same everything" (Casey, 1993). Unfortunately, that was part of the problem. The designers of the plant did not anticipate the cultural differences between the operators in India and their American counterparts. Nor did they take into consideration the fact that requiring the Indian operators to keep their logbooks in English, a second language for the Hindi personnel, impeded the transfer of information between operators. Finally, two safety mechanisms that could have contained the accident failed. The neutralizing soda scrubber system was grossly inadequate; it was designed to absorb 190 pounds of gas per hour at 15 psig and 95 degrees F, but, at the time of the accident, the MIC was flowing at 40,000 pounds per hour at a temperature of over 392 degrees F. The flare tower that could have harmlessly burnt off the gas was not in operation. (Based on Malone, 1990; Casey, 1993)

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5.3.2.1.5 Crash of a passenger airliner into the Florida Everglades. In 1972, a Lockheed L-1011 descended at night into the swamp of the Florida Everglades, killing all 99 passengers and crewmembers on board. During the ensuing investigation by the National Transportation Safety Board (NTSB), it was revealed that one small, burned-out landing gear indicator set in motion a sequence of events that ended in a completely avoidable tragedy. More accurately, the response of the flight deck crew to the inoperative bulb ultimately hardened the last links in the chain of errors that led to the eventual crash of the aircraft. While in flight, each of the three crewmembers (flight engineer, first officer, and captain) fixated on solving the same problem, an aberrant "landing gear down and locked" bulb, while neglecting to notice that the autopilot had become disengaged. Quietly, while all crewmembers were attending to the same nonemergency condition, the aircraft descended, under neither human nor automatic control, until it finally came to rest in the swamp below. (Based on NTSB, 1973)

5.3.2.2 Lessons learned. The following lessons learned summarize in condensed form the experiences of users and managers of systems whose design failed in some way to adequately consider human capabilities and limitations. It is often difficult to obtain detailed data directly related to such problems, since these could be used to indicate an error or tarnish the image of a contractor. To avoid legal ramifications, the lessons learned have been stated in very general form, and references to specific defense systems and manufacturers have been omitted. In some cases, HE was involved later in the process and the problems were turned into success stories. One major lesson learned is that costly engineering changes could have been prevented if HE had been involved earlier in the systems acquisition process.

- Landing gear visibility at night. Failure to design a helicopter landing gear so that it remains visible to the landing signal crewman at night can result in a wheels-up landing, causing damage to aircraft, safety hazards to aircrew and ground personnel, and operational loss of a valuable fleet asset. (Department of the Air Force, 1996)

- Effects of joint range of motion limits on strength. When the angle of a fully deflected aircraft rudder/brake pedal is beyond the limit of ankle mobility, the pedal will seem to have excessive resistance. In addition, this will prevent the pilot from fully utilizing the brakes of the aircraft. (McDaniel, 1998)

- Attitude Directional Indicator (ADI) with no velocity vector. HUDs without a velocity vector indicator do not provide a flight path marker, leading to possible situational awareness problems for the pilot. (Air Force HSI Office, 1995)

- Component accessibility. Failure to design aircraft components and equipment for easy accessibility causes excessive maintenance time for repair and decreased aircraft availability. (Department of the Air Force, 1996)

- Cross-connected hydraulic lines. Inadvertent cross-connection of hydraulic lines can easily occur when similar fittings are used for all lines, leading to extremely high human and equipment cost. (Department of the Air Force, 1996)

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- Command ejection option. Lack of a command ejection option in a multiple-ejection-seat system can have two major negative effects: seats can collide because ejections are not coordinated; and one or more people may be left within the vehicle if they are unable to eject themselves. Either of these situations could result in loss of life. (Department of the Air Force, 1996)

- Night-vision goggles and exterior lighting. Failure to provide fleet aircraft with exterior lighting compatible with the use of night-vision goggles for nighttime missions can result in mid-air collisions with aircraft that are not operating within the flight formation. (Department of the Air Force, 1996)

- Cargo-loading procedures. When a winch operator loading cargo aboard an aircraft cannot see the cargo being loaded and does not have communications with the rest of the loading crew, safety is adversely impacted. (Department of the Air Force, 1996)

- Overhead power lines and tall vehicles. It is important to identify overhead hazards such as low power lines when planning and organizing work involving tall vehicles. Without proper identification of workplace hazards, the ability to minimize exposure to and protect personnel from hazards is significantly reduced. (Dept. of Energy, 1998)

- Tactical altitude director system audio alarms. When a low-altitude warning system sounds frequent false alarms, pilots become accustomed to the audio alarm and tend to ignore it. This can result in loss of the aircraft and aircrew through failure to respond to a valid alarm. (Department of the Air Force, 1996)

- Life-raft deployment. Life rafts not properly designed for quick and easy deployment can result in death to passengers and crew. (Department of the Air Force, 1996)

- Human error in aircraft accidents. Studies of commercial jet aircraft accidents attribute over 70 percent of accidents to crew error. (Boeing, 1993)

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# 6. HE PROCEDURES FOR DOD ORGANIZATIONS

6.1 General. Identifying HE issues and specifying HE requirements and guidelines are critical to the successful accomplishment of any system acquisition or system modification program. This section describes the HE activities to be undertaken by the requiring DoD organization. HE procedures for the requiring organization are more general than those for the performing organization (for example, the contractor). A listing of policy, standardization, and other applicable documents is contained in Appendix D. These documents are cross-referenced by service and this section's paragraphs. The detailed contractor procedures (presented in Section 7) are derived from the HE practices and procedures described in this section.

6.1.1 DoD policy documents and agents. HE policy issues derive from DoDD 5000.1, and DoD 5000.2-R, mentioned in previous sections. The Office of the Under Secretary of Defense (Personnel and Requirements (P&R)) acts as the focal point for Human System Integration (HIS) (and therefore HE) within the DoD (Phone is 703-614-5259). Service focal points are identified below in applicable 6.1.2 subparagraphs.

6.1.2 Service implementations. Within each service, various agents and organizations focus attention on and implement the broad DoD goals for HE. The services differ in the extent of HE-related requirements imposed to implement these goals and in the degree of central control of the HE process.

6.1.2.1 Army implementation. HE requirements applicable to system acquisition appear in AR 602-1. DoD 5000.2-R requires the establishment of a comprehensive management and technical strategy for HSI early in the acquisition process. The Army's AR 602-2 provides the basis for the implementation of this requirement in the Army. The Army has several pertinent regulations and documents consolidated under the MANPRINT umbrella. The Army has also developed *A Handbook for MANPRINT in Acquisition* and the somewhat briefer *MANPRINT Guidebook for Systems' Design and Assessment (1997,* which includes HE program information in a less formal format. The Army focal point for MANPRINT is the Office of the Deputy Chief of Staff for Personnel, Directorate for MANPRINT (DAPE-MR), Pentagon, Washington, D.C. 20310-0300, Phone: 703-697-7384 or DSN: 227-7384. The Army functional HE expert POC is the Army Research Laboratory's Human Research and Engineering Directorate (ARL-HRED), Aberdeen Proving Ground, MD 21005-5425, Phone: 410-278-5800 or DSN: 298-3824).

6.1.2.2 Navy implementation. Requirements for implementing DoD HE goals in the design and acquisition of Navy systems are found in SECNAVINST 5000.2B (1996). In addition, Naval Air Systems Command (NAVAIR) process documentation, including the following Crew Systems Department Processes, provides pertinent information on implementing HE goals: (1) Provide Crew Systems Engineering for Acquisition; (2) Provide HE Support to the Acquisition Process; and (3) Perform Crew Systems Integration, Test and Evaluation (T&E). These process documents contain information on entry criteria, purpose, preceding processes, subprocesses, inputs, criticality, agents, tools, measurement criteria, related standards and guidance, outputs, and exit criteria. The Navy functional expert is CNO (N810) Requirements Officer, DSN: 224-7279; and the Navy Requirements POC is CNO (N125, HSI), and Navy HSI Policy is under ASN

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(RDA). The Marine Corps functional expert POC is CCDC Requirements Division Code C44, Ground DSN: 278-6179, Aviation DSN: 224-1824; Marine Corps Requirements Policy POC is GC MCCDC (Combat Development Command), DSN: 278-6174.

6.1.2.3 Air Force implementation. Air Force guidance on HE is found in a number of independent instructions. There is no centralized control of the entire HE process. The Air Force Human Systems Integration Office at the Human Systems Division (HSD/XRI), Brooks AFB, TX 78235-5120, phone 210-536-4461, acts to coordinate HSI efforts across the Air Force; however, it is not responsible for integrating actions within the HE domain. Within the Air Force, the using Major Air Command (MAJCOM), the Air Force Materiel Command product center, and test organizations share the responsibilities for putting forward HE requirements and implementing HE objectives. The Air Force functional HE expert POC is the Air Force Research Laboratory, Human Effectiveness Directorate (AFRL/HE, phone: 937-255-5227 or DSN 785-5227).

6.1.2.3.1 Operational requirements. AF Instruction 10-601, Mission Needs and Operational Requirements Guidance and Procedures (1994), states that "the lead MAJCOM develops measures of effectiveness (MOEs), if appropriate, explores the issues and alternatives, determines the preferred alternative, and prepares the operational requirements document (ORD) and the Preliminary Human Systems Integration Plan (P-HSIP." AFI 10-602, Determining Logistics Support and Readiness (1994), describes "operational suitability" as

> "The degree to which a system can be satisfactorily placed in field use, taking into account:
>
> - Logistics and supportability.
> - Availability, reliability, maintainability.
> - Transportability.
> - Interoperability.
> - Wartime usage rates.
> - Safety.
> - Human factors.
> - Compatibility.
> - Natural environmental effects and impacts.
> - Documentation (procedural manuals).
> - Training."

Note that at least eight of the eleven items (maintainability, interoperability, safety, human factors, compatibility, environmental effects, documentation, and training) involve direct HE issues, analysis, and inputs. In AFI 32-1023, *Design and Construction Standards and Execution of Facility Construction Projects* (1996), Human Factors (HF) is included as one of the major technology areas to be considered in military construction. AFI 63-112, *Cockpit Working Groups* (1996), implements AFPD 63-1, *Acquisition System* (1996), by setting the objectives, membership, and responsibilities of cockpit working groups (CWGs). CWGs involve acquisition

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personnel and operational aircrews in cockpit design and configuration at the earliest stages of development and modification. The CWG ensures that decisions affecting the cockpit take into account HF aspects and operational environment. This instruction applies to all Air Force personnel who evaluate cockpits in manned aerospace systems.

6.1.2.3.2 Safety and T&E requirements. Several Air Force safety-related instructions (e.g., AFI 91-202, *The US Air Force Mishap Prevention Program* [1995]) comment on the need to consider HF issues in system design to prevent accidents. In addition, a number of T&E related documents demonstrate the important role of HE in T&E. AFI 99-101, *Developmental Test and Evaluation* (1996), requires that the test focus on "determining human engineering aspects of the system and limiting factors" (2.24.6, Soundness of System Design). AFI 99-102, *Operational Test and Evaluation* (1994), provides a sample format for an OT&E test plan that includes an optional area for HF. AF Manual 99-110, *Airframe-Propulsion-Avionics T&E Process Manual* (1995), addresses the importance of HF throughout T&E planning and execution.

6.1.2.3.3 Critical Process Assessment Tools. The Air Force has developed a number of critical process assessment tools (CPATs) for acquisition that address HE requirements or processes. The Human Factors Engineering (HFE) CPAT (AF Space and Missile Center, 1997a) provides general guidance on HFE and its role in the acquisition process. It describes the relation between HE and the systems engineering process as follows:

> "Human factors engineering is an integral part of the systems engineering process and closely allied with the disciplines of reliability, maintainability, safety, environmental, productivity, test, and electromagnetic compatibility. The human factors critical process begins in the first phase of the systems engineering process, with requirements identification and analyses. As system functions are identified, they are evaluated to determine whether they are performed manually (with humans) or automatically (with equipment) or possibly both."

The Maintainability CPAT (AF Space and Missile Center, 1997b) stresses that the "human factors engineering function must interact with other disciplines within the Integrated Product Team (IPT)." Further, it clarifies the relationship between HFE and maintainability:

> "The Human Factors interface with Maintainability is concerned with the human performance of maintenance actions, and the resulting influences on the system design, to ensure that the maintainability goals may be realized with the human resources available in the operational environment. Similarly, the Safety discipline influences the conduct of maintenance tasks within the framework of safe practices in the operational environment."

These and other CPATs can be found in the Defense Acquisition Deskbook (1997).

6.1.3 Contract documents.

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6.1.3.1 Tasking. Section 4 is the primary source used by the Services to specify HE efforts during system acquisition. This is expressed as guidelines rather than rigid requirements, and applies on the basis of type of acquisition phase. These guidelines and practices are designed to support HE efforts whether carried out independently or as part of HSI initiatives. They accommodate all acquisition phases and a wide range of products, from small equipment items to major systems. The program processes or tasks outlined in Section 4 serve as a baseline for obtaining HE program information to be provided by offerors during the solicitation process. Section 4 should not be used verbatim, but should be tailored to the specific program and to the milestone phase of the program within the overall system life cycle to provide guidelines for enhancing essential human performance requirements, consistent with avoiding unnecessary program costs. Instructions for tailoring HE provisions are provided in Appendix A.

6.1.3.2 Data. The DoD HE practitioner should consider requiring generation and submission of contractor data only where the need and prescribed format are essential. They will likely be required to justify, in detail, the need for any proposed data items and, if approved, will be responsible for following the data item guidelines. These data requirements are set forth in DoD 5010.12-L, and in data item descriptions (DID Form 1664), DI-HFAC-80742B through DI-HFAC 80747B and DI-HFAC-81399A. These data items must be selectively applied, tailored, and justified based on the phase of system acquisition and the approved acquisition strategy. HE-related DIDs are discussed in more detail in 6.5.1.2 below and samples are provided in Appendix C. (Note: When this handbook was prepared, the Army Materiel Command, OPR for DI-HFAC-80742 through DI HFAC-80747, approved those DIDs only through January 1999. Those HE DIDs, not transferred to Navy or Air Force OPR(s) by that time will be cancelled. Accordingly, the latest issue of DOD 5010.12-L should be consulted to identify current human engineering DIDs.) In addition to HE DIDs, Logistics Management Information (LMI) DIDs may also be used to request data regarding either maintenance or operator tasks or any analysis conducted under Logistics Support Analyses (LSA). Requesting LMI data has the advantage of sharing data costs and information with other engineering and logistics specialties. (See MIL-HDBK-502 for information on LSA, and MIL-PRF-49506 for information on LMI.)

6.1.3.3 Design criteria. MIL-STD-1472 contains HE design criteria and principles that are applied to ensure mission success through integration of the human into the system, subsystem, equipment, and facility. It is used to achieve effectiveness, simplicity, efficiency, reliability, and safety of system operation. This standard is applicable to all aspects of HE design, including maintenance design and the design of training systems, equipment, and devices. MIL-STD-1472 design criteria may not always be formally invoked, however, in addressing the HE aspects of the design of DoD systems, equipment, and facilities. MIL-STD-1472 is a design criteria standard; it can not be placed on contract without a waiver from the acquisition decision authority; however, a waiver is not required to cite MIL-STD-1472 as a guide in the system specification. For aircrew stations, Joint Service Specification Guide (JSSG) for Aircrew Systems can assist with specific design guidance. The emphasis is on ensuring that the user-system interfaces support performance goals. Where applicable, non-DoD standards or criteria should be applied.

6.1.4 Organizational considerations. The HE function may be found at various organizational levels. For example, for a small system, the HE practitioner may report directly to

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the program manager or may work from a central HE office shared by several program offices. For large systems, there may be an HE manager who is designated as the HE representative to an integrated product team (IPT) or as the head of an HE- or crew-station-focused IPT. For such individuals, a primary task is ensuring close and continuous coordination with other members of the IPT. For larger systems, there will often be individuals who specialize in one aspect of the overall system development effort (e.g., specialists who focus on training development, training systems or equipment development, personnel requirements, or biomedical considerations). HE is described by or contained in programs or organizations with a variety of names. Some of the names under which HE operates are systems engineering, crew systems, ergonomics, human factors, human factors engineering, human-centered design, human engineering, HSI and MANPRINT. Whatever the organization or the title of the individual practitioner, it is important that HE personnel be able to communicate vertically with management and laterally with other technological disciplines or program groups addressing related issues. These groups include systems and specialized engineering, maintainability, system safety, reliability, logistics support, manpower, personnel, and training (MPT), T&E, survivability, biomedicine, and HSI. Coordination and cooperation among these disciplines can help ensure that HE issues in areas like those listed in Table II are adequately addressed.

6.1.5 HE planning activities. The planning of HE activities to support a major defense acquisition program is a substantial and diverse effort. The Army has formalized this process by requiring the development of a System MANPRINT Management Plan (SMMP) that identifies HE areas to be addressed and the approaches to be used in resolving anticipated HE issues and concerns. The activities required for much of the planning associated with integrated HE support are similar to one another. HE practitioners focus on identifying HE-related issues, design risks, and tradeoffs associated with various design concepts or alternatives. They identify and/or review contractor-proposed HE risk management approaches and, as appropriate, assist in their implementation. They ensure that HE-related goals and constraints are included in the planning documents and that HE issues are represented in the work breakdown structure (WBS) and associated integrated master schedule (IMS).

6.1.5.1 Traceability of requirements. To accomplish the necessary planning, HE practitioners must cross-reference the HE concerns identified in the primary planning documents to a number of other documents, plans, and reports. The following documents are especially critical:

- Mission Needs Statement (MNS)
- Operational Requirements Document (ORD) and Requirements Correlation Matrix/Specification Correlation Matrix.
- Cost and Operational Effectiveness Analysis (COEA)
- Test and Evaluation Master Plan (TEMP)
- Manpower Estimate (ME) reports
- Integrated Master Plan (IMP)
- Contract package (Request for Proposal, Statement of Work, design specifications, etc.)

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This critical cross-referencing process is often referred to as "traceability of requirements." Attention should focus on ensuring that all human-performance-related operational requirements stated in the ORD Requirements Correlation Matrix/Specification are present in other relevant documents and that user-performance-related thresholds with associated deviation limits or exit criteria have been included and have been clearly stated. These criteria will appear throughout the acquisition process in contract packages and in T&E plans and results.

6.1.5.2 Economy of effort. To avoid duplication of previous efforts and take maximum advantage of the knowledge gained earlier, the HE practitioner must ensure that HE issues, problems, and concerns identified previously are clearly represented in the planning efforts. It is helpful for the HE practitioner to develop a "hot list" of high drivers—HE issues that are critical to total system success. These issues may be culled from review of lessons learned from predecessor systems and from previously conducted HE research, T&E assessments, simulation efforts, tradeoff analysis, and test results from similar systems or subsystems. The issues identified should be kept as a prioritized listing for application in future design activities.

6.2 Application of HE during system acquisition. The purpose of this subsection is to assist HE practitioners in the requiring organization in performing their day-to-day tasks. Those who have considerable HE experience can use this subsection (in conjunction with Section 4) as a review or checklist to confirm that they are performing all necessary tasks. Personnel new to HE work can use the subsection as an aid to understanding and accomplishing their tasks. It is the nature of HE tasks to offer a seemingly endless number of problems and opportunities. There is no point at which the job is totally finished. The HE practitioner must select and work the tasks that are most significant to the program at the current point in the acquisition process. Often there are windows of opportunity during which the program office is considering a tradeoff or design issue. During such time windows, the HE practitioner has a brief period in which to influence the design decision by demonstrating compelling reasons why human-related issues or features should be included in studies, design decisions, or tests. The way to gain such influence is to show that the proposed design will affect human performance in a way that changes total system performance and/or affordability. As discussed earlier, the HE practitioner actively participates in three major areas of the system acquisition process: analysis, design and development, and T&E HE responsibilities in each area are discussed in detail below.

6.2.1 Analysis. Maximum operational and training effectiveness of the system is ensured by the continuous application of HE information beginning in the earliest phases of the system acquisition process. Sources of HE information include data bases, acquisition programs for similar or predecessor systems, laboratory research and study findings, and results generated by HE-related methods, tools, and simulations. Initial HE analytic support assists in determining concept feasibility. Later HE efforts focus on the examination of the system functions required to successfully accomplish mission objectives. Some of the more important HE activities in the analysis area are discussed below.

6.2.1.1 Input to Mission Needs Statement (MNS) and Operational Requirements Document (ORD). HE input to the MNS and ORD should address critical operational capabilities that relate to performance requirements for the user (operator, maintainer, and

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support personnel) for projected combat operational environments and missions. The perspective adopted should take into account the fact that users must perform their tasks under field conditions encompassing the entire range of anticipated operational tempos, mission durations, terrains, climates, weather conditions, and contamination conditions while wearing appropriate protective clothing and equipment. The need to accommodate these military environmental factors is often the driving force behind the use of DoD standards and handbooks, rather than commercial ones.

6.2.1.2 Front-end analyses. Front-end analyses include analytical planning studies based on predecessor or comparable systems that are carried out by the HE practitioner or performed under special contract early in the system acquisition process. Front-end analyses are typically conducted prior to Milestone 0 through the Concept Exploration phase, and are updated with more detail as necessary for later program phases.

6.2.1.2.1 Methods. In early acquisition, the HE practitioner, based on information from predecessor or comparable systems, can anticipate HE concerns by identifying preliminary function allocation, critical tasks, predicted peak workloads, crew size, and health hazard, safety, and survivability issues. Front-end analysis methods include early comparability analysis (ECA) based on predecessor or comparable systems. While ECA is frequently used for MPT analysis, it is a more general method that can also be valuable in identifying HE issues and concerns for predecessor or comparable systems that are important to consider in the new design. ECA analysis is now semi-automated. The HE practitioner provides the expertise to ensure that methods and tools are applied properly, that the proposed engineering design issues and thresholds are considered, that the results properly account for human strengths and limitations, and that their implications for system design are interpreted correctly.

6.2.1.2.2 Function allocation issues. One especially important focus of front-end analyses is function allocation, that is, how system functions and tasks are distributed among user, hardware, and software. ECA investigations of function allocation in a predecessor or comparable system—including estimations of anticipated user workload—can provide the basis for determining a high-level allocation of functions for the new system during early conceptual studies. As development progresses, a more detailed function allocation process will be conducted. (Function allocation methods are presented in 8.3.12.)

6.2.1.2.3 Impact. The information developed through front-end analyses affects the direction of the acquisition program by influencing the formulation of system requirements. It may also influence which system among alternatives is selected for development. Front-end analyses identify design risk areas and MPT resource requirements. The results of front-end analyses serve as input to system requirements and design criteria for the next phases of acquisition. Therefore, it is critical for the HE practitioner to become involved early to identify human-related limitations, constraints, thresholds, and consequences of proposed options. Without early involvement, HE practitioners could spend the rest of the program development phases trying to recover from early mistakes caused by lack of awareness of the human-related consequences of design alternatives.

6.2.1.3 Review of information from predecessor systems.

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6.2.1.3.1 Documentation. Information from studies undertaken in support of previous and/or comparable systems (even those under development, modification, or T&E) is a primary source for identifying HE issues to be explored and can provide valuable input for an ECA. Such information will appear in the system paper studies produced by development and program offices, service laboratories, and contractors' independent research and development (IRAD) efforts, and in T&E reports and lessons learned files. Other important sources are Army test incident reports (TIRs), Navy "yellow sheets," and Air Force Deficiency Reports (DRs), which document problems encountered with a system. During analysis, these documents can be examined for predecessor or comparable systems. In later acquisition phases, such reports may become available for the system currently under development.

6.2.1.3.1.1 Army test incident reports. Army Regulation 73-1, *Test and Evaluation Policy*, requires test incident reporting. Program managers, combat developers, evaluators, assessors, and others participating in the acquisition process must be informed of the system's performance during tests in a timely manner, so that corrective actions may be initiated and continuous evaluation conducted. The test incident report records the minimum essential data regarding test incidents, their respective corrective actions and status, and other test information. Critical and major TIRs require the production of data on corrective actions. All other TIRs are reviewed as necessary. A corrective action review team examines all corrective action data to verify that all proposed corrective actions are appropriate and effective. The review team consists of the program manager, combat developer (or functional proponent), operational evaluator, and developmental evaluator or assessor. The testers serve as advisers. TIRs are entered into a Test Incident Report Database. Army Materiel Command Regulation (AMC-R) 70-13, Test Incident and Related Reporting, covers the specifics of TIR implementation. Army HE practitioners may participate in development of or suggesting remedies to TIRs.

6.2.1.3.1.2 Navy "Yellow Sheets. "Yellow sheets" are reports of deficiencies discovered during DT&E. INSURVINST 13100.1 (1987) provides instructions for the preparation, submission, and distribution of "yellow sheet" reports and classification of deficiencies. The Navy uses these "yellow sheets" for documentation and board review. The Naval Board of Inspection and Survey, an independent body, makes decisions on the deficiencies identified. Determinations are made concerning the criticality of the deficiency and priority for the engineering change proposal (ECP). Through their role in testing, HE practitioners participate in the "yellow sheet" process of documenting deficiencies and recommending corrective actions.

6.2.1.3.1.3 Air Force Deficiency Reports (DRs). According to AF Manual 99-110, Test and Evaluation; Airframe-Propulsion-Avionics; Test and Evaluation Process, DRs (formerly known as service reports or SRs) are government-written and government-controlled documents that identify system (hardware and software) deficiencies. DRs are of paramount importance to testers and decision-makers because they provide feedback into the system engineering process so that corrections can be made. DRs are essential for the early correction of deficiencies and are recommended for implementation during contractor developmental test and evaluation (DT&E) using watch items in conjunction with formal DRs (see TO 00-35D-54, USAF Materiel Deficiency Reporting and Investigating System, 1991). DRs are directed and implemented in

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operational test and evaluation (OT&E) during government testing in accordance with TO 00-35D-54. Air Force HE practitioners may participate in developing or recommending solutions to DRs when they involve human interface issues.

6.2.1.3.2 Informal interviews with developers. While the data and findings from such resources are of primary interest, the observations of those involved in the HE portions of these system development efforts may prove invaluable as well. Informal interviews with previous developers and T&E personnel may yield important insights into otherwise undocumented development options. In addition, these experienced personnel may have considered and resolved issues and problems similar to those presently being faced.

6.2.1.3.3 Contact with users. The HE practitioner should also communicate—both directly and via correspondence—with potential user organizations. Visits to the operational environments of predecessor systems can provide insight into the operational realities that the proposed system will face and the challenges it will need to overcome. Networked simulation war games offer the opportunity to view predecessor systems in action and to obtain informal feedback from users as they participate in the exercise. In addition, military exercises, test ranges, and competitions can offer insight into HE issues, for example, by identifying tasks that are difficult, time consuming, awkward, or accident provoking. Conversations with operators or maintainers who use the system or equipment will frequently provide excellent information regarding envisioned program needs and desired functions. They may also provide the basis for innovative HE-related ideas that have applicability to the new system. If the HE practitioner can identify the greatest user frustrations with predecessor or comparable systems, then the practitioner can work to reduce or eliminate such frustrations in the new system. In many ways, the HE practitioner functions as the users' representative in the design process.

6.2.1.4 Concept exploration support. During the conceptual evolution of a system acquisition program, the user, development and planning organizations, and laboratories fund analyses and studies of the various proposed approaches to assist in determining the feasibility of the concept. These activities can include field assessments, user performance modeling, computer-based simulations of alternative system concepts and projected missions, and technology demonstrations, as well as initiation and tailoring of special studies. In these special studies, the HE practitioner may identify requirements for human performance research to address unprecedented human performance requirements of proposed defense system concepts and designs. Such research may then be accomplished within one of the military laboratories or by the contractor. The HE practitioner reviews proposed concept studies and simulations, suggests analyses, measures, and methodologies that will help identify HE issues, and comments on study and simulation results. The HE practitioner translates and applies user-centered research data and HE analyses in early studies. One goal is to identify and rank-order war-fighting needs for use in determining user-interface design issues. Most of these study efforts occur prior to Milestone 0 and during the concept exploration phase of the system acquisition process. One important early study is the cost and operational effectiveness analysis (COEA). HE practitioners should attempt to coordinate with those conducting a COEA to ensure that human-related issues are addressed in the alternative concepts being costed. Without this input, there can be serious miscalculation leading to faulty decision-making. These types of studies continue from Phase I through Phase

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III, if needed; updates and new studies are carried out in preparation for and during ECPs and system modifications.

6.2.1.5 Human Performance Research. While succeeding generations of weapon systems grow in capability, people remain relatively constant in terms of sensory, cognitive, and physical characteristics of the user populations. There are also some hard limits on the degree to which those characteristics can be modified by training. With increasing system requirements, human operators and maintainers must perceive targets, threats, and obstacles in new ways. They must make unprecedented, complex decisions using unparalleled quantities of information; undergo a profile of physical stress different from any in previous human experience; perform decision-making in environments of information gaps and overload; or perform more complex tasks in more rapid succession than ever before. In these cases human performance research should be conducted specific to the proposed new defense system in parallel with the more traditional engineering and cost analyses. This research will most likely integrate knowledge from the human factors literature with mission scenarios, workstation mockups, and task simulations. Results from this research would then be incorporated into the acquisition activities.

6.2.1.6 Awareness of recent advances in science and technology. The feasibility of a new system is often based on advances in science and technology and application of emerging technologies. The HE practitioner must remain abreast of advances applicable to HE efforts and responsibilities. Such advances include not only new and emerging technologies relevant to the specific system being considered, but also new HE information sources and assessment methodologies that may be useful in performing analyses and making feasibility determinations. Typically, there is at least one research laboratory or organization within each service that focuses on HE-related issues. These organizations undertake research to define the strengths and limitations of human users to identify the most efficient means of integrating users into emerging and future systems. They also develop HE models, tools, and databases to assist the HE practitioner. Application of the human performance data and tools can help ensure that the proposed system design appropriately accommodates the human's capabilities and limitations. In this way, the design risk is lessened, the total system performance is enhanced, the MPT demands are reduced, and hazards, safety, and survivability issues are identified. Because all the information needed is rarely available, a secondary consequence of technology reviews is the identification of gaps in HE information databases.

6.2.1.6.1 DoD Human Factors Engineering Technical Advisory Group (DoD HFE TAG). One way HE practitioners can stay abreast of new technologies and HE methods is to attend meetings of the DoD HFE TAG. Dissemination of technical information related to HE is one of the primary goals of the HFE TAG. Plenary sessions and meetings of the SubTAGs highlight the most relevant technologies and HFE updates (website: http://dticam.dtic.mil/hftag/affil.html).

6.2.1.6.2 Manpower and Training Research Information System (MATRIS). MATRIS is a computerized data base of scientific and technical information that includes a *Directory of Design Support Methods* (DDSM) which lists current HE and HSI tools and methods and provides information on current R&D work units. These work units can help the HE practitioner

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locate current R&D of interest to system design. A portion of the MATRIS DDSM is available at the MATRIS website: http://dticam.dtic.mil.

6.2.1.6.3 Crew System Ergonomics Information Analysis Center (CSERIAC). CSERIAC is a DoD information analysis center managed by the Defense Technical Information Center. CSERIAC assists HE practitioners in identifying up-to-date HE solutions from the scientific and technical literature and conducts searches and analyses that present design options for addressing HE design problems. CSERIAC also answers limited technical inquiries on HE-related topics. In addition, CSERIAC distributes HE tools developed by government laboratories and conducts state-of-the-art studies on current HE-related technological issues. Additional information is available about CSERIAC at their website: http://cseriac.flight.wpafb.af.mil.

6.2.1.6.4 Professional societies and industry groups. Professional societies and industry groups that have technical group focus on new technology issues can be of great interest to the HE practitioner. These groups can help the practitioner stay abreast of current HE research, development, and implementation. Often they develop new standards and focus on issues of concern to HE.

6.2.2 Design and development. HE support for the design and development area is intended to provide user-system interface design guidance which ensures that the strengths and limitations of human operators, maintainers, and supporters are taken into account during the design effort.

6.2.2.1 Design perspective. The DoD HE practitioner needs to foster a human-in-the-loop perspective in system design. The user-system interface design must consider equipment and human procedures, software and hardware characteristics, training requirements, and work environments. The DoD HE practitioner needs to ensure that the contractor, drawing on professional knowledge and expertise as well as the results of HE research and analyses, formulates HE design recommendations that consider this design concept. Therefore, the DoD HE needs to formulate requirements (as appropriate) and assessment criteria or thresholds that will encourage the contractor to use good human engineering practices. HE data bases, tools, and methods should be used extensively to ensure the system is designed with an effective human interface. The result of such efforts should be a design for an effective system that operates within human performance limits, meets system-level functional requirements, and fulfills mission goals, consistent with allocated manpower, personnel aptitude, skill, and training resources.

6.2.2.2 Application of new technology. A continuing, important aspect of the responsibilities of the DoD HE practitioner during early design and development is to monitor emerging technology areas to identify user-system interface concepts that may be relevant (e.g., automated speech technology, advanced decision-support technologies). Such efforts should not be deferred unnecessarily, since special studies may be required to ensure that new technologies are integrated effectively. Laboratory researchers will often fund studies on alternative user-system integration strategies if given sufficient notice.

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6.2.2.3 Program awareness and proactive participation. The DoD HE practitioner must also stay abreast of significant decisions made at higher levels to ensure that adequate HE support and research efforts can be planned and executed in a timely manner. It is not enough merely to be aware of decisions, planning, and scheduling issues, however. The HE practitioner must contribute to planning and scheduling efforts in an informed, proactive manner whenever the opportunity presents itself. The time to put forward HE points of view and solutions is when an issue is "hot" and a decision is imminent—this is when decision-makers are ready to listen. To be prepared for these windows of opportunity, the HE practitioner must keep a prioritized list of concerns and be willing to comment on proposed new design solutions as they arise. Doing so enables the HE practitioner to appropriately track and anticipate the sequence of events and to maximally impact the design. As noted earlier, the HE practitioner's activities and actions must also be directed toward ensuring that a sufficient budget is allocated to enable HE issues to be adequately addressed. The most effective way to deal with this practical matter is for the practitioner to be thoroughly aware of HE issues—and to articulate them.

6.2.2.4 Initial HE design recommendations. HE activities and efforts provide the basis for HE recommendations to the program manager, frequently via the IPT. Such recommendations are often related to the design of user-system interfaces—including both hardware and software components—and the associated human task procedures. The objective is to ensure that system design will facilitate operator task performance.

6.2.3 Test and evaluation (T&E). In T&E the total system is subjected to extensive empirical examination. HE support to the T&E effort is critical for ensuring that the system's operational and human performance requirements can be achieved in the intended military environment when the system is operated and maintained by typical users during the execution of typical scenarios. T&E provides a means to measure and evaluate a system's performance at selected times during the acquisition process. The purposes of HE T&E are to

- verify that personnel can safely perform tasks to time and accuracy standards without excessive workload;
- verify that system characteristics support effective, efficient operation;
- verify that the human engineering design of the hardware supports human use;
- determine adequacy of human performance as a component of system performance;
- determine the effects of operational variables on human performance;
- determine the appropriateness of modifications.

6.2.3.1 T&E focus in early acquisition. In earlier phases of acquisition (Phase 0 and I) DoD HE practitioners must work closely with the materiel developer, user representatives, and members of the training community in defining critical HE and human performance-related issues and criteria to be used in both developmental and operational T&E. These critical operational issues (COIs), test objectives, measurements (MOEs/MOPs), and thresholds must be related to the MNS and ORD (Requirements Correlation Matrix) and documented in the TEMP.

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6.2.3.2 T&E focus in later acquisition. For DoD HE practitioners during the later acquisition phases (I, II, and III), the primary focus is on evaluating the adequacy of the user-system interfaces. Most initial testing is done by the contractor in Developmental T&E.

6.2.3.2.1 Developmental T&E. According to DoD 5000.2-R, "Deficiencies encountered in developmental test and evaluation (DT&E) and initial operational test and evaluation (IOT&E) shall be resolved and fixes verified." DoD HE practitioners should be sufficiently aware of test results to ensure that HE-related issues are tested and that results are resolved so that the fixes can be verified in terms of their human implications. In many developmental tests conducted by the contractors, their personnel are used to operate and maintain the system. Since they may have extensive training, education, and experience that DoD personnel might not be expected to possess, and because tests may not be conducted under operational conditions, these DT&E tests may overestimate the human performance in the developing system.

6.2.3.2.2 Operational T&E. DoD 5000.2-R requires that "OT&E programs shall be structured to determine the operational effectiveness and suitability of a system under *realistic conditions* [for example, in the desert, humid, or arctic climatic conditions, under live fire, or in high workload conditions] and to determine if the minimum acceptable operational performance requirements as specified in the ORD have been satisfied." The following highlights mandatory procedures that could relate to the HE program.

- "*Typical users* shall operate and maintain the system or item under conditions simulating combat stress and peacetime conditions.
- The independent operational test activities shall use production or production *representative articles* for the dedicated phase of OT&E.
- The use of modeling and simulation shall be considered during test planning. Whenever possible, an operational assessment shall draw upon test results with the *actual system, or subsystem, or key components* thereof, or with operationally meaningful surrogates. When actual testing is not possible to support an operational assessment, such assessments may rely upon computer modeling, simulations (preferably with typical operators in the loop), or an analysis of information contained in key program documents. However, as a condition for proceeding beyond LRIP, initial operational test and evaluation shall not comprise an operational assessment based exclusively on computer modeling; simulation; or an analysis of system requirements, engineering proposals, design specifications, or any other information contained in program documents (10 USC §2399[1]).
- All hardware and software *alterations* that materially change system performance (operational effectiveness and suitability) shall be adequately tested and evaluated. This includes *system upgrades* as well as changes made to correct deficiencies identified during test and evaluation.

[1] Title 10, United States Code, Section 2399, Operational test and evaluation of defense acquisition programs

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- Operational testing and evaluation shall be structured to take maximum advantage of training and exercise activities to increase the realism and scope of operational testing and to reduce testing costs."

In OT&E, personnel operating and maintaining the system being tested should be members of the user population who are representative in terms of demographic, anthropometric, and physiological factors. Sample issues within each category include the following:

- Demographic: age, aptitude level (ASVAB), educational level, gender, Skill Specialty Code, specialized training and experience
- Anthropometric: standing height, sitting eye height, weight, hand reach,
- Physiological: color vision, dominant hand and eye, and strength.

In addition to these factors, the test should be conducted under taxing environments that the system is likely to encounter during military operations. These environmental factors include:

- physical (daylight/nighttime operations, heat, humidity, sand, and dirt);
- psychological (support environment: isolation, fear, communication, language);
- military (sustained or continuous operations, nuclear, biological, or chemical).

HE practitioners must also be sensitive to issues relating to human performance reliability and life support as well as the impact of environmental conditions and biomedical factors affecting human performance. The HE-related results of T&E, and lessons learned during these “user-in-the-loop” activities, yield a relevant assessment of the system’s capability to meet user needs. The findings also identify areas of potential improvements to increase the system's combat effectiveness and provide human performance data that can be used as the basis for design criteria for follow-on acquisitions or modifications. DoD HE practitioners document their findings in technical reports and may complete service-unique TIRs, DRs, or “yellow sheets.”

6.2.3.2.3 <u>HE test data</u>. Human engineering test data can be divided into three categories:

- engineering measurement,
- subjective judgment, and
- human performance measurement.

6.2.3.2.3.1 <u>HE engineering measurement</u>. Engineering measurement is usually the first kind of testing conducted. It is to evaluate compliance with good human engineering design practices, system specifications, and military and other standards. Issues such as system performance, accessibility, noise level, temperature, workspace, visibility, and operational control are considered.

6.2.3.2.3.2 <u>Subjective judgment</u>. The focus in this instance should be to employ objective methods to gather subjective data. Subjective judgment information is obtained from test personnel and participating users. Usually it includes characteristics not easily revealed by engineering measurement. While this method of data collection is often a favorite of field testers because of its ease of collection, subjective judgments are often inappropriately used. Subject

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judgments are best used to quickly identify critical issues that can later be validated through engineering measurement or human performance measurement. Methods of collecting subjective judgments include (1) recording observations, (2) conducting interviews, and (3) administering questionnaires. Recorded observations may be used to collect information not available from any other source. Observations, however, should be standardized using a checklist or other structured method. Conducting interviews should not be the first choice since they are time consuming and difficult to reduce to objective and valid data. This is often because the participant's judgment may be subject to bias. Interviews are primarily valuable as a follow-up technique to questionnaires or observed behavior. The HE practitioner must be careful not to ask leading questions or ask questions that the test participant may not be qualified to answer. Administering questionnaires is the most common method of HE T&E data collection. However, information gathered is often incomplete, hastily filled in, and emotionally affected. Common “traps” like the “halo effect” can interfere with accurate and reliable data collection. Questionnaires are useful in determining perceptions, opinions, user acceptance, and user “hot” issues. Since questions can be improperly written or easily misinterpreted, for accurate and reliable results, consult a questionnaire construction manual. Some of the issues regarding questionnaires and interviews are highlighted in the Section 8 T&E methods area.

6.2.3.2.3.3 Human performance measurement. These important measurements support evaluation of the effect of human performance on total system performance. For economy reasons, human performance measures are often collected in the process of addressing other issues. However, special care must be taken to collect and analyze human performance in a timely, objective, and accurate manner. Based on review of human performance and system requirement, the HE practitioner can target the most critical human performance issues. Human performance measurement should support identification of HE design improvements that have a high payoff. The basic measurements include human and combined human-system performance times, precision, and error rates. Both should be collected for each task exercised and measured because they interact. These data allow the HE practitioner and chief systems engineer to determine if the ORD performance requirements are achieved. Program managers sometimes fail to include the human-in-the-loop on tests. Since the human variability can add to performance time, precision, or increase errors, it is critical that representative personnel be involved in the test and that their performance be combined with the system performance to determine if the total system met its goals. Performance accuracy is usually affected by allowed time, and the need to be highly accurate affects required performance time (for example, targeting). In addition, on new tasks, the task time estimates may not have included all aspects of the task. Therefore, when the human is placed in the loop and must complete the entire task, one can discover omissions in the process and determine the actual performance time required. Human and human-system performance measurement is the most critical part of human engineering testing. Error rates are affected by performance time requirements. They can be quantitatively measured, but the tasks must be performed to a standard level of quality. Tasks not performed to standard may be identified in different ways: error frequency, error probability, errors per time unit, and errors per trial.

Data collection methods include the time-tagged video and digital data bus tracking methods. For example, the time-tagged video allows the HE practitioner to view and hear crew reaction to

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target presentation and instantly replay what happened. Under these conditions, human performance data may be more easily and accurately collected. Time-tagged video can help one clearly see the influence of human performance on system performance. Digital data bus-tracking methods allow an electronic device to be built into the system or a simulator which can collect HE data. It acts as a "spinal cord" with all commands and functions going through it tremendous amount of data available to test personnel. However, the HE practitioner must identify data requirements during test planning, and advocate the value of such tests to ensure they are implemented.

6.2.3.2.3.4 HE T&E priorities. In conclusion, the ultimate goal of the HE effort is to influence system design. T&E provides a means to measure the total system's performance. Three kinds of data are engineering measurements, subjective judgments, and human performance data. If the testing community wishes to know whether the system design has *complied* with the applicable HE engineering design criteria, then engineering measurements should be used; however, if they wish to know whether the test participant *likes* the item under test, then subjective judgment is appropriate. Finally, if testers wish to know how well the test participants *perform* using the system and how their performance relates to *total system performance*, then there is no substitute for human-in-the-loop performance measurement.

6.3 Program planning, budgeting, and scheduling. Planning and scheduling data enable the HE manager to track the sequence of program events to determine if HE inputs will have the optimum impact on design. Planning and scheduling information is generally easier to acquire than mission source data. However, a budget sufficient for performing and monitoring the HE effort is often not easily obtained, nor is it easily tracked if HE is at too low a level in the WBS. The following should be helpful in program planning, scheduling, and budgeting the HE effort.

6.3.1 General activities. HE efforts must be well planned and must conform to the overall program office IMS. HE practitioners focus on identifying HE-related tradeoffs and design risks associated with various design concepts or alternatives under consideration. Contractor-proposed HE risk management approaches are reviewed. HE-related goals and constraints must be identified and included in the planning documents. As indicated earlier, all major planning documents and schedules (e.g., WBS, ORD, TEMP, and IMS) should be reviewed and cross-referenced to ensure that all HE matters have been identified and included.

6.3.2 Work breakdown structure (WBS). The WBS is a numbered list of the development efforts to be conducted in the program, their subdivisions, and their interrelationships. The WBS is useful to the requiring organization for planning, costing, and scheduling of HE efforts. The program office, using guidance from MIL-HDBK-881, determines the format. DoD 5000.2-R, Part 6, Section B, directs that the WBS be developed from systems engineering efforts to define the total acquisition system.

6.3.2.1 Structure. The WBS is displayed as a product-oriented family tree consisting of hardware, software, services, data, and facilities. This tree depicts the relation of the elements of work to each other and to the end product. The government organization initially develops the program WBS down to the top three levels. The program WBS should reflect the specific goals

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of the program and the resources available to meet them. The contractor then generally prepares a more detailed contractor WBS. Figure 4 shows part of a program WBS for a hypothetical program and its relationship to the contractor WBS. The location of HE in the WBS and how it relates to the other WBS elements may vary considerably from program to program.

6.3.2.2 WBS level implications for HE. As the program proceeds through development and is further defined, program managers should ensure that the WBS is extended so that all high-cost and high-risk elements are identified at the management and reporting level. However, the contractor extends the WBS below the reporting requirement level to reflect how the work will be accomplished. It is critical that HE issues be listed at a sufficiently high level in the WBS to receive funding allocations, or else HE work will become optional. One way to elevate HE issues in the hierarchy is to combine them into a single critical element, such as the crew station, workstation, or design for maintainability. To achieve the objectives cited above, MIL-HDBK-881 is typically cited "for guidance only" in solicitations, and program managers use Appendix I (User Guide) of MIL-HDBK-881 when formulating WBS for their programs to ensure that only the minimum WBS requirements are levied on contractors. Such an approach requires the HE manager to closely monitor the WBS as it evolves to ensure that HE concerns remain appropriately represented.

6.3.3 Integrated management and scheduling plans. Two critical management documents derive from WBS efforts: the Integrated Management (or Master) Plan (IMP and the Integrated Management (or Master) Schedule (IMS). The contractor prepares both. The IMP identifies key events, milestones, reviews, all integrated technical tasks, and risk reduction activities. It is the specific tool used to track and measure successful task completion. The IMS depicts the work to be done in terms of supporting activities, schedules, and completion dates and is tied to the IMP. Preliminary and critical design review activities are represented (e.g., the initiation and completion of the Preliminary Design Review). Often the IMS is illustrated using automated tools that display an event network that can be adjusted as various events are delayed. Event networks show the impacts of these slips on other events. The linkage between the specification requirements, WBS, contractor's SOW, technical performance measurements, program events, and IMS provide traceability and serve as an important risk-management tool. Figure 5 shows these relationships. It is critical that the HE practitioner provide input to and review of the IMP and the IMS to ensure that HE efforts are appropriately identified and scheduled.

6.3.3.1 Timing of HE efforts. The HE manager should review the IMS and WBS to ensure that HE functions occur at the proper time with respect to the other program functions. Every program has unique scheduling requirements. The HE manager must understand the type of program IMS to identify the time-sensitive needs for the HE participation.

6.3.3.2 Program control. The program control function will be established by the program manager and will oversee data on planning and scheduling activities and on analysis of resources. Responsibilities of the control function include the programming of the government's activities, the contractor’s activities, and the review activities so that they mesh smoothly, as well as documentation and management reporting. The principal means used to perform this planning and scheduling are the WBS and the associated IMP and IMS.

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6.3.4 System baseline and configuration management (CM). In addition to the WBS, IMP, and IMS, another program management tool that must be monitored by the HE manager is the system baseline. The system baseline is a description of the system being developed in terms of program requirements, design requirements, and configuration. These aspects of the baseline may be established at any point in a development effort to define a formal point of departure for the control of future changes in the program or the design of hardware. The baseline is documented by approved program and contract documents and by specifications and drawings prepared by the government organization. The program office preserves the baseline through CM. Functional and program managers use CM to record, communicate, and control the integrity and continuity of the design, engineering, and cost tradeoff decisions made between technical performance, operational capability, and operation and support. CM is governed by MIL-STD-973. The CM effort encompasses technical and administrative direction and surveillance to identify and document the functional and physical characteristics of a configuration item, to control changes to an item and its documentation, and to record and report change processing and implementation status. CM thus provides a complete audit trail of decisions and design modifications. It is important that the DoD HE practitioner remain aware of such changes

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**Program WBS**

| 1 | 2 | 3 | 4 | 5 (WBS Level) |
|---|---|---|---|---|
| **FX aircraft** | | | | |
| | **Air vehicle** | | | |
| | | Airframe | | |
| | | Propulsion (SK-PW-52D) | | |
| | | Communications/Identification | | |
| | | Navigation/Guidance | | |
| | | **Fire control** | | |
| | | | Radar | |
| | | | | Receiver |
| | | | | Transmitter |
| | | | | Antenna |
| | | | | Radar applications S/W (to CSCI level) |
| | | | | Radar system S/W (to CSCI level) |
| | | | | Radar integ, assy, test and checkout |
| | **System test and evaluation** | | | |
| | | Development test and evaluation | | |
| | | Operational test and evaluation | | |
| | | Mockups | | |
| | | Test and evaluation support | | |
| | | Test facilities | | |
| | **Systems engineering/Program management** | | | |
| | | Systems engineering | | |
| | | Program management | | |
| | | Acquisition logistics | | |
| | **Peculiar support equipment** | | | |
| | | Test and measurement equipment | | |
| | | Support and handling equipment | | |
| | **Common support equipment** | | | |
| | **Training** | | | |
| | | Maintenance training | | |
| | | Aircrew training | | |
| | | Training course materials | | |
| | **Data** | | | |
| | | Technical publications | | |
| | | Engineering data | | |
| | | Management data | | |
| | | Support data | | |
| | | Data repository | | |
| | **Operational/Site activation** | | | |
| | | Contractor technical support | | |
| | **Initial spares and repair parts** | | | |

**Contract WBS**

| 1 (3) | 2 (4) | 3 (5) | 4 (6) | 5 (7) (Gov. WBS Level in parentheses) |
|---|---|---|---|---|
| **Fire control** | | | | |
| | **Radar** | | | |
| | | **Receiver** | | |
| | | **Transmitter** | | |
| | | **Antenna** | | |
| | | **Radar applications S/W** | | |
| | | | Build 1 | |
| | | | | CSCI 1…n |
| | | | | CSCITO CSCI integ. and chkout |
| | | | Build 2…n | |
| | | | | CSCI 1…n |
| | | | | CSCITO CSCI integ. and chkout |
| | | | Radar applications S/W integ., assy., test & evaluation | |
| | | **Radar system S/W** | | |
| | | | Build 1 | |
| | | | | CSCI 1…n |
| | | | | CSCITO CSCI integ. and chkout |
| | | | Radar system S/W integ., assembly, test & evaluation | |
| | | **Platform integration** | | |
| | | **Systems engineering/Program management** | | |
| | | | **Human engineering** | |
| | | **System test and evaluation** | | |
| | | **Training** | | |
| | | **Data** | | |
| | | **Peculiar support equipment** | | |
| | | **Common support equipment** | | |
| | | **Initial spares and repair parts** | | |

FIGURE 4. Work Breakdown Structure (WBS) (sample) showing relation of program WBS to contractor WBS.

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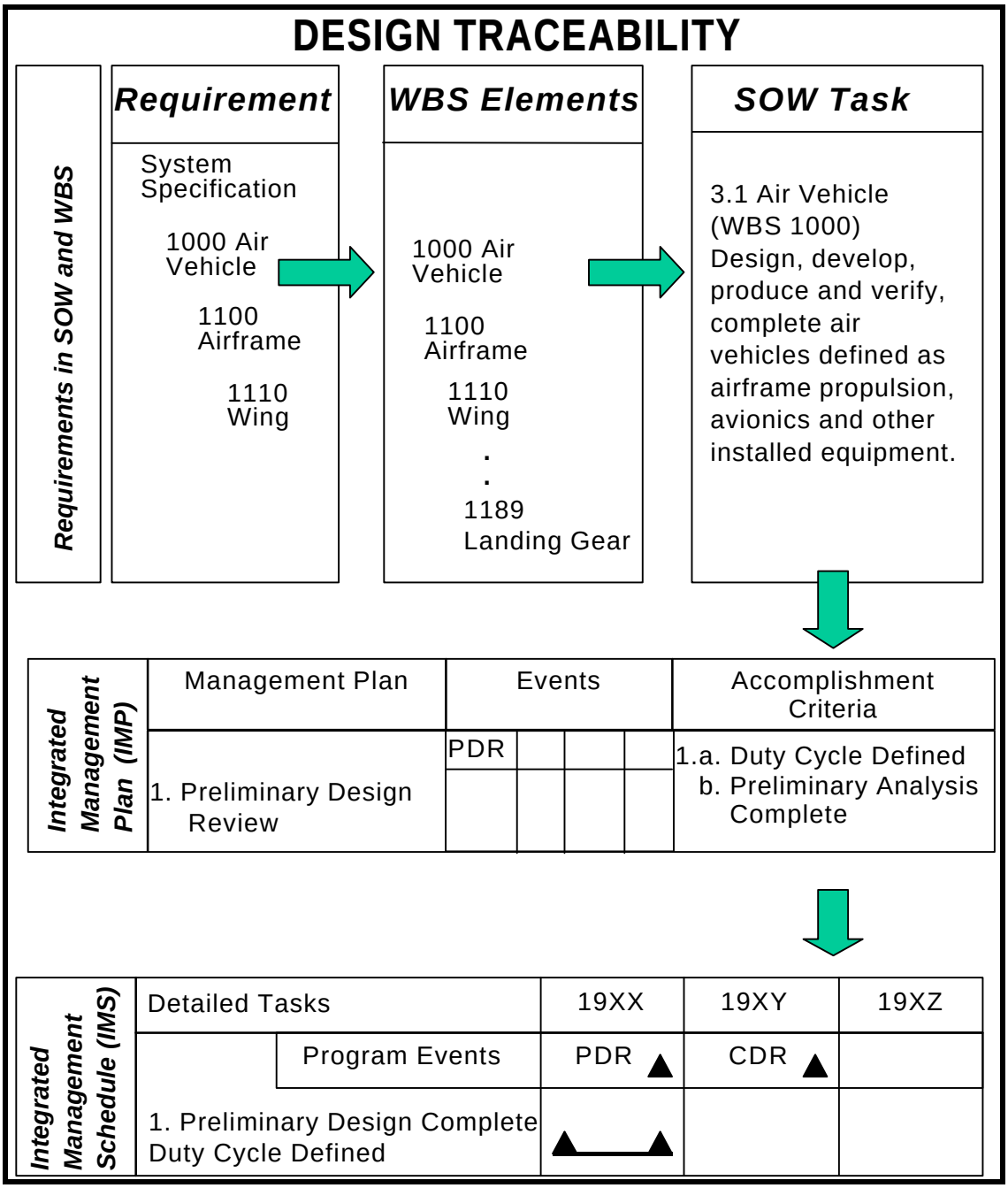


FIGURE 5. Relation among program planning documents supporting requirements traceability in design.

6.3.5 Budget. The HE manager's budget must be justified to program managers on the basis of anticipated improvements in performance, prevention of system problems, and cost savings. The HE budget is important because it determines what the HE manager will be able to do to monitor the program and what support can be obtained from laboratories or from research, development, and engineering (RD&E) centers. Typically, the budget allocation to HE for a major weapon system is relatively small, amounting to only a few percentage points of the total. The

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DoD HE manager determines the performing organization's budget indirectly, since the more HE tasks the manager requires as part of the contract, the more budget the performing organization must have. However, task assignments should be based both on the program need and on the comparative ability of the requiring and the performing organizations to do the job. A secondary effect for the HE manager is that the more tasks the contractor performs, the more review will be required by the program office.

6.3.6 Program phases. Programs may be expressed as RDT&E budget (and other) designations, that is, Basic Research, Applied Research, Advanced Technology Development, Engineering Development, and Operational Systems Development Programs may also be expressed in terms of acquisition process, including milestone reviews and approvals; i.e., Phase 0, Concept Exploration; Phase I, Program Definition and Risk Reduction; Phase II, Engineering and Manufacturing Development; Phase III, Production, Fielding/Deployment, and Operational Support. (See Table IV for a comparison of the interrelationships between RDT&E and acquisition phases).

6.4 Coordination. Coordination activity is important because it identifies and designates focal points to ensure efficient working relationships and exchange of information. Coordination enhances the collection and distribution of HE information and makes it easier to identify existing information, procedures, and methods so that effort will not be duplicated. The result is an improvement in HE methods, methods, and management procedures.

6.4.1 Participation in IPTs. Once program managers have been appointed for system acquisition programs, they will commission several IPTs. The HE practitioner must be a proactive participant in IPTs and working groups (such as the Army's MANPRINT Joint Working Group) if HE concerns are to be adequately and effectively identified, represented, and addressed. By offering to assist others with their IPT-related tasks, HE practitioners can often learn about HE issues, secure funding for HE analyses, and gain the opportunity to influence design. Through participation in the IPT, the HE manager informs the program manager what HE can do for the program.

6.4.2 Other internal coordination. Coordination is essential to identify and designate focal points that can help ensure efficient working relationships and exchange of information. It will enable the collection and distribution of HE information and help alert the HE practitioner of emerging issues that may impact on HE. Coordination will facilitate the identification of existing information, procedures, and methods so that effort will not be duplicated. It will help identify lessons learned and coordinate findings. The result will be an improvement in HE methods, and management procedures. While much of today's coordination takes place through IPTs, coordination with specific individuals is essential.

6.4.2.1 Program manager. The HE manager must educate the requiring organization program manager on what HE can do for the program in terms the program manager understands and is interested in. Included in this continual education should be findings on previous program experiences and scheduling information. The HE manager should be sure that the program

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manager understands the need for MIL-STD-1472 and other HE-related standards and handbooks (if they are required).

6.4.2.2 End user or customer. In many ways the DoD HE practitioner is the end user's representative to ensure that the human interface works well. The HE practitioner must understand the user's environment, mission scenarios, tactics, and uses of the system and equipment in that environment. To fully understand a user's HE needs the HE practitioner must communicate clearly with the customer about current HE-related problems and possible solutions. In addition, the HE practitioner should educate the customer on issues that will arise from new technologies and should be open to user comments on the impact of such technologies in the user's future anticipated environment. By coordinating with the user closely, the HE practitioner can help identify human interface problems early and secure the user's assistance in making human interface issues a priority during acquisition.

6.4.2.3 Technology organizations. The HE effort must be integrated into the total system program effort. To accomplish this integration, meetings, training, and documentation can be provided to familiarize other IPT members and principals from other laboratories and R&D centers with HE issues and concerns. Responsible personnel in these organizations should be contacted to determine the extent to which they are involved in the development effort and to exchange pertinent information. In addition to communicating with the program manager or IPT leader, the HE manager should contact the other technology organizations involved in an integrated systems approach on a daily basis to integrate the analysis, design, and test support HE has to offer and to determine if these organizations have additional information to provide in these areas. Table V shows the relationship of several important HE functions to other related program functions and to the acquisition phases.

6.4.3 Contractors. The HE manager or practitioner should remain aware of scheduled reviews and other opportunities to coordinate with the contractor. Joint government-contractor IPTs are formed to facilitate this coordination, and HE practitioners must be active members of such teams.

6.4.4 Interservice and other external organizations. For joint service programs, which are an increasing proportion of acquisition activities, good coordination with HE personnel from other services is important to ensure that all involved organizations and disciplines are receiving the proper support from HE and vice versa. Even in the absence of formal joint programs, coordination with HE personnel from other services can be useful. Where technical HE data on common items are involved, such coordination is strongly recommended. It is likely that all requiring organizations would benefit from the exchange of data on similar aspects of their various programs. Both the methodologies to be used and the design requirement solutions should be discussed. Effective coordination of HE efforts across the services can yield strong benefits, as can be seen from the success of the joint Air Force-Army working group in redesigning a transport aircraft to better accommodate parachutists, cited in 5.3.1. Selected conferences and meetings, such as those of the DoD HFE TAG, tri-service agencies, other government agencies and non-government organizations can be excellent sources to obtain information germane to critical HE issues arising in acquisition projects.

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TABLE IV. Acquisition cycle interrelationships.

| | RDT&E Funds | Acquisition Cycle Phases | HardwareType Produced | Major Milestones |
|---|---|---|---|---|
| Management & Support | Basic Research | Technology Base | Breadboard | |
| | | | | Milestone 0 |
| | Applied Research | Concept Exploration | Brassboard | |
| | | | | Milestone I |
| | Advanced Technology Development | Program Definition and Risk Reduction | Advanced Development Prototypes | |
| | | | | Milestone II |
| | Engineering Development | Engineering & Manufacturing Development | Engineering Development Production Prototypes | |
| | | | | Milestone III |
| | Operational Systems Development | Production Fielding/ Deployment and Operational Support | Production Hardware | |

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TABLE V. Relation of representative HE functions to other program disciplines and functions, and to acquisition and research phases.

| ACQUISITION PROGRAM & RESEARCH PHASES | CONCEPT EXPLORATION | | PROGRAM DEFINITION & RISK REDUCTION | ENGINEERING & MANUFACTURING DEVELOPMENT | PRODUCTION/ DEPLOYMENT |
|---|---|---|---|---|---|
| | BASIC RESEARCH | APPLIED RESEARCH | ADVANCED TECHNOLOGY DEVELOPMENT | ENGINEERING DEVELOPMENT | OPERATIONAL SYSTEMS DEPLOYMENT |
| HUMAN ENGINEERING ACQUISITION FUNCTIONS | *Participate in:* Experiments, Concept exploration & COEA studies, Mockups, Models, System analyses, Task & workload analyses, Function allocation studies Input to MNS, ORD | | Task & workload analyses, Function allocation studies, Design, models & mockups, Prototypes, Demonstrations, Procedures, IPTs | Evaluate detailed designs, Changes to baseline, Operability, Maintaina-bility, Developmental T&E, Demos, Procedures, IPTs, Design revs. | Conduct OT&E, Evaluate ECPs, Modifications |
| HUMAN ENGINEERING INTERFACES WITH RELATED DISCIPLINES | Biomedicine & life support<br>MPT<br>Maintainability<br>Reliability<br>Safety<br>Health hazard assessment<br>Survivability<br>Systems engineering<br>Logistics support | | Biomedicine & life sup.<br>MPT<br>Maintainability<br>Systems engineering<br>ISD/training system design<br>Life-cycle cost estimates<br>Health hazard & safety<br>Survivability | Biomedicine & life sup.<br>Logistics & MPT<br>Publication & manuals<br>Maintainability<br>Health, safety, reliability<br>ISD/training systems<br>Life-cycle costs<br>Developmental T&E | Biomedicine & life support<br>Publications & manuals<br>Maintainability<br>Health, safety<br>MPT<br>ISD/training sys<br>Operational T&E |
| OBJECTIVES | TECHNOLOGY RESEARCH | PAPER STUDIES | CRITICAL ISSUES EVALUATION | ENGINEER EVALUATION DT&E AND OT&E | OPERATIONAL HARDWARE |
| DoD PROGRAM MILESTONES | 0 | | I | II | III |
| Approval of: | Mission need and initiation of conceptual studies | | Initiation of new acquisition program | Engineering & Manufacturing Development & Low Rate Initial Production | Production, Fielding or Deployment |

6.5 Preparation of the Request for Proposal (RFP). Proper preparation of the RFP is by far the most significant single factor in ensuring that an adequate HE program will be applied. When preparing the RFP, inputs must be clear, accurate, and concise, with rationale provided to justify all inputs. There is rarely a way to recover from a poorly constructed RFP; therefore it is critical to invest the time to ensure a quality RFP. Remember that expensive ECPs are often the result of something left out of the RFP. Ambiguity in an RFP forces the HE practitioner or one's successor to have to live with that uncertainty. Since the acquisition process typically extends for many years, one may not be around to interpret issues that are ambiguous; therefore, it is better to take the time to be clear from the beginning (McCommons, 1988). HE inputs to the RFP vary considerably depending on the size and nature of the procurement. This subsection describes HE activities for both major and non-major acquisitions and for both traditional and streamlined acquisitions.

6.5.1 Traditional acquisitions. In traditional acquisitions, the HE practitioner should make inputs to the RFP based on previously developed source data and allocation decisions. HE input

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should be included in (1) the SOW, (2) the system specification, (3) the Contract Data Requirements List (CDRL), (4) the instructions to offerors, and (5) the proposal evaluation criteria.

6.5.1.1 Statement of Work (SOW) inputs. Within an RFP, the SOW identifies work statements (not performance requirements) that the contractor is to perform during a given phase of system development. The HE level of effort will vary with the development phase. Typically, the SOW should require the contractor to undertake program tasks appearing in Section 4 as they apply to the specific acquisition program and phase (see Appendix A). If there are specific HE objectives requiring emphasis, such as crew size or critical performance objectives, these should be stated in the specification. While it is generally easier to include all the HE efforts for the program in a single section of the SOW rather than distribute them to each of the applicable subsystems, cross-references to other portions of the SOW are encouraged. Remember that contractors only do work they get paid for, and that this work must be clearly defined in the SOW. When developing the SOW and specification, the foremost item to keep in mind is total system performance.

6.5.1.1.1 Performance Specification. System performance requirements are recorded in the system specification. Often total system requirements drive human performance requirements and there are places in the system spec to include relevant statements; e.g., MIL-STD-961D, paragraphs A.5.3.1.3, A.5.3.1.4, and A.5.3.1.4.1 (note the opportunities with regard to response times, sequencing, accuracy, operating conditions, error handling, emergencies). Other opportunities exist with regard to human performance reliability, maintainability, environmental conditions, safety (for example, collaborating with the safety officer to cite MIL-STD-1474).

6.5.1.1.2 Design Criteria. Based on the lessons learned from predecessor systems and expected HE interface issues expected with new technologies, it may well be appropriate to cite specific design criteria from either DoD or nongovernment documents. Listed below are examples of when citation of military or NGSs may be appropriate.

6.5.1.1.2.1 DoD Documents. For important HE issues, many HE design criteria already exist that can be cited by system specifications:

- MIL-STD-1472, containing time-tested, performance-based human engineering design criteria, can be applied if a waiver is obtained, (and can also be considered as a guide)
- MIL-STD-1474 can be applied to address noise issues if a waiver is obtained
- MIL-STD-1477 for Army air defense systems using symbols
- MIL-STD-1787 where required for aircraft symbols
- MIL-HDBK-759 (all systems)
- MIL-HDBK-767 where needed if interior noise in light armored tracked vehicles may be a problem.

6.5.1.1.2.2 Nongovernment Standards (NGSs). NGS should be considered priority citations where they cover necessary HE design criteria. The National Standards System

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Network (NSSN) is a good source of potentially applicable NGSs that's constantly being expanded and updated: http://www.nssn.org.

6.5.1.2 Data item descriptions (DIDs). Contracts almost always contain a list specifying exactly what data products the contractor must deliver. This list is called the contract data requirements list or CDRL (DD Form 1423; see Figure 6). Standardized data preparation instructions have been developed for the many products that might be contracted. These reporting requirements are called data item descriptions or DIDs. Depending on the acquisition phase, the budget, and the acquisition strategy—and with the approval of the data management officer and the program manager—the HE manager selects the appropriate DIDs for inclusion in the CDRL on a selective basis and where preparation and delivery of such data represent minimum essential information that cannot be obtained by less formal means. Purchasing data from the contractor is expensive; therefore, keep data to the minimum required to accomplish intended purposes, and be able to defend why you need it. The objective of requiring these data item deliverables is to provide the government organization with the information required to verify that system HE performance, design, and program requirements are being met, to identify risk areas, and to support the decision-making process. Currently, there is emphasis on minimizing explicit requirements and permitting the contractor considerable latitude in determining how the performance-based specifications and requirements will be met. If the government organization requires preparation of any HE data item deliverables, they must be identified in the RFP. Each separate HE data item must be included on a DD Form 1664 and in the CDRL, which must be incorporated as part of the contract. Each DD Form 1664 must refer to an authorized DID. DD Form 1664 must also include a specific contract reference (such as SOW paragraph number) that specifies and authorizes the work to be done for documentation in each data item. Also to be completed are blocks establishing the dates, delivery and destinations, approval authority, and approval procedures. The government HE manager should check with the lead data manager and consult data deliverable instructions when calling out CDRL deliverables. Procedures for requiring data items from contractors may vary from one service organization to another. Since preparation of data item deliverables is expensive and time consuming, only essential data items should be required. The DIDs that are selected should be tailored by the government to meet only required data needs and to limit their scope to the tasking provisions in the SOW specifying the work that generates such needed data. Tailoring means eliminating unnecessary items from the DID. Items cannot be added to approved DIDs. Also, DIDs must be accompanied by work effort items in the SOW. The contractor may also propose tailoring of HE tasking (including the proposed DIDs) in response to draft or standard RFPs. There are seven HE DIDs. Each is described briefly below, along with considerations for its use. A sample of each HE DID is provided in Appendix C.

(Note: When this handbook was prepared, the Army Materiel command, OPR for DI-HFAC-80742 through DI HFAC-80747 and DI-HFAC-81399A, approved those DIDs only through January 1999. Those HE DIDs, not transferred to Navy or Air Force OPR(s) by that time will be cancelled. Accordingly, the latest issue of DOD 5010.12-L should be consulted to identify current human engineering DIDs.)

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6.5.1.2.1 HE simulation concept (HESC). The HESC (DI-HFAC-80742B) should be called out when the government wants to ensure that the contractor obtains the best utilization of simulations. Dynamic simulation would normally take place early during the engineering and manufacturing development phase, but it could also be required as part of the Program Definition and Risk Reduction phase. The assumption implicit in requiring the HESC (or the HE test plan [HETP] described below) is that the effort required to prepare the plan is more than offset by the savings the plan will generate through the more effective use of HE resources. Figure C-2 shows the HESC DID.

6.5.1.2.2 HE test plan (HETP). Usually, a total program T&E plan is required. HE testing should be included as part of the total program T&E plan prepared by the government and contractor. If sufficient detail on HE testing is included in the program T&E plan, the HETP (DI-HFAC-80743B) may not be necessary. When it is needed, the HETP should be specified to ensure that human performance requirements for operations, maintenance, and support of a system are met and reported to the government. It should identify the types of tests to be conducted, the test subjects to be used and how they compare to the user population, and the data collection and reporting methods to be used. Information generated by the HETP, which is often presented in the HE test report (HETR) (described below), should enable the government to determine how the performance of human operators and maintainers influences total system effectiveness and reliability. The HETP should indicate how the test program results will influence the design and apply to follow-on equipment or similar systems. Neither the HETP nor the HETR is generally required for informal developmental testing. When it is required, the HETP is called for during acquisition phases in which T&E provisions are invoked—during the Program Definition and Risk Reduction phase, during the Engineering and Manufacturing Development phase or, occasionally, during the Production, Fielding/Deployment, and Operational Support phase. Figure C-2 shows the HETP DID.

6.5.1.2.3 HE test report (HETR). The government uses the data in the HETR (DI-HFAC-80744B) to determine the compatibility of the human performance requirements, personnel selection criteria, training program, and design of the personnel-equipment/software interfaces. This report is one of the more important and more frequently used DIDs, since it provides hard data to confirm that HE requirements have been met or to define the degree to which problems may exist. In addition to serving these purposes of acceptance and oversight, HE test data are also used to provide feedback to the system design or input into ECPs or newer designs. Because the size and scope of the report will usually depend on the particular system, the degree of user-system interface, and the acquisition phase, careful tailoring is suggested. As with all other DIDs, the tailoring of the HETR should be consistent with the tailoring of the tasking document. Figure C-3 shows the HETR DID.

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| D. SYSTEM/ITEM Crew System | E. CONTRACT/PR NO. 936758468B | F. CONTRACTOR John Doe, Inc. |

| | | | |
|---|---|---|---|
| 1. DATA ITEM NO. DI-HFAC-81399A | 2. TITLE OF DATA ITEM Critical Task Analysis Report | 3. SUBTITLE CTAR | 12. PRICE GROUP |
| 4. AUTHORITY (Data Acquisition Document No.) MIL-HDBK-46855A, DI-HFAC-81399A | 5. CONTRACT REFERENCE SOW 73.55.98H | 6. REQUIRING OFFICE ASC/YTX | 16. ESTIMATED TOTAL PRICE |

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|---|---|---|---|
| 7. DD 250 REQ X---- | 9. DIST STATEMENT REQUIRED Dist C | 10. FREQUENCY 1 | 12. DATE OF FIRST SUB. 15 Sep 2000 |
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|---|---|---|---|
| 1. DATA ITEM NO. | 2. TITLE OF DATA ITEM | 3. SUBTITLE | 17. PRICE GROUP |
| 4. AUTHORITY (Data Acquisition Document No.) | 5. CONTRACT REFERENCE | 6. REQUIRING OFFICE | 18. ESTIMATED TOTAL PRICE |

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| 7. DD 250 REQ | 9. DIST STATEMENT REQUIRED | 10. FREQUENCY | 12. DATE OF FIRST SUB. |
| 8. APP CODE | | 11. AS OF DATE | 13. DATE OF SUBS. SUB. |

16. REMARKS

14. DISTRIBUTION

| a. ADDRESSEE | b. COPIES Draft | Final Reg | Final Repro |
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| 15. TOTAL ------> | | | |

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FIGURE 6. CDRL (DD Form 1423) (sample).

6.5.1.2.4 HE system analysis report (HESAR). The HESAR (DI-HFAC-80745B) is useful for evaluating new systems or major elements in a system and for reporting the rationale for

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function allocation tradeoffs. The government uses this information to evaluate the appropriateness and feasibility of the system functions and roles allocated to operators and maintainers. This report may serve as a vehicle for requiring early HE efforts, since contractor HE personnel will be involved only if the SOW specifies their participation. The HESAR should be required during the Concept Exploration phase, Program Definition and Risk Reduction phase, or possibly modification phases, but should not normally be required during other program phases. Figure C-4 shows the HESAR DID.

6.5.1.2.5 HE design approach document–operator (HEDAD-O). The government uses the data from the HEDAD-O (DI-HFAC-80746B) to evaluate the operator interface and ensure that it meets the system and human performance requirements. The HEDAD-O may be useful during the first three phases of acquisition. It is most appropriate for the Engineering and Manufacturing Development phase when detailed design is being accomplished. Figure C-5 shows the HEDAD-O DID.

6.5.1.2.6 HE design approach document–maintainer (HEDAD-M). The HEDAD-M (DI-HFAC-80747B) is similar to the HEDAD-O except that it concerns maintainers. The government uses the data from this document to evaluate the maintainer interface and ensure that it meets the system and human performance requirements. The HEDAD-M is generally required during the first three phases of acquisition, primarily during the Engineering and Manufacturing Development phase. Figure C-6 shows the HEDAD-M DID.

6.5.1.2.7 Critical task analysis report (CTAR). The CTAR (DI-HFAC-81399A) provides a list of critical tasks to be reviewed and the rationale for their selection. Accordingly, the methodology, level of detail, and format of the report should be specified in the DID. The government uses the CTAR to verify that HE technical risks have been minimized and that any critical-task problems identified have been resolved. The CTAR cites 20 aspects of each critical task that are to be identified. If the CTAR is required, it should be developed and completed during the Engineering and Manufacturing Development phase, specifically no later than the Critical Design Review (CDR). After the CDR, it is too late for the information to impact system design. In some programs, enough data are available from prototype models during the Program Definition and Risk Reduction phase to support the CTAR. Normally, prior to this phase there are too few data available to enable the analysis. If the CTAR is required during the Program Definition and Risk Reduction phase, the DID reference should be modified to require less than the full 20 CTAR items. All 20 items are appropriate for the Engineering and Manufacturing Development phase. Figure C-7 shows the CTAR DID.

6.5.1.3 System specification. The structure of the acquisition program requires the development and updating of the system specification at the end of each acquisition phase. Performance requirements appear in the system spec. Do not place work statements in the spec, since they belong in the SOW. In some cases, the materiel developer or program office will prepare the system specification according to MIL-STD-961; or this function may be tasked to the prime contractor. Note, however, that the emphasis is on performance specifications and the use of nongovernmental standards (NGSs) for new systems, major modifications, and commercial

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and nondevelopmental items. Performance specifications include DoD performance specifications, commercial item descriptions, and performance-based NGSs.

6.5.1.3.1 Functional and performance provisions. HE provisions in the system specification may be descriptive (e.g., "reaction time shall not exceed ten seconds") or may cite another document (e.g., "symbols shall conform to MIL-STD-1477"). As noted by 6.5.1.1.1, ample opportunities exist to incorporate system-specific HE provisions into the system specification. A number of DoD standardization documents and NGS are available for citation where appropriate. Three types of DoD standards and handbooks are relevant for HE: (1) Interface standards, (2) design criteria standards, and (3) handbooks.

6.5.1.3.1.1 Interface standards. Interface standards specify the physical, functional or military operational environment interface characteristics of systems, subsystems, equipment, assemblies, components, items, or parts to permit interchangeability, interconnection interoperability, compatibility, or communications. These DoD standards require no waiver from the Milestone Decision Authority for citing as requirements in contracts when they are applicable. For example, MIL-STD-1477 is an interface standard that can be applied to specify the color and marking of Army system displays when applicable. MIL-STD-1787, also an interface standard, can be specified to prescribe aircraft display symbology.

6.5.1.3.1.2 Design criteria standards. DoD design criteria standards specify military-unique design or functional criteria that must be adhered to in the development of systems, subsystems, equipment, assemblies, components, items, or parts. A DoD design criteria standard requires the Milestone Decision Authority's waiver to be cited as a solicitation requirement. DoD HE design criteria standards provide important, time-tested, largely performance-based HE design requirements and guidelines. Such criteria may be found in MIL-STD-1472. Where the Milestone Decision Authority's waiver is not obtained (or requested), MIL-STD-1472 may be cited as a guide. Moreover, contractors may propose citing MIL-STD-1472 in the system specification. Other design criteria standards, such as MIL-STD-1474 that covers noise limits, may be used in a similar manner.

6.5.1.3.1.3 Handbooks. Handbooks are guidance documents that enhance user awareness by providing engineering information; lessons learned; possible options to address technical issues; classification of similar items, materials, or processes; interpretive direction and technique; and any other type of guidance information that may help the Government or its contractors in the design, construction, selection, management, support, or operation of systems, products, processor or services. Since they are guidance documents, handbooks require no waiver from the Milestone Decision Authority for citing in contracts. MIL-HDBKs contain a wealth of accumulated corporate memory and guidance about what has worked well in previous acquisitions. For example, this MIL-HDBK-46855A contains recommended HE program tasks and procedures for both government and contractors; and MIL-HDBK-759 contains detailed HE design principles, guidelines, and serves as a data source. Other MIL-HDBKs also serve as critical data repositories, such as MIL-HDBK-743A that contains anthropometry data of U.S. Military Personnel, MIL-HDBK-767 that contains design guidance for interior noise reduction in

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light-armored tracked vehicles, and MIL-HDBK-1473A that contains color and marking of Army materiel. Finally, human factors terms are defined in MIL-HDBK-1908A.

6.5.1.3.2 Government vs. NGSs. Where citation of HE standards or guidelines is required, NGSs should be considered as priority citations when applicable. However, DoD HE standards may be used when unique military needs are involved and no acceptable NGSs are available, or when the use of an NGS is not cost-effective or practical, or does not meet the user's needs. The National Standards System Network (NSSN is a good source that is constantly being expanded and updated: available at http://www.nssn.org.

6.5.1.3.3 Health and Safety Standards of the Occupational Safety and Health Administration (OSHA). Since OSHA statutes were not written to apply to military systems, there is often some confusion about whether or when OSHA standards must be followed. The following paragraphs clarify HE responsibilities regarding the application of health and safety standards in the HE design process. DoD policy, according to DoDI 6055.1, *DoD Safety and Occupational Health (SOH) Program* (DoD, 1998), is that OSHA standards apply to non-military-unique operations and workplaces and, under certain circumstances, apply to military-unique systems if the OSHA standards are more stringent than military standards.

6.5.1.3.3.1 Non-military-unique systems. DoDI 6055.1 states that DoD Components shall comply with the standards promulgated by OSHA in all non-military-unique DoD operations and workplaces (offices, maintenance shops, and other non-front-line activities). This applies regardless of whether work is performed by military or civilian personnel. However, DoD Components may develop and apply standards that are alternate or supplemental to such OSHA standards, and DoD standards may need to be more stringent than OSHA standards if the military situation warrants.

6.5.1.3.3.2 Military-unique systems. DoD policy instructs that DoD Components shall apply OSHA and other non-DoD regulatory safety and health standards to military-unique equipment, systems, operations, or workplaces, in whole or in part, insofar as is practicable and when supported by good science.

6.5.1.3.3.3 Alternate Standards Approval Procedures. According to DoDI 6055.1, if a DoD Component determines that compliance with an OSHA standard is not feasible or that no applicable OSHA standard exists, then "a proposed alternate standard shall be developed and submitted after consultation with other DoD Components and with affected employees or their representatives." For example, "OSHA health standards designed to protect personnel from 8-hour exposures to hazardous chemicals may not be applicable for 24-hour exposures, or for multiple exposures and various modes of entry into the body during military operations and deployment situations. When military design, specifications, or deployment requirements render these standards unfeasible or inappropriate, or when no standard exists for such military application, DoD Components shall develop, publish, and follow special military standards, rules, or regulations prescribing SOH measures, dosimetry, and acceptable exposure levels. Acceptable exposure measures and limits shall be derived from use of the risk management process described elsewhere in this Instruction."

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6.5.1.3.3.4 Implications for HE. These requirements make it incumbent on the HE practitioner to be familiar with military standards as well as OSHA and other nonmilitary human-related standards in the area of health and safety so that the most stringent standards available can be applied, to the extent practicable and when scientifically supportable. (The information in 6.5.1.3.3 through 6.5.1.3.3.3 is presented to support this aim, not to imply that citing OSHA regulations in the system specification is an HE function.)

6.5.1.4 Tailoring. The rationale for tailoring is the concept that many system acquisitions are so costly because they are designed and built according to specifications or other constraints that, in many cases, are not really useful or appropriate. Tailoring is the process of deleting unnecessary requirements from tasking documents, specifications, and DIDs to require only what is truly useful. There is little question as to the short-term cost-effectiveness of the tailoring of HE specifications. Before tailoring is carried out, however, a few significant factors must be considered:

- Acquisition phase
- Type of acquisition program (e.g., standard, NDI)
- Level of analysis and design detail needed (e.g., concept, system, or subsystem level)
- Probability that the program will complete the full acquisition cycle
- Savings in short-term program costs, long-term costs, or both expected from tailoring
- Cost to change the system design to meet long-term system performance requirements (e.g., maintainability and operability)
- Possible increases in life-cycle costs associated with waiving the reliability, maintenance, and operability requirements normally specified

Of course, every effort should be made to reduce unnecessary data requirements from DIDs. In some cases, because of program budget issues, hard choices must be made that could limit the ability of HE to obtain sufficient data for critical decisions. The HE practitioner must cooperate with the program office in limiting unnecessary data expenditures while standing up for provisions for critical HE data that can help make important program decisions. Therefore, both long-term life-cycle costs and short-term savings are significant. If the savings are short term only, they need to be balanced against possible increased life-cycle costs that short-term maneuvering could cause. Short-term budget savings could be erased by the need to implement ECPs later in acquisition after the system baseline is set or by the costly failures, due to the occurrence of operator or maintainer errors, or equipment malfunctions, or safety hazards. Some standards are “self-tailoring,” such as MIL-STD-1472.

6.5.1.5 Instructions to offerors. Areas that must be addressed in an offeror's technical proposal are described in detail in Section L of the RFP. A subsection “Instructions for Proposal Preparation” is typically included. The HE practitioner’s inputs to this subsection describe those portions of a proposal the offeror must address to clearly demonstrate how the HE program will be implemented. This handbook can be specified as a guide that prospective contractors can use

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(particularly Sections 4, 7, and Appendix A) to assist in meeting HE requirements. The HE practitioner should ask the offeror to describe the intended approach to the following important areas:

- Proposed HE organization
- Integration of HE with systems engineering and related design efforts
- Principal HE activities to be performed during system analysis
- Nature and extent of planned HE participation in system design efforts
- Critical HE T&E issues
- How coordination with related disciplines (e.g. concurrent engineering, IPTs, etc.) is to be accomplished
- Where HE is to be identified in the WBS (including HE as a separate item is usually recommended)

6.5.1.6 Proposal and source selection evaluation criteria. As part of the RFP preparation, a source selection plan will be developed that includes evaluation criteria against which each proposal will be appraised. Section M of the RFP informs the offeror of the exact proposal evaluation factors. In this section, the HE practitioner provides the technical criteria for the evaluation of the HE aspects of the proposal and recommends the relative importance to be ascribed to HE, compared to the other areas of consideration. The HE practitioner should convince the source selection authority of the need to give sufficient emphasis to HE, based on the critical operational needs of the system that involve human interaction. Traceability to the ORD is essential for HE issues to have sufficient weight in source selection. Allocation of emphasis to HE should ensure a best-effort contractor response to the HE aspects of the RFP. The content of the source selection criteria must be consistent with the instructions to offerors.

6.5.1.7 Draft RFPs. Frequently, to create a higher quality, innovative RFP, draft RFPs are issued to potential competitors for their review and comment. Such drafts offer the advantage of allowing the government to try out requests for specific program tasks, provisions, or methodologies. Industry feedback on draft RFPs can lead to substantial savings by pointing out unnecessary constraints and proposing innovative alternative solutions. The contractors' responses to the final RFP are generally of higher quality, since contractors have had more time to work on the requested proposal problem. The government HE manager should participate in review of the draft RFP to suggest the efforts needed to support HE concerns in the RFP and to learn of innovative contractor suggestions.

6.5.2 Streamlined Acquisition and Innovative Acquisition Approaches.

6.5.2.1 Nondevelopmental items (NDIs) and commercial-off-the-shelf (COTS) acquisitions. If the acquisition is for NDI/COTS items, the system or system components may have been built to either commercial standards or military standards. To procure such items, the government conducts a market investigation of organizations using all the candidate items offered by industry. The HE practitioner should provide input to this investigation. Based on the results of the investigation, and additional test data if required, the NDI procurement is initiated. HE

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participates in the development of the system NDI/COTS specification by providing HE-related performance requirements and human performance-driven HE design criteria. While different types of NDIs may be encountered, commonly these items are already available. The HE effort, therefore, should focus more on specifying human performance requirements and human performance-driven HE design criteria than on formulating specific tasking and data provisions as with more traditional acquisition routes. For NDI systems, commercial standards are generally used to guide the development of the candidate NDI/COTS systems. If some development is involved, however, there can be some greater—though judicious—use of military design criteria for selected aspects of the system. The role of the HE practitioner is to ensure that the NDI/COTS system can perform the required military mission with the people assigned, with the training offered, and under expected military environmental conditions. Source selection and the "best and final offer" process can be used as a means of encouraging the offeror to correct HE problems prior to selection, often at no cost to the government.

6.5.2.2 Statement of Objectives (SOO). Acquisition reform initiatives are prompting the use of new tools and methods for communicating program requirements in an RFP and for evaluating an offeror's proposals. One means that has been used (primarily by the Air Force) is the SOO. The SOO is a statement of contract requirements that identifies the scope of work to be performed. The SOO expresses requirements in terms of minimal needs and encourages the contractor to suggest the most cost-effective system. It was developed to be compatible with the MNS, ORD, Program Management Directive (PMD), and Acquisition Strategy Panel (ASP). Technical requirements from system specifications, risk assessment, and the draft WBS are included, expressed in terms of product-oriented goals rather than performance requirements. The SOO lays out the basic, top-level objectives of the acquisition. It normally describes tasks to be performed that cannot be contained in a specification or written into the schedule as contract line items. The SOO states overall program objectives (including supportability and resource use) and identifies program risk areas. The offeror responds to the SOO with a SOW that defines how the system will perform and how the work will be accomplished. Then the government organization thoroughly reviews the SOW to ensure that the proposal will achieve the operational objectives in the SOO. The discussion associated with the development of the SOO allows all functional representatives to buy in to the objectives. Even in programs that have a requirement for a government-drafted SOW, it is advisable to go through a SOO development process to clearly define the solicitation objectives. This approach provides potential offerors the flexibility to develop cost-effective solutions and to propose innovative alternatives. It also activates contractor creativity and allows the government to assess the offeror's understanding of all aspects of the effort to be performed by eliminating the "how to" instructions normally contained in the government-provided SOW. It is important that the HE manager provide input during the development of the SOO so that HE issues and concerns are adequately represented. The HE manager must also assist in reviewing the SOW drafted by the contractor in response to the SOO to ensure that the HE effort has been specified appropriately.

6.5.2.3 Advanced Concept Technology Demonstrations (ACTDs). ACTDs are a "quick and dirty" way to accelerate and facilitate the application of mature advanced technologies to solve important military problems. The ACTD constitutes an end run around the lengthy formal

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acquisition process. If HE is not considered in the development of ACTDs, HE horror stories may result.

6.5.2.3.1 Purpose of ACTDs. The primary goal of ACTDs is to assess the military utility of a significant new technological capability and to conduct assessments that can clearly establish its operational utility and system integrity. The ACTD process is a pre-acquisition activity that provides the user with the opportunity to evaluate new capabilities and determine the military utility of a system before acquiring new or additional units through a formal acquisition program. To streamline the process, the ACTD does not concern itself with perfecting advanced technology for operability, maintainability, or supportability, but emphasizes the integration of mature or emerging technologies into fieldable prototypes that can typically be completed in three years or less. ACTDs allow the user to develop, refine, and assess operational concepts and requirements for the new capability, in actual operational environments.

6.5.2.3.2 Transition of ACTDs to standard acquisition. Recommendations for entering an ACTD into the acquisition cycle will depend on (1) the existence of validated requirements; (2) military utility, as determined by the operational user; (3) the maturity of the technology; and (4) the ease with which the ACTD can be integrated into a field-usable product. Not all ACTDs will be selected for transition to the formal acquisition process. If the user concludes that acquisition is not justified, the residual capability can be used as is, development can continue, or the ACTD can be terminated. Transition to the formal defense acquisition process will be necessary when development or production is desired. The acquisition category will depend on the number and cost of the systems required. A decision must be made as to where the ACTD is entered into the acquisition process. If significant further development is needed, the system might enter into the development portion of the Engineering and Manufacturing Development phase. If the capability of the ACTD is adequate and the system is needed quickly, entering it into the Low-Rate Initial Production portion of the Engineering and Manufacturing Development phase is an option.

6.5.2.3.3 HE concerns regarding ACTDs. Since ACTDs focus primarily on the hardware and software necessary to quickly meet mission requirements, HE considerations are sometimes bypassed in the rush to field systems. Occasionally, HE personnel are allowed to consult on ACTD development or a laboratory will conduct human interface technology demonstrations to improve user-system integration. As with any system design program, the earlier HE practitioners become involved, the more likely they will be able to head off any human interface problems later.

6.6 Proposal evaluation.

6.6.1 Examination of HE approach. The HE manager should play an active role in the proposal evaluation process. The source selection team should include the HE manager to ensure that proposed approaches to user-system interfaces meet the source selection criteria. The HE manager must be able to determine whether the potential contractor understands what needs to be done. This includes an understanding of the HE requirements and scope and magnitude of the project, risk assessment, and life-cycle cost implications. The proposal should demonstrate a realistic approach and allocate adequate resources, including budget and talented HE personnel, to accomplish the necessary HE activities. The contractor must clearly show that HE concerns

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and requirements are recognized, that a preliminary analysis was made in arriving at the approach, and that the requirements will be satisfied in a timely and cost-effective manner. The areas in which tradeoff decisions will need to be made should be identified, and candidate alternatives and the rationale for their selection should be indicated. The government HE manager must check to ensure intended compliance with HE provisions of the SOW, CDRL, and system specification.

6.6.2 Evaluation of experience. The HE experience of the offeror that is directly applicable and related to the current acquisition program should be evaluated. The offeror must clearly indicate the relevance of experience gained in similar programs of equal or greater complexity. The offerors may also wish to provide "lessons learned" and to show how their experience will benefit the proposed program. Resumes of proposed HE personnel should be examined for successful HE experience.

6.6.3 Organizational evaluation. The relation of HE to other disciplines involved in the development effort as well as the relation of HE to program management should be clearly identified by the contractor and given proper emphasis. Consideration of cost-related factors and design issues as they affect HE should also be evident in the proposal.

6.7 Contractor monitoring. Once the contract award is made, monitoring begins. Contract monitoring can be accomplished in a number of ways, such as through IPT meetings, conferences, design reviews, trade study reports, CDRL reports, HE data file reviews, baseline configuration reviews, and frequent telephone calls or visits to the contractor’s site and test facilities. Joint government-contractor IPTs may be formed and joint reviews scheduled. The contractor’s data files, plans, and schedules may also be shared electronically, and the government HE practitioner may be able to monitor a variety of activities effectively and efficiently via computer.

6.7.1 Program planning review. All reviews should be identified in the IMP and the IMS. A program kick-off meeting for just HE alone is a good idea so that ambiguities in the plan can be discussed and necessary changes can be made. Such a meeting is also helpful because it allows the government and contractor to meet face to face and go through the plan and schedule, section by section, prior to later design reviews. The meeting should be held at the contractor's facility so that the facility and the work already performed can be shown to the government.

6.7.2 Data requirements review. If progress reports are to be of value to the government, they must be reviewed and evaluated. The government's HE data review function may vary from assuming complete responsibility for review, as in the case of data submitted in response to specified HE CDRL items, to just "commenting" as in the case of concurrence action data. The purpose of the review is to ensure that the contractor's efforts are of acceptable quality and conform to the contract specification and SOW. Formal design reviews are not for designing the system, but rather for making decisions based on the facts. The government HE manager must also attend major design reviews, such as the Preliminary Design Review (PDR) and Critical Design Review (CDR). The HE manager must ensure that his or her counterpart in the contractor organization takes a significant part in presenting the program data. The increased attention and emphasis on evaluation during early design phases have stimulated more frequent use of mockups

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to assist in design evaluations. If early development of mockups is required in the Engineering and Manufacturing Development phase, such mockups can serve as a design configuration aid. Modern CAD/CAM and virtual simulations or mockups can also aid in the evaluation. One advantage of such virtual drawings and mockups is that they can be transmitted electronically, which can eliminate unnecessary delay and reduce travel requirements. The HE manager may also wish to attend certain T&E events that are significant to the user-system interface. The HE manager may initiate design review reports and may participate in the review of ECPs when required.

6.7.3 Baseline monitoring. Frequently, the system design will progress by means of an evolving baseline configuration. To ensure that all subsystems or components of the WBS are directed toward the same configuration, a baseline with configuration control is maintained. This baseline is modified only with the agreement of all affected. The modifications are published (often electronically today) for information and review to all those organizations that should be involved. As noted earlier, the HE manager should track this baseline configuration for all components that interface with humans. This daunting job is carried out to ensure that no potential HE problems arise as the design evolves. Often, changes to improve one subsystem can have negative effects on operability, accessibility, maintainability, or other human-interface aspects. The HE practitioner must be alert to the human impacts of baseline changes.

6.7.4 Data file review. During design reviews (or at any convenient time), while the government HE manager is visiting the contractor, the contractor's HE data file should be reviewed. This file should contain copies of correspondence, reports, analyses, specifications, sketches, drawings, checklists, and test data reflecting HE actions and providing decision rationale. This review provides an opportunity to assess how well the contractor is performing HE tasks. Contract provisions may specify that such files are to be shared electronically, so that much of this effort can be accomplished without a site visit. Much can be learned through site visits, however, and understanding may be substantially enhanced through direct observation and communication. In addition to data files at the contractor’s facilities, correspondence, reports, analyses, specifications, sketches, drawings, checklists, and test data are often circulated around the program office, especially when they are relevant to an upcoming decision. HE practitioners should ensure that they are on the list to receive such information, especially when it involves one of the identified critical HE tasks or subsystems.

6.7.5 Contract monitoring limitations. Generally, during program acquisition, the HE manager must be knowledgeable and must be available to answer the performing contractor’s questions, provide data, and present design alternatives or suggestions. However, the HE manager must ensure that any suggestions given are interpreted simply as an option and not as contract direction, which can be given only through the contracting officer. Also, if contractors are in competition with each other during a given phase, the government HE manager must be careful to provide the same help and information to all competing contractors, so that there is no perception of bias or difference in the treatment of competitors. During source selection, all efforts of the government HE manager must necessarily be conducted only through procurement officials, if at all, and then with much greater care than if there were no competition.

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6.7.6 Meetings. Within a few weeks of the contract award, a guidance meeting should be arranged between the government and contractor to discuss the necessary HE program effort. The government should inform the contractor of the evaluation of the HE inputs to the proposal. The government HE monitor should provide the contractor with detailed information on the problems and needs the HE effort should address. Discussions of government data sources and analyses not previously known to the contractor can be helpful. HE design criteria and applicable HE design requirements derived from the contractor's proposal should be discussed. Significant human performance requirements should be defined to avoid later misunderstanding. The contractor's choice of analysis, design, and test methods may be reviewed. HE practitioners also participate in PDRs and CDRs. Results of HE efforts, including applicable tradeoff studies and critical task analysis, are reported. A joint government-contractor IPT may be formed to create further opportunities for related, follow-on meetings.

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## 7. HE PROCEDURES FOR CONTRACTORS

After the award of the contract for each acquisition phase, the largest portion of the program effort is in the hands of the contractor. Along with several other functional design areas, HE must refine its program planning and scheduling effort. It must initiate the development of system concepts, conduct design trade studies, participate in the design of the program development model, and evaluate the design model through the use of appropriate modeling, simulation, and testing methods. This section is provided to assist the performing (contractor) HE organization in the accomplishment of these tasks. Section 6 should also be reviewed to understand the government's role and perspective in the procurement process.

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7.1 HE design standards and guidelines. Contractor tasking requirements are those cited directly in the contract Statement of Work (SOW) and might reflect the process typified by Section 4. Typically, the contractor is permitted to determine how performance specifications are to be met. However, there may occasionally be instances where the government does cite specific HE design standards or guidelines. Some of these standards and guidelines are included in Appendix D, which tabulates them by service and cross-references them to the paragraphs of this handbook. They are included in Appendix D to provide a single integrated listing for government and contractor readers of this handbook. It is important to distinguish between (a) standards and handbooks that may be imposed by a procuring government organization on contractors and (b) the regulatory and policy documents that are imposed on procuring government organizations by higher headquarters. Such policy documents provide a management framework for procurement activities and usually are not specified in contracts. In addition to this handbook (MIL-HDBK-46855A), two significant general DoD standards/guidelines for HE practitioners are the design criteria standard MIL-STD-1472, and the *Technical Architecture Framework for Information Management (TAFIM)*. A third significant document is the *Joint Service Specification Guide (JSSG) for Aircrew Systems*, expected to be released shortly after this handbook was written. The purpose, scope, applicability, and general content of these documents are summarized below. Information is also provided on other useful government and nongovernment standards and guidance documents.

7.1.1 MIL-STD-1472 . As previously indicated, the contractor is allowed considerable freedom in determining how to meet performance specifications. If there are specific HE design criteria to be met, they may be identified by citing some portions of MIL-STD-1472. This standard establishes general HE design criteria for of military systems, equipment, and facilities. Its purpose is to present HE design criteria, principles, and practices to be applied in system and facility design so as to (a) achieve the required performance by operator, control and maintenance personnel; (b) minimize skill and personnel requirements and training time; (c) achieve required reliability of personnel-equipment combinations; and (d) foster design standardization within and among systems.

7.1.1.1 Content. Topics addressed by MIL-STD-1472 include the following:

- Satisfactory atmospheric conditions, including composition, pressure, temperature, and humidity, and safeguards against uncontrolled variability beyond acceptable limits
- Acceptable range of acoustic noise, vibration, acceleration, shock, blast, and impact forces, and safeguards against uncontrolled variability beyond safe limits
- Protection from thermal, toxicological, radiological, mechanical, electrical, electromagnetic, pyrotechnic, visual, and other hazards
- Adequate space for personnel and their equipment, including adequate movement envelopes for the actions and activities required to carry out operational and maintenance tasks under both normal and emergency conditions
- Adequate physical, visual, auditory, and other communication links between personnel, and between personnel and their equipment, under both normal and emergency conditions

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- Efficient arrangement of operation and maintenance workplaces, equipment, controls, and displays
- Provisions for ensuring safe, efficient task performance under reduced and elevated gravitational forces, including safeguards against injury, equipment damage, and disorientation
- Adequate natural or artificial illumination for the performance of operational, control, training, and maintenance tasks
- Safe and adequate passageways, hatches, ladders, stairways, platforms, and inclines, and other provisions for ingress, egress, and passage under normal, adverse, and emergency conditions
- Acceptable personnel accommodations, including body support and restraint, seating, rest, and sustenance (i.e., oxygen, food, water, and waste management)
- Provisions for nonrestrictive personal life support and protective equipment
- Provisions for minimizing psychophysiological stress due to mission duration and fatigue
- Design features to ensure rapidity, safety, ease, and economy of operation and maintenance in normal, adverse, and emergency maintenance environments
- Satisfactory remote-handling provisions and tools
- Adequate emergency systems for contingency management, escape, survival, and rescue
- Compatibility of the design, location, and layout of controls, displays, workspaces, maintenance access, stowage provisions, passenger compartments, allocated tasks, and control movements with the clothing and personal equipment to be worn by personnel operating, riding in, or maintaining military systems or equipment.

7.1.1.2 Voluntary use of MIL-STD-1472. Since MIL-STD-1472 is a DoD design criteria standard (see 6.5.1.3.1.2), a waiver must be obtained to place it on contract; thus, fewer Requests for Proposal (RFPs) will normally have this standard called out. This fact does not prevent the contractor from proposing that MIL-STD-1472 be used for appropriate parts of the system, particularly those components that need to interface with humans effectively in the military environment. This kind of appropriate use of MIL-STD-1472 can be to the advantage of both the contractor and the government, since the readily available standard can help the system meet unique military human-interface requirements.

7.1.2 Technical Architecture Framework for Information Management (TAFIM). The TAFIM outlines a general architectural framework for DoD information systems. The TAFIM does not designate a specific system architecture. Rather, it provides the vision, guidance, and general strategy for the evolution of DoD information systems and their technical architectures to an open systems environment with the attributes of interoperability, portability, and scalability. The TAFIM embodies a common conceptual framework, defines a common vocabulary, and specifies a base of technical standards that permits DoD components to better coordinate DoD information systems development, acquisition, and support.

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7.1.2.1 Goals. The emerging concepts for warfighting require that information be managed as a department-wide resource. Joint campaigns should fully exploit the "information differential," that is, the superior access to and effective use of information on the strategic, operational, and tactical situation that advanced U.S. technologies can provide our forces. Achieving this information differential requires a seamless interface between the "foxhole" and the support base, between intelligence and operations, and between the DoD and its suppliers. However, before the TAFIM was developed, there was no unifying DoD guidance on information technology and management that could satisfy these goals.

7.1.2.2 Content. The TAFIM contains eight sections designed to achieve an integrated technical architecture and standard, easily learned interface. Of primary interest for HE is Section 8, which contains the DoD Human Computer Interface (HCI) Style Guide. This style guide provides a common framework for HCI design and implementation. Since most systems now interface with humans through computer, the style guide influences the human-system interfaces for all defense systems except those that are specifically exempted. (Aircraft, for example, are exempted and will be governed by the *JSSG for Aircrew Systems*.) Workstation platforms and other user devices that become available in the early twenty-first century are expected to be many times more powerful than the machines of the early 1990s. Workstations will adhere to a full suite of federal, national, and international standards that have been adopted by the DoD. Because platforms conform to a common set of interface standards, it will be possible to configure software across a distributed environment and tailor the software to support specific functional processes with a common human interface. The TAFIM, Section 8, describes features, functions, and field display formats that should be handled consistently by all DoD applications, unless otherwise exempted from this standard.

7.1.3 Joint Service Specification Guide (JSSG) for Aircrew Systems. The complete set of JSSGs establish a common framework to be used by government-industry program teams in the aviation sector for developing program-unique requirements documents for air systems, air vehicles, and major subsystems. As previously noted, the *JSSG for Aircrew Systems* is currently a draft but, at the time of this writing, was expected to be released shortly. Although still a draft, it has been included here because of its potential utility and pervasive application for aeronautical systems. The purpose of this specification guide is to provide assistance in the development of performance requirements to be used in the procurement of crew systems during air system development. The JSSG provides a set of model paragraphs for performance requirements and verification criteria as well as extensive guidance in tailoring these paragraphs to develop the program-unique specification.

7.1.3.1 Scope and applicability. The *JSSG for Aircrew Systems* outlines a unified process for applying the relevant technical disciplines to the development, integration, test, deployment, and support of military aircraft crew systems. It supports a human-centered crew system approach to the acquisition process in which the platform is designed around the human, and human-related performance requirements are the driving force. It is intended to be used at the system, subsystem, and component levels and is constructed in sections to aid the user in accomplishing the end task. The *JSSG for Aircrew Systems* covers the following areas:

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- Aircrew systems engineering
- Aircrew systems automation, information, and control/display management
- Cockpit/crew station/cabin
- Aircrew alerting
- Aircraft lighting
- Sustenance and waste management (S&WM)
- Crash survivability
- Energetics
- Life support/personal protection
- Oxygen systems
- Emergency egress
- Deployable aerodynamic decelerator (DAD) systems
- Survival, search, and rescue (SSAR)
- Aircraft windshield/canopy systems (W/CS)

7.1.3.2 Content. Like other JSSGs, the *JSSG for Aircrew Systems* contains a compilation of candidate references, generically stated requirements, verification criteria, and associated rationale, guidance, and lessons learned for program team consideration. Part 1 of the JSSG is a template for developing the program-unique performance specification. It contains sample language for requirements and verification criteria, and leaves blanks that must be completed to make the items meaningful. As a generic document, the JSSG contains requirement statements for the full range of aviation sector applications. The user must tailor the material by (1) deleting nonapplicable requirements and (2) filling in the blanks to form a complete and consistent set of requirements to meet program objectives. Part 1, Section 4, "Verification Requirements," must be tailored to reflect an understanding of (1) the design solution; (2) the identified program milestones; (3) the associated level of maturity expected to be achieved at those milestones; and (4) the specific approach to be used in the design and verification of the required products and processes. Part 2 of the JSSG contains a set of handbooks that provide the rationale, guidance, and lessons learned for each statement in Part 1. The materials in Part 2 are generic in nature and document what has been successful in past programs and practices. They must not be interpreted as limiting the use of new practices, processes, methodologies, or tools.

7.1.4 Other DoD HE standardization documents. Other useful DoD interface standards, design criteria standards, and handbooks on HE are listed below:

- MIL-STD-1474D, *Department of Defense Design Criteria Standard, Noise Limits*
- MIL-STD-1477C, *Department of Defense Interface Standard: Symbols for Army Systems Displays*
- MIL-STD-1787B, *Department of Defense Interface Standard: Aircraft Display Symbology*
- MIL-HDBK-743A, *Anthropometry of U.S. Military Personnel*

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- MIL-HDBK-759C, *Department of Defense Handbook: Human Engineering Design Guidelines*
- MIL-HDBK-767, *Design Guidance for Interior Noise Reduction in Light-Armored Tracked Vehicles*
- MIL-HDBK-1473A, *Department of Defense Handbook: Color and Marking of Army Materiel*
- MIL-HDBK-1908A, *Department of Defense Handbook: Definitions of Human Factors Terms*

An index of nongovernment standards (NSGs), handbooks, and guidelines on HE are available from the Manpower And Training Information System (MATRIS) (1997). These NGSs are current through 1997, and were prepared as a temporary expedient pending activation of the National Standards Systems Network (http://www.nssn.org, which is now available, more current, and searchable.

7.1.5 Nongovernment standards. While the number of NGSs that have been adopted by the DoD has increased substantially in recent years, all NGSs cited by HF standardization documents had been adopted before the military specification and standard (MilSpec) reform. MilSpec reform has encouraged program offices to cite NGSs where possible, because their use can decrease the cost of systems and equipment, allow application of the latest commercial technology, and save money. A waiver is now required to cite HE and other design criteria standards as requirements in RFPs. NGSs adequately cover military requirements in many areas.

7.2 Program organization and management. The HE function may be found in various places in contractor organizations and may be described by a variety of organizational names. Some of the names under which HE operates are crew systems, ergonomics, human factors, human systems integration, human factors engineering, human engineering, systems engineering, behavioral sciences, bioengineering, biotechnology, and bioastronautics. Because HE activities are broad in scope, they are frequently carried out within the context of integrated product teams (IPTs) or working groups.

7.2.1 Contractor HE tasks. Contractor HE program tasks for the analysis, design and development, and test and evaluation (T&E) phases are described in detail in Section 4. To develop a common frame of reference, they are highlighted here.

7.2.1.1 HE Analysis. Using a baseline mission scenario, contractors can assist government counterparts with requirements analysis through early acquisition contracted studies. Analysis should include application of HE methods, including the following (see Section 4 for more detailed explanation):

- Define and allocate system functions in an iterative manner to
  - automated operation/maintenance,
  - manual operation/maintenance, or
  - some combination thereof.
- Select equipment items to be operated, maintained, or controlled by personnel.

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- Analyze tasks, workload, and situation awareness issues. (An approach for conducting a task analysis is given in Appendix B.)
- Identify critical tasks and ones that reflect possible unsafe practices, or show the potential for improvements in operating efficiency for further analysis.
- Identify sensory, cognitive, and physiological limitations that could interfere with effective, efficient and safe operation.

7.2.1.2 Design and development. During design and development, the HE inputs are made as a result of implementing the analysis guidelines. HE inputs should be converted into detail engineering design features. Design of the equipment should satisfy human-system performance requirements and meet the applicable HE design criteria such as MIL-STD-1472. During the design and development activities, the contractor HE practitioner should accomplish the following:

- Identify and remedy human-system interface design incompatibilities and excessive skill/physical requirements by using appropriate design criteria;
- Use developmental HE testing of the system or equipment to verify proper operation, defining need for maintenance;
- Participate in and evaluate equipment for adequacy during design reviews;
- Conduct experiments, tests (including dynamic simulation), and studies to resolve HE and life support problems specific to the system using representative users;
- Conduct these experiments, tests, and studies timed to influence design;
- Research HE problems to identify previous findings and solutions to avoid "reinventing the wheel";
- Use computer models, three-dimensional mockups, and scaled models to identify and resolve design issues;
- Review electronic engineering drawing promptly to avoid redesign later;
- Ensure that operational, training, and technical publications apply HE principles to procedural manuals;
- Evaluate software that affects controls and displays for its impact on the human-system interface, considering automated system functions requiring human monitoring or intervention as part of the human-system interface;
- Consider multifunction controls and displays that vary in function depending on system software as part of the human-system interface.

7.2.1.3 T&E. The contractor HE manager should establish and conduct an HE T&E program to

- demonstrate conformance of system, equipment, and facility design to HE design criteria;
- confirm compliance with system performance requirements where personnel performance is a system performance determinant;

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- secure quantitative measures of system performance that are a function of the human interaction with equipment;
- determine whether undesirable design or procedural features have been introduced; and
- review all failures occurring during T&E to differentiate between failures of equipment alone, failures resulting from human-system incompatibilities, and failures due to human error.

Human errors occurring in the performance of critical tasks during T&E should be analyzed to determine the reason for their occurrence. The contractor should identify to the procuring activity those HE design characteristics or procedures that may contribute substantially to human error and should propose corrective action.

7.2.2 Relation of HE to program organization. The specific relation of HE to other contractor groups within a program or project varies. The RFP, SOW, or draft Work Breakdown Structure (WBS) location for HE within the project. However, the contractor is given substantial latitude in this regard. HE is typically included as a part of systems engineering, product assurance, logistics engineering, design engineering, or similar organizational groups.

7.2.3 HE in large acquisition programs. For larger acquisitions, the combination of planning, scheduling, WBS development, and budget estimation implies an organization of HE practitioners to perform the work. If multiple HE practitioners are expected to be involved in the program, they should confer regarding the HE effort. The results of their discussion should be used as the basis for further, early discussions with the contractor's overall program manager to ensure that HE issues and concerns are appropriately represented within the contractor's organization.

7.2.4 Specific design support. Upon initiation of the Engineering and Manufacturing Development phase, the contractor's HE organization frequently assigns HE personnel to support specific project design areas (e.g., displays, crew system design, communications, maintainability). In this way, individuals become skilled at dealing with specific types of HE problems (e.g., speech interference levels and communication problems) and specific types of positions (e.g., pilot, navigator, tank commander, sonar operator, maintainer). The application of appropriate HE design considerations to each type of hardware and software interface is thereby facilitated.

7.2.5 Integrated product teams. If the contractor's overall program organization emphasizes an IPT approach, HE practitioners may be distributed among several teams. In other organizations, a working IPT may be formed with representatives from those groups and disciplines that have strong ties to the tasks and functions of human operators (for example, cockpit working group or crew station IPT) and maintainers (e.g., safety, reliability, and maintainability group, or training group). The formation of such an IPT facilitates communication, coordination, and focus on HE issues. Because of the breadth of HE concerns, if HE functions within an IPT (such as a crew systems IPT), it is often best if an HE practitioner/manager serves as team leader.

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7.2.6 Contractor HE manager's role. While a human-issue-oriented IPT may exist, it is generally appropriate to identify a contractor HE manager as a focal point for issues relating to the design of user-system interfaces. The HE manager should establish an HE organization that communicates directly or indirectly with the contractor's overall program manager. The HE manager should direct and monitor the accomplishment of HE tasks and functions performed by HE personnel. This manager should have significant HE experience with user-system efforts on previous system or equipment acquisition programs. The primary control, direction, and supervision of the technical HE aspects of the program should rest with the HE manager. The HE manager should be responsible for implementation of the following HE program functions:

- Provide a single focal point for all HE-related matters;
- Revise and consolidate input to all plans and contractual documents related to HE;
- Maintain approval authority on all HE-related items contained in the Contract Data Requirements List (CDRL);
- Coordinate HE-related matters with program management and all program elements and disciplines;
- Participate in all system design reviews to ensure (1) that all HE-specified requirements are complied with; (2) that HE schedule and CDRL delivery dates are compatible; and (3) that HE analysis methods permit integration and use of the findings and data in a timely and cost-effective manner;
- Participate in the development of the Test and Evaluation Master Plan (TEMP) to ensure that all HE issues and considerations are appropriately addressed, with special emphasis on those relating to the Operational Requirements Document (ORD) Requirements Correlation Matrix/Specification;
- Provide informal technical support to program engineering activities;
- Provide HE support for investigation and reporting of all human-initiated failures occurring during T&E, including all incidents and accidents related to HE;
- Participate in program baseline configuration control activities, including the review and approval of all system configurations and changes thereto that involve the human operator, maintainer, or support person.

7.3 Application of HE during system acquisition. The contractor should prepare the Integrated Management (or Master) Plan (IMP) containing the Integrated Master Schedule (IMS) as a part of the proposed program development effort. (See Figure 7.) The IMP should include the required HE support and cite its organizational and functional relationship to related technical disciplines, such as those listed previously in Table I. The contractor's program manager must ensure that the HE effort is appropriately assigned and funded at a level that will satisfy contractual requirements.

7.3.1 Initial activities. During the initial acquisition phase, as a minimum the first few HE activities must be performed by the government. These include development of the Mission Need Statement (MNS), Operational Requirements Document (ORD), and Requirements Correlation Matrix (RCM); preparation of the draft RFP; and finalization of the RFP. Contractors may

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contribute to these activities, however, by conducting contracted conceptual studies, such as needs analyses. These special studies often feed the development of the MNS, ORD, and RCM, and must be appropriately timed to meet the government's needs. Although the contractor HE manager may have previous experience on similar programs, the manager must remain mindful of the eventual DoD users and determine their problems, needs, and recommended solutions. New systems or equipment may have subtle differences from previous ones—differences that need to be acknowledged. Questions such as the following should be asked because their answers are very important to efforts during the Concept Exploration and Program Definition and Risk Reduction phases:

- What tradeoffs were (should be) considered in the human-system function allocation?
- What does the user's command/agency anticipate to be the most critical operator and maintainer tasks or issues?
- Are there important issues or concerns related to human reliability or human performance time?
- Given the proposed design, will typical human performance jeopardize successful mission performance by failing to meet performance specifications pertaining to accuracy, response times, or level of reliability?

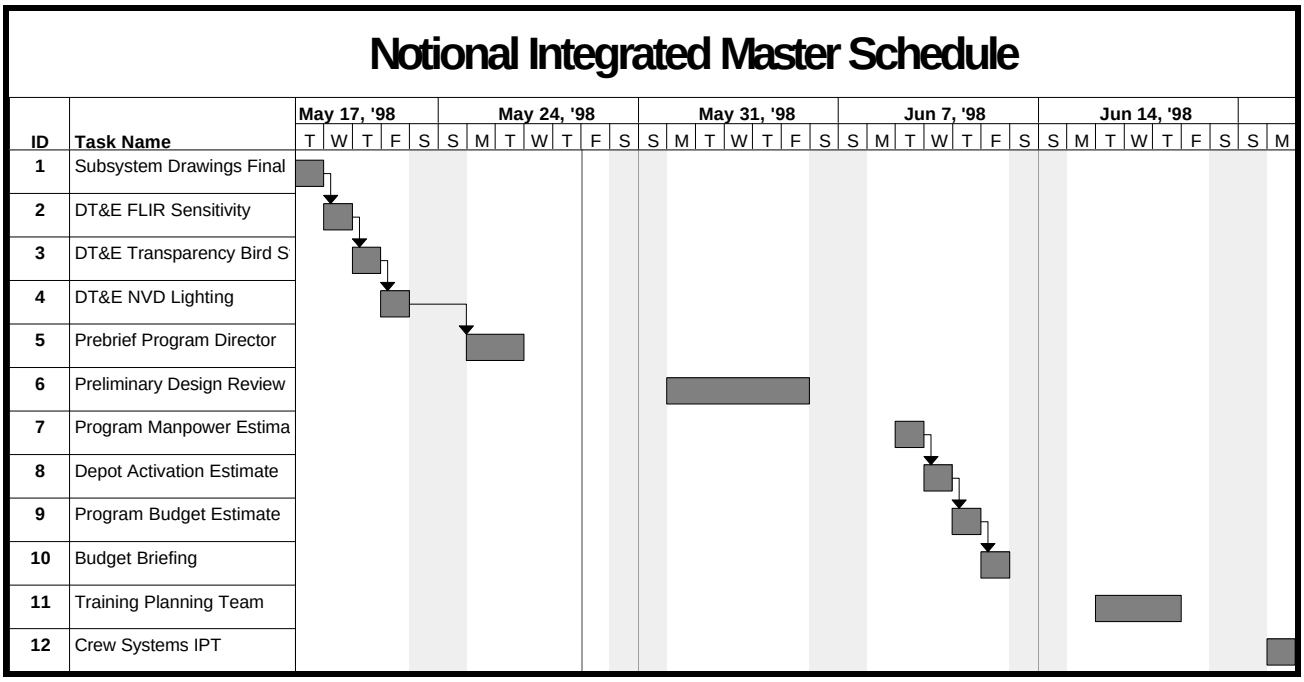


FIGURE 7. Notional Integrated Master Schedule (IMS) contained in the Integrated Management Plan (IMP).

- Is it likely that improper operator performance will lead to system failure, result in excessive maintenance downtime, damaged equipment, or injury to personnel, or compromise security?

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- What crew system problems does the user command/agency anticipate (e.g., problems related to manpower requirements, skill requirements, safety, workload and situational awareness issues, duty cycles, stress, nighttime operation, crew coordination)?
- What, if any, solutions does the user agency propose to solve the problems?

Although each of these questions should be asked, the answers obtained should not be accepted blindly. It is not the responsibility of the user agency or command to design the new system. The contractor HE manager must remember that it is up to the organization, with program office guidance, to design the user-system interfaces of the new system.

7.3.1.1 General availability of mission information. The source of information from which the contractor HE effort starts on a new program varies with the system development phase and the size and complexity of the system, equipment, or facility to be developed. In the Concept Exploration phase, little if any HE information is apt to exist that can be used directly to develop a task analysis or user-system hardware concepts if the new system is to be a radical departure from predecessor systems. If the new system is to be an evolution of existing systems, however, comparable data may be readily available. If data are not available, then the contractor HE practitioner will have to initiate development of this information (e.g., functional flow diagrams) from descriptions of top-level system functions and mission objectives. Paragraph 8.3 (HE Analysis Methods) of this handbook describes these methods. Mission task data are now available from the Chairman of the Joint Chiefs of Staff (CJCS) Universal Joint Task List (CJCS Manual 3500.04A) and the individual service-specific mission task lists.

7.3.1.2 Mission data sources. Some data sources may be identified in the RFP, and some data may be contained in the RFP or included as an attachment to it. Advanced development efforts are usually large enough so that several program reports containing HE information or source data are available. The information generated during the conceptual phase of the program should be studied to determine the concepts for the user-system interfaces. Many of these reports are likely to be available within the contractor's organization (e.g., in systems engineering or systems analysis groups). Thus, the necessary reports should first be sought within the contractor's organization. They may have to be requested internally through the contractor's program manager. If such information is not available internally, it can be requested from government developmental planning offices or from government laboratories through program management channels. Some reports may be available directly from the Defense Technical Information Center (DTIC), from MATRIS, or from the Crew System Ergonomics Information Analysis Center (CSERIAC). (The latter two government resources are described in 6.2.1.6.) The contractor should not hesitate to request government assistance in identifying sources and obtaining existing HE-related program data if the necessary information is not available internally. During a competitive program phase, there may be a general lack of HE data pertaining to one or more areas (e.g., due to security classification reasons). If a potential contractor lacks relevant experience or expertise in a given area, the contractor may wish to consider forming partnerships or using subcontractors who have the pertinent knowledge and experience. It is difficult for a contractor to initiate a major acquisition HE program without having been significantly involved in the preliminary research and the exploration phases of the total program. The time to acquire technical expertise is long before the RFP is issued.

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7.3.1.3 Additional sources. Advances in science and technology. New science and technology often makes innovation in new and modified systems possible. To offer government customers state-of-the-art systems and system modifications, contractors must stay abreast of applicable emerging technologies. Typically, there is at least one research laboratory or organization within each service that focuses on HE-related issues. These organizations define the strengths and limitations of human users to identify the most efficient means of integrating users into emerging and future systems. They also develop HE models, tools, and data bases to assist the HE practitioner. Application of the human performance data and tools can help ensure that the proposed system design appropriately accommodates the human's capabilities and limitations. In this way, the design risk is lessened, the total system performance is enhanced, the MPT demands are reduced, and hazards, safety, and survivability issues are identified. Two organizations can assist with remaining current with human centered technology: MATRIS and CSERIAC. MATRIS maintains a computerized data base of scientific and technical information that includes a Directory of Design Support Methods (DDSM) which lists current HE and HSI tools and methods and provides information on current R&D work units. These work units can help the HE practitioner locate current R&D of interest to system design. A portion of the MATRIS DDSM is available at the MATRIS website. CSERIAC is a DoD information analysis center managed by the Defense Technical Information Center. CSERIAC assists HE practitioners in identifying up-to-date HE solutions from the scientific and technical literature and conducts searches and analyses that present design options for addressing HE design problems. CSERIAC also answers limited technical inquiries on HE-related topics. The CSERIAC Gateway newsletter is offered free of charge and highlights significant HE-related scientific and technical findings. In addition, CSERIAC distributes HE tools developed by government laboratories and conducts state-of-the-art studies on current HE-related technological issues. Additional information is available about CSERIAC at their website.

7.3.2 Program control. During recent years, the scheduling and budgeting aspects of system/equipment acquisition have sometimes become paramount, even at the cost of system performance, if necessary. To ensure complete control of total program scheduling, subsystem development, and the efforts of each technical discipline, individual managers (including the HE manager) must schedule their particular tasks to mesh with the principal tasks/events of the total program. Overall program control is established by the contractor program manager. This includes analysis and design review activities, WBS documentation, and management reporting.

7.3.3 HE scheduling. The contractor HE manager should perform HE planning and scheduling by beginning with a detailed review of the WBS and the associated Integrated Management (Master) Plan (IMP) and Integrated Management (Master) Schedule (IMS). The milestone chart for the entire program should be examined. All scheduled reviews that are affected by HE considerations should be noted. Any HE-related CDRL items and Data Item Descriptions (DIDs) should be noted, and HE tasks related to their accomplishment should be identified. Examples of such tasks are operations analysis, definition and allocation of system functions, potential equipment selection, task analysis, design criteria application, equipment procedures development, T&E, and any significant studies or simulations. Inputs to these tasks (including designation of sources) and outputs from these tasks (including designation of

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recipient/user) should be identified. The IMS chart (e.g., Gantt chart or PERT diagram) should initially schedule the production of HE products for the latest time that they can be used effectively. The starting points and time spans for the HE activities and tasks are determined by subtracting estimates of the time it will take to complete each task from the previously identified end date. Based on the HE task start times, all data inputs to the HE tasks should be scheduled. This first schedule may not prove to be feasible, but it is a necessary starting point for iterations. If contractor HE manpower utilization has not been planned, an approximate estimate should be made for each HE activity appearing on the schedule. These estimates are based largely on previous program experience. HE manpower needs may have to be adjusted; some tasks may be reduced to meet the schedule requirements of the overall program.

7.3.4 Coordination. After determining what HE tasks are required (7.3.1) and what the program schedule is (7.3.3), the contractor HE manager must coordinate the HE program tasks with the program managers and others. The human is a part of most program subsystems. Of all the disciplines involved in the design and development of a military system, HE requires the most coordination. Most of this coordination is horizontal interaction with other disciplines through involvement in an IPT or working IPT (WIPT); however, vertical communication with management is also critical to ensure that the information derived from the horizontal communication and coordination actually impacts the HE system design.

7.3.4.1 The government HE manager. The contractor HE manager must coordinate with the government HE manager to exchange information and to identify and resolve potential problems. Associated discussions should address any HE issues related to work completed and progress reported. The nature and direction of scheduled tasks should also be considered proactively. In addition to regularly scheduled meetings (e.g., weekly telephone calls, video-teleconferences, or multiparty-electronic mail conferences), there should be frequent coordination by telephone and electronic mail to address immediate and emerging or unforeseen issues.

7.3.4.2 The contractor program manager. The contractor HE manager must communicate to the contractor program manager what it is that HE can do for the program. Information from lessons-learned data bases and T&E reports for predecessor systems as well as the contractor's own previous program experiences will be useful in preparing for these discussions. The need for MIL-STD-1472 provisions (if they have been called out in the system specification) should be explained. The program manager should understand the need for HE to contribute to the development of all user-system interfaces, whether they are hardware or software based. Furthermore, the HE review of all drawings or CAD/CAM images for design components that have an impact on the user-system interface is imperative. This requirement should be supported by the government program manager and should be listed in the WBS. Prior experience with HE activities will prove helpful when addressing scheduling issues. The contractor HE manager must also coordinate with the contractor program manager to ensure that there is sufficient budget for the HE effort.

7.3.4.3 Other areas and disciplines. The HE effort affects every portion of the total system that has a user-system interface. HE applies the knowledge of operator/maintainer capabilities and limitations derived from previous research, special studies, and specifications to

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the design and development of the system and its support equipment and procedures. To accomplish this, the contractor HE practitioner must work with personnel in a number of other technical areas and disciplines, such as those in Table I. In addition to coordinating with the program manager, the HE practitioner should contact the organizations representing these areas and disciplines to inform them of the analysis, design, and test support that HE has to offer.

7.3.4.3.1 Internal and external organizations. Typically, the contractor HE manager or practitioner should coordinate with a number of personnel within the program's contracting group as well as within the government program office. For example, HE studies and analyses can help identify unusual personnel screening requirements or labor-intensive or multiple-person tasks that could affect manning levels. Workload and crew size analysis is essential to predicting manpower requirements. Workload and crew size can also relate to safety issues. Issues such as these should be coordinated with staff in the contractor or government program offices who are attempting to compute the manpower and personnel requirements and their impact on life-cycle cost. Affordability of the total life-cycle cost is critically important with today's downsizing of forces. Effective HE can help reduce the burden of personnel costs over the life cycle, making the system more affordable. In addition, the HE practitioner should also work with training specialists to support the development of training systems, including specialized training equipment, training simulators, and procedural manuals and documentation needed to train both operators and maintainers of the entire system. A close examination of how tasks will be trained often reveals awkward task procedures and system designs. The HE practitioner should also work with safety, health-hazard, medical, and survivability personnel on human safety, life support, and survivability issues. Coordination with those responsible for system safety, system reliability and maintainability, and system survivability ensures that system requirements are met and that the system is free of less than ideal designs that could lead to an increase in manpower utilization, training requirements, or accidents. In addition, such coordination may also reveal issues of common concern or potentially duplicative activities that may be eliminated or minimized.

7.3.4.3.2 Technical functions and disciplines. The HE effort must be integrated into the total system program. Coordination is carried out to ensure that other technical disciplines are receiving the proper support from HE and vice versa. Table V shows the relationship of several important HE functions to other related program disciplines and functions and to acquisition phase. (The Fielding/Deployment and Operational Support phase is not shown in this table.) As typical and important examples of such coordination, HE receives inputs regarding mission operations analysis and HE provides outputs from HE analysis regarding proper crew size. If there are subsystems that will be significantly affected by the results of the HE effort, the appropriate government and contractor managers should be forewarned. It is, of course, the responsibility of the contractor HE manager to ensure that the HE analysis, design, or test effort is well documented for presentation to the government HE manager.

7.3.5 Baseline monitoring. A method frequently used by program management to keep the program moving and the design improving at the same time is the establishment of a baseline configuration. The design is controlled by drawings and documents describing the total system. The initial configuration is established by the program manager with the assistance of the chief

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systems engineer (or equivalent) and others. Prior to the program Critical Design Review (CDR), informal meetings are called to review changes to the baseline. After the CDR, a more formal process is established to consider proposed design changes and their associated documentation. Once the CDR has been completed, the baseline configuration is approved. Subsequent design changes are submitted as engineering change proposals (ECPs), which must be reviewed and approved (and paid for) by the government.

7.3.5.1 Typical baseline configuration. A typical baseline configuration might start out during the Concept Exploration phase as a description of the system in terms of required system performance specifications. This description eventually evolves into configuration item performance and design requirements at the end of the Engineering and Manufacturing Development phase. Configuration definition must be maintained through the subsequent Production, Fielding/Deployment, and Operational Support phase.

7.3.5.2 Baseline configuration use. The baseline system design provides a single, readily accessible reference source for all program groups. It is used to determine the potential impact of possible cost and performance tradeoffs. The baseline configuration provides a model that can be used for planning and scheduling purposes. It is imperative that manufacturing and engineering groups use the same system configuration. It is also imperative that a contractor HE manager or practitioner monitor the baseline configuration to be sure that it includes proper consideration of HE user-system interface issues and necessary HE design criteria.

7.3.6 Budget. Accurate estimation of the HE manpower resources required to perform HE program tasks is one of the most difficult undertakings to accomplish. The personnel resources required to perform all contractor-executed HE tasks typically account for the major portion of the contractor's HE-related costs. At the present, the best basis for estimating HE manpower requirements is prior experience.

7.3.6.1 Sample budget allocation. The sample budget allocation in Figure 8 shows HE manpower estimates, excluding T&E support. This example has been developed to assist contractor HE managers who are new to the job of estimating the level of HE effort required for the HE analyses and design tasks to be performed. There are too many variables to attempt to depict a more definitive allocation of scheduled HE manpower. If the contractor HE manager has worked with this type of budgeting and scheduling before, then it may be better to base recommendations on experience. The primary factors presented in the table are the types of HE analysis to be performed and the program schedule. The HE manpower estimates in the table are shown as percentages of the total manpower available to do HE tasks. The available manpower could vary from less than one full-time person to considerably more depending on the HE portion of the total program and the total program size. The numbers across the top of the chart represent the percentage of the schedule through CDR. Depending on the program, these values could represent weeks or days. The two reference milestones used are the Preliminary Design Review (PDR) and the CDR. The PDR is often referred to as the initial design review. It is the point in the schedule at which the design specifications and drawings receive preliminary approval by the government. The CDR, or final design review, is generally the time at which the design

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receives the approval required from the government to proceed into the next acquisition program phase.

7.3.6.2 Budget variations. As indicated earlier, there are variations in the types of HE analysis and design required. Performing operations analyses will greatly assist the contractor in the effort to understand the proposed system and its operation as it was initially envisioned. More analysis may be required in one area than in another. For example, programs with large operational crews tend to require considerable emphasis on human-system function allocation and workload analysis.

7.3.6.3 HE budget estimate. One of the most critical aspects in ensuring the success of the HE portion of the program is securing an adequate budget. While HE does not normally consume a large percentage of the total budget, it is crucial that all necessary analysis, tradeoff studies, T&E, and other HE activities be planned and budgeted.

| Type of activity | Time (% of schedule shown) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | 40 | PDR | 60 | 70 | 80 | 90 | CDR |
| | | | | | | △ | | | | | △ |
| Operations analysis | | | | | | | | | | | |
| Scenarios | | 25% | 5% | | | | 5% | | | | |
| Mission Profiles | | 15% | 10% | | | | 5% | | | | |
| | | | | | | | | | | | |
| Definition and allocation of systems functions | | | | | | | | | | | |
| Functional flows | | 25% | 25% | 20% | 10% | | 5% | | | | |
| Operator capabilities estimation | | 10% | 10% | 5% | | | | | | | |
| Function allocation | | 10% | 20% | 30% | 25% | 20% | 10% | 10% | | | |
| | | | | | | | | | | | |
| Equipment identification | | | 10% | 10% | 5% | | 5% | | | | |
| | | | | | | | | | | | |
| Analysis of tasks | | | | | | | | | | | |
| Gross task analysis | | | 5% | 20% | 20% | 25% | 10% | 10% | 5% | | |
| Critical task analysis | | | | | 15% | 20% | 20% | 20% | 20% | 15% | 10% |
| Workload analysis | | | | | | 10% | 10% | 20% | 20% | 20% | 20% |
| | | | | | | | | | | | |
| Design support | | | | | 10% | 10% | 15% | 25% | 40% | 50% | 55% |
| | | | | | | | | | | | |
| Supervisory and clerical | | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| | | | | | | | | | | | |
| TOTAL | | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

Note: Assume no separate operations analysis effort; assume small precontract effort

FIGURE 8. Hypothetical example of program manpower estimates.

7.3.6.3.1 Initial estimate. A rule of thumb frequently followed by contractors is to use as the initial estimate of the budget for the HE effort either 1 percent of the total budget for the

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Concept Exploration phase or 1 percent of the total budget for the Engineering and Manufacturing Development phase (for large programs), whichever is greater. Crew system development costs, of which HE efforts are a major part, have approached 2 percent of weapon system development costs in some systems. There are several factors that can increase or decrease this percentage. Principal among them is the size of the operator and maintainer crews. However, there is considerable HE activity beyond this development stage. Often substantial HE support must be provided for software usability testing and for the development and evaluation of training simulators, equipment, and procedural manuals for both operator and maintainer functions.

7.3.6.3.2 Early influence and program manager's role. Regardless of the extent of HE work that *should* be done, the most important factor affecting the amount of HE work that *can* be done is the decision of the contractor's overall program manager regarding the HE budget. Early in the process, the budget manager must be informed of the level of HE budget required to address all identified HE issues and concerns. If insufficient budget appears to have been provided to perform all the HE tasks required by the SOW, the contractor's overall program manager must be informed of the consequences as soon as this circumstance becomes known. If the manager is not convinced, priorities must be established for each of the HE tasks, and the total level of effort must be adjusted accordingly. Obviously, however, the nature, extent, and reasons for HE activities and support should be clearly identified as early as possible in the acquisition program and should be represented adequately in the contractor's proposal.

7.3.6.3.3 HE budget shortfalls. An apparent HE budget shortfall should arise rarely, if at all, due to faulty contractor HE estimates. Such a shortfall could justifiably occur in response to accommodations that must be made to program changes when the program manager decides to incorporate an unanticipated technological breakthrough. Another justified circumstance would be when additional, unprogrammed evaluations must be carried out. Such evaluations may be needed to better understand and resolve unusual findings that could not have been anticipated based on other, previous information (such as the results of similar or related evaluations of predecessor systems). Budget shortfalls are more likely to result from overall program budget cuts. When budget cuts occur, it is important to have each HE activity clearly justified and prioritized. This way, the contractor HE manager can provide appropriate rationale for keeping the budget and, if cuts are necessary, can give up only the activities that are least important to the success of the program.

7.3.7 Allocation of effort. It is unusual for a prime contractor to allocate a complete HE effort to a subcontractor—or even to an associate contractor. However, the use of consultants, subcontractors, and associate contractors to perform portions of the total HE program is not uncommon. Competent consultants are available to work specialized aspects of HE, for example, biomedical, anthropometric, and biodynamic modeling or user-computer interfaces.

7.3.7.1 Planning of divided efforts. If an acquisition contract is split between two or more large contractors and one is not designated as the prime contractor, an integrating agency or organization is necessary to coordinate the effort. It is critical for the integrating agency to develop an integration plan that allocates the HE effort among the participating contractors. The

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participating contractors should incorporate the results of the integration plan into their individual HE plans. The integrated plan should define the level of effort each associate contractor must maintain. It should describe the HE tasks each contractor must perform (including task analysis formats to be followed) and the HE data outputs from those tasks. The plan should focus on issues of HE information exchange and the timing of deliverables needed by participants and the government. The plan is submitted to the integrating agency or organization in accordance with the HE program schedule.

7.3.7.2 Subcontractors. The HE effort to be performed by subcontractors is generally proportional to the dollar value of their contract and the nature of their work. The prime contractor HE manager will decide how much HE the subcontractor will perform and is always responsible for the total HE effort.

7.3.8 Proposal preparation and tailoring

7.3.8.1 Draft RFP. If the government has issued a draft RFP, the contractor responds by providing a critique and suggestions. With the additional knowledge gained from the draft RFP, the contractor should produce a better quality proposal. The contractor's HE manager should participate in the review of the draft RFP and make suggestions regarding the nature of the HE portion of the draft.

7.3.8.2 Proposal contents. Once the RFP is officially issued, the decision as to how to respond is invariably made by the offeror's program manager within the limitations of the proposal evaluation criteria supplied with the RFP. The program manager should carefully review each of the requested tasks listed in the RFP SOW and all CDRL items that appear. As a minimum, the offeror must state agreement with the SOW or take exception to those portions with which the offeror does not wish to comply. The HE effort should be described in the technical portion of the proposal.

7.3.8.2.1 Contractor HE strategy for proposal. One important aspect of the proposal is presenting the contractor's HE strategy so that DoD evaluators can understand the contractor's plan for ensuring that HE issues will be addressed sufficiently and in a timely and logical manner. HE issues that should be covered by the contractor's proposal include the following:

- Contractor HE organization – where in the organization the HE function is structurally located and how HE functions will relate to other engineering and logistics disciplines. Also, (if possible) resumes of personnel selected to implement the HE program should be included.
- HE Subcontractor Efforts – when significant portions of HE work are to be subcontracted, supply detail on the taskings, how prime contractor check and how integration will be accomplished.
- Planned HE Analyses – provide a schedule of the planned HE analyses to be conducted and show their relationship to key program development milestones so that it is clear how HE studies will influence system design.

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- HE in System/Equipment Procedure Development—provide a strategy for allocating functions and tasks to operators and maintainers of the system or equipment. A plan for properly developing procedures to ensure that they comply with effective HE guidelines and then can be turned into appropriate operational, technical, training, and job aid manuals and electronic media.
- Design impact on MPT and safety—show how the contractor will structure the system to stay within manpower, personnel, and training (MPT) goals, and meet or exceed safety requirements. The interaction between HE personnel determining the human interface and those responsible for conducting MPT and safety analyses is critical.
- HE in T&E—critical HE-related tests should be highlighted and timed to influence design decisions.

7.3.8.2.2 Other contractor HE issues for the proposal. Other HE issues that should be addressed in contractor proposals include the following:

- Procedures proposed for complying with any HE requirements; these may include anticipated trade studies as well as analyses, design, and evaluation methods; all proposed tailoring of HE items should be described, as well;
- Summaries of HE efforts accomplished (and lessons learned) during previous program phases;
- Descriptions of proposed HE participation in simulation, mockups, detail design, CAD/CAM image review, testing, and verification;
- Special HE objectives (e.g., crew size and performance) and any anticipated problem areas, along with the proposed means to meet these objectives and address these problem areas.

7.3.8.3 Tailoring and costs. Contractor HE activities should be identified and incorporated as an integral part of the total program management and engineering effort, interfacing with all levels of program management. Specification tailoring is essential to reduce both acquisition and life-cycle costs. The cost of imposing HE requirements should be evaluated against the benefits that will be realized. This consideration becomes increasingly important during the latter acquisition phases when the costs of implementing changes become increasingly higher. Against such costs, HE practitioners must examine the impact of potential changes to the user-system interfaces. They must determine likely effects at the system level and estimate the impact of same on the system’s capability to perform its assigned mission.

7.3.8.4 Government contact. After the issuance of the RFP and before the contract award, it is important to understand that the government's evaluators are not free to converse with prospective contractor organizations on an informal, day-to-day basis. During this period, any communication should be documented and coordinated through the appropriate contracting officer.

7.3.9 Contract performance. Detailed HE planning and scheduling are required so that HE activities identified in the contract SOW and associated CDRLs can be completed at the

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appropriate time when they can have the desired effect. To accomplish the necessary planning and scheduling, the contractor HE manager must participate in program meetings and coordinate the required contract tasking and deliverables. The following sections provide information relating to the accomplishment of these activities.

7.3.9.1 Meetings. Indiscriminate use of meetings can be a significant waste of personnel, travel, and related resources. However, certain meetings are essential. Formally scheduled meetings are identified in the WBS or an associated IMS. The government program manager may request or recommend additional formal meetings. Typically, there are joint government-contractor IPTs, WIPTs, or other working groups that provide a ready means of coordination. The contractor HE manager may also propose additional HE-related meetings; however, such requests should be carefully considered, since they impose unprogrammed costs. While some unanticipated events or outcomes may provide a valid reason for calling a meeting, other means of achieving the same result should be considered (such as electronic mail, telephone contact, or video teleconferencing).

7.3.9.1.1 Kickoff meeting. If a new program has a substantial HE component, it will probably be beneficial to hold an initial HE guidance meeting within a few weeks of the contract award. The contractor should suggest this meeting as a part of—or as an adjunct to—the proposal, even if it is not required by the government. There is no substitute for a face-to-face discussion of what the contractor intended in the proposal and what the government interpreted from the proposal. Further, this initial meeting provides an opportunity to focus on the system performance specifications and SOW (or statement of objectives, or SOO) on a paragraph-by-paragraph basis, if necessary, to ensure a mutual understanding between the contractor and the government. At this meeting, the contractor may request more detailed guidance. The government may wish to offer or provide technical data. Also, the contractor may request help or obtain advice in solving various kinds of program problems. The results of previous related efforts should be discussed. Also, consideration of—and agreement regarding—each of the identified HE activities is important.

7.3.9.1.2 Design reviews. To be functional and effective, the contractor's HE organization (or principal HE representatives) must participate in all major design reviews, for example, all System Design Reviews (SDRs), the PDRs, and the CDRs. The contractor's principal HE representative should present the results of HE analysis and design support efforts. The following are examples of the types of information to be reviewed:

- Concept of operations
- Mission segments with peak workloads and methods of dealing with this workload
- Operating modes for each display station and the displays and controls used for each function
- Format and content of each display and the control and associated data entry devices
- HE aspects of user-computer (software) interfaces and function allocation
- HE aspects of hardware and facility design, such as design for the user population (anthropometry), workspace design, and design for environment, maintainability, and accessibility

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- Risk and tradeoff studies

This information should be presented in sufficient detail to allow the government to determine the adequacy and usability of the user-system interfaces. Technical interchange (TI) meetings on any HE subject may also be held at the request of the government or contractor.

7.3.9.2 CDRLs and DIDs. Contracts usually contain a list specifying the data products the contractor must deliver. This list is called the Contract Data Requirements List (CDRL, DD Form 1423) (see Figure 6). Standardized data preparation instructions have been developed for the many products that might be contracted. These reporting requirements are called data item descriptions (DIDs, DD Form 1664). For a specific contract, the appropriate DIDs are selected and included in the CDRL by the government. The CDRL (list of deliverables) should be in agreement with (and follow from) the HE tasking statement in the SOW. Subject to the note on the first page of Appendix C, there are seven DIDs pertaining to HE:

- HE Simulation Concept (HESC) (DI-HFAC-80742B)
- HE Test Plan (HETP) (DI-HFAC-80743B)
- HE Test Report (HETR) (DI-HFAC-80744B)
- HE System Analysis Report (HESAR) (DI-HFAC-80745B)
- HE Design Approach Document–Operator (HEDAD-O) (DI-HFAC-80746B)
- HE Design Approach Document–Maintainer (HEDAD-M) (DI-HFAC-80747B)
- Critical Task Analysis Report (CTAR) (DI-HFAC-81399A)

The HE DIDs are reproduced in Appendix C. The following sections describe the contents of each HE DID.

7.3.9.2.1 HE Simulation Concept (HESC). The HESC outlines the contractor's intended use of mockups and engineering simulators in support of HE analysis, design, and T&E efforts. The HESC should describe the need for mockups or simulators, as well as the overall concept of use. It should also set out how the data and findings from the proposed use of mockups and simulators can be integrated with or will relate to information from other HE activities (e.g., other intended simulations, evaluations, and analyses) that are planned or have been accomplished. The rationale for the selection of the specific simulator or simulation should be provided, and previous validation efforts (and their results) applicable to each simulator or simulation approach or technique proposed for use should be described. When required, the HESC may be called for during the Engineering and Manufacturing Development phase. The HESC should be coordinated with appropriate contractor engineering personnel prior to its release to the government.

7.3.9.2.1.1 Areas of application. For each intended use of a simulation, mockup, CAD/CAM analysis, or simulator, the HESC should describe the following:

- Human performance and workload analysis, test, and demonstration
- System design, development, and demonstration
- System effectiveness studies, tactics development, and verification

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- Development and verification of operator skill, knowledge, and other training data
- Operator procedures development and verification, including degraded mode and emergency procedures
- Maintainer procedure and accessibility
- Training system design and verification studies
- Development and verification of technical publications

7.3.9.2.1.2 Schedule. The contractor's HE organization must also develop a schedule for the simulation activities to be undertaken. This schedule should be cross-checked to ensure compatibility with the schedule for the development and availability of other program analyses and products to ensure that the planned simulation activity will yield credible information in a timely manner.

7.3.9.2.1.3 Use of government resources. The HESC must describe any intended use of government facilities, models, data, or other government property. Also, if government personnel are to participate in or otherwise support the simulation activities, the HESC must identify the required qualifications for such personnel, the number needed, and the extent of participation required. Their participation must be reflected in a schedule. The nature of the scenarios and missions to be used must be described in detail. This description must include information regarding the mission objectives, the operational environments, and the geographical, terrain, and weather conditions, as well as any additional information that may relate to the outcome of the simulation(s).

7.3.9.2.2 HE Test Plan (HETP). The purpose of the HETP is to provide the government with details of the intended testing of personnel with hardware/software interfaces to show compliance with system operator-and maintainer–relevant requirements in the performance specifications. The HETP should describe the contractor's plan for both gathering and analyzing the data that will provide the principal basis for assessing operator and maintainer performance, determining the accuracy of personnel selection criteria, evaluating the adequacy of training, and assessing the acceptability of the hardware/software user-interface designs. The objective of the plans and analyses described is to generate findings that will reveal the extent to which all operations- and maintenance-related human performance requirements can be met under all projected conditions of use by individuals who are representative of the anticipated population of military users. In addition, the HETP must describe actions that will yield data reflecting the cost (in terms of all resources required) of the contractor's training program for operators and maintainers. It must also include some measure (based on human performance time and error) of the prospective effectiveness of the contractor's training program for both operators and maintainers. The HETP should be coordinated with contractor T&E personnel prior to its release to the government. The government will use this information to evaluate the planning for validation of human performance required and attained, accuracy of personnel selection criteria, adequacy of training, and acceptability of the design of the personnel-equipment/software interface. The HETP may provide a means for requiring HE efforts early in the program. It may be applicable during the Concept Exploration or Program Definition and Risk Reduction program phases.

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7.3.9.2.3 HE Test Report (HETR). If the HETR is required, it may serve as the principal means of reporting information relating to the validation of human performance requirements, personnel selection, training, and design of the personnel equipment/software interface.

7.3.9.2.3.1 Use. The HETR, if required, will be used to determine whether and to what level or standard(s) a trained, typical operator or maintainer can perform all assigned tasks in the sequence specified. It is also used (a) to determine whether and to what extent each individual's performance is affected by the equipment configuration, the performance of other system personnel, or both; and (b) to assess the impact of measured user performance on the attainment of task, task group, and mission requirements. (A task group comprises all operations and maintenance tasks required of an individual assigned to a given crew position.)

7.3.9.2.3.2 Position, task, and environment. The HETR is prepared for each user position in the system being developed. The purpose of each test and the equipment or concept being tested should be identified for each test. All discrete tasks comprising each task group should be described, and the operational environment in which each is to be performed should be delineated. Any pertinent performance standard or assumed level of error that has been previously stated or identified in a system development document should be cited. The ambient environment existing at the time of the test (e.g., temperature, humidity, light, noise, vibration level) should be described for each user position. Exposure parameters for any toxic or hazardous substance present at the time of testing (including a statement as to whether they were within acceptable safety limits) must be reported as well.

7.3.9.2.3.3 Participant information. Characteristics of the test participants (e.g., anthropometric measurements, hearing and vision capabilities, aptitudes, skill and training level), the clothing and accouterments worn, and the equipment used all must be described in the HETR.

7.3.9.2.3.4 Methods, procedures, and analyses. The HETR should describe the methods, procedures, and instrumentation used to collect the data, as well as the methods used to reduce and analyze the data. The statistical confidence levels used must be cited. Human errors must be documented to the extent possible (with inclusion of statements by those making the errors), the likely causes of such errors identified, and the expected consequences on system performance described. All user-system incompatibilities must be described, and potential means of remediation (e.g., equipment redesign, task modification, change in personnel selection qualifications or level of training) must be recommended. Each recommendation must be accompanied by a supporting rationale in narrative form. Similar reporting requirements must be met for any safety violations or hazardous conditions or actions observed. Deviations from the planned test conditions must be listed, the reasons for the deviations must be explained, and the presumed impact of such deviations on the interpretation of the test data (i.e., validity and generalize ability) must be described.

7.3.9.2.4 HE System Analysis Report (HESAR). The HESAR details the contractor's system analysis efforts and their results. It should describe the system's performance objectives, mission(s), and mission contexts (environmental conditions; day/night operations; geographical

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location; enemy force concentrations, threats, and capabilities; countermeasures, etc.). It should also delineate the system functions that must be performed to meet system objectives and, perhaps more importantly from the HE perspective, how those functions are to be allocated. Also to be included are descriptions of information flow and processing, and estimates of potential operator/maintainer processing capabilities. One of the major purposes of the HESAR is to provide the rationale for and results of the human-system/software allocation tradeoff analyses that have been performed. The HESAR should also describe the selected design configuration. The report should not duplicate data available in other engineering reports; however, the results of function allocation tradeoff studies are seldom reported elsewhere. The material presented in the HESAR should be coordinated with the contractor's systems engineering group prior to its release.

7.3.9.2.5 HE Design Approach Document–Operator (HEDAD-O). The HEDAD-O describes (a) the layout, detail design, and arrangement of crew system equipment and displays that have an operator interface, and (b) the operator tasks associated with the system. The HEDAD-O must also clarify the extent to which the human performance requirements and design criteria (e.g., from MIL-STD-1472 or TAFIM) have been incorporated into all components of the system that must interface with humans. Results of operator task analysis must be presented as part of the rationale supporting the layout, design, and integration of crew systems.

7.3.9.2.5.1 Detailed contents. The HEDAD-O should contain the following information relating to operator and crew station: a list of each item of equipment and system display with an operator interface, a list of specifications and drawings approved by HE, and a description of the crew station emphasizing HE design features. Features to be described include:

- the layout and arrangement of each crew station and a representation of each item of equipment;
- the layout and detail design of each control/display panel;
- operator vision and lines of sight (both the internal view of crew station controls and displays, and the external field of view);
- environmental factors; normal and emergency ingress and egress; crew station lighting characteristics and lighting control systems;
- crew station warning, caution, and advisory signals;
- seating; restraint systems; communications systems and communications systems control;
- any special features of design, layout, or arrangement required by the mission or system environment; designs for multiple-operator stations (if any); and
- any special requirements related to mission or system environment.

The HEDAD-O must also describe the geometric layout of the crew stations; the rationale for the HE design, layout, and arrangement of each item of the crew station that has an operator interface; and a narrative that provides the rationale for any deviation from design criteria, such as MIL-STD-1472.

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7.3.9.2.5.2 Use. The HEDAD-O is not intended to present the contractor's entire system design. Rather, it should describe only the HE portion of the design. It should agree with, but not duplicate, other design CDRL deliverables available to the government. The material in the HEDAD-O may be presented by contractor HE representatives in summary form at the Engineering and Manufacturing Development design reviews. As with other HE deliverables, this report should be coordinated with the contractor systems engineering group prior to release to the government.

7.3.9.2.6 HE Design Approach Document–Maintainer (HEDAD-M). The HEDAD-M describes the characteristics, layout, and installation of equipment that has a maintainer interface. Maintainer tasks associated with the equipment are also detailed. The HEDAD-M must also clarify the extent to which HE requirements and design criteria (e.g., from MIL-STD-1472) have been incorporated into the design, layout, and installation of equipment. Results of maintainer task analysis must be presented as part of the rationale supporting the layout, design, and integration of the entire crew system.

7.3.9.2.6.1 Detailed contents. The HEDAD-M should contain the following information relating to the maintainer and crew station: a list of each item of equipment with a maintainer interface, a list of specifications and drawings that have been or will be approved by HE, and a description of system equipment, emphasizing HE design features. Features to be described include the location and layout of system equipment, the design of equipment, and the installation of equipment. The list of specific information required is extensive. Among other things, the HEDAD-M should describe

- equipment maintenance requirements;
- maintainer requirements;
- task requirements; environmental considerations; safety issues;
- limitations imposed or inherent due to the state of the art;
- special tools and equipment;
- results of task analysis supporting layout, design, and
- installation of equipment; and sketches, drawings, or photographs of equipment associated with alternatives to the baseline design and layouts.

The results of the analysis of maintainer tasks must also be reported in considerable detail as part of the rationale supporting equipment layout, design, and installation. Among other items, this description of maintainer tasks must include information regarding

- task frequency of performance,
- data source used for the analyses,
- support equipment required,
- detailed task sequence,
- task performance time, and
- a variety of HE considerations, such as

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- maintainer fatigue
- identification of potential hazards, safety, and protective clothing
- maintainer access
- maintainer communication and
- labeling.

7.3.9.2.6.2 Use. The uses of the HEDAD-M are similar to the uses for the HEDAD-O. Although HE usually provides output data directly to maintainability and logistics organizations, the HEDAD-M could serve as a means for supplying much of these data.

7.3.9.2.7 Critical Task Analysis Report (CTAR). The CTAR provides a description and analysis of each critical task. This report is prepared when critical operator or maintainer tasks have been identified. The existence of critical tasks is a function of the system design. A task is critical when it meets the definition provided in MIL-STD-1908. It is the contractor's job to design systems that minimize the occurrence of critical tasks. One means of accomplishing this, for example, is to design system, software, and procedures so that there are either parallel system functions or functions with feedback loops that provide higher inherent system reliability and thereby minimize the possibility of critical tasks. For each critical task, the CTAR must define task-relevant information required by and available to system users and the actions necessary to accomplish the task, including all responses to specific information and combinations of information, and all self-initiated behaviors. The functional impact of the execution of each critical task on both the immediate subsystem and the overall system must be described and all affected missions and phases must be noted. The CTAR must provide a thorough description of each critical task. Twenty specific task-related items of information are requested. Among other things, the report must describe task execution time, workspace envelope, necessary tools and equipment, and job aids, training, or references required. Personnel performance limits and the nature of any required interactions among personnel must also be described. For maximum utilization and benefit, if the contractor systems engineering group has not already been involved in the preparation of the report, then the CTAR should be coordinated with this group prior to its release to the government.

7.3.10 Contractor processes

7.3.10.1 Analysis. Generally, the analysis process starts with the system mission as described by a baseline scenario. The mission objective is studied, and the functions that must be performed by the system are identified, described, and sequenced. These functions are then analyzed to determine their proper allocation to personnel, software, or equipment, or some combination of these. Once functions are allocated, the personnel functions are further analyzed to determine the specific operator/maintainer tasks that must be performed to accomplish them. The tasks are then detailed to show estimated time and space relationships. All tasks are reviewed to determine their criticality, and critical tasks are analyzed in detail. Workload analysis is performed to evaluate allocation of functions to the crew. HE analysis methods for performing many of these tasks are described in 8.3.

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7.3.10.2 Design and development support. A typical design support activity starts with the results of the analytical activity. These results are translated into hardware and software derived design requirements that are, in turn, written into the applicable specifications and included in the hardware drawings and software programs. To evaluate these derived requirements (e.g., operator time-critical and reliability-critical requirements), studies and laboratory tests may be conducted. Mockups and models may be constructed or dynamic simulations performed. A significant part of the HE activity is to coordinate with the designers and others to ensure that the HE requirements are incorporated into the hardware and software designs. HE design support methods for accomplishing many of these tasks are described in 8.5.

7.3.10.3 Test and evaluation. Normally, the contractor HE T&E effort is applied to developmental T&E and not operational T&E, which is accomplished by government personnel. The contractor HE T&E effort starts early with planning. This planning may entail the preparation of an HETP (see 7.3.9.2.2). While the planning effort is generally accomplished by the same HE practitioners who have performed the analysis and design support work, the remaining HE T&E activities may be performed by a different group of HE personnel located at the test site. The HE T&E practitioner should start by reviewing the program HE data file (see 7.3.11), including HE design criteria and rationale. The practitioner should become thoroughly familiar with all the user-equipment and user-software interfaces. Part of the HE T&E practitioner's responsibility should be to determine applicability of the design criteria. The equipment should also be reevaluated to determine if any operator or maintainer tasks originally determined to be critical tasks are still in that task category. The practitioner should look for new critical human performance tasks. One of the major HE T&E activities is monitoring tests. The full-scale equipment design should be reviewed, in either a static or dynamic (in use) condition, to determine compliance with performance specifications and any design criteria that may have been stipulated. Derived human performance requirements, including required skills, skill levels, numbers of personnel, and training, should be validated. The HE practitioner should determine if planned procedural use of the equipment and software is satisfactory. A preliminary analysis of HE T&E problems should be conducted and solutions recommended. These should be documented and reported. HE test reports and progress reports should be prepared as applicable. In addition, each service has a test incident or deficiency report (Army test incident reports, Navy "yellow sheets," and Air Force deficiency reports) that must be submitted in accordance with service policy (see 6.2.1.3.1.1 through 6.2.1.3.1.3 for more information). HE T&E methods for accomplishing many of these tasks are described in 8.7.

7.3.11 HE data file. The contractor's HE organization should establish and maintain an HE data file that contains all HE and HE-related data generated on the program. These data, such as HE analyses, design review results, drawings, checklists, and other supporting background documents reflecting HE actions and decision rationale, should be maintained and made available to the government at the contractor's facility. Typically, these data will be reviewed at various contractor meetings such as design reviews, audits, demonstrations, and T&E functions. The data file is organized to provide traceability from the initial identification of HE-related performance specifications and the subsequent internal generation of HE requirements during analysis or systems engineering through design and development to the verification of

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these requirements during T&E of the approved design, software, and procedures. Electronic file sharing and review of CAD/CAM images is now possible.

7.4 General contractor considerations. The purpose of this subsection is to briefly present basic considerations not covered elsewhere. These include the type of data required to start any HE effort, when to perform the effort, the level of detail required, and the type of specific results normally expected from the HE effort. Other paragraphs of this handbook deal with these topics in relation to specific HE procedures and methods; however, this subsection discusses these basic considerations in relation to the overall HE effort.

7.4.1 Data. There is great variation in the degree to which data such as mission requirements, system requirements, or operational concepts are supplied to the contractor's HE practitioners. Mission analysis and functional flow diagrams may not be routinely provided to the HE group. In such a case, this information must be located or generated by HE personnel. Software and display/control designers possess data and information on the capabilities and limitations of their products and should provide HE practitioners access to these data. Data pertaining to human cognitive, sensory, and physical characteristics, performance capabilities, and limitations may be derived or inferred from MIL-STD-1472, from a number of non-DoD HE or HF handbooks, and from research reports and HE or HF professional journals. Data regarding predecessor system performance capabilities and limitations typically come from research reports and from contacts with those involved in the HE aspects of the design and testing of such systems. The specific data sources for these inputs are either too numerous or too intangible to list here. The data for later design and testing phases are obtained from HE analysis or from other technical disciplines.

7.4.2 Timing. Without the proper scheduling, the HE analysis, design, and testing effort may be late in relation to need and, therefore, of little use to the system designer. It is not enough merely to perform these HE efforts. The results of the effort must be completed or partially completed at a point in the schedule when they can properly impact the system design. It is the contractor HE manager's responsibility to cross-check HE activities and their schedule with the overall program development master schedule to ensure that this occurs. However, there are occasions when HE efforts performed on a portion of a program must be repeated. This is apt to be due to the evolutionary nature of the design process; that is, a portion previously tested later changes to the point where the previous HE data are no longer applicable. Such an occurrence may be unavoidable when a decision is made to incorporate a highly significant technological breakthrough. However, such circumstances are the exception. In general, given appropriate crosschecking and attention to scheduling changes, then the earlier an analysis or test can be performed the greater the likelihood that the results can meaningfully impact the system design. Late findings of serious HE problems can necessitate very expensive redesign or retraining efforts. Worse yet, late inputs may be disregarded, thus increasing the potential for serious system failures and accidents at some point in the future.

7.4.3 Level of detail. Just as the HE effort may be performed too soon or too late, the analysis, design, or testing can be performed at too gross or too detailed a level. If the level is too gross, then a critical HE-related concern may fail to be identified; if it is too detailed, then

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unnecessary cost or delay may result. The following paragraphs offer guidance in determining the appropriate level of detail for HE efforts.

7.4.3.1 Analysis. The level of analytical detail required strongly affects the HE personnel resources required. Analysis must be performed judiciously to ensure that proper emphasis is given to each of the various tasks or mission functions that are candidates for HE analysis. Some HE evaluations will require more detailed analyses than others. For instance, assessments of the layout, content, and sequence in which information is accessed and displayed on a multi-function visual display may require extensive and detailed analyses. On the other hand, some evaluations can be accomplished more quickly at a more global level—for example, determining the appropriate direction of movement for a door handle. Function allocation tradeoff studies must provide a level of analytical detail that permits a definitive allocation of functions among operators, equipment, and software. More detailed task analysis should be performed only on critical tasks. The contractor HE practitioner or manager should decide which analyses will generate worthwhile data or useful design criteria. Unnecessary duplication should be avoided.

7.4.3.2 Design support. If other organizations have the charter to perform the detailed design of program hardware, it behooves the contractor HE practitioner to do more than merely provide human performance data and HE design criteria from existing references. While the HE practitioner should not produce the complete design, neither should the practitioner simply offer negative criticism of other organizations' designs. All HE inputs must provide enough detail to support the designer by fully describing any shortcomings and recommending appropriate remedial HE design alternatives.

7.4.3.3 HE test and evaluation. The contractor HE T&E manager should decide what level of detail or resolution is needed to properly evaluate a user-system interface. The user-system interface should be tested under the most demanding anticipated operational scenarios and environments consistent with the identified mission. As emphasized earlier, these tests should be conducted with users who are representative (e.g., in terms of physical attributes and aptitudes and level of training and experience) and who are wearing clothing and accouterments appropriate for the operational/tactical scenario being considered (e.g., suitable protective clothing and tactical weapons). The sensitivity of the tests and the level of resolution required of the measures used should be consistent with the nature and demands inherent in the tasks being evaluated. For instance, evaluation of control inputs by a pilot during the flight of a high-speed tactical aircraft engaged in simulated tactical combat may require the collection of very high resolution data—the timing of control inputs may have to be measured in thousandths of a second and equally sensitive levels of resolution may be needed to assess the direction and magnitude of the forces applied. In contrast, much grosser measures of timing, magnitude, and direction may be sufficient to adequately evaluate control inputs made to the lever of a piece of heavy equipment intended for use in construction operations in a logistical support area.

7.4.4 Applications. The purpose of HE activities in the three major areas (analysis, design and development, and T&E) is to help develop and justify a system design. HE analysis is carried out at successively more detailed levels to identify increasingly more significant detailed design criteria. Design criteria must be incorporated into mockups, drawings, and specifications. The

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end product of HE T&E is to verify system design, discover system inadequacies, and provide recommendations for improved or remedial design. In addition, a byproduct may be to provide information for a data base of human performance and crew systems design-related data to be used in later programs. Generally, the outputs of these efforts should be consolidated, summarized, and depicted in the most appropriate formats (e.g., graphs, tables) to facilitate understanding by non-HE program personnel who must read and interpret them. When HE findings are prepared and presented, they should be prioritized and organized in such a way that significant design issues can be readily discriminated from those of lesser importance or impact. Failure to do so runs the risk of having insignificant results acted upon and critical data ignored. All findings must be well documented, and files must be maintained. By themselves, verbally stated HE recommendations and inputs to program designers and program management will have little chance of acceptance and implementation.

7.5 References. (References cited in Section 2 are not repeated here)

Chairman of the Joint Chiefs of Staff (CJCS) (1996, Sep). *Universal Joint Task List (CJCS).* Washington, DC: Author. Available: http://www.dtic.mil/doctrine/jel/cjcsd/cjcsm/m3500_4a.pdf

*Joint Service Specification Guide: Aircrew Systems Engineering Handbook* (DRAFT JSSG-1776-1). (1998). Washington, D.C.: DoD.

MATRIS (1997). Index of Non-Government Standards on Human Engineering Design Criteria and Program Requirements/Guidelines. Available from: http://dticam.dtic.mil/hm/pubs.html

MATRIS (1998). Directory of Design Support Methods. Available from: http://dticam.dtic.mil/hm/pubs.html

MIL-HDBK-1473A, *Department of Defense Handbook Color and Marking of Army Materiel.* (Aug 97)

MIL-HDBK-743A, *Anthropometry of U.S. Military Personnel Guidelines*

MIL-HDBK-767, *Design Guidance for Interior Noise Reduction in Light-Armored Tracked Vehicles*;

MIL-STD-1474D, *Department of Defense Design Criteria Standard, Noise Limits (Aug 97)*

MIL-STD-1477C, *Department of Defense Interface Standard: Symbols for Army Systems Displays;*

MIL-STD-1787B, *Department of Defense Interface Standard: Aircraft Display Symbology*

TAFIM, Chapter 8, Available: http://www-library.itsi.disa.mil/tafim/

## 8. HE METHODS AND TOOLS.

8.1 Overview. Over the years, HE practitioners, engineers, and psychologists in a variety of subdisciplines have developed many powerful methods to aid in HE work. This section provides information regarding a number of the methods that can be applied by HE practitioners during the system acquisition process. The focus of the section is on HE methods that are stable over time. Automated tools are not included because they typically have rapidly evolving names and features. Instead, descriptions of currently available HE tools can be found at the website for the Manpower And Training Information System (MATRIS) (http://dticam.dtic.mil/).

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8.1.1 Content. This section provides HE activities and responsibilities for each type of HE function (analysis, design and development, and T&E). Tools are deferred to an automated listing at the MATRIS website.

8.1.1.1 Methods. This section provides information on traditional methods that have remained stable over time and that can be applied by HE practitioners to accomplish the processes described by Section 4. Many of the methods included in this section are used by other engineering disciplines; however, here the focus is on their application in the HE environment to accomplish HE tasks enumerated in Section 4 and described in 7.3. Method descriptions were derived from a variety of sources, including human factors and engineering textbooks, human factors handbooks like the *Handbook of Human Factors and Ergonomics* (Salvendy, 1997), and the *Engineering Data Compendium: Human Perception and Performance* (Boff & Lincoln, 1988), the initial version of DOD-HDBK-763, Geer (1981), and technical reports and papers.

8.1.1.2 Tools. Automated tools have also been developed to aid HE work and may also be used to accomplish the processes of Section 4. Automated tools are not included because they typically have rapidly evolving names and features. Instead, descriptions of currently available HE tools can be found at the MATRIS website cited by 8.1. The same basic description and point of contact information is available from the webpage.

8.1.2 Purpose. The intent is to provide a means for exploring what methods are available and to give the HE practitioner assistance in assessing the value of the methods for a particular application. Space constraints make it impossible to provide detailed instructions on how to carry out each method. Users needing more detail about the methods can consult the sources listed in 8.8 for available references. Specifically, the information in this section and at the MATRIS website is intended to help the HE practitioner:

- identify available HE methods and tools,
- identify when in the systems acquisition process they are normally employed,
- assess their value for a particular application,
- understand, in very general terms, how each is applied

8.1.3 Organization.

8.1.3.1 Methods. The methods are grouped broadly into the three categories of Section 4: HE analysis, HE design and development, and HE T&E. The paragraphs that follow discuss nearly 50 HE methods of potential usefulness to HE practitioners. The characteristics of each method are described, and sample formats and output examples are provided to illustrate the details of the methods. Each of these three categories is organized to present the following information:

- Introductory material
- Method selection chart
- Method application chart

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- Method description consisting of
  - Title, definition, and general purpose
  - Description
  - General procedure for applying
  - Uses to which it (or its output) is typically put
  - Comparison with other methods

8.1.3.2 Tool descriptions. The tools in the MATRIS website are handled similarly to 8.1.3.1, except that a single method selection chart and a single method application chart are presented. Each chart covers analysis, design and development, and T&E, in sequence.

8.1.4 Applicability of method descriptions. While the description of an individual HE method may include an example relating to a particular acquisition system (e.g., aircraft, tank, or ship), each method typically has applicability to a much broader range of user-system interfaces. Accordingly, each of the principal methods subsections (8.3, 8.5, and 8.7) also includes a table indicating how the HE data and information yielded by each method can most appropriately be applied. Although they are grouped into categories supporting analysis, design and development, and T&E, most of the methods described in this section have broad applicability across acquisition phases. For example, the HE methods characterized as analysis methods are most frequently used to support HE activities that occur during the early phases of the acquisition process—in particular, during the Concept Exploration and the Program Definition and Risk Reduction phases. While they are most frequently utilized at these times, however, their application is not constrained to these phases. As with most of the other HE methods, it is possible that many, if not the majority of them, may be used throughout the system acquisition process.

8.2. HE analysis.

8.2.1 Activities. Development of human performance and HE design criteria, and accomplishing applicable HE analyses require a concerted analysis effort. The general and detailed HE analysis processes are described in 4.1.1.1 and 4.2.1, respectively, and described in 7.3.10.1.

8.2.2 Responsibilities. During the formative Concept Exploration phase of system development, the HE practitioner has a number of important ongoing analysis responsibilities. These include the following:

- Prepare HE inputs to the request for proposal (RFP) response.
- Prepare HE inputs to subcontractor RFP packages and review HE-related portions of contractor proposals, as applicable.
- Be a major participant in the process used to allocate system functions to humans, system hardware, system software, or combinations thereof.
- Ensure that each candidate function allocation is both feasible and well integrated with the remainder of the system in all respects from an HE standpoint.
- Identify and perform detailed analysis of all user-related critical tasks (including both individual and collective crew tasks and hardware-and software-based tasks).

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- Analyze physical, sensory-perceptual, and cognitive workload at all levels (i.e., for the individual crewmember, for crew subgroups, and for the crew as a whole).
- Perform and document the results of preliminary HE-related hardware and software design tradeoff studies.
- Identify human-system interface incompatibilities and potential HE problem areas.

8.3 Methods. HE analysis methods described below comprise a large segment of HE methods. While they are listed in the analysis section, they may also be used in design and development, and in T&E activities. The following subsection describes the HE analysis methods that can be used to accomplish the analysis effort. Table VI summarizes these analysis methods and shows their characteristics that may be used for selection. Table VII presents applications of these methods.

8.3.1 Mission Analysis. Mission analysis is used to define what tasks the total system (hardware, software, and liveware) must perform. The mission or operational requirements are a composite of requirements starting at a general level and progressing to a specific level. Mission requirements define the system in terms of the operational capabilities needed to accomplish the mission. The definition of mission requirements is the first step in establishing HE design criteria. HE practitioners can use mission analysis (1) to reduce the scope of HE analyses (i.e., knowing how the system is to be used, the practitioner can discard options that do not apply); (2) to fully examine system application in each anticipated operational environment; (3) to explore "what-if" contingencies for various mission scenarios; (4) to provide input into flow analysis used later in the system analysis; and (5) to ensure that all tasks associated with a given mission are identified and adequately considered. Subject-matter experts should provide the information for the HE mission analysis. The HE practitioner should remember that any HE mission analysis is based on the use of a specific platform, not on general mission needs (as in mission needs analysis). Two methods—mission profiles and mission scenarios—are especially recommended for mission analysis. These methods are described below.

8.3.1.1 Mission profile. A mission profile is a method of representing the events or situations that operators or maintainers could confront in a new system. A mission profile provides the HE practitioner with a simple method to visualize system and operator requirements during particular stages of operations.

8.3.1.1.1 Description. A mission profile provides a graphic, two-dimensional representation of a mission segment (see Figure 9). Although generally associated with aircraft systems (altitude/distance profiles), mission profiles are readily adaptable to other types of systems, such as navigation (latitude/longitude profile) and underwater operations (depth/distance profile). One prominent feature of a mission profile is the notation of significant tasks associated with the completion of the mission. For example, turns onto different headings, acceleration to a given speed, radio interactions, and other important tasks are typically indicated on the profile.

8.3.1.1.2 Procedure. A mission profile is constructed by plotting significant mission events on a rectangular coordinate system, using appropriate scales (e.g., miles or feet) (see Figure 9). If all essential operational requirements cannot be logically depicted on a single profile,

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then additional profiles must be developed to ensure that all requirements are identified and addressed. Data for generating a mission profile are obtained from statements of top-level objectives and system operational requirements, as well as from experience with similar previous systems.

8.3.1.1.3 Use. Mission profiles should be developed and used by HE practitioners as early as possible in the program schedule. Mission profiles provide the building blocks for mission scenarios. The actions annotated on the profiles can be used to define operator interactions with the system and to identify and assess the impact of external factors. In addition to providing the starting point for generating a mission scenario, mission profiles provide information that is useful in creating functional flow diagrams. Table VII lists several applications for mission profiles.

8.3.1.2 Mission scenario. A mission scenario is a detailed narrative description of the sequence of actions and events associated with the execution of a particular mission. A mission scenario is deterministic in that it presumes the mission and the events will occur as conceptualized and described.

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TABLE VI. HE analysis methods selection characteristics.

| HE ANALYSIS METHOD | SELECTION EVALUATION CHARACTERISTIC | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Most applicable program phase | | | | Relative complexity | | | Used for | | Breadth | | Relative time to perform | | | Relative cost | | | Relative cost effectiveness | | |
| | Concept Exploration | Program Definition & Risk Reduction | Engineering Manufacturing & Dev. | Production/Deployment/Operations | Simple | Average | Complex | Gross Analysis | Detailed Analysis | Single Task | Multi Tasks | Short | Medium | Long | Low | Medium | High | Low | Medium | High |
| 1 Mission Analysis | X | | | | X | | | X | | X | X | X | X | X | X | X | | | X | X |
| 1a Mission profile | X | | | | X | | | X | | X | | X | | | X | | | | | X |
| 1b Mission scenario | X | | | | X | | | X | | X | X | | X | X | | X | | | X | |
| 2 Task analysis/description | X | X | X | | X | | | X | X | X | | | X | | | X | | X | X | |
| 3 Predetermine time standard | X | X | | | | X | | X | X | X | X | X | | | | X | | | | |
| 4 Cognitive task analysis * | | | | | | | | | | | | | | | | | | | | |
| 5 Functional flow diagram | X | X | | | X | | | X | | | X | X | X | | X | X | | | X | X |
| 6 Operational sequence diagram | X | X | | | | | X | | X | | X | | | X | | | X | | X | |
| 7 Flow-process chart | X | X | | | | X | | | X | X | | | X | | | X | | | X | |
| 8 Decision/action diagram | X | X | | | X | X | | X | | | X | X | X | | X | X | | | | X |
| 9 Action/information requirement | X | X | | | | X | | | X | X | | | X | | | X | | | X | |
| 10 Timeline | X | X | | | | X | | X | X | X | X | X | | | | X | | | | X |
| 11 IDEF * | | | | | | | | | | | | | | | | | | | | |
| 12 Function allocation trade | X | X | | | | X | | X | X | | X | X | X | | | X | | | X | X |
| 13 Workload analysis | | X | X | X | | X | | X | X | X | X | | X | | | X | | | X | |
| 14 Situation awareness analysis * | | | | | | | | | | | | | | | | | | | | |
| 15 Link analysis | X | X | X | | | X | | | X | | X | | X | | | X | | | X | X |
| 15a Link table | X | X | | | X | | | | X | | X | X | | | X | | | | | X |
| 15b Spatial operational sequence diagram * | | | | | | | | | | | | | | | | | | | | |
| 15c Adjacency layout diagram | X | X | | | X | | | | X | | X | X | | | X | | | | | X |
| 16 Human performance reliability analysis * | | | | | | | | | | | | | | | | | | | | |

* Note: Selection information was not available for asterisked items for the 1998 update.

In addition, data for other items collected in 1986 may be dated or not applicable if automated techniques are used.

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TABLE VII. HE analysis method applications.

| HE ANALYSIS METHOD | APPLICATION | Mission effectiveness criteria | Detailed design requirements | Concepts formulation ideas | Personnel requirements information | Operational procedures development | Training system development | Maintenance system development | System operational evaluation | Additional HF analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 Mission analysis | | X | | X | | | | | | X |
| 1a Mission profile | | X | | X | | | | | | X |
| 1b Mission scenario | | X | | X | | | | | | X |
| 2 Task description/analysis | | X | X | | X | X | X | X | X | X |
| 3 Predetermined time standard | | X | X | X | X | X | X | X | X | X |
| 4 Cognitive task analysis * | | A | A | A | A | A | A | A | A | A |
| 5 Functional flow diagram | | | X | X | | X | X | X | | X |
| 6 Operational sequence diagram | | X | X | X | X | X | X | X | X | X |
| 7 Flow process chart | | X | X | X | X | X | X | X | X | X |
| 8 Decision/action diagram | | | X | X | | X | X | X | | X |
| 9 Action/information requirement | | | X | X | | | | | | X |
| 10 Timeline | | X | X | X | X | X | X | X | X | X |
| 11 IDEF * | | | A | A | A | A | A | A | A | A |
| 12 Functional allocation trade | | | X | X | | | X | X | | X |
| 13 Workload analysis | | X | X | X | X | X | X | X | X | X |
| 14 Situational awareness analysis * | | A | A | A | A | A | A | A | A | A |
| 15 Link analysis | | | X | X | | | X | | X | X |
| 15a Link table | | | X | X | | | X | | X | X |
| 15b Spatial operational sequence diagram | | | X | X | | | X | | X | X |
| 15C Adjacency layout | | | X | X | | | X | | X | X |
| 16 Human Performance Reliability Analysis* | | A | A | A | A | A | A | A | A | A |

* These items were added since the last publication. Original items were collected from a survey of HE subject matter experts in 1986. Based on the literature available the new items (asterisked) are assumed to be applicable to areas marked with an "A."

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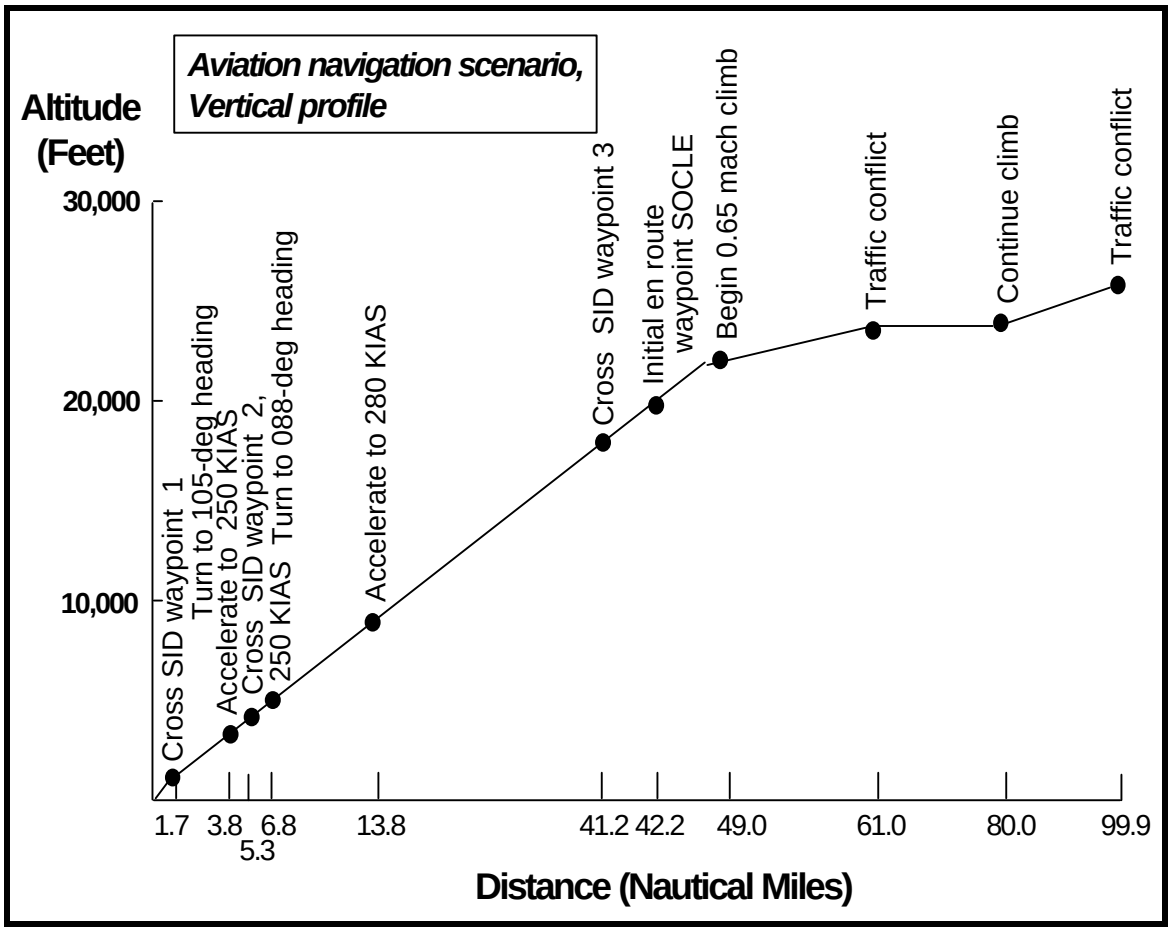


FIGURE 9. Mission profile (sample).

8.3.1.2.1 Description. A mission scenario should describe each distinct event occurring during the projected mission. These events should be portrayed from the perspective of the human's interaction with the system. Each scenario should identify and describe in narrative form all operator actions and associated system capabilities needed to complete the mission. Any other factors that could affect the execution of the mission, such as geographic location, climate, and disposition of forces, should also be described. The level of detail depicted in a scenario varies according to its purpose. The scenario can be written at the system level to describe the interaction between the system and the environment. Alternatively, it can be written at a more detailed level to describe activities and events associated with specific aspects of the mission, such as emergency procedures or new tactics.

8.3.1.2.2 Procedure. Scenarios are developed from the threat/concept and the mission profiles. They must fully describe the events implied by the profile. This narrative should characterize the proposed mission in detail, identifying key events and implied requirements that might otherwise be overlooked. This includes all essential system functions, such as failure modes or emergency procedures. Since mission scenarios are narrative in format, there are no standard rules other than to observe the rules of good grammar and to use a clear and precise writing style.

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However, all factors that influence the mission should be considered for inclusion into a fully developed mission scenario. Among these are:

- Weather conditions (e.g. temperature, cloud cover, sea state, humidity)
- Assumed operational tactics and related constraints (e.g., those related to boundary conditions)
- Available subsystems and their capabilities (e.g., types of armament, threat detection)
- Geographic position and associated characteristics (e.g., terrain elevation)
- Start time and location, and end time and location
- Threat placement within the boundaries of the scenario

Since mission scenario generation is pertinent to all types of systems, the above list is by no means complete, and the HE practitioner must keep in mind any additional factors that are applicable for a given scenario. Elements of each scenario should be sufficiently detailed to convey the mission and permit the breakout of mission elements such as mission phases, activities within each phase, time constraints, and sequential dependencies. Mission scenarios should identify which activities and events appear to be feasible, which may overstress the system, and—for high-level scenarios—which mission functions must be broken down to lower, more detailed levels to determine their feasibility within the context of the scenario. If possible, the user command should be contacted to obtain information to assist in the development of the scenarios.

8.3.1.2.3 Use. The information derived from a mission scenario is useful to the HE practitioner in performing additional analysis activities. This information is especially useful in developing functional flow diagrams, decision/action diagrams, and action/information requirements for the system. Other applications for missions scenarios are indicated in Table VII.

8.3.1.3 Comparison of mission analysis to other methods. Mission analysis is the basis of most of the later analysis methods. Mission analysis is especially useful for deriving data for input into flow charting analysis methods.

8.3.2 Task description/analysis. Task description/analysis is a method supported by several different methods designed to record and analyze how the human is involved in a system. Resulting from the functional allocation process, task description/ analysis provides the HE practitioner with an organized listing of how the human interacts with the system.

8.3.2.1 Description. Task description/analysis is a systematic process in which tasks are described in terms of the perceptual, cognitive, and manual behavior required of an operator, maintainer, or support person. Depending on the acquisition phase, task description/analysis can be relatively high level to furnishing detailed subtask information. The task description/analysis may show the sequential and simultaneous manual and intellectual activities of a person, as well as interaction with equipment. It is part of the systems engineering analysis where required. Task analysis inventories and analyzes tasks using the following taxonomy described in MIL-HDBK-1908:

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Mission
Scenario and conditions
Function
Job
Duty
Task
Subtask
Task Element

The task description/analysis method provides the skills and information required to complete the task; equipment requirements; task setting; time and accuracy requirements; and probable human errors and consequences. Task description/analysis uses the data from other methods to develop descriptions that may be used to

- check that human-machine interfaces are compatible with operator abilities;
- aid in the development of training plans and manuals; and
- assist in the manpower planning process.

Depending upon the level of analysis, the task description/analysis method may range from system-level functions to specific display, control, and decision activity details.

8.3.2.2 Procedure. See Appendix B.

8.3.2.3 Use. The HE practitioner should conduct a task description/analysis on all critical tasks. Other tasks that may require task description/analysis could include tasks that are

- potentially hazardous,
- time consuming,
- difficult,
- show potential for improvements, or
- required by the procuring activity.

Task description/analyses may be used to guide HE practitioners in further system development by ensuring the compatibility of human and machine.

8.3.2.4. Comparison to other methods. Task description/analysis can be considered the summary product resulting from all other HE analysis methods. Task description/analysis uses inputs from most of the other HE analysis methods to form a complete picture of how the machine and human interact within a system. The task description/analysis organizes what is known about each task.

8.3.3 Predetermined time standards (PTSs). PTSs are internationally recognized time standards used for work measurement. They are employed to estimate performance times for tasks that can be decomposed into smaller units (elemental component activities) for which execution times can be determined or estimated. A main assumption underlying any PTS is that

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the time necessary to accomplish these fundamental motions is constant. PTSs assign times to component activities that are too short to be measured accurately using other means (such as stopwatches or time records). In many instances, the times used in the various PTSs are derived using high-speed photography. PTSs are based on performance of a "trained, average worker working at a normal pace."

8.3.3.1 Description. To apply a PTS, an actual or proposed complex task is analyzed in detail and decomposed into its elemental component activities. The PTS times associated with each elemental activity are then combined to yield an estimate of the time required for the entire task. The elemental component activities are assumed to be executed serially. If, upon examination and analysis, some of the component activities are found to be capable of being performed simultaneously (i.e., in parallel), then more sophisticated means of combining the times must be used. At the simplest level, the elemental components, along with their assigned times, are depicted in PERT-chart fashion, and the total estimated task time is determined using a critical path analysis. Approximately 50 different PTSs are in use today, with most focusing on physical movements; however, recently a few have focused on mental activities. Each has its own particular method of using the basic motions, its own set of motion-time tables, and rules regarding the use of its motion-time values. Some of the more familiar PTSs are the following:

- Work-Facto®
- Mento-Factor® (used for mental activity)
- Methods Time Measurement (MTM), which has several specialized submethods
- Maynard Operation Sequence Technique (MOST®)
- Modular Arrangement of Predetermined Time Standards (MODAPTS)
- MicroMotion Analysis, and MacroMotion Analysis

8.3.3.2 Procedure. For simplicity, the MTM system is taken as a representative example of a PTS and the procedure for using this PTS is described. To use the MTM, the HE practitioner must conduct a comprehensive and detailed examination of the task to be analyzed. First the overall task is broken into its basic elements or motions. Then these basic motions are classified according to defined MTM categories and any necessary measurements are made (e.g., reach distance, distance to placement location). The execution time for each motion, expressed in time measurement units (or TMUs), is available in the published MTM data tables. The practitioner totals the TMUs assigned to each basic motion in the task to obtain the total time to accomplish the task (see Table VIII). In the MTM system, the TMU allotted for each motion is defined as 0.00001 hours or 0.0006 minutes. Thus, the practitioner would multiply the total number of TMUs by 0.0006 to obtain the time in minutes. The TMU values for each motion were derived from large-scale studies using high-speed motion pictures of industrial processes. Caution should be used before conducting time studies to this degree of accuracy, however, since time increments of less than 0.1 second are seldom significant where humans are involved in system performance. If this scale of time is critical to system performance, the human should be removed from the loop.

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TABLE VIII. Methods time measurement (MTM) table sample.

| DISTANCE MOVED (in inches) | TIME MEASUREMENT UNIT (TMU) | | | | HAND IN MOTION | |
|---|---|---|---|---|---|---|
| | A | B | C or D | E | A | B |
| 1 or less | 2.0 | 2.0 | 2.0 | 2.0 | 1.6 | 1.6 |
| 1 | 2.5 | 2.5 | 3.6 | 2.4 | 2.3 | 2.3 |
| 2 | 4.0 | 4.0 | 5.9 | 3.8 | 3.5 | 2.7 |
| 3 | 5.3 | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 10 | | | | | | |
| 12 | | | | | | |
| 14 | | | | | | |
| 16 | | | | | | |
| 18 | | | | | | |
| 20 | | | | | | |
| 22 | | | | | | |
| 24 | | | | | | |
| 26 | | | | | | |
| 28 | | | | | | 21.7 |
| 30 | | | | 22.9 | 16.3 | 23.2 |

*Data would be entered here*

| CASE AND DESCRIPTION | |
|---|---|
| A | Reach to object in fixed location, or to object in other hand or on which other hand rests. |
| B | Reach to single object in location which may vary slightly from cycle to cycle. |
| C | Reach to an object jumbled with other objects in a group so that search and select occur. |
| D | Reach to a very small object or where accurate grasp is required. |
| E | Reach to indefinite location to get hand in position for body balance or next motion or out of way. |

8.3.3.3 Use. PTSs can be used to analyze existing procedures to determine if the process time can be improved. They can also be applied when a procedure is in the planning stage, before mockups or prototypes exist, to estimate the time necessary to accomplish a task. Because the execution times for some elemental activities (such as those associated with hand movement to a control) are related to distance, PTS estimates may also assist in evaluating potential work area configurations. Table VII lists several applications for which PTSs are useful. PTSs are most accurate when the task to be studied can be readily and accurately decomposed into its elemental parts. These methods are best suited to longer, repetitive tasks that can be broken down into a number of elemental component activities. The practitioner must be trained in the proper application of PTSs. For further information on PTSs, consult Niebel (1993).

8.3.3.4 Comparison to other methods. PTS methods are most easily used in conjunction with other methods that accurately decompose the task to which the PTS is to be applied. For example, PTSs could be used with a process flow chart or a task analysis to estimate the amount of time the charted process or task would take.

8.3.4 Cognitive Task Analysis (CTA). CTA is a task analysis method that focuses on describing the cognitive skills and abilities needed to perform a task proficiently, rather than the specific physical activities carried out in performing the task. CTA is used to analyze and understand task performance in complex real-world situations, especially those involving change, uncertainty, and time pressure.

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8.3.4.1 Description. Compared with conventional task analysis, CTA takes the practitioner a step further by providing a means to examine the essential thought processes underlying the behaviors identified using traditional task analysis methods. CTA focuses on difficult decisions, judgments, and perceptual skills—elements that cannot be observed directly, but nevertheless play an important role in many tasks. CTA encompasses both (1) knowledge elicitation methods, or methods for identifying the knowledge and cognitive skills used to perform a given task (interviews with subject-matter experts, or probe questions); and (2) knowledge representation methods (conceptual graphing or mapping), or methods for structuring and depicting this cognitive information in a usable format so it can be meaningfully applied. CTA methods require experienced interviewers to elicit needed responses from SMEs.

8.3.4.2 Procedure. Many powerful methods have been developed for conducting CTA (for a comprehensive review, see Cook, 1994). Because these methods have been developed somewhat independently in research facilities throughout the world, there is considerable variety in approach, emphasis, and resource requirements. Three methods are presented here as examples of CTA: (1) the Precursor, Action, Results, and Interpretation method; (2) Conceptual Graph Analysis; and (3) the Critical Decision Method.

8.3.4.2.1 Precursor, Action, Result, and Interpretation (PARI) method. In the PARI method, subject-matter experts are consulted to identify which issues to probe, and to aid in eliciting cognitive information from other subject-matter experts. For example, subject-matter experts may be asked to generate lists of potential equipment malfunctions and then engage in group discussions to reach agreement regarding a set of malfunction categories. Experts then design representative scenarios illustrating each category of malfunction. These scenarios are used to elicit information from a different set of subject-matter experts regarding how they would approach the situation presented in each scenario. Each expert is asked focused questions to identify actions or solution steps and the reasons (precursors) for those actions. The expert is then asked to interpret the system's response to his/her actions. The knowledge gathered in the interviews is represented using flowcharts, annotated equipment schematics, and tree structures (see Figure 10). Among other applications, the PARI method has been used to develop an avionics troubleshooting tutor. For further information on the PARI method, see Hall, Gott, and Pokorny (1995).

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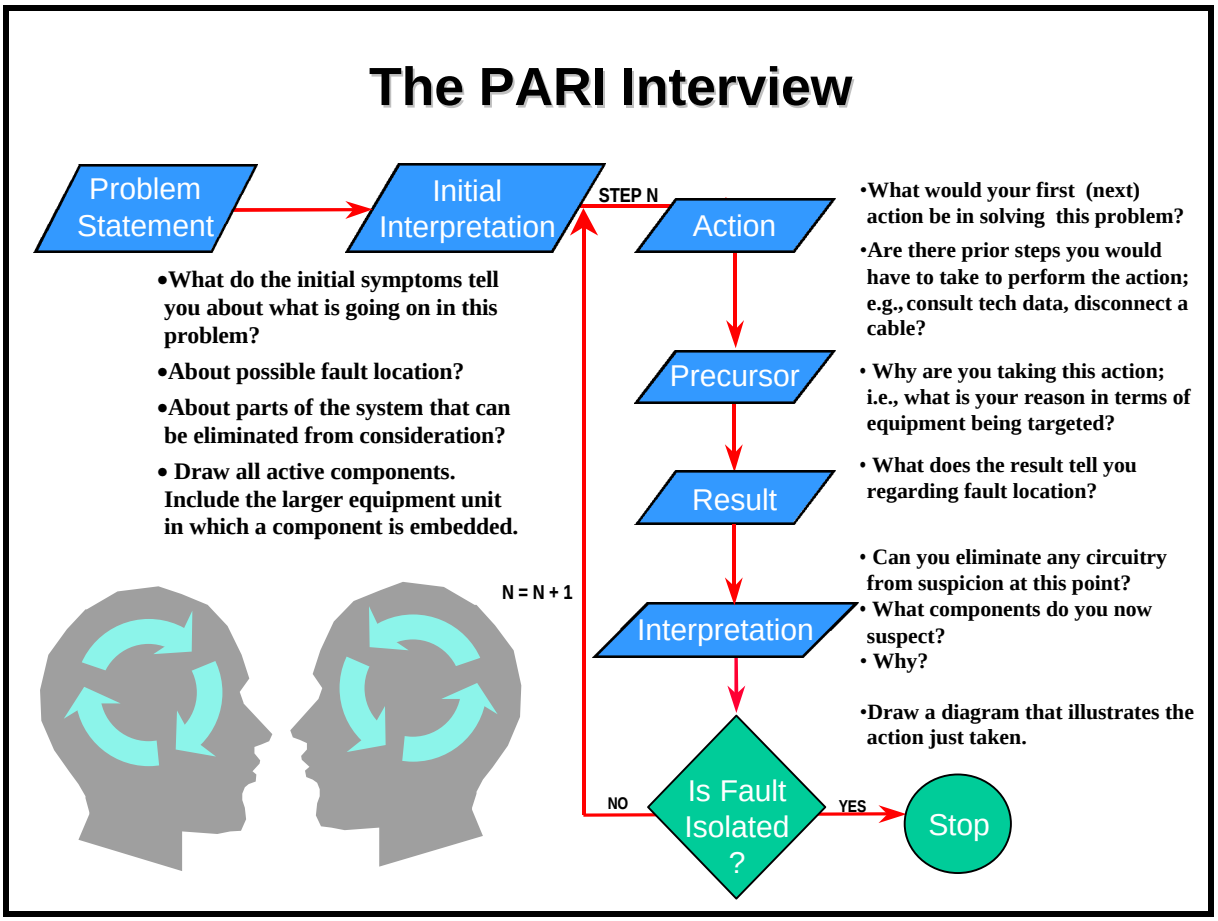


FIGURE 10. PARI interview structure (sample). (From Hall, Gott, & Pokorny, 1995, used by permission.)

8.3.4.2.2 Conceptual Graph Analysis. The Conceptual Graph Analysis (CGA) is based on the generation of conceptual graph structures to conduct CTA. Conceptual graph structures are a method of visually depicting internal knowledge structures. These graphs consist of nodes connected via arcs (see Figure 11). Nodes in a conceptual graph contain either single concepts or single statements. The statements are one of five categories:

- state,
- event,
- style,
- goal, or
- goal/action.

The arcs show relationships and are labeled and directional showing the type and direction of a relationship between two nodes. Arcs are categorized into four substructures:

- taxonomic,
- spatial,
- causal, or
- goal.

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The information contained in the conceptual graphs is elicited in four steps during CGA. The first step to start the conceptual graph is document analysis. Any pre-existing documents concerning the task to be analyzed are used to generate conceptual graphs. After (or in place of) document analysis, free generation is used. Free generation consists of an SME describing the information needed to complete the task of interest. After these steps are used to start the graph, question probes are used to fill in any gaps in the conceptual graph. Question probes are designed specifically to fill the gaps in the conceptual graph. The HE practitioner asks the node-category, with specific question probes for each node on the graph. If all the knowledge needed to complete the task of interest is present in the conceptual graph after the question probes, the rest of the information needed is filled in via observation/induction. This step is especially useful for graphing implicit knowledge that an SME is unable to completely verbalize. CGA provides the HE practitioner with a complete graph or concept map of the knowledge needed to complete the task of interest. For further information on CGA, see Gordon, Schmierer, and Gill (1993).

8.3.4.2.3 Critical Decision Method. The Critical Decision Method emphasizes the elicitation of knowledge from individuals skilled at performing a given task. In the Critical Decision Method, a series of in-depth interviews with a subject-matter expert are conducted in which the expert is asked to recount a challenging or critical incident in which his/her skills were called into play. The interviewer then uses probes to identify decision points, shifts in situation assessment, critical cues leading to a specific assessment, cognitive strategies, and potential errors (see Table IX). The knowledge elicited using the Critical Decision Method can be represented in a variety of ways. Often narrative accounts are used. In some cases, knowledge is represented in the form of a cognitive requirements table that lists the specific cognitive demands of the task, as well as contextual information needed to develop relevant training or system design recommendations.

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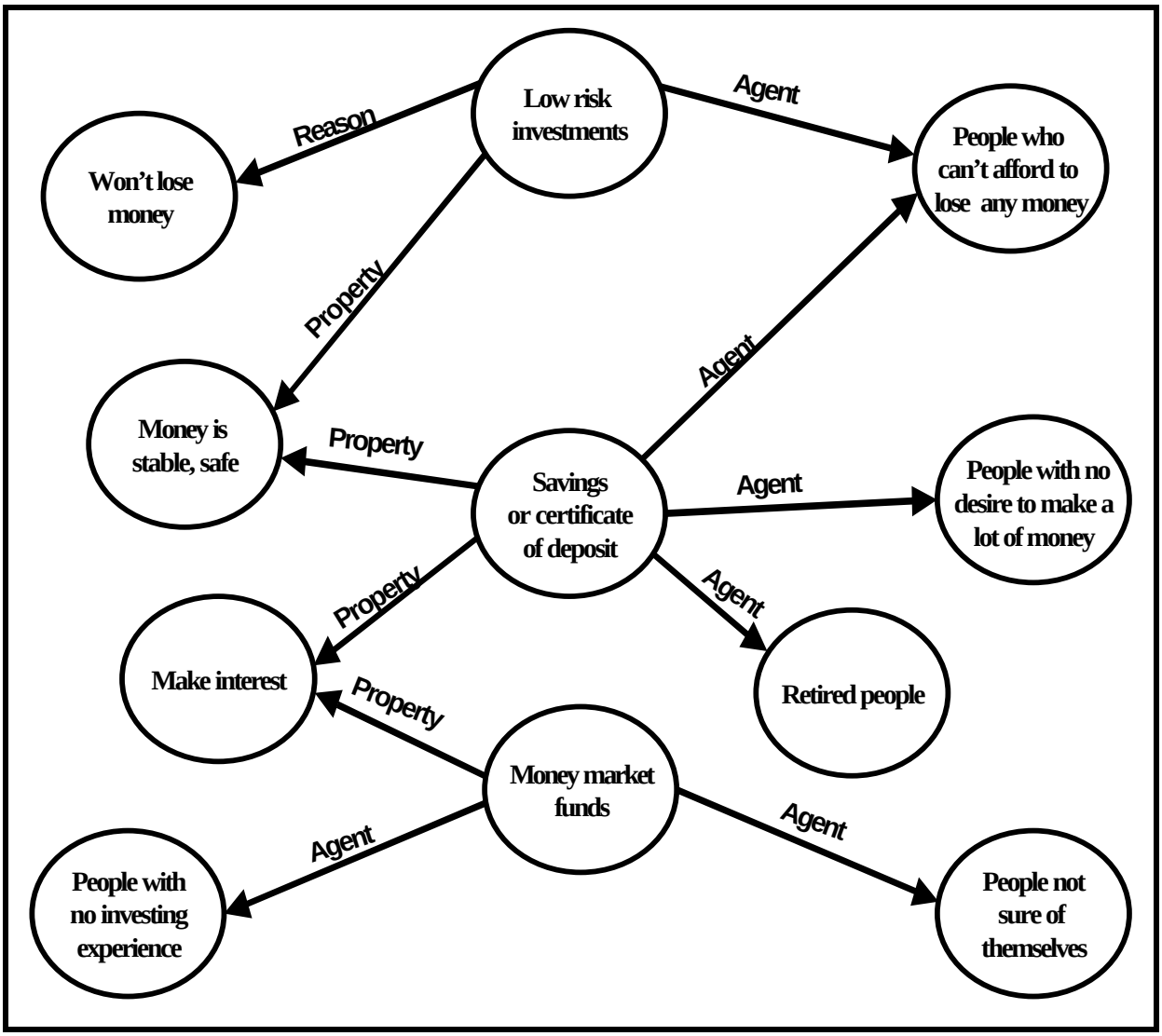


FIGURE 11. Cognitive graph (map) (sample). *(From Moore & Gordon, 1988*, used by permission.)

For further information on the Critical Decision Method, see Klein, Calderwood, and MacGregor (1989) and Klein (1995).

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TABLE IX. Interview structure for the Critical Decision Method (From Klein, 1993).

| Interview cycles | |
|---|---|
| Stage | Task |
| First cycle | Interviewee briefly describes event |
| Second cycle | Interviewee puts timeline with event |
| Third cycle | Interviewer uses cognitive probes to fully understand decisions |
| Fourth cycle | Interviewee compares performance with novice. |
| Cognitive probes | |
| Probe type | Probe Content |
| Cues | What were you seeing and hearing? |
| Knowledge | What information did you use in making decision and how was it obtained? |
| Goals | What were your specific goals at that time? |
| Situation assessment | If you had to describe the situation to someone else at this point, how would you summarize it? |
| Options | What other courses of actions were considered, or were available to you? |
| Basis of choice | How was this option selected, others options rejected? |
| Experience | What specific training or experience was necessary or helpful in making this decision? |
| Aiding | If the decision was not the best, what training, knowledge or information could have helped? |
| Hypotheticals | If a key feature of the situation were different, what difference would it have made in your decision? |

8.3.4.3 Use. CTA is a complex method that requires considerable time and expertise and is therefore expensive to use. For this reason, the HE practitioner may want to apply CTA selectively to tasks that are

- ill-structured and difficult to learn,
- carried out in complex, dynamic real-time environments that involve uncertainty,
- involve several subtasks that must be performed simultaneously.

Other factors that may indicate the need for CTA include task criticality, task frequency, and cognitive complexity of the task. If the task is a simple and orderly sequence of overt behaviors, CTA is probably not required. CTA has been applied successfully in a variety of areas, including system design, training design, interface design, accident investigation, and consumer research. CTA has been used extensively in the creation of expert systems, job aids, and training programs. CTA attempts to capture the experience, knowledge, and intuition of subject-matter experts. This information can then be incorporated into a system to train novices that may help them develop expertise more rapidly than classical training methods would.

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8.3.4.4 Comparison to Other Methods. As opposed to traditional task analysis, CTA attempts to capture and relay information related to the mental processes, and not focus on the physical steps needed to accomplish the task of interest. CTA allows the HE practitioner to study not only what is happening, but why it is happening.

8.3.5 Functional flow diagram. Functional flow diagrams are the most popular systems method used for the determination of system requirements. Functional flow diagrams can provide a detailed outline of all system requirements. They may be used as an extensive checklist of system functions that must be considered in ensuring the ability of the system to perform the mission. This analysis of system functions is required to determine solutions for later trade studies. Functional flows are necessary to determine effectively which system functional elements should be performed by operators, equipment, software, or some combination of these.

8.3.5.1 Description. Starting with system or mission objectives, functional flows are developed iteratively for more and more detailed system requirements down to the level of specific operator tasks. In general, during the construction of higher level flows, no distinction should be made between operator, equipment, or software implementation of system functions, The lack of distinction is for the purpose of conducting unbiased system trade studies. Functional flow diagrams are often referred to as functional block diagrams, functional flows, or functional flow block diagrams. All these terms refer to the same analysis method. It may have evolved from the use of schematic block diagrams that depict the relationships between various equipment items in a system. The most significant difference between the schematic diagram and the functional flow is the addition of the verb to the noun label in each schematic block. By the use of verb-noun functions, the system is prevented from becoming prematurely committed to an arbitrary design implementation solution. A function may be defined as a verb-noun phrase that must be accomplished by a system. All functions can be broken down or divided into more detailed functions.

8.3.5.2 Procedure. Sample functional flows are shown in Figure 12. These flows are constructed by arranging in system sequential order all the various functions that are believed to pertain to a particular system (or subsystem, depending on level of detail). Each function is a verb-noun combination. Occasionally nouns are assumed and adjectives are added. Each individual function is contained within a rectangular block. Each block is numbered for reference, more or less according to its sequence on the page.

8.3.5.2.1. Reference block. If the function is repeated in other portions of the total series of functional flows, the same number should be used and the block may be drawn as a reference block. Each functional flow diagram contains a reference to its next higher functional flow through the use of a reference block. Reference blocks may also be used to indicate functions occurring at the same level on different pages. The blocks in Figure 12 that are broken in the middle are reference blocks. The numbers are important to ensure traceability either back to the higher level functions or between functions.

8.3.5.2.2 Symbols. The functional flow symbology used in Figure 12 is typical. The direction between the function blocks indicates the normal sequence of occurrence of system functions. Contrary to the ground rules for constructing schematics, the arrows between

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functional flow blocks should show the general flow of the diagram toward the right and, if necessary, down. Arrows should not be used on either the top or bottom of the blocks, They should enter the block from the left and exit to the right. Wherever arrows are joined or split out, they should be connected by an “and”, “or”, or “and/or” gates or junctions as indicated in the sample. The significance of the “and” junction is that all the following or preceding functions must be performed. The “or” junction indicates a choice between two or more of the following or preceding functions as to which one is performed. The “and” and “or” junctions may be combined if it will not cause confusion and page space is limited.

8.3.5.2.3 Functions. A function is that which must be accomplished by the system. All functions can be broken down or divided into more detailed functions. Top-level and first-level functions tend to be identical for similar systems. A specific operational requirement may call for modification to these higher level functions; however, the changes generally occur to the lower level functions. For large programs, such as a complete air cushion vehicle system, they are gross system operations. The second level functions would then tend to describe system operational (or maintenance) functions within the various mission phases. The third level may define specific functions with measurable performance units. Functional allocation between operator, equipment, and software may occur at this level. Fourth-level functions may be the level at which gross operator task analysis may occur. The total concept of functional level detail or definition must be based on the total size or scope of the particular system to be analyzed. Naturally, the smaller the system being worked, the more detailed the corresponding numerical level of functional analysis will be. Larger systems or programs will require more levels to get to the same degree of detail. In view of this possible ambiguity as to functional level definition versus program scope, it is recommended that the parties concerned, i.e., requiring organization and performing organization, agree on the definitions before considerable effort is expended on this or similar methods. The definition of functional levels is not as important as the assurance that analysis is conducted to a sufficient degree of detail to determine significant operator performance requirements, particularly the details of critical operator tasks. The reference number groups recommended for use with each of the levels is as follows: 1.0, 2.0, 3.0 ... for top level functions: 1.1, 1.2, 1.3 ... for first level functions: 1.1.1, 1.1.2, 2.1.1 ... for second level functions; and 1.1.1.1, 1.1.1.2, 2.1.1.1 ... for third level functions and so on.

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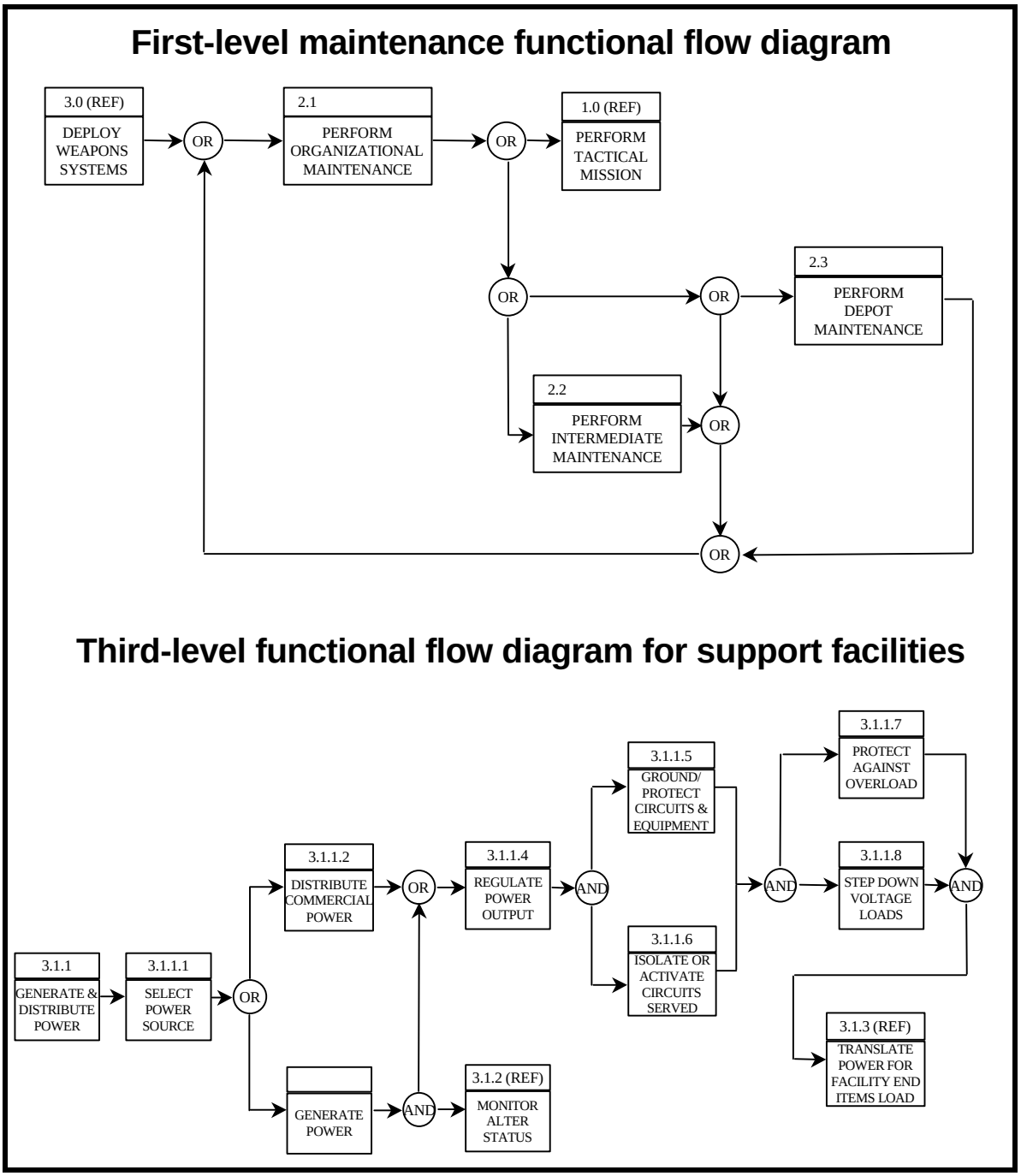


FIGURE 12. Functional flows (sample).

8.3.5.2.4 Requirements. Once the functional flows are constructed, the functions and subfunctions should be reviewed and analyzed in depth for probable variations related to the system requirements. Even during early development, both alternative mission requirements and the expected downstream developmental impact of such alternatives should be appraised to produce an early estimate of likely crew interface requirements, capability, special provisions needed, potential problems and probable solutions. In some cases, the HE practitioner may also

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need to produce preliminary workload data and to provide information for manning and training estimates. In any case, the practitioner must anticipate a wide variety of possible requirements to form a judgment for crew performance feasibility, support requirements and development needs.

8.3.5.2.5 Construction. Some of the essential features to remember about the procedure for constructing functional flows are as follows:

- Functional flow blocks must contain a verb and a noun;
- It is essential to initiate the flows without any allocation to operator, equipment, or software;
- Each expanded level of functional flow will contain more and more detailed information. The detail may be carried on to as many levels as appropriate. It is normally necessary to go to at least the third level;
- Functions are numbered in a manner that preserves continuity of function and logical breakout from function origin;
- The diagram should be organized so that one can easily find the input and follow the flow through the function blocks to the resulting output;
- It is generally good practice to limit the size of the diagrams. They should be divided up if too large for foldout pages in documents. Reference blocks may be used. If designed for display on walls, the functional flows may be of relatively large size.

8.3.5.3 Use. Functional flow diagrams are extremely useful to the human factors engineer for a number of reasons.

a. The functional block numbering system provides a rationalized traceability from lower to higher level functions and between functions at the same level. Functional flows are flexible in that a change in one part of a total functional flow generally causes minimal effect on other parts. Because of this, they are easy to use to show the effects of preliminary functional allocation trades to human, machine, or software. Because of this flexibility and ease of use, they are an ideal method to use for the rapid analysis of system functions proposed by other program personnel such as subsystem designers. Functional flows are the ideal way to show the relationships between functions. They may be structured in such a manner as to show as many as 40 or 50 different functions on one foldout page. If wall space is available, complete systems or subsystems may be laid out, depending on the level of detail desired.

b. Functional flows are relatively easy to develop. Whereas some human factors engineering analysis methods require special training prior to their use, the functional flow diagram requires only minimal training. The functional flow diagrams are also a relatively fast analysis method and, accordingly, they tend to be very cost effective. The only reason for not using this analysis method would be to use another method in its place, such as the decision/action diagram (see 8.3.8) which incorporates most of the same features as the functional flow. Functional flows do not contain information pertaining to decisions and time-based information flow, although functional flows tend to be sequential. Functional flows generally do not indicate operator, equipment, or software allocations, except at a lower, more detailed level. The data for the functional flows originally come from the operations analysis program effort. Data for more detailed lower-level functional flows also come directly from the higher-level flow diagrams and from subsystem design groups. In a similar manner to all other analysis methods, functional flow

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diagrams are not an end in themselves. There is little or no point in constructing them if they are to be completed only to be filed away.

c. As more and more detailed functional flows are developed, specific systems requirements begin to emerge. These requirements may then be documented by incorporation into system specifications.

d. As previously indicated, functional flows are used to assist in the performance of functional trades (i.e., trades performed to choose between or among two or more functional alternatives). The results of the trades should evolve into detailed system requirements or specifications. The functional flows are seldom adequate to develop detailed system requirements where operators are involved. Additional analysis methods such as time lines, requirements allocation sheets, or operational sequence diagrams need to be generated to develop system requirements pertaining to system decision functions or time constraints.

e. Review of Table VII indicates several specific output applications that result from performing functional flow analysis.

8.3.5.4 Comparison to other methods. The method is best used during concept formulation and early phases of demonstration validation and perhaps full-scale development. In summary, functional flows provide a detailed and comprehensive inventory of all system requirements and an extensive checklist of system functions and factors that must be considered in ensuring ability to perform the mission. Properly structured, the inventory will proceed from functional indentures common to all similar systems (e.g., land vehicles, surface ships, and aircraft), through indentures peculiar to a type (e.g., trucks, landing craft, and fighters) and on to functional elements that are specific to mission operations. Detailed analysis of the functions is necessary to determine detailed system requirements, possible equipment, and human/equipment trades to effectively determine which elements are performed by equipment and which should be performed by people.

8.3.6 Operational sequence diagrams. The OSD is probably the most powerful single manual analysis method that the HE practitioner can use. This is because of all the outputs and applications that derive from its use (see Table VII), it is particularly useful for the analysis of highly complex systems requiring many time critical information-decision-action functions between several operators and equipment items. The OSD has been used on numerous Military programs such as HAWK, Polaris, and Airborne Warning And Control System (AWACS).

8.3.6.1 Description. The OSD was derived from the FPC. It retains the same basic attributes of the FPC. It is a graphic presentation of operator tasks as they relate sequentially to both equipment and other operators. OSD symbology also meets the American Society of Mechanical Engineers (ASME) flow chart standards. The OSD is an FPC expanded in terms of channels or workstations. By using symbology to indicate actions, inspections, data transmitted or received, data storage, or decisions, the OSD shows the flow of information through a system. The information flow is shown in relation to both time and space (workstations). The OSD may be used to develop and present the system reaction to specified inputs. It is one of the cheapest and quickest ways to simulate the system. Whereas mockups and prototypes may be more

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complete for some simulation aspects, they are more expensive. Computer programs are also generally more expensive, depending upon how often they are used. In the OSD, the interrelationships of operators and equipment (human-machine interfaces) are easily visualized. Whenever information transferred is mismatched with the format to be received, interface problems are clearly indicated. Operator activities are sequentially categorized. Decision and action functions are clearly identified and task frequency and load become obvious.

8.3.6.2 Procedure. A sample OSD is shown in Figure 13. An explanation of OSD symbology is included in Figures 14 and 15. The following instructions describe how to construct the OSD:

a. In a similar manner to FPCs, the flow of events and tasks is always from the top of the sheet toward the bottom. The operators and machines are entered into the column headings on the OSD. It generally proves convenient to place in adjacent columns the operators and the machines with which they interface. Also, it helps to group together all the operators and equipment of a specific functional division (e.g., weapons control). In some cases, the operators or maintainers and equipment in a system will have been specified by the time the OSD is constructed. However, if the people and equipment have not been specified, the practitioners will have to specify them tentatively. In either case, in the process of doing the OSD, it may be found that too many or too few operators or machines have been selected. The reason for doing the analysis is to “drive out” crew size and interface requirements.

b. The OSD is initiated by the first event designated by the scenario (see 8.3.1.2). The event and event times are written in the two left-hand columns. All the machines or humans who will receive the input are shown and the transmission/reception mode is noted by using the appropriate letter code. The subsequent actions taken by the crew/equipment (operations, transmissions, etc.) as they react to the input are shown. External outputs are plotted in the far right-hand column. As the reactions are plotted, the practitioner should be cognizant of the time required to perform the actions. The process of plotting the inputs and subsequent reactions is continued as dictated by the events given in the scenario or narrative. No attempt is made to keep the actual space between scenario time events proportional to the time itself.

c. It is important to remember that the reader of an OSD should be clearly shown the operation of the system, and all the steps shown on the OSD should be described by a brief notation describing the process or action. As with the case of the FPC, the HE practitioner should be sure that all logical possibilities are included, all loops are completed or terminated in a valid exit, and all tasks are capable of being performed by the operators.

8.3.6.3 Use. The reason the OSD is so useful in terms of outputs is simply that so much must go into it. The integration of all the data that goes into a typical OSD is generally a tedious and time-consuming process. Experience has shown that the construction of OSDs requires a trained individual with analytic skills. The information to construct an OSD may come from scenarios, functional flow diagrams, time lines, decision/action diagrams, workstation layouts, or other sources. If the HE practitioner is dependent on other organizations for this information, the practitioner must conduct numerous interviews of other organization personnel or have an

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extremely efficient program requirements documentation effort to draw on. Table VII indicates several specific output applications that result from performing an OSD analysis.

8.3.6.4 Comparison to other methods. OSD should be used during the earlier program phases. It should be emphasized that the OSD is like any other paper simulation method in that it must be validated as soon as practical in an environment closely similar to the actual working environment. Although much more complex, OSDs are somewhat similar to decision/action diagrams. Often when decision/action diagrams are used, OSDs are not. Another method that is similar to the OSD is the Functional Sequence Diagram (FSD). Its format is very nearly identical to the OSDs. It is easier to construct but does not provide as much useful information as the OSD. The difference between the two methods is that the FED does not make a distinction between operators and equipment.

8.3.7 Flow process charts. This method is one of several HE methods derived from industrial engineering procedures.

8.3.7.1 Description. Flow Process Charts (FPCs) are basically plots of the sequence of operator activities or information transfer as a part of a system. The plots or flow of activities and information exchange are plotted in time sequence. Figure 16 is an example of such a plot. It is very similar to the information flow chart mentioned previously. The difference between the two methods is that the FPCs use a wider variety of symbology and are generally performed at a more detailed operator task level. This symbology is consistent with the ASME (1972), flow chart standards.

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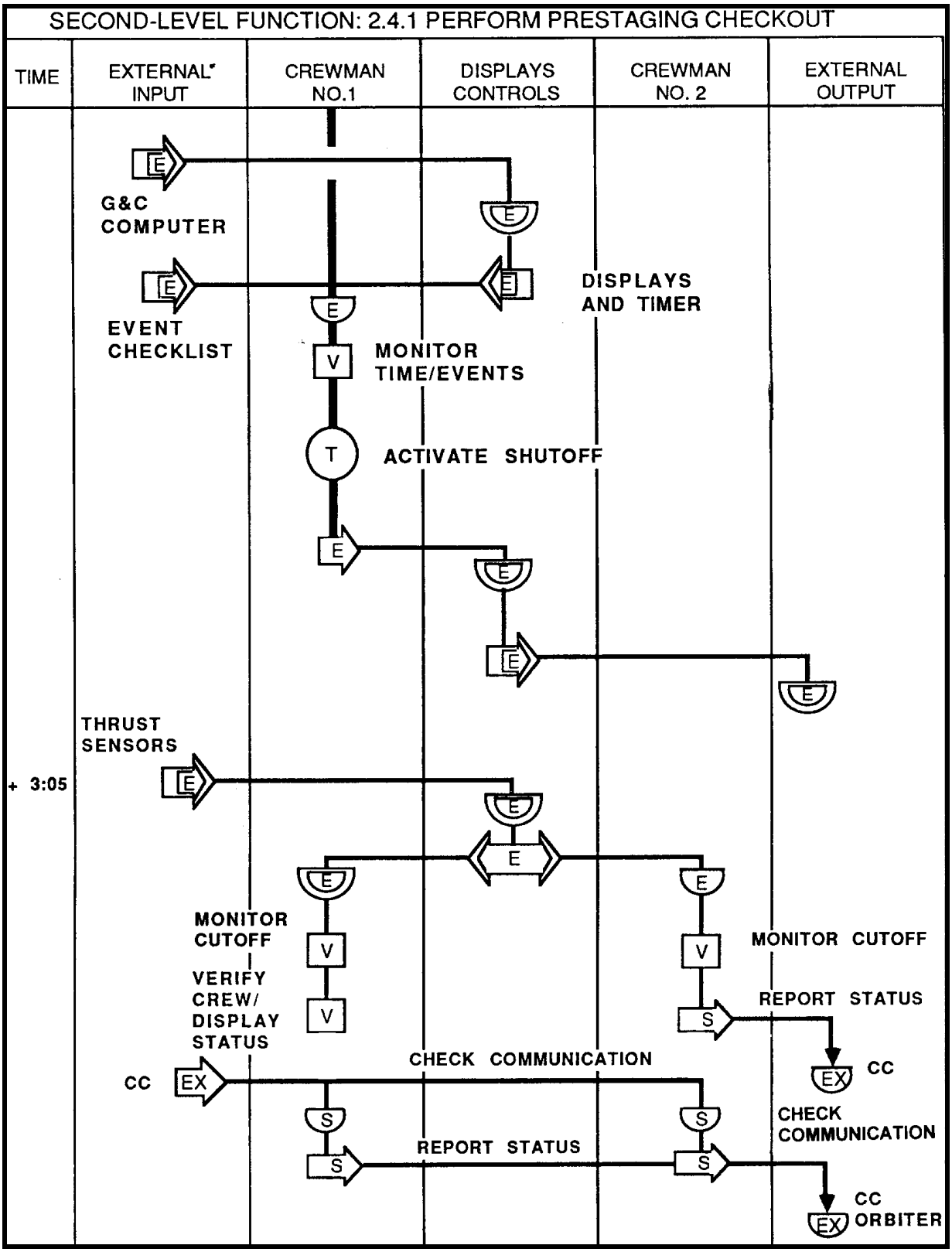


FIGURE 13. Operational sequence diagram (sample).

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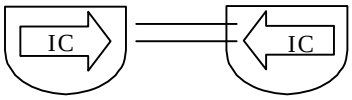
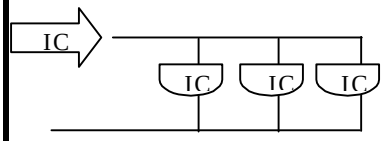
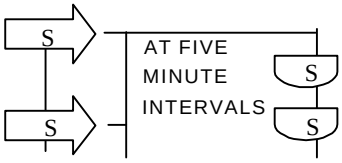
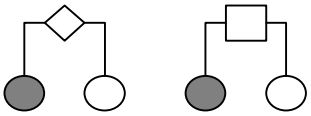
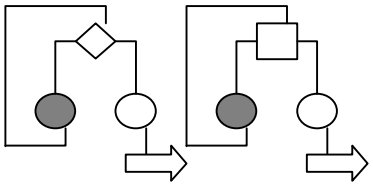
| | |
|---|---|
|  | Exchange of information or discussion by two principals involved. Used with appropriate source codes. |
|  | Acknowledgment of receipt of information used with appropriate source codes. |
|  | Continuous flow of information throughout event<br><br>Receipts are picked off where needed in sequence without repeating entire process. Time intervals may be indicated as shown. |
| | Double symbols indicate automatic transmission, receipt, storage, or operation. |
|  | DECISION<br>LEFT NO<br>RIGHT YES<br><br>INSPECTION<br>NO GO<br>GO |
|  | A repeated process usually repeated until a desired condition exists before continuing. Note: The last repeat of several may be shown in normal sequential order to give a clearer picture of the event. |

FIGURE 14. Special combinations of OSD symbols.

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| SYMBOLOGY | | DEFINITION |
|---|---|---|
| ○ | **Operate -** | an action function, to accomplish or continue a process (sometimes used for received information). |
| □ | **Inspect -** | to monitor or verify quantity or quality. An inspection occurs when an object is examined (sometimes used for action). |
| ⇨ | **Transmit* -** | to pass information without changing its form. |
| ◡ | **Receipt* -** | to receive information in the transmitted form (sometimes used for stored information). |
| ◇ | **Decision -** | to evaluate and select a course of action or inaction based on receipt of information. |
| ▽ | **Storage -** | to retain (sometimes used for transmitted information). |

* - mode of transmission and receipt may be indicated by a code letter within the ⇨ and ◡ symbols, such as the following:

## Code

**V - Visual**

**E - Electronic**

**S - Sound (verbal)**

**IC - Internal Communication**

**EX- External Communication**

**T - Touch**

**M - Mechanically**

**W - Walking**

**H - Hand Deliver**

FIGURE 15. FPC and OSD symbology.

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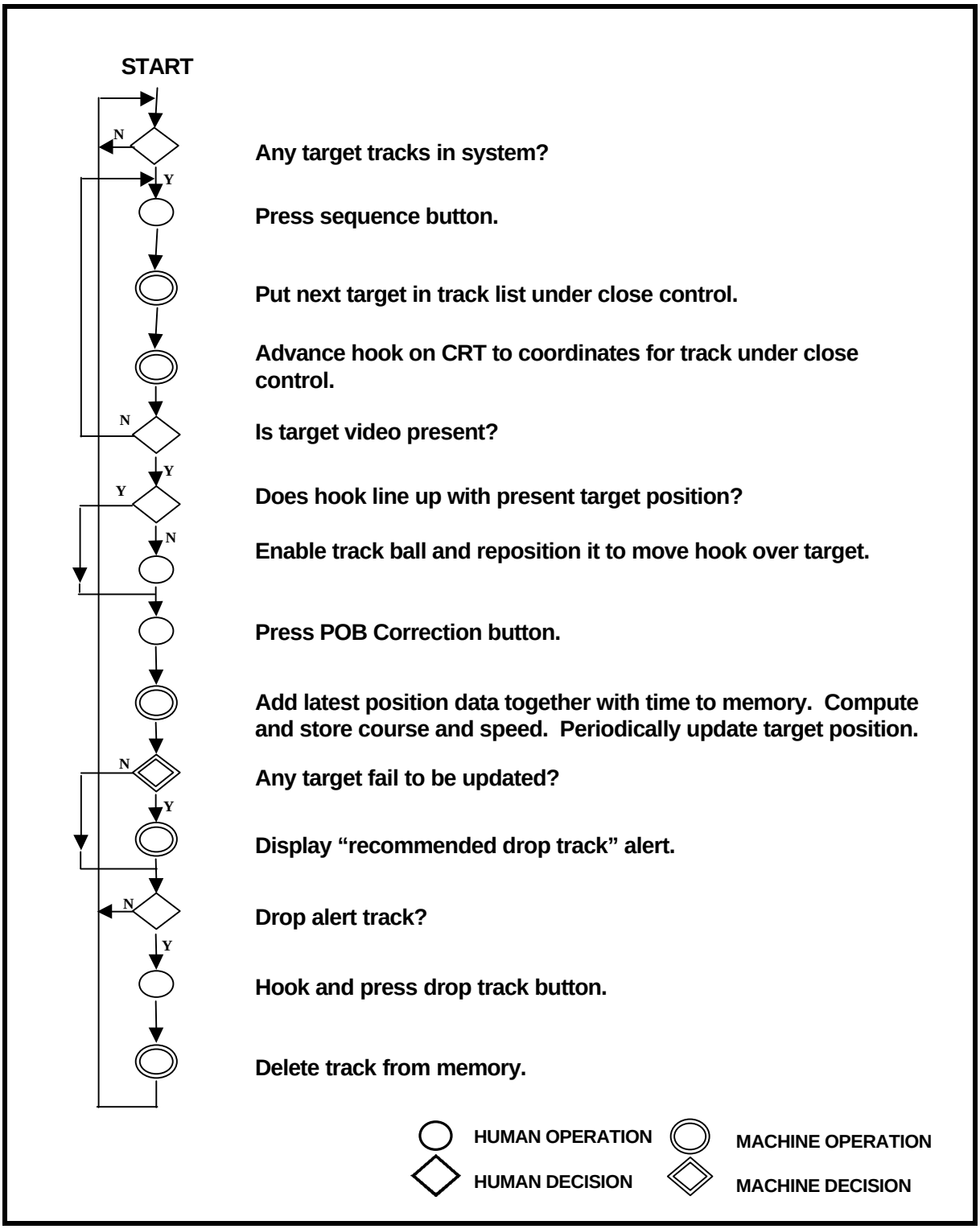


FIGURE 16. Flow process chart (sample).

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8.3.7.2 Procedure. The FPC is oriented vertically, frequently with a time scale to one side or another of the function or task symbology. Each task performed by the operator is recorded with the proper symbology (see Figure 15) and with a brief description of the task. A time value, and perhaps a distance, is also recorded if appropriate. Start and stop points of the charted activity are indicated. In preparing these charts, the HE practitioner should ensure that all logical possibilities are included, all loops are completed or terminated in a valid exit, and all tasks are capable of being performed by the operator. The following aspects must be considered: (a) how each operator will make decisions, (b) what criteria are to be used for decision-making and (c) what information requirements must be met to provide a basis for decision-making.

8.3.7.3 Use.. The purpose of constructing the flow process charts is to aid in developing and evaluating concepts for each operator station. If a single operator station is being analyzed, it is a good method to use; however, if more than one station is being analyzed, a separate chart must be developed for each station. The OSD, discussed in 8.3.6, is a better method to use for multiple operator station analysis. Table VII indicates the applications or outputs from the FPCs.

8.3.7.4 Comparison to other methods. A comparison of the FPC method with the other analysis methods is indicated in Table VI.

8.3.8 Decision/action diagrams. The decision/action diagram is a method similar to functional flows. It is used to show the flow of required system data, in terms of operations and decisions. Like functional flow diagrams, decision/action diagrams may be developed and used at various levels of detail. The initial decision/action diagram charts are concerned with gross functions without regard to whether functions are performed by human, machine, software, or some combination of these. The decision/action diagrams prepared subsequent to tentative human-machine-software function allocations will reflect this allocation in the decisions, operations, and branching that are represented. At the program concept formulation stage, however, these charts would ordinarily be prepared at a detailed level only for the more critical human-machine functions.

8.3.8.1 Description. This method may also be referred to as information flow charts, decision logic diagrams, or operation/decision diagrams. The term, information flow charts, generally refers to a type of decision/action diagram that has a vertical orientation on the page rather than the left to right horizontal orientation that decision/action diagrams use (see 8.3.7, flow process charts). Special symbology may also be used with the information flow charts at a more detailed level to indicate allocations to human or machine (e.g., single line symbols mean manual, double line mean automatic).

a. The decision/action diagrams are so similar to functional flow diagrams that the use of both methods is not recommended. The most significant difference between the two methods is the addition of the decision blocks (diamonds) to the functional flow diagrams. The decision/action diagrams are generally used when the program is software oriented.

b. In that it records the sequence of operations and decisions that must be performed to satisfy a definite system function, the decision/action diagram is similar to the flow charts used by computer programmers. Both charts are based on binary choice decisions and intervening

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operations. There are two important reasons for using binary decision logic as a standard in performing decision/action diagramming:

1. To expedite communications through use of simple yet universally applicable conventions.
2. To provide for easy translation of decision/action flow charts into logic flow charts for computerized sections of the system.

c. A decision at a general level may split into several decisions at a more detailed level, for example:

*General level:* - Do any targets need identification processing?
*Specific level:* - Do any newly entered targets need identification processing?
- Do any target tracks need confirmation of tentative identification?
- Do any confirmed identifications need rechecking?

d. Each of these more detailed decisions may have associated with it one or more detailed operations. Similarly, an operation at a general level may break down into more detailed decisions and operations.

e. The example in Figure 17 is a gross level detection and tracking function. No functional allocation has been made to human or machine. Note that at this level the chart is applicable to several detection and tracking systems; the decisions and operations are essentially common between them. Even here, however, the usefulness of the flow chart diagramming method is apparent because it makes the practitioner begin to consider implementation alternatives, such as:

1. By what means can any given signal be compared with known targets in the system?
2. How can probable targets be marked so their reappearance can be readily recognized?

f. The information necessary for the initiation of decision/action diagrams comes from the mission profiles and scenarios. Data for more detailed lower-level decision/action diagrams may come directly from higher-level flow diagrams and from subsystem design groups as equipment detailed characteristics become well defined.

8.3.8.2 Procedure. The procedure for constructing decision/action diagrams is essentially the same as that for functional flow diagrams, They are constructed by arranging in sequential order all the functions and decisions that pertain to a system or subsystem (depending on level of detail). Each function is a verb-noun combination with occasional adjectives or other modifiers. Each function phrase is relatively short and is contained within a rectangular block. Each decision function is placed in a diamond-shaped outline symbol and is written in a question format that may be answered with a binary, yes-no, response. Both the functional action blocks and the decision diamonds should be given reference numbers in a manner similar to the numbers assigned to

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functional flow diagrams. The numbers are important to ensure traceability between decision/action blocks. The decision diamond blocks may be drawn in solid or dashed lines to indicate primary decision functions or shared decision functions, respectively. The use of arrows between function/decision blocks is similar to functional flows. Note that flow paths should be complete. Every path should either recirculate or end in a valid exit with a reference block. The junctions between arrows are handled with “and”, “or”, or “and/or” gates in the same manner as with functional flows (see 8.3.5).

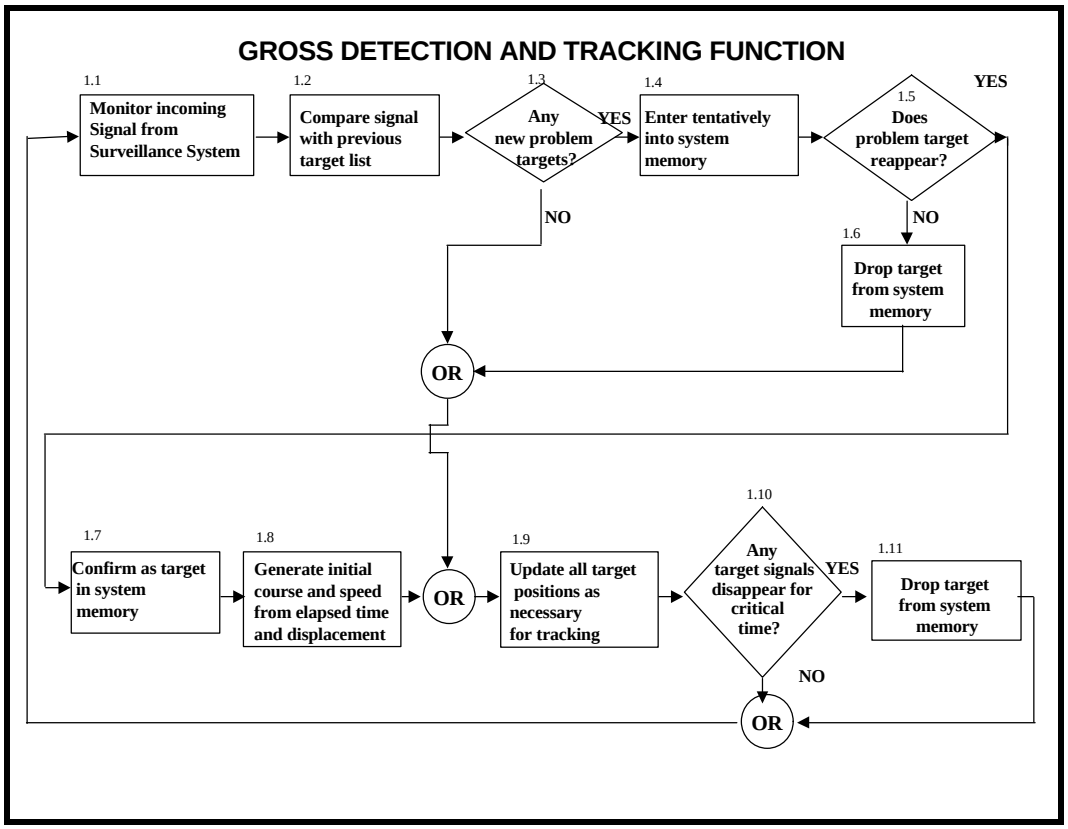


FIGURE 17. Decision/action diagram (sample).

8.3.8.3 Use. The results of the decision/action diagram analysis are used to develop specific system requirements and assist in the performance of trade studies. Additional analysis methods such as time lines are almost always needed following the construction of the decision/action diagrams to investigate the effect of the critical system parameter, time. Worthwhile computer simulations have been successfully performed with the addition of time data to detailed decision action diagrams that include preliminary allocations of functions to operators. Table VII indicates several specific output applications that result from performing decision/action diagrams. The method is well suited to initial development of software programs in general, and display software in particular.

8.3.9 Action/information requirements. Given the functional flows, or decision/action diagrams, analytic procedures for performing preliminary functional allocation are somewhat dependent on the practitioner’s objectives. For the purpose of performing functional allocation

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trades, one alternative method is to make the allocation from the level of the detail provided in the functional flows. However, experience suggests that more detail than that provided at the functional level may be desirable before making allocation trades.

8.3.9.1 Description. A format which has been useful in producing functional allocation detail in an appropriate context is the method "action/information requirements." Figure 18 illustrates such a form. Use of this format helps in defining those specific actions necessary to perform a function and, in turn, those specific information elements that must be provided to perform the action. It breaks up the referenced "functional requirement" into useful groupings of "action requirements" and "information requirements." This particular sample format is expanded to include detailed aspects of the function such as related information requirements, sources, and problems. Related accident features and survey commentary are also included in this example. However, the precise format of this particular form does not need to be rigidly controlled.

8.3.9.2 Procedure. The procedure for developing or completing action/information requirements forms is much more informal than that for most analysis methods. Often the three columns illustrated on the left side of the form in Figure 18 are all that are used. The first column is used to list the function and function number from the functional flow diagrams. The second column is used to list each of the action requirements indicated by the function. The third column is used to list the information requirements that come from the listed function. If more detail is desired for the preparation of the allocation trades, additional columns may be added on the right side of the form. In the example in Figure 18, related information requirements, sources, and problems are listed. A second column lists related accident features and the third column lists any other commentary. In this case, the column is used for survey results pertinent to the function being scrutinized. Additional data could be listed, such as the capabilities of operators or equipment for handling these functional requirements.

8.3.9.3 Use. Use of this method provides information to

- identify equipment which satisfies the system requirements,
- perform associated human/equipment capability tradeoffs for preliminary functions allocation,
- integrate similar or correlated system/action/information requirements to develop new concepts, or
- easily pair action requirements with possible control hardware and information requirements with possible display hardware.

The information used to construct these forms comes primarily from the functional flows. Additional data may be obtained from subsystem design engineers. The results obtainable from this analysis method are used by HE practitioners in the performance of functional allocation trades.

8.3.9.4 Comparison to other methods. The action/information requirements forms should be used after the functional flows but before the functional allocation trades. The appropriate time during the program to perform this analysis method would therefore be during the concept formulation or after early phases of demonstration and validation. If there is relatively little

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difficulty in obtaining sufficiently detailed functions from which functional allocation trades may be performed, this method is not recommended.

8.3.10 Timeline. A timeline plots task flow as a function of time. Timelines enable the HE practitioner to appraise time-critical sequences to determine if the temporal relationships among all tasks are compatible. Timelines can also be used as a baseline for workload evaluation (see Figure 19).

8.3.10.1 Description. Timelines allow the HE practitioner to examine the temporal demands of the tasks comprising a process and compare them to the time available for the execution of the tasks. Sequential relationships among the tasks can be analyzed. Timelines also provide the HE practitioner with a preliminary, graphic method of assessing operator workload on a time-based scale. Because any time segment may be selected, timelines allow the HE practitioner to examine a process at the level of detail necessary to ensure thorough analysis.

8.3.10.2 Procedure. Timelines are typically developed and used after a detailed functional flow diagram has been generated. The functional flow diagram depicts the tasks and their allocation, thus providing the HE practitioner with the information necessary to plot the sequence of tasks. Timelines are typically generated in a horizontal format with the time axis across the top of the page. The tasks, along with their corresponding reference numbers from the functional flow diagram, are listed along the left side of the page (see Figure 19). The entire duration of the task sequence or process of interest must be determined and an appropriate time scale selected for the timeline (i.e., hours, minutes, or seconds as needed to depict the level of detail desired within the space available).

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| APPROACH REQUIREMENTS ANALYSIS | | | TRADE-OFF INFORMATION AND DATA INTEGRATION | | |
|---|---|---|---|---|---|
| Approach-land functional requirements | Action requirements | Information requirements | Relation information requirements sources and problems | Related accident features | Related survey commentary |
| 1.0<br>Initiate pre-approach procedures | 1.0.1<br>Review approach information | 1.0.1.1<br>Approach orientation | Approach plate data<br>• Obstacle location<br>• Course/path data<br>• Terrain characteristics | Data misinterpreted/not used effectively<br>Hazards misappraised | • Can't remember all details |
| | | 1.0.1.2<br>Approach constraints<br>• Approach<br>• Requirements<br>• Obstacles<br>• Hazards<br>• Weather<br>• Minima | • Hazards<br>• Minimum decision<br>• Altitudes<br>• Position data | Navigation position errors | • Study time is limited while setting up approach<br>• Improve to emphasize basic data-critical items bolder; e.g. go-around heading/altimeter |
| | 1.0.2<br>Coordinate. with approach control | 1.0.2.1<br>Communication<br>• Path<br>• Designation<br>• Unique limits/constraints<br>• Environmental conditions<br>• Barometric pressure | Coordination and confirmation of approach clearance<br>Altimeter setting | Clearances/procedures are misunderstood/not followed/in error.<br>Altimeter misset/ misread<br>Confusion of<br>• Inches mercury vs. millibars<br>• Sea level vs. field elevation reference | • Need clear picture of position situation<br>• Need precede for better coordination. between aircraft and traffic control to improve understanding of situation/control instructions<br>• Improve altimeter display<br>• Standard set reference elevation<br>• Redundant setting checks |

FIGURE 18. Action information requirements form (sample).

The individual tasks involved in the overall task sequence or process of interest are first located on the diagram in their approximate positions by order of occurrence by placing a bar on the timeline at the appropriate location. The HE practitioner must then assign a time duration to each task and to each interval that may occur between tasks. Data from previous systems (if available) may provide the most reliable information for establishing the time base and determining these task and interval times. If such time data do not exist or are inadequate, the use of a predetermined time standard is recommended (see 8.3.3).

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| TIME LINE SHEET NO 2.3.3 | FUNCTION: SAM THREAT | OPERATOR / MAINTAINER: PILOT |
|---|---|---|

| REF. FUNC | TASKS |
|---|---|
| 2.3.3.1 | Maintain aircraft maneuver |
| 2.3.3.2 | Monitor flight parameters |
| 2.3.3.3 | Monitor navigation data |
| 2.3.3.4 | Monitor displays for ETA |
| 2.3.3.5 | Adjust throttles (as required) |
| 2.3.3.6 | Check ECM mode |
| 2.3.3.7 | Monitor threat warning indicator |
| 2.3.3.8 | Detect threat locked on |
| 2.3.3.9 | Monitor threat display |
| 2.3.3.10 | Comm-SAM strobe position |
| 2.3.3.11 | Monitor threat display |
| 2.3.3.12 | Detect SAM launch |
| 2.3.3.13 | Activate ECM chaff |
| 2.3.3.14 | Comm-launch IND to STK FR |
| 2.3.3.15 | Sight SAM visually |
| 2.3.3.16 | Comm-start evasive maneuver |
| 2.3.3.17 | Increase thrust |
| 2.3.3.18 | Track SAM visually |

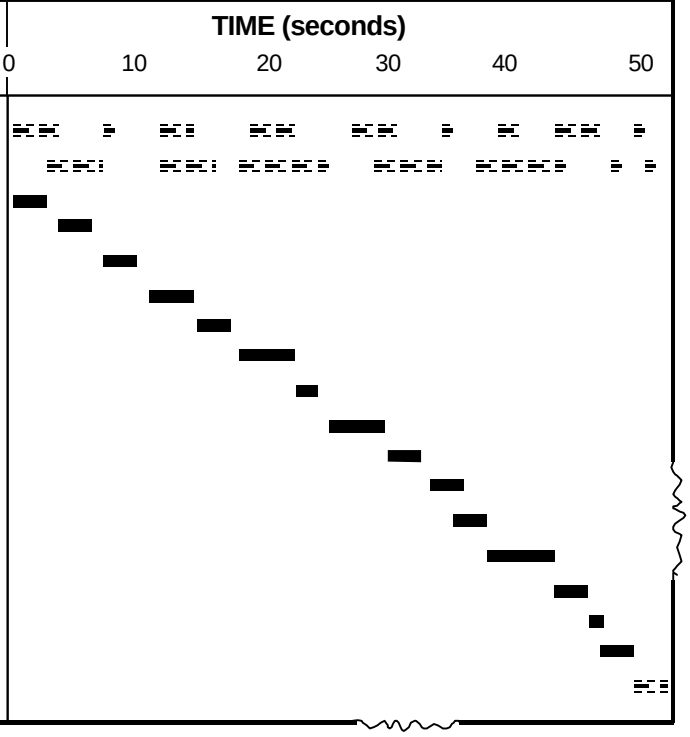


FIGURE 19. Timeline (sample).

The time for each task is then indicated by adjusting the length of the bar to reflect the duration of the task. A timeline may also identify possible external time constraints that may apply to and affect the performance of the task. These events can be represented by inserting vertical lines at the corresponding points and labeling or referencing them appropriately. Once the subtask durations, intertask intervals, and relative relationships are plotted, the HE practitioner can identify those tasks that overlap in time.

8.3.10.3 Use. Timelines are typically used to identify time overlap among potentially incompatible tasks. The HE practitioner can then focus on developing ways to alter the design or the process to ensure appropriate task performance and to prevent or minimize the potential for overload. Timelines provide the basis for more detailed task analyses and analyses of operator workload. They may also be used to roughly evaluate the validity of initial function allocations by identifying areas of task overlap and tasks for which there is inadequate time to permit proper execution. Table VII indicates several specific areas of application for timelines.

8.3.10.4 Comparison to other methods. Timelines complement functional flow diagrams by adding task times and times for intertask intervals. Functional flow diagrams can provide some

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information on potential task-time conflicts, particularly as they relate to the sequencing of subtasks. Because timelines provide empirical or estimated time data, however, they offer additional insight regarding the potential for actual task overlap or inadequate time for task execution (with consequent operator overload). Note that the nature of the tasks involved is not depicted on the timeline; hence, the potential for operator overload or operator error due to other causes (e.g., physical incompatibilities, poor software or display design) is not revealed. Note also that timelines represent a single, static representation of the temporal relationships that are anticipated to exist during system operation. Other approaches, such as computer-based network modeling simulations and queuing models, can provide more detailed and accurate estimates of the likelihood of task overlap or operator overload, and of the times needed for the execution of long sequences with multiple subtasks. Unlike timelines, in which evaluations are based on single-valued estimates of time, these more sophisticated approaches carry out iterative computations in which probability distributions are used to generate a range of time estimates for each task or intertask interval. Such methods allow the practitioner to conduct probabilistic assessments and sensitivity analyses regarding the likelihood of occurrence of time-related problems. However, these methods may require time or resources (e.g., software tools) that are not available.

8.3.11 Integrated Computer-Aided Manufacturing Definition (IDEF). IDEF is a method of system modeling that enables understanding of system functions and their relationships. Using the decomposition methods of structural analysis, the IDEF methodology defines a system in terms of its functions and its inputs, outputs, controls, and mechanisms (ICOMs). Currently, IDEF comprises the suite of methods listed below; others are under development.

- $IDEF_0$ - Function modeling
- $IDEF_{1X}$ - Data modeling
- $IDEF_2$ - Dynamic modeling
- $IDEF_3$ - Process flow and object state description capture method
- $IDEF_4$ - Object-oriented design method
- $IDEF_5$ - Ontology description capture method

$IDEF_0$ and $IDEF_{1X}$ were developed into Federal Information Processing Standards Publications (FIPS PUBS) 183 and 184 (1993a & b), respectively, by the National Institute of Standards and Technology (NIST). Although IDEF methods were originally carried out manually, a number of automated tools are now available to assist IDEF users. Over the years, IDEF has been applied to a number of system acquisition planning projects and HE-related projects during early acquisition. HE practitioners may find IDEF helpful, especially for function allocation. The $IDEF_0$ and $IDEF_{1X}$ methods are discussed in this section. For more information on $IDEF_3$, see Mayer, Menzel, Painter, Dewitte, and Blinn (1997); for information on $IDEF_4$, see Mayer, Keen, and Wells (1992); for information on $IDEF_5$, see Preaketh, Menzel, Mayer, Fillion, and Futrell (1994).

8.3.11.1 Integration definition language for function modeling ($IDEF_0$). $IDEF_0$ is a method for generating a graphic model that describes interactions among the functions, decisions, actions, and activities of a system. $IDEF_0$ can be used to analyze existing systems or define requirements and functions for systems under development.

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8.3.11.1.1 Description. $IDEF_0$ uses structural decomposition methods to break down the system into components at a level of detail that is easily understandable. $IDEF_0$ is used to generate a graphic model of the system that consists of boxes representing functions (or processes) and arrows representing inputs, controls, outputs, and mechanisms (ICOMs). These box and arrow plots show how the functions interact with one another. Along with the graphic representation, a glossary of terms and a text narrative are also generated to provide further explanation.

8.3.11.1.2. Procedure. The graphic portion of an $IDEF_0$ model is created using a standard set of graphic elements (boxes, arrows, rules, and diagrams) and a standard syntax defining how the various graphic elements are employed. Boxes describe what happens within a function. Each box has a name (an active verb phrase) that characterizes the given function. Boxes are numbered in the lower right corner for reference. Arrows represent the ICOMs related to the completion of the function and are labeled with noun phrases. The notation on the box and arrow drawings should use standard terminology (as defined in NIST, 1993a) to aid in communication. Each side of the function box has a specific meaning in terms of box and arrow relationships. The left side of the box receives inputs, which are transformed or consumed. The top of the box relates to controls, which specify the conditions required for the correct outputs. Outputs leave the function on the right side of the box. The bottom shows mechanisms or resources, which support function execution. Arrows indicate mechanisms/resources that are explicitly called; other mechanisms/resources may be inherited from the “parent” function. Arrows pointing downward from the bottom are “call” arrows, which enable data sharing between IDEF models. A basic function box with related arrows is shown in Figure 20. The $IDEF_0$ method can be used to decompose the system to increasingly finer levels of detail by creating a new subdiagram to explicate each function (see Figure 21). The HE practitioner can thus plot the system at a level appropriate for the desired analysis. A text description and glossary are added to the model for clarification. The glossary should contain any acronyms, abbreviations, or unfamiliar terminology. The text narrative should provide additional detail regarding the information contained on the diagrams. (For further details on $IDEF_0$, consult NIST, 1993a.)

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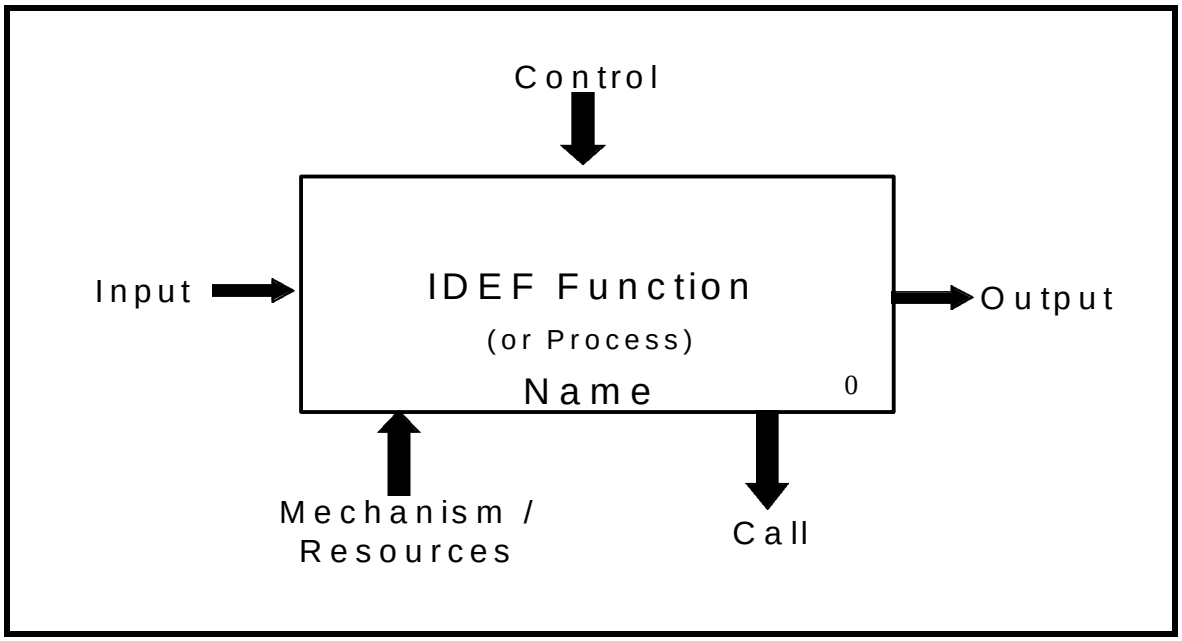


FIGURE 20. Basic function box for an $IDEF_0$ graph. (Adapted from NIST, 1993a.).

8.3.11.1.3 Use. $IDEF_0$ may be used to decompose a system from high-level to low-level functions by creating a series of interrelated parent-child diagrams (Figure 21). $IDEF_0$ can be applied to both new and existing systems. For existing systems, $IDEF_0$ may be used to chart all the functions and ICOMs necessary for system operation. For new systems, $IDEF_0$ may be used to define requirements and functions, so steps can then be taken to ensure that these requirements and functions can be accommodated. $IDEF_0$ is helpful for understanding how the parts of a system work together to accomplish system-level goals. Table VII indicates several specific applications for $IDEF_0$ models. To make the most effective use of this method, the HE practitioner should be experienced with its application.

8.3.11.1.4 Comparison to other methods. $IDEF_0$ is rather unique and adaptable as a modeling method, because it models the functions and resources of a system rather than the process flow of the system. It is important to note that, unlike other charting methods, $IDEF_0$ does not necessarily show the order in which the functions are carried out; rather, it portrays the relationships between functions.

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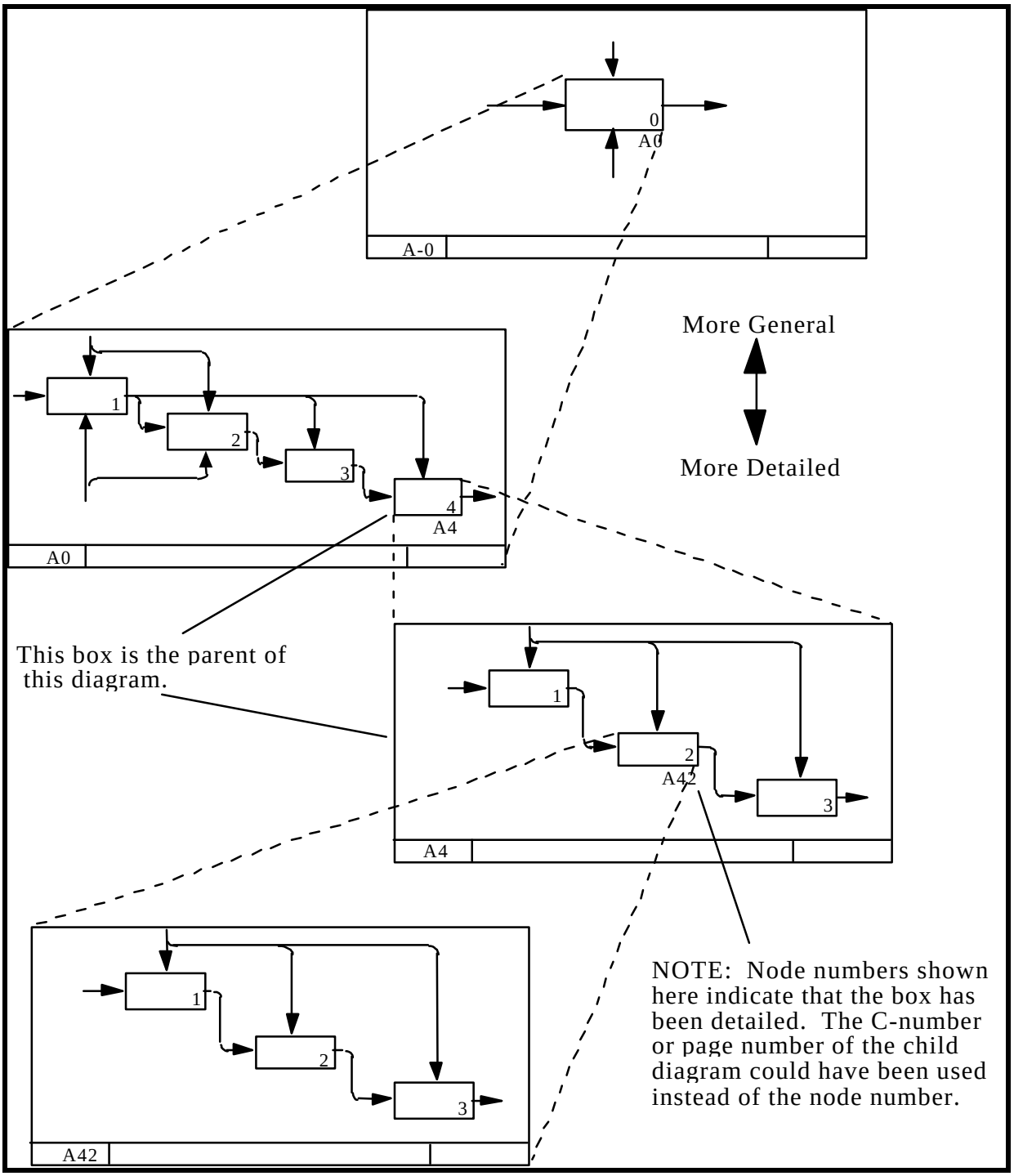


FIGURE 21. System decomposition using multiple $IDEF_0$ graphs. (From NIST, 1993a.)

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8.3.11.2 Integration definition for information modeling ($IDEF_{1X}$). $IDEF_{1X}$ is a method for developing logical data models that describe the structure of information within a system. Models generated with $IDEF_{1X}$ may be used to manage data, integrate information systems, and construct databases within a system.

8.3.11.2.1 Description. $IDEF_{1X}$ is used to generate a graphic representation (model) of the way the data in a system are structured. As with the other IDEF methods, the syntax and semantics of $IDEF_{1X}$ are standardized enough to ensure proper communication, but flexible enough to accommodate a wide variety of systems.

8.3.11.2.2 Procedure. The procedure for developing an $IDEF_{1X}$ model is complex; however, because of the potential usefulness of this method to HE, the essentials are described here. For more detailed information, see NIST (1993b). The following are the basic semantic elements and syntax used in constructing $IDEF_{1X}$ models:

- Entity—a set of real or abstract things (people, objects, places, events, equipment, subsystems, ideas, combination of things, etc.). Individual occurrences of an entity are known as instances. Entities are represented as boxes; boxes are square-cornered for independent entities and round-cornered for dependent entities.
- Attribute—property used to define an entity. An attribute is owned by only one entity, but may be inherited by other entities in a hierarchical relationship below it.
- Connection relationship—link connecting two entities. Connection relationships are represented as lines between entity boxes. The connection starts with the parent entity and ends with the child entity. Each connection line is labeled with a verb phrase that describes the relationship between the linked entities.
- Key—a group of attributes that uniquely identify an instance of an entity. Each instance has only one primary key. An instance can have several alternate keys that describe the entity.

The semantic elements and syntax for an $IDEF_{1X}$ model are shown in Figure 22. In addition to graphic representations (or model views), each $IDEF_{1X}$ model must have a statement of purpose, a statement of scope, and a description of the conventions used during construction. Conventions must not violate any of the rules governing model syntax or semantics.

8.3.11.2.3 Use. $IDEF_{1X}$ is used to model information in a consistent and predictable format. This method provides a standardized means of graphically representing the data resources required for system operation. $IDEF_{1X}$ can also provide an application-independent view of the data that can be validated by users. To make the most effective use of the $IDEF_{1X}$ method, the HE practitioner should be experienced with its application.

8.3.11.2.4 Comparison to other methods. The $IDEF_{1X}$ method differs from process-oriented methods designed to capture the flow and use of information in a system. In an $IDEF_{1X}$ model, the information is not necessarily shown as it is used; rather, the structure of the information is portrayed. The HE practitioner must keep this characteristic in mind when employing $IDEF_{1X}$ to describe a system.

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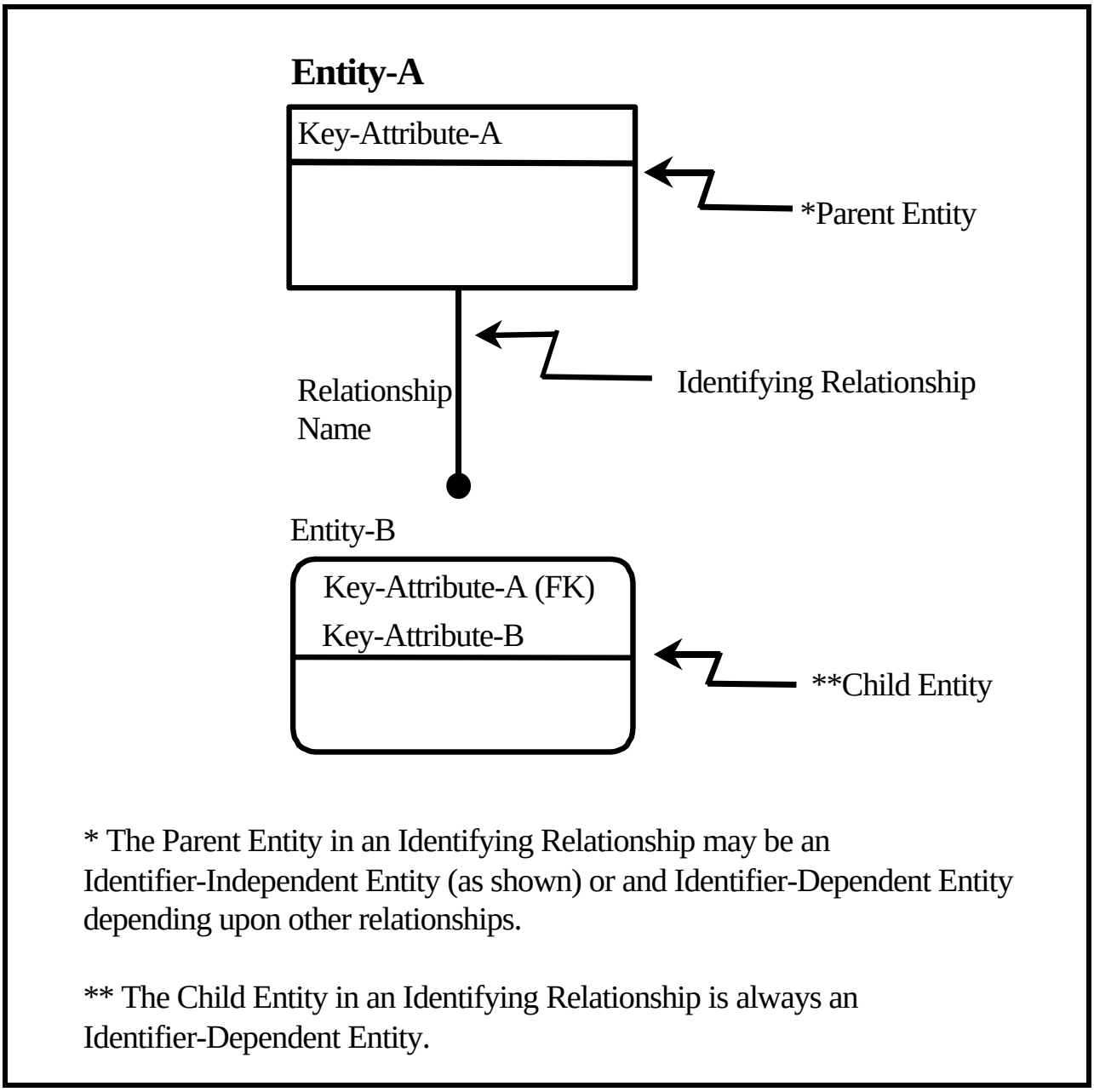


FIGURE 22. IDEF$_{1X}$ graph showing conventions for defining entities and their relationships. (From NIST, 1993b.)

8.3.12 Function allocation trades. With the completion of the functional flow diagrams, decision/action diagrams, or action/information requirements, it is appropriate to perform preliminary trade-off studies of human-machine allocations for each of the functions being considered. Too often the allocations are based only on past experience, or worse yet, the allocations are simply arbitrary. A rationalized choice of functions is necessary for optimum system design. These human-machine allocations provide the baseline for down-stream efforts relating to crew task control/display operations requirements, crew station configuration

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concepts, workload evaluation and crew station design, development, and evaluation. Additionally, function allocations dictate crew workload and significantly affect manning, training, and procedures requirements. Early appraisals of the allocation impact on these requirements are necessary as part of the initial HE review process. Early appraisals that anticipate program and operational requirements are reflected in the earliest system development phases.

8.3.12.1 Descriptions. Working in conjunction with project subsystem designers (perhaps as a team to do this task) and using the functional flows, and other HE methods, plus past-experience with similar systems, the HE practitioner makes a preliminary allocation of the actions, decisions, or functions shown in the previously used charts and diagrams to operators, equipment, or software. The assignment of the functions, actions, or decisions to operators, equipment, or software must be based on

- the known limitations of operators or maintainers,
- the state of-the-art performance of hardware and software, and
- estimated performance to be required in terms of speed, accuracy, and workload.

The need for a cooperative effort between subsystem designers and HE practitioners at this point is extremely important. Each must contribute to make the allocations meaningful. Three specific recommended methods to perform the details of function allocation trades are listed below. In addition, many other function allocation methods are highlighted in the State-of-the-Art report on *Improving Function Allocation for Integrated Systems Design* (Beevis, Essens, and Schuffel, 1996) and function allocation methods are compared in Older, Waterson, and Clegg's *Ergonomics Abstracts* article, entitled *A Critical Assessment of Task Allocation Methods and their Applicability* (1997).

8.3.12.1.1 First method. The first method is simply "trial and error" substitution of each of the alternatives into a system or subsystem model. Each alternative is then evaluated on a basis of total system or subsystem reliability or speed. This method has some obvious drawbacks. It is not recommended for a systems analysis where a large number need to be allocated. The method lends itself for use to computer analysis much better than manual (paper and pencil) analysis. Computer-aided methods that may be used for this type of analysis are described in following paragraphs of this guide.

8.3.12.1.2 Second method. The second method is based on an evaluation matrix (see Figure 23). Candidate subsystem functions are listed and compared against the "Fitts Law" human-machine capabilities (see Table X). The form used to perform this method is called a function allocation screening worksheet. Plausible operator roles or equipment functions (e.g., operating, monitoring, maintaining, programming, communicating, etc.) are identified using the screening worksheet. By comparing the functions to be performed with the inherent capabilities of man or machine to accomplish the functions, operator and equipment tasks are allocated. The comparison is evaluated and, based on the practitioner's judgment, a weighted numerical score is assigned to each function/capabilities criteria relationship.

8.3.12.1.3 Third method. The third method is also based on an evaluation matrix and is often referred to as a design evaluation matrix. In thins method, candidate subsystem alternatives

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are listed and compared against selected criteria for allocation (response time, error rate, operability, cost, etc.). As in the case of the screening worksheets, the evaluation criteria are weighted since some factors are obviously more important than others. Each of the function/ evaluation criteria relationships is assigned a numerical score, as to how each function best meets the selected evaluation criteria. HE criteria such as that in MIL-STD-1472 may be used as the selection evaluation criteria. Figure 24 is a sample matrix used for a crew size trade study.

**KEY**:

5/25

rated score — weighted score

SCALE 1-5 5 BEST

| HYPOTHETICAL TRACKING FUNCTIONS | INHERENT OPERATOR CAPABILITIES | | | | | INHERENT EQUIPMENT CAPABILITIES | | | TOTAL SCORE | | PROPOSED ALLOCATION | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Detecting signals in the presence of high noise environment (X5) | Recognizing objects under varying conditions of perception (X4) | Handling unexpected occurrences or low-probability events (X4) | Reasoning inductively (X1) | Profiting from Experience (X2) | Responding quickly to signals (X3) | Performing precise routine, repetitive operations (X2) | Computing and handling large amounts of stored information quickly and accurately (X4) | Operator | Machine | Operator | Both | Machine: Equipment | Machine: Software |
| 1. Determine target tracks in system | 5/25 | 2/8 | 3/12 | 3 | 3/6 | 3/9 | 4/8 | 1/4 | 81 | 41 | X | | | |
| 2. Actuate sequence | 1/5 | 1/4 | 1/4 | 1 | 1/2 | 1/3 | 1/2 | 1/4 | 20 | 24 | | X | | |
| 3. Put next target in track list under close control | 1/5 | 1/4 | 1/4 | 1 | 1/2 | 9 | 5/10 | 1/4 | 21 | 43 | | | X | X |
| 4. Advance hook on Display to track Coordinates | 1/5 | 1/4 | 1/4 | 1 | 2/4 | 3/9 | 5/10 | 1/4 | 70 | 39 | X | | | |
| 5. Determine if hook lines up with present target position | 4/20 | 2/8 | 2/8 | 3 | 2/4 | 3/9 | 4/8 | 1/4 | 73 | 40 | X | | | |
| . . . etc. | | | | | | | | | | | | | | |

FIGURE 23. Function allocation screening (sample) worksheet (evaluation matrix).

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TABLE X. Human-machine capabilities (Fitts Law).

| HUMANS EXCEL IN | MACHINES EXCEL IN |
|---|---|
| Detection of certain forms of very low energy levels | Monitoring (both people and machines) |
| Sensitivity to an extremely wide variety of stimuli | Performing routine, repetitive, or very precise operations |
| Perceiving patterns and making generalizations about them | Responding very quickly to control signals |
| Ability to store large amounts of information for long periods – and recalling relevant facts at appropriate moments | Storing and recalling large amounts of information in short time-periods |
| Ability to exercise judgment where events cannot be completely defined | Performing complex and rapid computations with high accuracy |
| Improvising and adopting flexible procedures | Sensitivity to stimuli beyond the range of human sensitivity (infrared, radio waves) |
| Ability to react to unexpected low-probability events | Doing many different things at one time |
| Applying originality in solving problems, i.e., alternative solutions | Exerting large amounts of force smoothly and precisely |
| Ability to profit from experience and alter course of action | Insensitivity to extraneous factors |
| Ability to perform fine manipulations, especially where misalignment appears unexpected | Ability to repeat operations very rapidly, continuously, and precisely the same way over a long period |
| Ability to continue to perform when overloaded | Operating in environments which are hostile to man or beyond human tolerance |
| Ability to reason inductively | Deductive processes |

8.3.12.2 Procedure. The procedure for accomplishing the first of the three function allocation trade methods is actually the same as the procedures for accomplishing some of the other human factors analysis methods. The procedure for the second two are similar to each other but not similar to the first.

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8.3.12.2.1 Trial and error method. The trial and error method may be performed once one of the alternatives for a particular function is tentatively chosen; the alternative should be evaluated for use by performing one of the analysis methods on it. For example, the time line analysis method should be used to evaluate an allocation trade where either operators or equipment are chosen to perform time critical tasks. The resulting allocation choice is then the solution that best meets the system time requirements. In a similar manner, other allocation trades may be accomplished to evaluate human-machine functional performance in terms of reliability. The following paragraphs will indicate which methods are best suited for testing particular performance parameters.

8.3.12.2.2 Evaluation matrix. Function allocation screening worksheets are constructed by listing each of the several functions to be allocated on the left side of the worksheet. Two sets of evaluation criteria are listed across the top of the sheet. The first set pertains to operator capabilities; the second set pertains to equipment capabilities. Each of the capabilities evaluation criteria is taken from the often used "Fitts Law" Table X. To balance out each of the evaluation capabilities, each one against all the others, numerical weightings have been assigned as appropriate for the system being analyzed. For example, "response to signals" may be particularly important as compared to "inductive reasoning" and it should therefore be weighted more heavily. Although not a part of the "Fitts Law," such factors as cost may be added to these other characteristics. Such parameters are generally considered for evaluation using the design evaluation matrix method discussed in the following paragraph. Whenever an evaluation characteristic (across the top of the sheet) is applicable to a listed function (left side of sheet) a weighted "X" is placed in the column/row intersection. The actual evaluation is made by totaling each of the weighted "X's" for the "operator" versus the "equipment" allocation. The results of the allocation are tabulated in the far right-hand columns as either "operator", "both", or "equipment." The "both" column is used when the sums from both sides of the worksheet are within approximately 80 percent of each other. A more detailed analysis may be required to obtain a detailed breakout of operator or equipment-allocation. If a more precise evaluation of each of the functions is desired, a numerical score (e.g., 1-5) may be used rather than just an "X" to indicate how well a particular "Fitts Law" evaluation characteristic applies to a function. This procedure is used in the Figure 23 construction. The number entered in the row/column intersection is the weighted evaluation factor times the score. As with the simpler method indicated above, the total scores are added on each side of the worksheet to obtain a proposed function allocation. It should be noted that whereas this method does not ensure the absolutely best allocation of functions, it goes a long way beyond the "gut-feel" method so often used.

8.3.12.2.3 Design evaluation matrix. Construction of the design evaluation matrix is similar to the functional evaluation screening worksheet in that the subsystem alternatives are listed along the left side and the evaluation factors are listed across the top of the sheet. The main difference is that the trade to be performed is not necessarily between man or machine for a particular single subsystem or functional listing. The trade to be performed is between each of the alternatives listed along the left side of the sheet. Another difference between the two methods is that the lists for the design evaluation matrix tend to be of several crew or equipment alternatives rather than just operator versus equipment alternatives (see Figure 24). The evaluation characteristics listed across the top of the sheet pertain more to performance parameters than to

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inherent capabilities. The evaluation characteristics should be weighted and the suitability of a particular functional alternative to an evaluation characteristic should be scored on a scale of 1 to 5. The addition of each of the weighted scores determines the best alternative.

| TRADE OPTIONS | Weighing Factor | 10 | 5 | 5 | 4 | 4 | 3 | 3 | 3 | 2 | 1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Evaluation Characteristics | Cost | Autonomy | Response Time | Multi-mission/ Flexibility & Growth | Reliability | Safety | Rescue Capability & EVA | Re-planning | Operating Weight | Other | SCORE |
| One Crewmember | | 5 | 2 | 5 | 3 | 2 | 1 | 1 | 1 | 5 | 2 | |
| | | 50 | 10 | 25 | 12 | 8 | 3 | 3 | 3 | 10 | 2 | 126 |
| Two Crewmembers | | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 5 | |
| | | 40 | 20 | 20 | 16 | 12 | 12 | 12 | 12 | 8 | 5 | 157 |
| Four Crewmembers | | 1 | 4 | 3 | 5 | 3 | 4 | 4 | 4 | 4 | 1 | |
| | | 10 | 20 | 15 | 20 | 12 | 12 | 12 | 12 | 8 | 1 | 122 |

**OUTCOME:** two crewmember option by **20%**

**CELL INDEX FACTOR KEY**
1= unfavorable
2= slightly unfavorable
3= neutral
4= favorable
5= very favorable

(Evaluation characteristics are analyzed with respect to crew considerations only.)

**WEIGHING FACTOR KEY**
1= low weight
10= high weight

FIGURE 24. Design evaluation matrix (sample).

8.3.12.3 Use. Initial function allocations are typically obtained from information taken from mission requirements, functional flows, or other preliminary analysis diagrams. Function aspects such as difficulty, priority and criticality are appraised and operator/equipment methods for meeting the requirements are evaluated. The results of function allocation trades are used to:

- determine impact of crew tasks, skills and information needs;
- appraise related crew task capability and limitations;
- identify corresponding control/display concepts;
- trade specific and detailed control/display/crew performance capabilities;
- perform extensive task analysis and workload evaluations; and
- identify control/display/crew operations requirements to proceed to crewstation configuration development.

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8.3.12.4 Comparison to other methods. Function allocation studies are best performed early in the program.

8.3.13 Workload Analysis. Workload analysis provides an appraisal of the extent of operator or crew task loading, based on the sequential accumulation of task times. Application of this method permits an evaluation of the capability of the operator or crew to perform all assigned tasks in the time allotted by mission constraints. As capability is confirmed, hardware design requirements can be more precisely designated. Conversely, as limitations are exposed, alternate function allocations and operator or crew task assignments are considered and implemented.

8.3.13.1 Description. Workload analysis or workload profiles, as they are often referred to, are a graphic presentation of an operator's workload constructed by plotting percentage of task involvement against a time base (see figure 25). Although workload analysis depicts individual activity, its greatest effectiveness is realized when several operator/maintainer positions are plotted together on the same graph. By doing this, any unbalanced workload distributions among the operators become readily apparent. Earliest possible workload appraisals are needed to ensure that resulting task loads are within the scope of the crew size and capability. Workload analysis was developed to verify that no combination of tasks required more task load capacity or time to perform than is available. One concept in workload analysis is to divide the operator tasks into categories corresponding to perceptual-motor channels. This analysis refinement concept does not necessarily have to be accomplished to successfully perform workload analysis. However, the more detailed the analysis, the better the output data. The following guidelines should be noted.

a. In some situations, operators can effectively perform more than one task at a time. However, it is obvious that an operator cannot accomplish two tasks simultaneously if both tasks require the use of a single perceptual-motor channel nearly 100 percent of the time. The workload analysis chart exposes such conditions when properly developed. When such conditions are noticed, it is apparent that one of two things must be done. Either a task must be given to another operator or the operator must be provided with some type of equipment assistance.

b. The task loading estimates may come from several sources. For example, the task may be the same as, or similar to, another task in another system which is in actual operation. Task time data from previous systems is generally the most reliable since it has been verified in practice. When such information is not available, the next best data is the use of PTS methods to establish task times (see 8.3.3).

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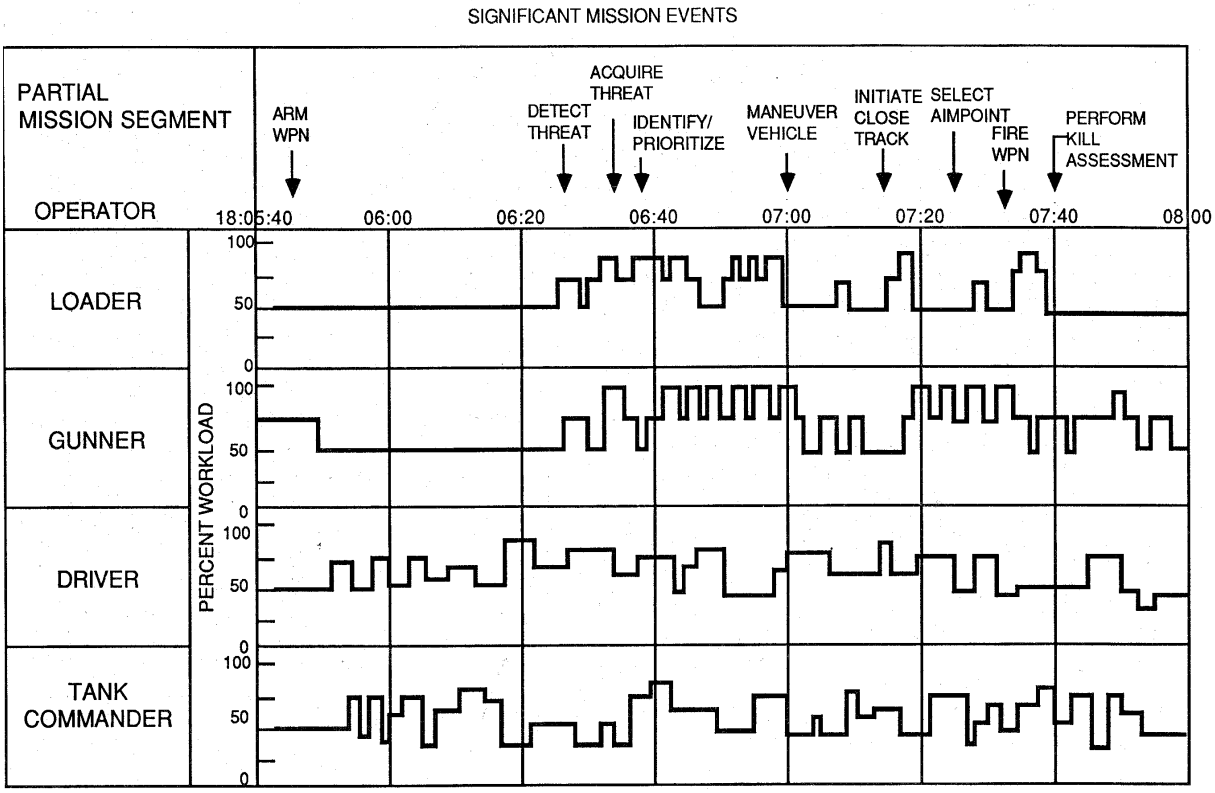


FIGURE 25. Workload analysis profile (sample).

c. When experienced operators or other data sources are not available, the HE practitioner, together with knowledgeable project designers, must make an "educated guess" about the task workload implications. The HE practitioner will have to do what one does with all problems of this sort; the practitioner will have to break the task down into its simplest elements and extrapolate from what the practitioner knows about other subtask elements.

8.3.13.2 Procedure. In application, workloads are estimated at either a gross level or detailed level in terms of both time and number of perceptual-motor channels considered for analysis. As workload situations tend to become more critical, shorter time increments are examined. Also, as workload increases for a given situation and as the situation becomes more critical, it is desirable to make workload assessments on the basis of each of the operator's perceptual-motor channels. These are generally listed as

- external vision (distance vision),
- internal vision (within an armored personnel carrier or console panel area), or
- left hand, right hand, feet, cognition, audition, and verbal channels.

The following workload estimate ground rules should be used:

8.3.13.2.1 Calculations. Workload calculations are based on estimates of the time required to perform a given task divided by the time allowed or available to perform the task. The

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HE practitioner is cautioned that if one evaluates workload by considering each of the distinct perceptual motor channels, one cannot equate a 75 percent loading on each channel to an overall 75 percent loading. The precise summation effects of all or several of the channels cannot be accurately predicted. Quite possibly the results of a 75 percent loading on each channel would result in a total overload situation (>100%). The practitioner is also cautioned not to average workload over the time increments being considered. A workload estimate of 100 percent and an estimate of 50 percent for two sequential tasks occurring within a given time increment must be considered as an overall estimate of 100 percent (not 75%). If it is necessary to provide visibility to the 50 percent loading situation, then the time increments must be broken down into smaller time periods. The point of the analysis is to discover significant workload conditions including peaks, not to mask them out.

8.3.13.2.2 Operator loading. In general, workloads over 100 percent are not acceptable, between 75 percent and 100 percent are undesirable, and under 75 percent are acceptable provided that the operator is given sufficient work to remain reasonably busy.

8.3.13.2.3 Estimating. Since the process of estimating workload is based on the estimate of time required to do the task, it is only as accurate as that data. It is also limited by the knowledge of the time available to do the task and the unknown discrete channel summation effects. Depending on these variables alone, the accuracy of most workload assessments is probably in the ± 20% range. If more accurate assessments are required, full-scale simulations of the crew tasks may be necessary.

8.3.13.2.4 Charts. The workload analysis may be made up of a simple continuous chart from the beginning to end of a mission, or there may be several charts, each of which expands a particularly critical segment of the mission. As previously indicated, the time scale should be commensurate with task complexity; e.g., 15-minute intervals may be all that is necessary for simple workload analysis evaluations and 5-second intervals may be required for more complex tasks. Whatever intervals are used should be common for the total group of tasks and operators when they interact.

8.3.13.3 Use. Table VII indicates the applications or outputs of workload analysis.

8.3.13.4 Comparison to other methods. Workload analysis is most generally performed after concept formulation when sufficient other analysis has been performed to develop the input data to workload analysis. It continues past development and possibly past EMD (production decision).

8.3.14 Situation awareness (SA) analysis. SA is the experience of fully understanding what is going on in a given situation, of seeing each element within the context of the overall mission or goal, and of having all the pieces fit together into a coherent picture. More formally, SA may be divided into three levels of awareness (Endsley, 1997):

- Level 1 - perception of the status, attributes, and dynamics of relevant elements in the environment

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- Level 2 - understanding of the significance of these elements in light of current goals
- Level 3 - ability to project the future actions of these elements, at least in the near term

The objective of SA analysis methods is to measure the operator's performance at all these levels.

8.3.14.1 Description. As the amount of data provided to a system operator increases, the ability of the operator to accurately assess the current or future status of the system may be adversely affected. Understanding what influences the operator's SA and how to maintain adequate SA is therefore of concern to HE practitioners. SA analysis methods allow HE practitioners to gain insight into

- how expert and novice operators understand situations,
- how they differ in SA, and
- what inputs the operator uses to comprehend situations.

Current methods for assessing SA include the Situation Awareness Global Assessment Technique (SAGAT) (Endsley 1988); Situational Awareness Rating Technique (SART) (Selcon & Taylor 1989); Situation Awareness–Subjective Workload Dominance (SA-SWORD) (Vidulich & Hughes, 1991); Crew Situational Awareness (Moiser & Chidester, 1991); and Situational Awareness Rating Scales (SARS) (Waag & Houck, 1994). The SAGAT and SART methods will be described here as examples of an objective method and a subjective method of SA measurement, respectively.

8.3.14.1.1 Situational Awareness Global Assessment Technique (SAGAT). SAGAT is an objective SA assessment method that is typically used during real-time, human-in-the-loop simulations, such as simulation of a fighter aircraft cockpit. At random times during the simulation—or at particularly critical or sensitive points—the simulation is interrupted to assess the degree to which the user or operator is "situationally aware" of important aspects of the operational context. The operator's SA can be assessed by comparing the actual situation present in the simulation with the operator's perception of the situation. SAGAT provides a reasonably unbiased measure of SA for all operator SA requirements that can be described objectively, compared realistically with perceptual self-reports, and computed in terms of errors or percent correct (ANSI, 1992). As the basis for a SAGAT assessment, the HE practitioner must conduct an in-depth analysis of the task the operator is to perform, to devise simulations and queries relevant to the issues of interest. The operator's responses to these queries during testing are then compared to the correct answers as determined from a computerized record of the actual circumstances at the instant the simulation was interrupted. SAGAT, as a global measure, provides data on all three levels of operator SA listed above. The scope of the queries may include system functions status as well as relevant features of the external environment. Studies have shown that SAGAT has empirical validity as well as predictive and content validity (ANSI, 1992).

8.3.14.1.2 Situation Awareness Rating Technique (SART). SART is a subjective SA method that uses operator self-ratings to assess perceived SA. SART provides subjective estimates of attentional supply and demand and situational understanding (Selcon & Taylor,

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1989). SART uses a questionnaire to measure subjective SA in 10 dimensions. Users rate their perceived SA along each dimension on a scale of 1-7 (see Figure 26). The 10 SA dimensions are grouped into three general domains:

- demand on attentional resources,
- supply of attentional resources, and
- understanding of the situation.

There is also a three-dimension (3-D) version of the SART scale based on these three groupings that is used when the 10-dimension (10-D) version would be too time-consuming. In addition to the scale ratings on the 3-D version, a summative score is derived that is interpreted as an estimate of overall SA. SART analysis begins with the creation of scenarios or simulations that feature the situations of interest. During these trials or scenarios, the operator is provided with either a 3-D or 10-D SART chart to record his/her perception of SA at a given point in time. Typically, the operator fills out a 3-D chart during the scenario and completes a 10-D chart after the scenario or simulation is finished. The scores from the charts are statistically analyzed to determine how aspects of the task affect SA. Since SART is a subjective measure, the HE practitioner should remember that these data may reflect the operator's comprehension of the "real-world" situation during testing. SART does not distinguish whether the operator's situational awareness is due to the actual situation or derived from a faulty assessment of the situation.

8.3.14.2 Use. SA assessment methods allow the HE practitioner to measure quantitatively and qualitatively how well an Operator perceives a given situation. The HE practitioner may use these measures to help identify where, when, or how the system fails to provide adequate cues, supplies too much information, or delivers the information in such a way that its urgency or interpretation is unclear. Such an evaluation will enable the HE practitioner to provide needed design recommendations. For a more in-depth look at specific areas of use, see Garner and Assenmacher (1997).

| Situational Awareness Domains | Situational Awareness Constructs | Rating Scale | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Low 1 | 2 | 3 | 4 | 5 | 6 | High 7 |
| ***Demand*** | Instability of situation | | | | | | | |
| | Variability of situation | | | | | | | |
| | Complexity of situation | | | | | | | |
| ***Supply*** | Arousal | | | | | | | |
| | Spare mental capacity | | | | | | | |
| | Concentration | | | | | | | |
| | Division of attention | | | | | | | |
| ***Understanding*** | Information quantity | | | | | | | |
| | Information quality | | | | | | | |
| | Familiarity | | | | | | | |

FIGURE 26. 10-Dimensional SART scale. (Adapted from Selcon, S.J. & Taylor,

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R.M., 1989).

8.3.14.3 Comparison to other methods. SA is closely related to other methods of HE analysis, such as cognitive workload measurement. While mental workload measures identify where in a task or series of tasks the operator is likely to become overloaded, SA methods examine the operator's perception and understanding of the elements that comprise the task or scenario. In general, SA methods provide greater focus on what specific information is apt to be lost or overlooked. While SA assessment has a global component (e.g., mental overload will impair SA), the emphasis in SA is on the allocation of attention in specific contexts. SAGAT, for example, can show the HE practitioner what the operator is not likely to perceive. Mental workload measures tend to be more global in nature and will not provide this information.

8.3.15 Link analysis. Interactions between components in a system (human or machine) are defined as links. Generally, links can be subdivided into three classes: communication (auditory or visual); control (from human to machine); and movements (eye, body, hand, or foot). Communication links comprise information interactions whether they are human-machine, machine-machine or human-human. Link analysis can be used by the practitioner as an aid in developing an optimal layout for a work area, workstation, or control/display panel. It also helps in identifying where bottlenecks occur in a task, process, or when too many steps are required to accomplish a task. Table VII shows the many applications for which link analysis may be used. Since link analysis is conducted from observable, measurable data, it is objective and quantifiable. Link analysis is also a direct method that requires little additional training to perform. Three specific link analysis methods are highlighted below: (1) the link table, (2) the adjacency layout diagram, and (3) the spatial operational sequence diagram. For additional information on link analysis, see Kirwan and Ainsworth (1992) or Sanders and McCormick (1993).

8.3.15.1 Link table. A link table provides a simple and easy method of representing the interactions between system components.

8.3.15.1.1 Description. A link table records the frequency and type of interactions that occur between system nodes (crewmembers, workstations, and equipment) during a task or process (see Figure 27). The table is constructed in much the same way as a highway mileage chart, and annotates the interactions between each pair of nodes. This format allows the HE practitioner to easily see which nodes require the most interaction. The practitioner can then ensure that these high-usage nodes are positioned so as to facilitate the interactions. A link table is typically created after the development of an operational sequence diagram (OSD) (see 8.3.6), since the OSD provides information on the number of interactions in a process or task.

8.3.15.1.2 Procedure. To create a link table, the nodes of interest are determined by examining an OSD or using a data collection method such as direct observation or videotape analysis. The nodes are listed vertically along the left side of the page. Then a series of parallel lines are drawn at an angle upward and downward from each node item to form a diamond-shaped matrix (see Figure 27). Once the matrix is completed, the number and type of interactions between the nodes are listed in the boxes at the intersections of each pair of nodes. If the interactions differ in type or criticality (e.g., human-machine or human-human; high priority or

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normal priority), this also may be indicated in each box by a letter code. A link table cannot be generated without some prior analysis of the interactions between nodes so that they can be characterized appropriately.

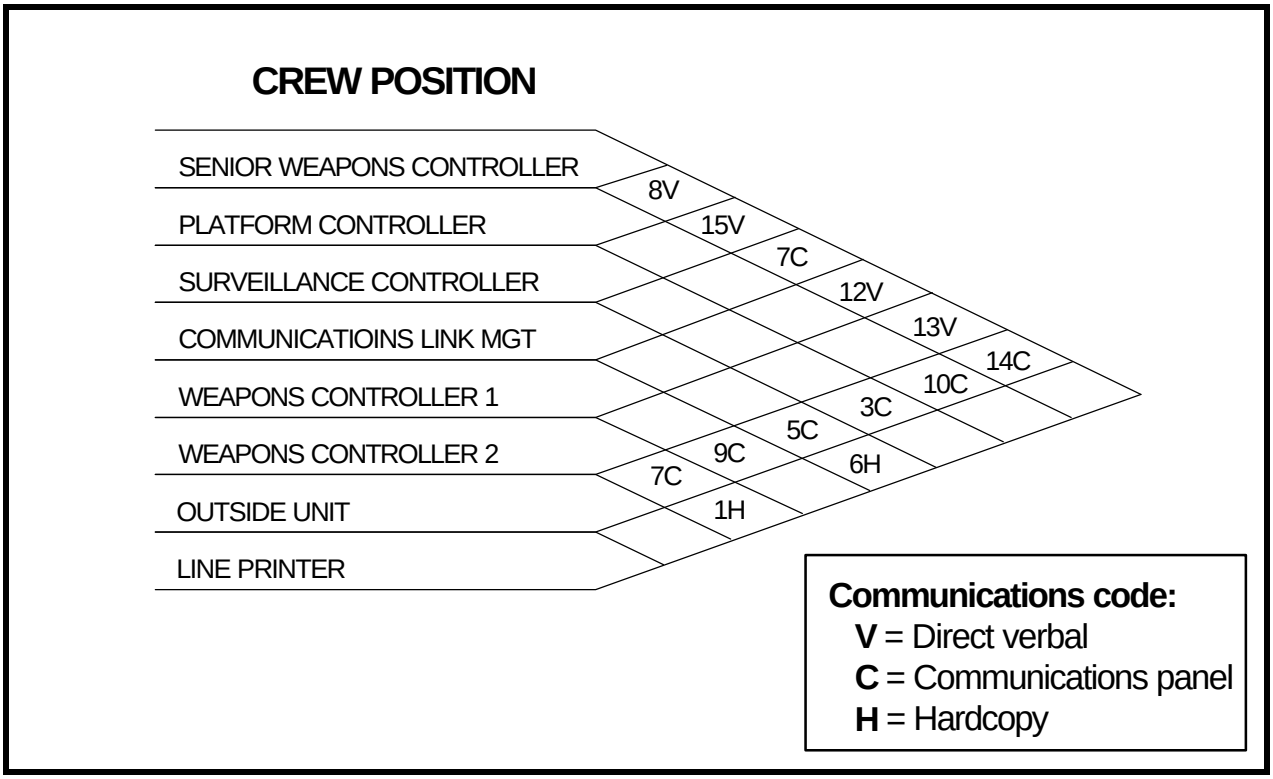


FIGURE 27. Link table (sample).

8.3.15.2 Adjacency layout diagram. Adjacency layout diagrams have been used for a number of years by HE practitioners to depict link data graphically. In addition to identifying interacting nodes, these diagrams provide information about the relative position of the nodes. The HE practitioner can use these link data to begin to optimize the workspace layout from an HE perspective.

8.3.15.2.1 Description. In an adjacency layout diagram, the link data are superimposed onto a drawing of the proposed work area. This method can be applied to all levels of link-related analysis. It may be used to map the links between a variety of referents, for example, between crewmembers, between operator and workstation, or between operator and computer screen. Although these diagrams add the dimension of relative location, they may become quite cluttered with links, which can detract from their usefulness.

8.3.15.2.2. Procedure. Starting with a scale drawing of the work area to be analyzed and the link frequency data (from a link table, direct observation, or videotape analysis), the HE practitioner plots the interactions on the drawing by connecting the components involved in the interaction (see Figure 28). This provides a graphic display of the interactions that occur during the task or process. With this information, the HE practitioner can then attempt to locate the

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paired components of the high-priority and high frequency communication links close to each other. The assumption is that decreasing the distance between linked components will facilitate interaction between them, thereby optimizing the communication process. The frequency or priority of a link can be indicated by variations in line width. The wider the line, the more frequent the communication or the higher the priority. Note, however, that if the HE practitioner elects to use this form of line coding, one must clearly indicate what is being coded: priority of interaction or frequency of interaction. High-priority messages are not necessarily communicated frequently. If both factors (frequency and priority) are to be represented, it is strongly recommended that two separate line-coding features (e.g., line width and line color) be used.

8.3.15.3 Spatial operational sequence diagram (SOSD). The SOSD is similar to the adjacency layout diagram except that time-ordered sequence information is included. The addition of sequence information allows the HE practitioner to identify a process or task that requires excessive or repetitive steps.

8.3.15.3.1 Description. Like the adjacency layout diagram, the SOSD provides the HE practitioner with a scaled drawing of the work area on which links are indicated; however, the SOSD also shows process sequence data. In addition, it may annotate the type of event (such as an action or decision) occurring in the process or task.

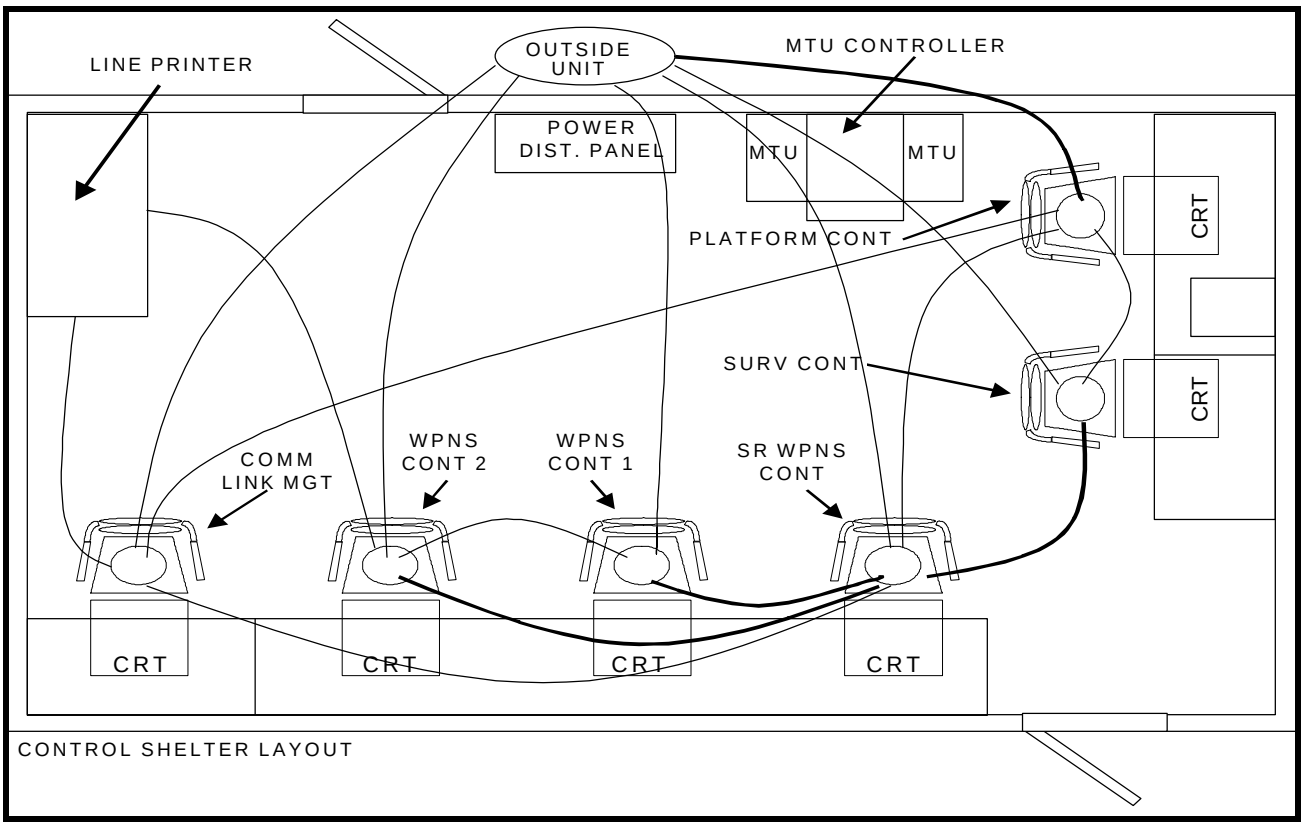


FIGURE 28. Adjacency layout diagram (sample).

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8.3.15.3.2 Procedure. Compiling an SOSD requires the same type of data needed for the other two types of link analysis described above. The links are plotted as on an adjacency layout diagram, and their order of occurrence is encoded in the nodes (see Figure 29). Note that these sequence data do not indicate the duration of any particular link. Additional data may also be encoded in the notation. For example, standard ASME flowchart symbology can be used to indicate the nature of the link (decision, action, information), and different types of line coding may be employed to show which links occur during normal operations and which occur in contingency modes.

8.3.15.4 Comparison of link analysis to other methods. Link analysis helps in the design optimization process by providing HE practitioners with information on the number, sequence, and types of interactions among personnel and equipment, and their relative location. However, it provides no temporal data and therefore needs to be used in conjunction with another method (such as timeline analysis, queuing modeling, or simulation) that provides information on time flow. Data collected from adjacency layout diagrams lend themselves to use in methods for optimizing physical location, but the HE practitioner needs to remember that other factors (e.g., sensory modality, message priority) could also influence what is the optimal layout.

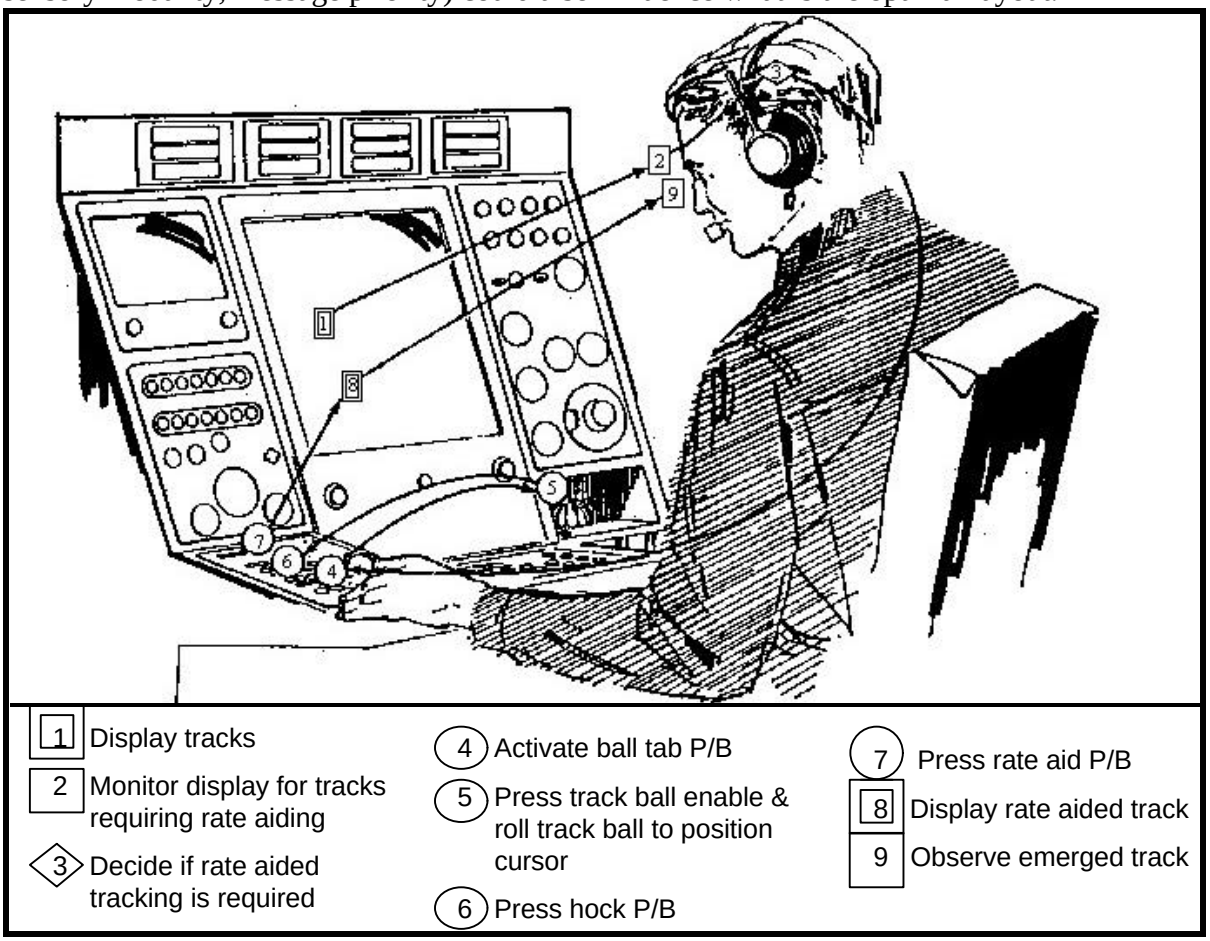


FIGURE 29. Spatial operational sequence diagram (sample).

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8.3.16 Human performance reliability analysis (HPRA). HPRA consists of an analysis of the factors that determine how reliably a person will perform within a system or process. The metric for this analysis is the probability that the human will perform a specified task under specified conditions within a system or process. Although the method provides a probability number for use in other system engineering and human factors analyses, its real purpose is to identify the factors in the system or process design or environment that hinder reliable human performance. HPRA sets a systems engineering context for the work done by HE practitioners. In many respects, it serves as a bridge between those practitioners and system engineers, design engineers, and others.

8.3.16.1 Description. HPRA has been widely used for many years in the nuclear power industry, aerospace industry, transportation industry, and more recently, biomedical engineering. General analytical methods for conducting HPRA include probability compounding, simulation, stochastic methods, expert judgment methods, and design synthesis methods. Individual HPRA techniques usually provide both quantitative and qualitative evaluation of the system or process under study. Among published HPRA methods are the Technique for Human Error Rate Prediction (THERP), Reliable Human Machine System Developer (REHMS-D), Success Likelihood Index Method using Multi-Attribute Utility Decomposition (SLIM-MAUD) (Embrey, Humphreys, Rosa, Kirwan, & Rea, 1984), and Maintenance Personnel Performance Simulation (MAPPS). Most formalized HPRA methods have received sufficient validation to make their use worthwhile. As with most quantitative prediction methods, numerical predictions vary from method to method, but all are successful in identifying areas where improvement is needed. Most HPRA methods in current use can be implemented on a computer or workstation. Some of them, such as MAPPS (micro-MAPPS) and REHMS-D, are available as software for personal computers. Users of HPRA methods must be sensitive to the limitations of the input data (i.e., task error probabilities). Much of the human reliability data available for use in HPRA is applicable to only a limited set of circumstances; for example, some performance reliability databases are appropriate only for nuclear power plant settings. Special attention must be given to identifying data sources for computerized tools in which task error probabilities are embedded in the software. The qualifications and training required to conduct HPRA vary from method to method. The use of THERP, simulation, and expert judgment methods requires considerable expertise. REHMS-D, which is somewhat simpler, demands less HE proficiency because much HE knowledge is embedded in the tool. (For further information see Reason (1991), Hollnagel (1994), and Woods, Johannesen, Cook, & Sarter (1994).)

8.3.16.2 Procedure. The procedure for conducting HPRA varies depending on whether the specific method used is primarily analytical or is oriented toward design synthesis. In a synthesis method such as REHMS-D, system requirements must be identified and allocated to human functions, and then the details of the human functions must be designed to support the allocated requirements. In HPRA analytical methods, existing designs are evaluated and compared to stated system requirements. In these methods, there is no top-down allocation. Most of the methods require an initial functional analysis of the system or process. The results are then mapped onto an operational sequence diagram, probability or action tree, or some other similar structure. Depending on the method used, the probability of correct human performance for each task performed is extracted from a data table, expert judgment, or knowledge stored

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within software. The probabilities are compounded and a reliability value is obtained for each human function. The practitioner then can determine which functions require improvement. In the case of REHMS-D, the software performs two levels of sensitivity analysis to assist the practitioner in identifying the best opportunities for improvement. Each method has its own reporting formats.

8.3.16.2 Use. HPRA can be used for any system or process that involves a human operator. The choice of a specific HPRA method depends on the system or process under study and the applicability of the data required to support the method. In general, HPRA can be used to evaluate radar, sonar, and similar monitoring systems; most kinds of control rooms; transportation systems; crew-served military weapon systems and platforms; biomedical systems; manufacturing processes; and logistics processes.

8.3.16.2 Comparison to other methods. Unlike most HE methods, HPRA provides HE output that can be incorporated directly into analyses of system or process effectiveness. It provides a context and metric for other HE investigations, such as task analysis.

8.4 HE during design and development.

8.4.1 HE design and development support activities. The purpose of HE design and development support activities (see 4.2.2) is to ensure a human-system interface design that incorporates all necessary HE design criteria. The human-system interface is not limited to system hardware, but includes software, procedures, work environments, and facilities associated with the system functions requiring personnel interaction. HE design and development support is accomplished, in part, by converting the results of HE analysis activities into HE training and skill level design criteria. It is also heavily dependent on the selection of applicable HE design criteria such as MIL-STD-1472. The general HE design and development support process is described in 7.3.10.2. The following two paragraphs describe ongoing HE design and development support activities and responsibilities. Methods used in accomplishing these support efforts are discussed in 8.5.

8.4.2 HE design and development responsibilities. HE design principles, methods, and standards should be applied to the design and development of the system equipment, software, procedures, work environments, and facilities that are used, operated, or maintained by humans. This HE effort should convert the mission, system, and task analysis data into detail design and development plans to create a human-system interface that will operate within human performance capabilities, meet system performance requirements, and accomplish mission objectives. Specifically, the HE practitioner is responsible for

- Ensuring that HE inputs are incorporated into system design requirements documentation
- Developing design concepts for each operator, maintainer, and supporter workstation arrangement to ensure that it can be easily operated and maintained
- Identifying potential HE problem areas that may require attention
- Preparing inputs to contractor/subcontractor RFP packages, as applicable

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- Participating in and reviewing studies, experiments, modeling efforts, mockups, and engineering drawings to ensure effective HE design
- Ensuring that human procedures, manuals, and job aids are developed and function efficiently
- Participating in developmental T&E to ensure that HE issues are addressed and resolved so that the system or equipment can perform mission requirements with effective human interfaces

8.5 HE design and development methods. Many of the design aids, tools, or methods that are most useful in carrying out HE design and development support activities are presented in the following paragraphs. Depending on the nature of the program, only a portion of these methods would normally be used. In addition, the analysis methods described in 8.3 will continue to be applied during design and development activities. Table XI summarizes important information about each design and development method so the methods can be compared easily. Table XII lists typical applications for each method.

8.5.1 Design criteria checklist. A design criteria checklist consists of a series of subsystem, equipment, or facilities design criteria taken from HE standards, such as MIL-STD-1472, and HE design guidance documents, such as MIL-HDBK-759. Individual checklists are typically unique to a particular system. Checklists provide the HE practitioner with an organized means of evaluating success or failure in achieving the design goal.

8.5.1.1 Description. Often during the early stages of a program, the HE practitioner develops a design checklist tailored for that program. Design criteria applicable to the specific program are extracted from various standards and handbooks and listed in a program-unique checklist. The checklist may be divided into sections or categories of design criteria corresponding to major aspects or components of subsystems, equipment, or facilities. For example, the checklist might have categories for visual displays, audio displays, or controls. Checklists generally list each design criteria item with space to the right that can be used to indicate compliance, noncompliance, or nonapplicability. Figure 30 shows a sample page from such a checklist.

TABLE XI. HE design and development methods selection

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| | SELECTION EVALUATION CHARACTERISTIC | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Most applicable program phase | | | | Relative complexity | | | Relative time to perform | | | Relative cost | | | Relative cost effectiveness | | |
| HE DESIGN & DEVELOPMENT METHOD | Conceptual | Definition | EMD | Prod/deploy | Simple | Average | Complex | Short | Medium | Long | Low | Medium | High | Low | Medium | High |
| 1 Design criteria checklist | | X | X | X | X | X | | X | X | | | X | | | | X |
| 2 Drawing | X | X | X | X | | X | | | X | | | X | | | X | |
| 3 Visibility diagram | X | X | | | | X | | | X | | | X | | | X | |
| 4 Reach envelope | X | X | | | | X | | | X | | | X | | | X | |
| 5 Mockup | X | X | X | | | X | | | X | | | X | X | | X | X |
| 6 Scale model | X | X | | | | X | | | X | | | X | | X | X | |
| 7 Manikin | X | X | X | | | X | | | X | | X | | | | X | X |
| 8 Specification | | X | X | X | X | X | | | X | X | | X | | | X | |
| 9 Computer-aided design (CAD) environment * | A | A | A | A | | | A | | A | | | | A | | | A |

* Note: Selection information was not available for the asterisked item for the 1998 update, and is assumed based on references, indicated by an "A." Also, data for other items collected in 1986 may be dated or not applicable if automated techniques are used.

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TABLE XII. Application areas for HE design and development methods.

| HE DESIGN & DEVELOPMENT METHOD / APPLICATION | Concept formulation ideas | Detailed design requirements | Personnel requirements information | Operational procedures development | Training system development | Maintenance system development | System operational evaluation | Additional human factors analysis |
|---|---|---|---|---|---|---|---|---|
| 1 Design criteria checklist | | X | | | X | X | | |
| 2 Drawing | X | X | | | X | X | X | X |
| 3 Visibility diagram | X | X | | | X | | X | X |
| 4 Reach envelope | | X | | | X | X | X | X |
| 5 Mockup | X | X | X | X | X | X | X | X |
| 6 Scale model | | X | X | X | X | X | X | X |
| 7 Manikin | | X | | | | X | X | X |
| 8 Specification | | X | X | X | X | X | X | X |
| 9 CAD environment * | | A | | A | A | A | | A |

* This item was added since the last publication. Original items were collected from a survey of HE subject matter experts in 1986. Based on the literature available the new item (asterisked) was assumed to be applicable to areas marked with an "A."

8.5.1.2 Procedure. To use a design criteria checklist, the HE practitioner reads the criterion, observes the item of hardware (or mockup or drawing), and checks the appropriate space to indicate applicability and compliance. Many checklists provide additional space for comments regarding the reason for noncompliance or other remarks appropriate to the listed design criteria item. The following should be noted regarding checklists:

a. When using a checklist, the HE practitioner should have at least some knowledge of the purpose or function of the design item being evaluated. The HE practitioner must also have a good working knowledge of the checklist criteria that will be used. The practitioner should determine whether any previous checklists were completed for the item of hardware, even if the

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hardware was only in drawing form at the time. A more formal T&E procedure will occur when the item being evaluated is at least in the prototype hardware stage of development. Less formal checklist T&E may be carried out with hardware drawings or, possibly, mockups. In any case, the gathering of the checklist data should not interfere with any other testing being done. The use of the checklist is essentially a static operation, as opposed to a dynamic test in which the practitioner must observe operators performing their tasks and equipment properly responding to the operators' manipulations.

| MIL-STD-1472 compliance | YES | NO | N/A | COMMENTS & DISPOSITION |
|---|---|---|---|---|
| 5.1.2.1.1.2 Access. Providing that the integrity of grouping by function and sequence is not compromised, the more frequently used groups and the most important groups should be located in areas of easiest access. Control-display groups required solely for maintenance purposes shall be located in positions providing a lesser degree of access relative to operating groups. | | | | |
| 5.1.2.1.1.3 Functional group marking. Functional groups may be set apart by outlining with contrasting lines which completely encompass the groups. Where such coding is specified by the procuring activity, and where gray panels are used, noncritical functional groups (i.e., those not associated with emergency operations) shall be outlined with a 1.5 mm (1/16 in) black border (27038 of FED-STD-595), and those involving emergency or extremely critical operations shall be outlined with a 5 mm (3/16 in) red border (21136 of FED-STD-595). As an alternate method, contrasting color pads or patches may be used to designate both critical and noncritical functional areas, subject to prior approval by the procuring activity. When red compartment lighting is used, an orange-yellow (23538 of FED-STD-595) and black (27038 of FED-STD-595) striped border shall be used to outline functional groups involving emergency or extremely critical operations. Control-display areas in aircraft crew stations shall be delineated in accordance with MIL-M-18012. | | | | |
| 5.1.2.1.1.4 Consistency. Location of recurring functional groups and individual items shall be similar from panel to panel. Mirror image arrangements shall not be used. | | | | |
| 5.1.2.2 Location and arrangement. If an operator must use many controls and displays, they shall be located and arranged to aid in identifying the controls used with each display, the equipment component affected by each control, and the equipment component described by each display. | | | | |
| 5.1.2.3 Arrangement within groups. Controls and displays within functional groups shall be located according to operational sequence or function, or both. | | | | |
| 5.1.2.3.1 Left-to-right arrangement. If controls must be arranged in fewer rows than displays, controls affecting the top row of displays shall be positioned at the left; controls affecting the second row of displays shall be placed immediately to the right of these, etc. | | | | |

FIGURE 30. MIL-STD-1472 design criteria checklist (sample).

b. The result of the checklist evaluation is a verification of the fact that the design item meets all pertinent HE design criteria. If the item is found not to be in proper compliance with some design criterion, then this information will be provided to design engineering personnel. In some situations, there may be a satisfactory reason why an item of hardware does not or should not meet the HE design requirements. In this case, a request for deviation from HE design criteria may be submitted to the program office for their approval.

8.5.1.3 Use. The design criteria checklist is used more often than any other method to evaluate design hardware. It is an excellent way to quickly gather qualitative data on system hardware components. However, to be of real value, the checklist must contain considerable

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detail. Depending on how the checklist is structured, including the required amount of detail, can extend the time needed to complete the checklist. Using a checklist requires more knowledge of basic HE design criteria than knowledge of system performance. Table XII shows the applications for which a design criteria checklist may be used.

8.5.1.4 Comparison to other methods. Table XI provides a comparison between the checklist method and other design and development methods. The use of the design criteria checklist is strongly advised for both design and T&E program activities. If a checklist is not used, there is significant risk that lack of compliance with critical design requirements will be overlooked. The disadvantage of using a checklist is that it produces binary data: the design item is either in compliance with the design criterion being verified or it is not. However, many criteria items have the potential for yielding an exact quantitative evaluation; thus, considerable data will go unrecorded. The checklist focuses on evaluating equipment, facilities, and some aspects of software. In the commonly used formats, the checklist should not be used to evaluate personnel skills, manpower quantities, training, and technical publications.

8.5.2 Drawing. An engineering sketch or drawing is a precise outline drawing (generally without shading) used to provide visual information about the design of the equipment item, subsystem, subassembly, or facility that is a component or part of the total system. Drawings are fundamental to the equipment design and production process and are the main method of design modification. Drawings can be a hard copy rendering produced by conventional drafting methods or an electronic rendering produced using computer-aided design (CAD) systems. The HE practitioner uses drawings to identify design problems and suggest alternative solutions that better accommodate human operators and maintainers.

8.5.2.1 Description. A drawing can show even intricate and complicated shapes clearly by depicting related views of the equipment item, subsystem, subassembly, or facility. Exact and detailed sizes are provided without ambiguity. Individual parts are identified for assembly and are located in the assembly in their correct functional position. In addition, descriptive notes provide information regarding materials, finishes, and directions for manufacture and assembly. Engineering drawings or sketches of interest to the HE practitioners may be categorized as (a) hardware drawings, (b) workspace layout drawings, (c) console drawings, and (d) panel drawings. Console drawings, in particular, should contain information on the human-system interface; for example, they should indicate the seat reference point (SRP) and eye reference point (ERP). Interface control drawings (ICDs) are another type of drawing that should require HE review. As their name implies, these drawings are used to describe and eventually to control proposed interfaces between components, subsystems, or different contractors' equipment items. Vision plots and reach envelopes are two additional types of drawings of particular interest to HE (see 8.5.3 and 8.5.4). In today's concurrent engineering environment, CAD engineering drawings should be readily available for timely checks of design progress. Such checks will help prevent effort from being spent on designs that will not permit good human interface.

8.5.2.2 Procedure. Generally, HE practitioners use engineering drawings to review design concepts. However, the HE group may actually prepare engineering drawings for their own use and the use of others. For HE to develop engineering drawings, the proper resources must be

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available, including drawing equipment and the skills of engineers, drafters, or industrial designers. The following should be noted:

a. The preparation of workspace layout drawings requires skill in descriptive geometry. The HE practitioner must be able to project views and cross sections of the workspace geometry and the human subject into various auxiliary planes, which often are not parallel to the normal planes of the three-view orthographic engineering drawings. Also, for visual clarity and understanding, perspective drawing methods should be understood and used. The ability to mentally visualize the geometry of workspace layouts and to accurately prepare drawings depicting the interface relationships can save time and effort during mockup studies.

b. More normally, HE practitioners use engineering drawings developed by project design personnel. Of course, HE practitioners must be sufficiently knowledgeable about standard drawing practices to understand the information being presented. HE design criteria checklists (8.5.1) may be used along with fractional-scale plastic manikins (8.5.7) to verify the HE adequacy of the design. Once this adequacy has been ensured, the drawings should be approved to indicate their compliance with HE design criteria.

8.5.2.3 Use. If HE practitioners have prepared the engineering drawings, then it is assumed that the drawings incorporate all appropriate HE design criteria and that HE approval is automatically provided. If the drawings have been prepared by other project engineering personnel, HE practitioners should thoroughly review them to ensure that appropriate HE design criteria have been included. The HE design criteria checklists should be used at this time. Completion of the checklists will provide justification for HE approval (or lack of approval) of the drawings. In addition to providing a means for HE to verify the design, engineering sketches and drawings specify the detailed design of the hardware item. They furnish a baseline configuration record (see 6.3.4, 6.7.3, and 7.3.5), they provide inputs to initiate mockup construction, and they supply manufacturing with the necessary data from which to produce the hardware product. Table XII shows several applications for drawings.

8.5.2.4 Comparison to other methods. Table XI provides a comparison between drawings and other design and development methods.

8.5.3 Visibility diagram. The vision plot or visibility diagram is a special diagram that shows the visual envelope of a specific system operator or maintainer. This method is critical to the process of display layout, since it clearly shows obstructions and other problems in the visual field or viewing envelope.

8.5.3.1 Description. The visual envelope can be analyzed by providing multiple views of the operator or maintainer in front of the console, equipment, or other instruments and controls. However, rather than showing the side, top, or front view, the visibility diagram shows the actual field of view from the operator's eye reference point (ERP).

8.5.3.2 Procedure. The HE practitioner, drafter, or CAD operator preparing engineering drawings works from the two- or three-view orthographic drawing of the operator or maintainer

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workstation. Using descriptive geometry, the HE practitioner measures the angles from the ERP to significant items shown in the orthographic drawing. Windows, instruments, or controls are generally the primary items of interest in the visibility diagrams. The angles to several points on each of the significant items are measured and plotted to approximate the shape of the item. All straight lines shown on the orthographic projection (with the exception of vertical lines and lines within the horizontal plane through the ERP) will be plotted as curved lines. Straight lines below the horizontal plane will curve up, and lines above the plane will curve down. Software is now available to construct visibility diagrams on computer.

8.5.3.3 Use. Visibility envelopes are useful in assessing what users can and cannot see. They are extremely critical in cockpit or flight deck design for determining where window posts are located with reference to the pilot's view of the runway at various landing approach geometries. While in new aircraft design aerodynamic considerations tend to dictate the use of flat, smooth surfaces around the cockpit area, the configuration cannot violate the pilot's minimum visual requirements as described in military specifications. Likewise, when maintainers need to visually inspect equipment items, the visibility diagram helps identify awkward or impossible maintenance tasks due to visual accessibility limits. The visibility diagram provides a technique for comparing the design to the specification. It also provides a record of the system design and generally eliminates the expense of constructing preliminary mockups, which would otherwise be required just to evaluate operator vision. Table XII shows additional applications for visibility diagrams. Finally, it is important to understand that the specific technique described above for developing vision plots and visibility diagrams was developed for aircraft crew stations and may not be readily adaptable to other types of vehicles, such as tanks, trucks, or ships.

8.5.3.4 Comparison to other methods. Table XI compares visibility diagrams to other design and development methods.

8.5.4 Reach envelope. A reach envelope drawing shows the envelope within which controls must be located to be successfully reached by the operator or maintainer. This knowledge helps ensure that system and equipment designs accommodate operators and maintainers.

8.5.4.1 Description. Until recently, the operator or maintainer was generally described as one with a 5th percentile functional reach. Current bimodal male-female population data bases may not include sufficient data to calculate the lower limit percentile for determining the desired reach envelope. Reach envelopes vary for the 5th percentile operator or maintainer for known populations. This is because of variations in seat design and shoulder and lap constraints, or equipment adjustability. Reach envelopes are also developed and used for overhead reach and for reach in various other body postures, such as lying prone under a tank to perform maintenance.

8.5.4.2 Procedure. Reach envelopes are developed by modifying or adapting existing data or collecting new data. Functional reach is the parameter of primary interest. Functional reach measurements are made with the tips of the subject's thumb and forefinger pressed together. Secondary parameters such as shoulder height are also of interest and are combined with functional reach measurements to provide the total reach envelope data. Appropriate combined

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reach data are available in MIL-HDBK-759 and other sources. Automated anthropometric tools are available that provide population data which can be used with CAD drawings (see the Directory of Design Support Methods at the MATRIS home page.) If, because of peculiarities in a given new seat design or operator restraint system, it is not possible to use existing data, then new data can be collected. To develop new data, the HE practitioner must assemble a group of subjects of the appropriate sizes and numbers to match the user population and must obtain a sample of the seat to be used in the new system. The following aspects of the procedure should be noted.

a. Reach capability data must be collected for each of the subjects under various conditions, such as with and without a pressure suit, at different seat back angles, and with and without a shoulder restraint; data must also be collected in various directions and at various heights in relation to the seat reference point (SRP) or ground reference plane. Once the data are obtained, statistical distributions of reach data may be plotted and a percentile curve or statistical estimate may be selected and prepared.

b. Reach envelope drawings are then plotted and overlaid on drawings of the console or cockpit. The SRP or other hardware reference is necessary to establish where the reach envelope should be located.

c. Examination of two or more different orthographic views of the control panel hardware with the reach envelopes overlaid will show if the necessary controls are within the operator's reach or if the controls and the operator must be moved closer together.

8.5.4.3 Use. Reach envelope drawings are important for accommodating design of consoles, cockpits, and other workstations, particularly if the operator is restrained and the console is large with side wraparound panel areas or vertical panel areas that project above the eye reference point (ERP). Effective use of reach envelope drawings will avoid later mockup construction efforts. Engineering drawings and sketches may be validated prior to the development of mockups and prototype hardware. If properly presented, reach envelope drawings may be easily understood by non-HE personnel and can be very useful as a part of hardware design review presentations. Table XII shows several applications for reach envelope drawings.

8.5.5 Mockup. A mockup is a large-scale, proportioned model of the final equipment, subsystem, or system used for validation of layout. Mockups are extremely valuable for depicting three-dimensional relationships that would otherwise be difficult to represent before the system goes into manufacture. It is now possible to generate computerized (virtual) mockups from CAD drawings.

8.5.5.1 Description. Mockups can contribute significantly to the development of the human-machine system. They should be considered as tools for evaluating the system design before the actual manufacture of system hardware. There are three basic types of physical mockup, which are described in the following paragraphs. In addition, virtual mockups can now be generated directly from CAD environments.

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8.5.5.1.1 Class I. A class I mockup is used primarily for determining basic shape, allotting space, proving concepts to familiarize personnel with the basic design of the system or equipment, or presenting new ideas. Such a mockup is usually made of inexpensive materials (heavy cardboard, cardboard with a foam core, fiberboard, low-grade plywood, etc.) and is proportionally but not dimensionally accurate unless such accuracy is specifically requested. Unless otherwise specified, the complete structure is not simulated (e.g., hidden structure is not included; repetitive elements are simulated using skip spacing, such as by showing every other or every third element). Internal components are represented by actual small items of hardware or by cutouts of drawings or photographs of the items. The external dimensions of the mockup are usually not critical. Internal dimensions having to do with workspace design, displays, and controls should be reasonably precise. Mockup plans can be sketches, development layouts, coordination sheets, or oral descriptions.

8.5.5.1.2 Class II. A class II mockup is used primarily to assist in the development of the system/equipment detail design and as a demonstrator for customer evaluation. It is constructed from a good grade of wood, metal, or plastic. Overall dimensions and sizes of parts, features, etc., are as close to drawing tolerance as practical. The locations of features and parts and the spacing of frames, stringers, etc., are held to drawing tolerances. All structure is simulated except hidden parts that would be inaccessible after the mockup is completed. In hidden areas, accuracy is not maintained; instead of frames, stringers, etc., simple braces for strength are used. Installations and materials in critical areas follow mockup drawings. If operational hardware is desired, the degree of operation must be specified. The number and type of operations that may be provided vary widely. The more complex mockups differ little from simulators. Mockup plans can be sketches, layouts, or coordination sheets.

8.5.5.1.3 Class III. A class III mockup is primarily an engineering/manufacturing/ simulation vehicle or facility and is used to plan the layout of plumbing lines and wiring runs, to determine the size and installation of systems or equipment, and to prove out all installations prior to actual production. Such a mockup is normally constructed after production contracts have been negotiated and the number of contracted items is sufficient to warrant the expense. It is usually constructed of production type materials, metal, plastic, or a good grade of wood. Structural items and external features of installed equipment (e.g, black boxes, pumps, actuators, etc.) are made to production tolerances and are of production materials, except where material substitution is authorized. Internal features of installed equipment are not required. All attachments, wiring, connectors, plumbing, and other hardware must be identical to that defined on the production drawings except where deviations are authorized. Actual equipment is used whenever specified or whenever practical. Mockup drawings can be released production drawings and/or completed layouts.

8.5.5.2 Procedure. Mockups should be made initially with the easiest to use and cheapest material possible. Consoles, racks, and even complete workstations or cockpits can be constructed quite easily from various thicknesses of foam-core cardboard sheets using a sharp matte knife and a hot glue gun. Console panel layout drawings may be simply glued to the foam-core cardboard to simulate displays and controls. Test participants or evaluators may simulate

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display reading or control actuation by simply touching the drawing and performing the appropriate hand (foot) motion. As the system design progresses and mockup tolerances become more critical, plywood material should be used. Plywood is more rigid and durable than foam-core cardboard, although considerably more costly. Plywood mockups may be converted from a static to a dynamic representation of the system. Console panel drawings that were glued to the plywood may be replaced by the actual displays and controls.

8.5.5.3 Use. Mockups can be used in the design of wiring, cabling, pipe runs, and duct work so that three-dimensional problems can be visualized. Operator and maintainer reach, handling, and manipulation distances, as well as clearance spaces, access openings, and visual envelopes, can be determined from mockups and the results compared with system design requirements. Photographs, videotapes, or motion pictures may be made using the mockups to provide coordination aids and maintain records. It is cheaper to develop a static mockup or even a functional mockup, which includes the proposed electrical wiring, than it is to build prototype hardware with numerous design errors. A functional mockup makes it possible to study the performance of personnel in simulated operational situations. The HE practitioner can thus evaluate the operational characteristics of equipment in terms of human performance. More realistic lighting and sound measurements can be taken. Procedures can be verified. Test participants can be observed and interviewed with much greater confidence in the validity of their responses. In addition to all the above, mockups—along with photographs, video tapes, or movies—serve as an aid in designing presentation reviews and, later, in training system development. Table XII lists some of the applications of mockup construction.

8.5.5.4 Comparison to other methods. Table XI provides a comparison between mockups and other design and development methods.

8.5.6 Scale model. Occasionally, when the fabrication of a full-scale mockup of hardware or facilities would be too elaborate or too expensive, a scale model is used in its place. Unfortunately, scale models are of much less value for HE because of the lack of good HE evaluation tools, such as three-dimensional scale-model manikins. Scale models are more easily transported and stored than mockups. Scale models can be helpful in performing some logistics analyses, but are not very useful, for example, for conducting compliance reviews using design criteria checklists.

8.5.7 Manikin. A manikin is a figure or template representing the physical dimensions of the human body. Two-dimensional manikins are useful in evaluating initial operator or maintainer accommodation in the early part of the design process before costly mockups are created. A 5th percentile manikin would be useful in examining reach issues, while a 95th percentile manikin could assist in evaluating clearance issues. Sophisticated three-dimensional manikins are now used in crash tests to determine the forces exerted on the human body in alternative designs and when wearing safety equipment. Also, virtual manikins that instantly adjust percentile sizes are available in CAD environments.

8.5.7.1 Description. A useful tool for evaluating engineering drawings and sketches is the two-dimensional articulated Plexiglas manikin. A set of these manikins may be obtained or

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prepared in a range of body sizes and scales for use by HE or project design groups. They are usually made to represent two-dimensional anthropometric aspects of humans as seen from the side. For maximum flexibility, a large number of sizes, shapes, and scales corresponding to common scales for engineering drawings (e.g., 1/10 and 1/4 scale) will be required. Software (virtual) manikins are also available and can be used with CAD drawings to determine how well various body sizes are accommodated by the design.

8.5.7.2 Procedure. Plastic manikins are used by placing them in the workspace positions indicated on engineering drawings and articulating the figures into various reasonable positions to check for interference, verify access clearances, or confirm successful reach. To a limited extent, manikins may be used to check visual envelopes. If the user population percentiles that must be accommodated are known (e.g., 5th through 95th percentile males and females), then the appropriate manikins (5th and 95th percentile male and female manikins) should be used to determine if the design is compatible with anthropometric parameters represented by the specified population subgroup. Because the manikins are made of clear plastic, it is easy to see the amount of overlap if the manikin's dimensions exceed the space provided on the scaled drawing. Virtual manikins are integrated into the CAD environment and can be displayed with electronic drawings of the equipment or system component to assess fit.

8.5.7.3 Use. Frequently, manikins are used by engineers, drafters, or CAD operators to illustrate a drawing with sketches of various-sized personnel in different critical positions. Plastic manikins can serve as a template around which the engineer or drafter traces to draw the outline of a properly scaled person in the desired articulated position on the drawing. The use of manikins is most worthwhile during drawing preparation and evaluation. While a full set of plastic manikins or the software for virtual manikins may cost from several hundred to ten thousand dollars, their use tends to recoup this investment by ensuring proper initial design of mockups and prototype hardware so that expensive redesign is avoided. Manikins do have limitations. They cannot possibly be completely and properly articulated, and therefore provide only an approximate tool. Manikins alone cannot be used to determine precise design compliance or deviation from criteria. Other forms of manikins, such as full-scale three-dimensional manikins, have been developed for use in the design of escape systems and other systems and equipment employed under hazardous conditions. Their use is more appropriate to the T&E phase of HE activities than to the design support phase. Table XII suggests possible applications for manikins.

8.5.7.4 Comparison to other methods. Table XI provides a comparison between manikins and other design and development methods.

8.5.8 Specification. A specification is a document used in development and procurement that describes the technical requirements for a system or item of equipment, including the procedures for determining that the requirements have been met. Clearly stated specifications are desirable to both the contractor and the customer, since they will help eliminate misunderstandings between parties in the contract.

8.5.8.1 Description. One of the most important methods for ensuring the adequacy of HE design in a system is to include applicable human performance requirements and HE design

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criteria in the system specification, item specification, and software specification (see MIL-STD-961).

8.5.8.2 Procedure. The HE practitioner should ensure that applicable human performance requirements and HE design criteria are incorporated into each appropriate specification. Appendix D lists some relevant standards and handbooks with cross-references to the applicable service. Because it is self-tailoring, it is reasonable to reference MIL-STD-1472 in the specifications, as applicable. Program-Unique specification preparation guideliners appear as Appendix A of MIL-STD-961.

8.5.8.3 Comparison to other methods. Table XI provides a comparison between specifications and other design and development methods.

8.5.9 Computer-aided design (CAD) environment. Today's computer-aided design environment features the use of automated drafting tools to assist in creating and modifying an engineering design. CAD tools allow project teams to distribute and update designs easily, perform rapid prototyping, and generate electronic mockups. The benefits of the CAD environment include:

- *Portability and transmissibility*. Design changes can be sent to geographically separated design team members in minutes or hours, instead of days.
- *Concurrent evaluation.* Several design alternatives may be evaluated at once, since CAD allows multiple versions of a design to be created much faster and at much less expense than with pen and paper drawings; design changes can also be accomplished easily and rapidly.
- *Storage and reuse*. A design may be stored and individual parts of the design may be retrieved for later use in similar systems with no need for redrafting.
- Because of these advantages, the use of CAD tools in an electronic environment is the keystone of the concurrent engineering and IPT process.

8.5.9.1 Description. CAD tools provide the HE practitioner with an environment conducive to evaluating human-system interface capabilities and accommodations. Before the advent of reliable and easy-to-use CAD tools, analysis of the human-system interface was costly and time-consuming. CAD tools and models allow the HE practitioner to assess and, if necessary, modify system designs early in the design process, before physical mockups or prototypes are created. Because HE practitioners can use CAD tools to perform an initial ergonomic analysis of most design features (e.g., reach analysis, vision analysis, predictive strength analysis), they are able to respond quickly to design modifications from a concurrent engineering team or IPT. Such early HE input can reduce the need for costly rework and avoid situations where personnel must accommodate to a suboptimal system design.

8.5.9.2 Use. With CAD, all initial prototypes are maintained in electronic format, so the engineering team can make rapid changes to the prototype design without re-creating expensive physical mockups. Most initial HE testing regarding physical dimensioning and layout can now be done in the CAD environment. Several human modeling tools are available that allow the HE practitioner to test anthropometric measurements against most physical aspects of the system in

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the electronic mockups before a physical prototype is created. The following are a few of the analyses the HE practitioner can now perform using CAD software packages:

- *Body size analysis*, using male and female anthropometric databases that provide HE practitioners with a complete range of human body sizes that otherwise may not be accessible for testing.
- *Reach envelope analysis* (based on anatomical link data and data on joint mobility limits), to evaluate the placement of controls and other objects with respect to the operator. (Figure 31 shows a sample reach envelope analysis using an electronic human model.)
- *Visual field analysis* to check for visual obstruction due to protective equipment or physical components of the system (e.g., objects hidden by frame members).
- *Accessibility analysis* to evaluate, for example, whether enough clearance has been provided for tool access to the required parts, whether an area is large enough for projected operator or maintainer movements, or whether ingress and egress openings are large enough for whole-body access.
- *Strength analysis* to ensure that operators or maintainers can generate sufficient forces and torques in the necessary postures. For a more in-depth discussion of the types of analyses that may be accomplished using human CAD models, see McDaniel (1997).

8.5.9.3 Comparison to other methods. CAD is a work environment, rather than a method per se. As should be apparent from the preceding paragraph, most of the other design and development methods described in this subsection can now be implemented on computer in a CAD environment. Table XI provides a formal comparison between CAD and other HE design and development methods.

8.6 HE during test and evaluation. To verify the human-system interface for equipment or software, to identify and resolve HE problems in system design, and to gather data for use in design of later systems, a concerted HE T&E effort must be accomplished. The general HE T&E process is described in 7.3.10.3. The following two paragraphs describe ongoing HE T&E activities and responsibilities. Methods used in accomplishing these efforts are reviewed in 8.7.

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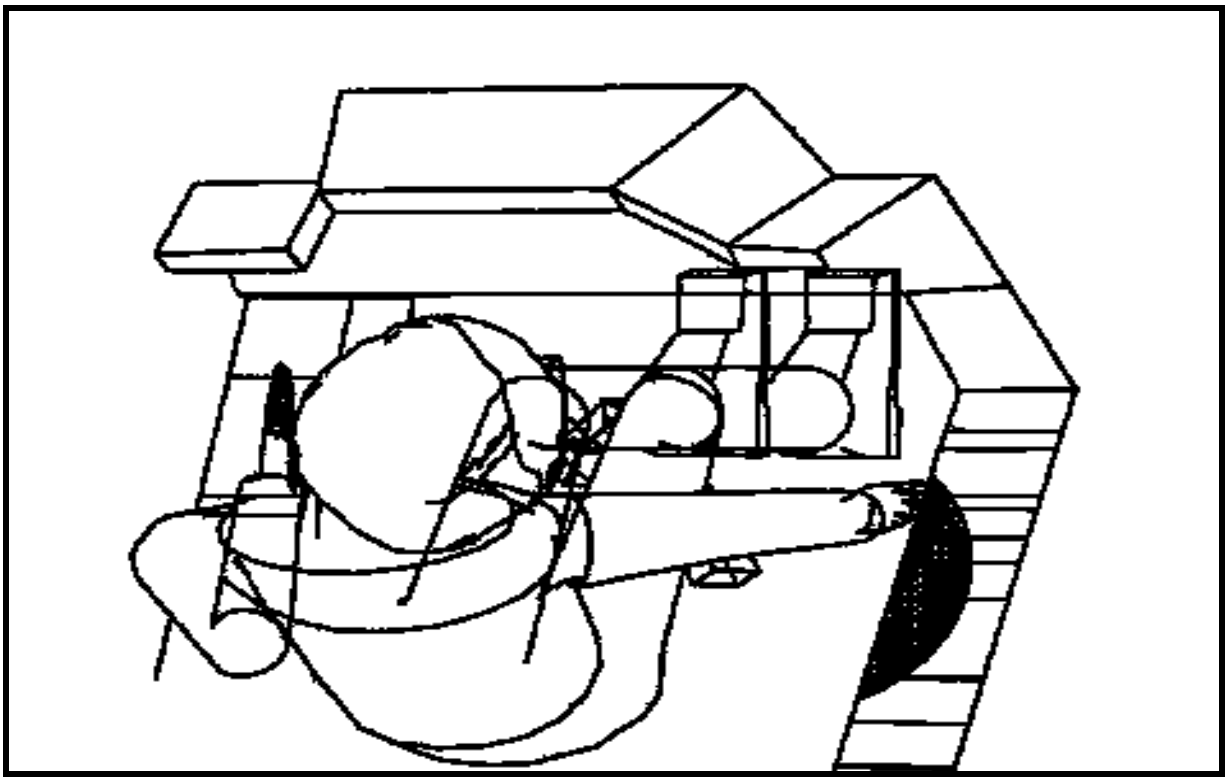

FIGURE 31. Reach analysis using COMBIMAN, a computerized model of a seated operator/pilot (sample).

8.6.1 HE T&E activities. The first major T&E activity is careful planning. This planning involves converting operational requirements found in the MNS and ORD into test objectives. Major objectives are often called critical operational objectives (COIs). COIs are measured by corresponding MOEs and MOPs. Development of a complete and well-planned TEMP is critical to T&E functions. Selection of representative critical versus noncritical tasks is important for identifying the priority of items for HE-related tests. Personnel who are to be used for the tests must be representative of the intended military user population in terms of skill, size, and strength. They should be wearing appropriate field garments and equipment when performing the selected tasks. Test data must be collected in an objective and complete manner. Discrepancies between required human performance and the performance actually achieved under field test conditions must be analyzed to determine whether the deficiencies are due to procedures or design. When failures occur, error analysis should isolate failures resulting from human-system incompatibilities from those due to random human error. Significant human-system-related errors are recorded on Army TIRs, Navy yellow sheets, or Air Force deficiency reports, and may result in ECPs, when appropriate.

8.6.2 HE T&E responsibilities. During the T&E stage of system development, the HE practitioner has the following important responsibilities:

- Ensure that applicable HE T&E requirements are adequately traced to operational requirements (e.g., the ORD), and that appropriate tests for these items are planned and appropriately accomplished;

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- Ensure that important aspects of HE performance are scheduled for adequate testing in time to impact system design decisions;
- Demonstrate conformance of the HE aspects of system design to the system, equipment, and facility design and performance criteria where the operator, maintainer, or supporter is a significant part of such system performance;
- Ensure that quantitative measures of system performance are used to test human interaction with equipment;
- Validate human performance requirements;
- Determine if undesirable design or procedural aspects have been introduced.

8.7 HE T&E methods. Many of the most frequently used T&E methods are presented in the following paragraphs. In addition to these T&E methods, some of the analysis or design and development methods described in 8.3 and 8.5 may also be used to assist with T&E tasks. One important analysis method that is often used in T&E is workload analysis. As is the case with analysis and design methods, only a few of the T&E methods would be used for a given program. Table XIII compares the various T&E methods along several dimensions. Table XIV shows typical applications for the data obtained from their use.

8.7.1 Continuous direct observation. Continuous direct observation is simply the process of taking a relatively continuous record of a task or work activity or some other component of the test program. This observation activity provides the HE practitioner with data regarding the system design that has been collected in a real-world environment. Such data afford insight into system flaws and strengths and provide evidence and justification for system modification proposals.

8.7.1.1 Description. In continuous direct observation, an observer may keep a running log or description of the test activity as the observer understands it. The data may be recorded by hand, or one of the more sophisticated methods or tools may be used for recording events and times. Automatic recording methods such as still photography, movies, sound recording, or video recording may also be used in conjunction with direct observation (see 8.7.11–8.7.14).

8.7.1.2 Procedure. The observer should be skilled at discriminating what significant events occur during the test and should be competent in the operation of the equipment used (e.g., zoom lens, boom mike, etc.). Significant events should be summarized and interpreted for later action. The observer must be familiar with the anticipated human-machine system performance. Test participants will be observed while they are using either mockups or actual hardware. The observer should be particularly interested in obtaining data on operator task performance times and errors. Data regarding the observer's estimates of participants' training, skills, and numbers of personnel should also be recorded. Life-support, safety, and hardware design criteria may also be observed. Since the direct observation method relies on the use of mockups or hardware, the most appropriate time to employ this method is after the system concept has evolved sufficiently to the point that three-dimensional mockups are available.

8.7.1.3 Use. Observation is one of the most common methods of evaluating personnel and system performance. It is used to some extent in some form in all T&E. Despite the increasing use

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of automatic recording devices, the requirement for direct observation will never be completely eliminated. Observation may be used on any portion of a total system, a subsystem, or system components. It is useful for T&E of both single task performance and the simultaneous operation of several tasks by several test participants. It is simple to perform in comparison with other T&E methods. During the conduct of the test, it is possible for the observer to do more than simply record test occurrences. The observer may evaluate test data to make possible recommendations or suggest test action items. If direct continuous observation is not used, there is a risk of missing an overall impression of the test as well as random test events or details. Some applications for continuous direct observation are shown in Table XIV.

8.7.1.4 Comparison to other methods. Table XIII provides a comparison between this method and other T&E methods. One of the disadvantages of using this method is the need for specialized observers for each different aspect or category of the test. It is seldom possible for a single observer to learn enough about all aspects of the system to do an adequate job of observing all system tests. The use of continuous observation implies that some periods of test observation are not productive in terms of gathering HE T&E data.

8.7.2 Sampled direct observation. This method is identical to continuous direct observation except that the HE practitioner observing the test spends less time. With sampled direct observation, the observer collects data only during the times that critical system functions are being performed. This method is valuable to the HE practitioner for the same reasons that direct continuous observation is valuable. Although less observer time is required during data collection with sampled observation, the fidelity of the data is not as high as with continuous observation. Nevertheless, in situations where time is at a premium or there are long periods of relative system inactivity, direct sampled observation can be a useful method.

8.7.2.1 Description. In sampled direct observation, the particular times chosen to perform the observation should, of course, coincide with the times during which critical or problematic tasks are being performed. Task analysis can assist in identifying critical and problematic tasks. If current system task analysis data are not available, critical and problem tasks can also be identified using the system analysis for the program's predecessor system. If the critical tasks cannot be determined by either method, then a “best guess” sampling technique (choosing sample periods based on suspected problem areas identified from the predecessor system) may be used.

8.7.2.2 Use. The uses of sampled observation are similar to those for continuous observation. The differences between the two relate to cost savings and the risk of missing significant T&E data. It stands to reason that, if tests are not observed continuously, test observers may be used to carry out other HE T&E tasks on other tests or perform data reduction and evaluation for previously conducted tests. The number of personnel required to perform HE T&E may be cut by a factor of one-half or more. The disadvantage of the sampling method is that there is a risk of missing important operator performance data or other important HE-related data. If critical tasks cannot be predetermined, test sampling should be performed with relative frequency. Each basic category or type of operator/equipment task should be observed several times to prevent skewed data. Table XIV shows some general areas of application for sampled direct observation.

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8.7.2.3 Comparison to other methods. Table XIII compares sampled direct observation and other T&E methods.

8.7.3 Specification compliance summary sheet. The specification compliance summary sheet is a form used to verify that system performance is in accordance with specified system and human performance requirements, and HE design criteria. This method is useful because it gives the HE practitioner a means of quantifying noncompliance problems. Specification compliance summary sheets are an excellent means of quantifying and documenting customer expectations for the system.

8.7.3.1 Description. Briefly, the total process of verifying compliance with human performance and HE specifications is as follows: (a) decide the best method to use in verifying the specification requirement (i.e., analysis, demonstration, inspection, measurement); (b) perform the analysis test; and (c) document the results. In all cases, reports are written describing the analysis or test results. The specification compliance summary sheet is a way of summarizing the compliance or lack of compliance with requirements.

8.7.3.2 Procedure. The HE practitioner/evaluator first needs to have a thorough knowledge of all HE aspects of the contract statement of work and the accompanying system specifications. In particular, the practitioner should understand the specification Section 4 requirements (quality assurance/testing).

8.7.3.3 Use. This method is used by only a few HE T&E organizations. However, this lack of use is not an indication of a lack of need for this type of evaluation. The contract and related system specifications are by far the most important program requirements. This method is unique in that it zeroes in on these important requirements, rather than concerning itself with T&E of indirect system requirements. Some of the applications for which this method can be used are listed in Table XIV.

8.7.3.4 Comparison to other methods. Table XIII shows a comparison of this method to other T&E methods. The specification compliance summary sheet is an excellent way to verify the specification requirements. The only disadvantage associated with the use of this form is the large amount of time required to fill it out. The effort preceding the use of this form may be considerable, but that effort is part of the already existing HE T&E program. If this method is not used, there is a risk that some important aspect of HE design criteria may be overlooked both by designers and by test observers.

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TABLE XIII. T&E methods selection chart.

| | SELECTION EVALUATION CHARACTERISTIC | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Most applicable program phase | | | | Relative complexity | | | Relative time to perform | | | Relative cost | | | Relative cost effectiveness | | |
| HE T&E METHOD | Concept | Program Definition | EMD | Prod/Dev/Ops | Simple | Average | Complex | Short | Medium | Long | Low | Medium | High | Low | Medium | High |
| 1 Continuous direct observation | | X | X | | X | | | | X | | | X | | | X | |
| 2 Sampled direct observation | | X | X | | X | | | X | | | X | | | | X | |
| 3 Specification compliance summary sheet | | X | X | | X | | | | X | | | X | | | X | |
| 4 Technical manual function evaluation | | X | X | X | X | | | | X | | | X | | | X | |
| 5 HEDGE | | X | X | X | X | | | | X | X | | X | | | X | X |
| 6 Environment and engineering measurement equipment | | X | X | X | | X | | X | X | | | X | | | X | |
| 7 Systems records review | | X | X | X | X | | | | X | X | | X | | | X | |
| 8 Test participant history record | | X | X | X | X | | | X | | | X | | | | X | |
| 9 Interview | X | X | X | X | | X | | | X | | | X | | | | X |
| 10 Questionnaire | X | X | X | X | X | | | | X | | | X | | | | X |
| 11 Motion pictures | | X | X | | | X | | | X | | | | X | X | X | |
| 12 Sound recording | | X | X | | X | | | X | | | X | | | X | | |
| 13 Video recording | | X | X | | | X | | | X | | | | X | | X | |
| 14 Still photography | | X | X | X | X | | | X | | | X | | | | X | |
| 15 Event recording | | X | X | | | X | | X | X | | X | X | | | X | |
| 16 Secondary task monitoring | | | X | | | | X | | X | X | | | X | X | | |
| 17 Physiological instrumentation | | | X | | | | X | | X | X | | | X | X | | |
| 18 Physical measurement | | X | X | | | X | | | X | | | X | | | X | |
| 19 Online interactive simulation | | X | X | | | | X | | | X | | | X | X | X | |
| 20 Statistical analysis | | X | X | | | X | X | | X | X | | X | | | X | |

Note: Information for the above items was collected in 1986 and may be dated or not applicable if automated techniques are used.

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TABLE XIV. Application areas for T&E methods.

| HE T&E METHOD / APPLICATION | Concept formulation ideas | Detailed design requirements | Personnel requirements information | Operational procedures development | Training systems development | Maintenance system development | System operational evaluation | Additional human factors analysis |
|---|---|---|---|---|---|---|---|---|
| 1 Continuous direct observation | X | X | X | X | X | X | X | X |
| 2 Sampled direct observation | X | X | X | X | X | X | X | X |
| 3 Specification compliance summary sheet | | X | | | | X | X | |
| 4 Technical manual functional evaluation | | | | X | | X | X | X |
| 5 HEDGE | | X | | | | X | X | |
| 6 Environmental & engineering measurement equipment | X | X | | | | | X | |
| 7 System records review | | | X | X | X | X | X | X |
| 8 Test participant history record | | | X | | X | | X | X |
| 9 Interview | X | X | X | X | X | X | X | X |
| 10 Questionnaire | X | X | X | X | X | X | X | X |
| 11 Motion picture | X | X | X | X | X | X | X | X |
| 12 Sound recording | X | X | X | X | X | X | X | X |
| 13 Video recording | X | X | X | X | X | X | X | X |
| 14 Still photography | X | X | X | X | X | X | X | |
| 15 Event recording | X | | | | | X | X | X |
| 16 Secondary task monitoring | X | | X | | | | X | X |
| 17 Physiological instrumentation | X | | | | | | X | |
| 18 Physical measurement | X | | X | | | | X | X |
| 19 Online interactive simulation | X | | X | X | X | | | X |
| 20 Statistical analysis | | X | X | | | | X | |

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8.7.4 Technical manual functional evaluation. As its title indicates, this method is designed to evaluate technical manuals or publications pertaining to the test. This method ensures the HE practitioner that the technical manual or publication meets the criteria established for it. Since technical manuals are critical for effective system operation and maintenance, and since they are a prime tool for the operator and maintainer, it is critical for HE to determine if they describe procedures in a way that enables the user to comprehend clearly what is to be accomplished.

8.7.4.1 Description. In this method, test observers complete a form assessing the technical manual while they are performing their other direct observations of the test. This form evaluates the usefulness and adequacy of the technical publication in the following three areas:

- job instructions,
- training, and
- job performance aids.

Job instructions describe how to accomplish a task by providing step-by-step procedures along with the necessary illustrative drawings. Most technical publications that require validation or verification provide support for training. There are three major types of job performance aids:

- *Job guides* (including inspection guideline manuals). These guides contain instructions for fixed-procedure tasks such as checkout, adjustment, removal, and replacement.
- *Fully proceduralized troubleshooting aids* spell out the steps to follow in isolating malfunctions to a replaceable or repairable unit. The steps start with observable symptoms of malfunction.
- *Troubleshooting decision aids* provide diagrammatic and supporting textual information that will help the technician decide what steps to take in isolating malfunctions to a replaceable or repairable unit.

The sample evaluation form shown in Figure 32 is structured so that the first three questions in the evaluation section require two judgments: one regarding how the section being evaluated can be classified and the other regarding its adequacy. The two questions are to be answered by the test evaluator or observer, as well as by the test participants. The remaining questions (4 through 7) deal with the qualitative characteristics of the technical manual.

8.7.4.2 Procedure. Most sections of the form are self-explanatory; however, the sections listed below should be completed as indicated:

- *Evaluator:* Identify the individual(s) interviewed or those contributing to the evaluation.
- *Paragraphs or sections evaluated:* List only those paragraphs for which the evaluation applies. In some cases, paragraphs can be grouped in large blocks.
- However, there will be some cases where several separate forms will have to be completed.

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- *Publication verification personnel requirements*: When verification is performed, the name and rank or paygrade as well as skill specialty code (SSC) of the participants is required.

Prior to conducting this type of evaluation, the observer or evaluator must have knowledge of the technical manual to be evaluated. The evaluator must also be familiar with estimated system and operator/maintainer performance. The total technical manual functional evaluation process will result in either verification of the technical data or revisions or recommendations for new technical data. These revisions will be coordinated with the publications writers.

8.7.4.3 Use. Depending on the scope or charter of the HE T&E effort, technical manual evaluation may or may not be performed. If it is performed (by HE practitioners), it may be accomplished at any time during the evaluation of an evolving system (as opposed to a future or existing system). The effort required to perform this evaluation is relatively low. Failure to perform the evaluation can result in maintenance and operational mistakes that would otherwise have been avoided. The cost to perform the evaluation must be considered relatively low, particularly compared to the potential cost of the mistakes. General areas of application for technical manual functional evaluation are listed in Table XIV.

8.7.4.4 Comparison to other methods. Table XIII shows a comparison between technical manual functional evaluation and other T&E methods.

8.7.5 Human Factors Engineering Data Guide for Evaluation (HEDGE). HEDGE is a comprehensive T&E procedural manual that can also be used as a T&E method. HEDGE provides the HE practitioner with explanations of methods and sample checklists for evaluating system design and performance.

8.7.5.1 Description. HEDGE is designed to assist the HE practitioner in the areas of test plan preparation, test conduct, test data evaluation and analysis, and test report preparation. HEDGE consists of two documents: the first contains detailed HE test data; the second is a guide book supplement that provides specific HE design criteria. HEDGE is fully described in the technical report of the same title issued by the U.S. Army Test and Evaluation Command (Carlow Associates, 1990). HEDGE has also been automated (see MATRIS web page for details).

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## TECHNICAL MANUAL FUNCTIONAL EVALUATION

Assess the usability of the identified paragraphs for instructions. training, and/or job performance aids *(see instructions on reverse side).*

Publication Number:_____ Title:_____

Evaluator:_____ Date: _____

Paragraphs or sections evaluated: (*give number and subject*}

_____ _____
_____ _____
_____ _____
_____ _____
_____ _____
_____ _____
_____ _____

*Note: paragraphs or sections covered should be consecutive and grouped so that answers given apply to all paragraphs listed.*

| PUBLICATION NAME | VERIFICATION | PERSONNEL NAME | REQUIREMENTS |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Conditions at verification** *(include equipment involved, where performed, etc.)*:

_____

_____

_____

| | **Evaluate on:** | | | If yes, are they adequate? | |
|---|---|---|---|---|---|
| | *(Use Additional Sheets for Comments)* | **Yes** | **No** | **Yes** | **No** |
| 1. | Do the paragraphs constitute job instructions? | | | | |
| 2. | Should the paragraphs be used for training? | | | | |
| 3. | Do they constitute job performance aids? | | | | |
| 4. | Are the steps in logical sequence? | | | | |
| 5. | Do the steps eliminate back tracking as much as possible? | | | | |
| 6. | Did the participants demonstrating the operation experience difficulty as evidenced by errors, slow performance, or need for assistance? | | | | |
| 7. | Are the functions described sufficiently new or complex to require training? | | | | |
| 8. | It is necessary to provide additional background or supplementary information for the user to understand the What? How? When? and Where? | | | | |

FIGURE 32. Technical manual functional evaluation form (sample).

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8.7.5.2 Procedure. The procedure for using HEDGE is a five-step process that is well detailed on the first few pages of the HEDGE manual. The first step is to classify the test item as a vehicle, weapon, electronics, etc. The second step is to identify both the user functions and user tasks related to this type of equipment; in other words, to determine what to evaluate and which criteria to use in the evaluation tests. The third step is to decide what HE considerations and what item components are relevant. The test observer should review the task list and test item design description to identify which of the test item components presented in the matrix apply to the item under test, and which HE considerations are important. The fourth step is to use the matrix to locate the exact test criteria for the identified HE considerations and task item components. The last step is to prepare the HE test plan, which includes an objective (taken from HEDGE), criteria (taken from HEDGE), and methodology (taken from the HEDGE Supplement). The data required also are provided in both the HEDGE and HEDGE Supplement. It is recommended that the test observer be thoroughly familiar with the HEDGE contents before starting this procedure. The end products of the effort should be both an itemized listing of all items with HE-related deficiencies and a general feeling regarding operator acceptance of the hardware item.

8.7.5.3 Use. HEDGE may be used on any program at any time during program evolution. HEDGE is especially valuable because it provides both the basis on which to build an HE checklist (see 8.5.1) and procedures for completing all the rest of the necessary HE T&E planning and test execution. As indicated in Table XIV, HEDGE has broad applicability. No special test equipment is required to employ this method, and it will be useful for any military system. If HEDGE is not used, appropriate HE test planning must be based on other, less coordinated resources.

8.7.5.4 Comparison to other methods. Table XIII compares HEDGE to other T&E methods.

8.7.6 Environment and engineering measurement equipment. Several items of T&E equipment are useful to the HE practitioner/test observer. A few of these measuring devices are described in individual paragraphs, but most are included here. Many of these measuring devices require calibration, and care should be taken to ensure that the equipment has an up-to-date certification of its measurement capabilities. In addition, many adjustments or calibrations are required in the field, and users should be familiar with the operation of the specific instrument before trying to collect actual test data. The following subparagraphs list and define each item of HE test equipment and provide a brief description of their use:

a. *Photometer*. Measures ambient illumination over a range of levels from approximately .005 to 25,000 footcandles. This is an extremely useful tool. It is particularly valuable for verifying specification compliance with light-level requirements. Sophisticated mockups or prototype equipment or facilities are required for its proper use. Most photometers are relatively easy to use.

b. *Spot Brightness Meter*. Measures the brightness of a small area in footlamberts within angles of approximately one degree or less. This tool is most useful for measuring

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prototype hardware display brightness, such as from LEDs or CRTs. Specification compliance may be verified with the spot brightness meter.

c. *Sound Level Meter and Analyzer.* Measures steady-state sound in the approximate range of 10 to 150 decibels for standard weighted noise curves. The analyzer provides octave-band analysis for the more critical speech-range center frequencies. Specification compliance in terms of noise curves and speech interference levels may be verified with this equipment. Possible hazards to test personnel may be checked to avoid exposure to excessive sound levels. Most sound level meters are relatively easy to use.

d. *Vibration Meter and Analyzer*. Measures amplitude and frequency components of complex vibrations. Analyzer may be used to determine amplitudes at selectable frequency bands in a range from 2.5 Hertz to 25 kilohertz. Potential vibration hazards to test participants may be checked before actual test exposure. Specification compliance may also be verified.

e. *Thermometer*. Measures air, surface, or liquid temperature. May provide a digital readout in either Celsius (centigrade) or Fahrenheit. Should include capability for attachment to several temperature sensor probes.

f. *Anemometer.* Measures local airflow in the range of 0 to 1000 feet per minute. This device is most useful for determining crew comfort conditions.

g. *Hygrometer or Psychrometer*. Measures relative humidity by wet and dry bulb thermometer method. This device is also very useful for determining crew comfort conditions.

h. *Gas Tester.* Permits convenient short-term sampling and evaluation of many toxic gases, vapors, and fumes.

i. *Force, Torque, and Dimension Kit*. Various instruments for measuring a wide variety of operator or equipment forces, torques, and distances. The force measurement limits should be from 1/4 ounce to 250 pounds. Torque measurement should range from 1/2 inch-pound to 160 foot-pounds. A tape measure should be capable of measuring distances up to 50 feet. Scales should also allow measurement in centimeters, millimeters, inches, and fractions of inches. A protractor is useful for angular measurement.

j. *Anthropometry Instrument Kit.* Allows measurement of significant body dimensions using the anthropometer, spreading calipers, sliding calipers, goniometer, and tape measure. The measurement of test participants is critical to the evaluation of workspace layouts, particularly when egress and ingress are important considerations. Care should be taken to ensure that proper measurement procedures are followed when obtaining participant anthropometric data.

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8.7.7 System records review. This method utilizes existing system evaluation records for HE analysis and review. The method is particularly useful to the HE practitioner when the system is not located nearby or access to the system is not possible. It also has the advantage of permitting a "blind" or objective evaluation.

8.7.7.1 Description. A number of typical T&E program records exist that HE practitioners may find useful to review. This method is unique, since during system records review, there is normally no direct contact between the test evaluator and the test participants. Analytic skills are needed to identify HE issues and trends from the evaluation records of the system.

8.7.7.2 Procedure. The HE practitioner needs only to obtain permission to review the existing test records or other system data, then they can perform the sometimes tedious task of looking through them. The HE practitioner should, of course, have some knowledge of the system to know what to look for in terms of anticipated human performance. Typically, system records will contain test logs, maintenance records, and debriefing records. The HE practitioner may find data on equipment operation problems, technical publication inadequacies, human-initiated errors, and training inadequacies.

8.7.7.3 Use. This method is best used for gathering human-system performance data. Because the HE practitioner does not actually observe the test, it is doubtful that an adequate evaluation can reliably be made just by reading a verbal description of what occurred. Human performance tests may have to be scheduled to allow for formal observation by HE practitioners. Table XIV shows several applications for this method.

8.7.7.4 Comparison to other methods. Table XIII provides a comparison between this method and other T&E methods. The problem with a review of test records is that they tend not to be designed for gathering HE data. What the practitioner is able to obtain from these records may be misleading. There is significant risk that HE problems that would be readily apparent in direct observation will be unobserved or obscured by other, less important test data. To enhance the value of system records review, the personnel who create these records should be instructed in the value of HE and HE T&E. It is generally agreed that the use of this method is not typically required. It is recommended that it be performed only when direct HE observation is not possible. The debriefing records should be the most useful of all the system records normally available.

8.7.8 Test participant history record. This is not a direct test method but rather a method of ensuring the quality and integrity of the T&E process. In this "method," a form or questionnaire is used to obtain background information on test participants that could be useful in interpreting their performance on the test. It is critical that test subjects are representative of the user population, and this "method" helps document and ensure that participants are, indeed, representative, or to determine that a personnel variable might account for any variance in human-system performance.

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8.7.8.1 Description. The test participant history record form is used to collect data on personnel just prior to participating in the tests, if possible. Otherwise, the form may be completed as part of the post-test interview. The sample form shown in Figure 33 emphasizes the participant's training, experience in systems similar to the one being tested, and participation in previous testing related to the same overall system presently being tested. The form may need to be modified to suit the needs of the particular test situation.

8.7.8.2 Use. In collecting and reporting human subject test data, HE practitioners must comply with the applicable regulations regarding informed consent, privacy, and related requirements. They must ensure that the identity of the subject will not be made available to the public without the subject's consent. The purpose of this form is to aid in evaluating the test data obtained. For example, if the test participant has had little or no experience in performing tasks similar to the ones he or she performs on the current test, and the participant does very well, then the examiner can conclude that the human-system interface being tested has been well designed and developed. If, on the other hand, the participant's performance is poor, the problem may or may not be due to poor human-system interface design. A more experienced test participant will have to be given the same tasks to perform. The time and effort required to complete the form is small. The potential value of having the test participant's significant history is large. General application areas for test participant history records are shown in Table XIII.

8.7.8.3 Comparison to other methods. Table XIII provides a comparison between this method and other T&E methods.

8.7.9 Interview. In the HE T&E interview method, the HE test evaluator simply discusses the test events with the participant in a structured interview. The interview can reveal system inadequacies, which in turn can help the HE practitioner understand critical system design areas and target them for modification.

8.7.9.1 Description. The interview should be structured to ensure that the most information is obtained in the least amount of time. Specific variations on the general interview method may be useful for particular situations. For example, considerable test evaluation data may be obtained from training instructors. They are particularly knowledgeable about the problems students encounter in learning and operating new systems because of inadequacies in system design.

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## PERSONNEL DATA FORM

A. *To be completed by test participant:*

1. Name_____ 2. Date _____

3. Skill Specialty Code (SSC) _____ 4. ID No. _____

5. Crew Position (in the test)_____ _____

6. Months of experience (in tested crew position) _____

7. Height._____ 8. Weight_____ 9. Date of birth _____

10. Length of service _____years, _____months

11. Civiian Education: (a) 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 (circle number of years)

b. Major area (if applicable):_____

B. *To be completed for each participant by test control:*

12. Physical Profile:

| P | U | L | H | E | S |
|---|---|---|---|---|---|
| | | | | | |

13. Aptitude Scores:

| | | | | |
|---|---|---|---|---|
| (a) CO _____ | (b) FA _____ | (c) EL _____ | (d) OF _____ | |
| (e) GM _____ | (f) MM _____ | (g) CL _____ | (h) ST _____ | (i) GT _____ |
| (j) SC _____ | (k) El _____ | (I) Gl _____ | (m) Cl _____ | (n) AD _____ |
| (o) SK _____ | (p) Tl _____ | (q) Al _____ | (r) AP _____ | (s) PA _____ |
| (t) MK _____ | (u) WK _____ | (v) AR _____ | (w) MC _____ | |

14. Latest SSC test score: _____

15. End-of-training test score: _____

16. Minimum performance (a) required: _____ (b) attained: _____

17. List of military schools and courses completed: _____

FIGURE 33. Personnel data form (sample).

8.7.9.2 Procedure.

8.7.9.2.1 General interviewing procedure. The first step in conducting the interview is to develop a format for asking questions of the participants (interviewees). The format may be

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structured like a checklist to ensure that all pertinent aspects of the test are considered. The second step is to select an interviewer who has had experience with the system being evaluated. It is important for the interviewer to have observed the actual test. The next step is to arrange a time to conduct the interview with the test participant. The following general guidance is applicable to interviews.

a. The interviewee should be questioned about the task performed. The interviewee should describe what he or she thinks the test task consists of in terms his or her duties and those of others. The interviewee's perceptions and opinions of the adequacy of the equipment, technical data, logistics, and preparatory training should be obtained.

b. The interview should be conducted as soon as practical after the actual test, ideally within a few hours. To avoid group influences, the interviewer should conduct the interview one on one with a single test participant, if possible, rather than questioning several participants at once. The location selected for the interview should be relatively quiet with a minimum of distractions. The interview should be completed in less than half an hour. Interviews that last longer than this may start to become boring and become an imposition on the interviewee.

c. The HE interviewer must ensure that what is documented are the interviewee's actual opinions on the test situations and not the interviewer's opinion or what the interviewee thinks the interviewer wants to hear. Participants must be ensured that they are not being graded in any way on their responses. The HE interviewer should try to quickly develop rapport with participants. If the participant agrees, a tape recording may be made of the interview. However, even when participants agree, some individuals tend to be intimidated by the use of tape recordings, so caution must be used in this regard.

8.7.9.2.2 Critical incident method. Another type of interview method is the *critical incident method*. The critical incident method consists of a set of procedures for collecting observations of human behavior in a way that facilitates their potential usefulness in solving practical problems. A critical incident is any observable human activity whose purpose and serious effects seem clear to the observer. The five-step procedure can be summarized as follows:

1. determine the general purpose of the activity;
2. develop plans for collecting data on incidents involving the activity and draft instructions to the individuals who are to report their observations;
3. collect relevant objective data;
4. analyze the data; and
5. interpret the data and compare the activity to the statement of requirements.

Gathering the series of incidents consists of inquiry as to the most effective or ineffective behavior (or critical incident) for specified activities or jobs. Although information on the incidents may be collected through interviews, it may also be obtained by written responses. The end product of the interview is a quantity of data (facts, perceptions, and opinions) to be reviewed and evaluated to identify system successes and problems, and present recommendations.

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8.7.9.3 Use. The interview is one of the most important evaluation methods used. It is simple, inexpensive, and fast, and provides considerable flexibility. For every test, there is a certain amount of test data that cannot be obtained through normal observation. Interviews with test participants draw directly on this type of data and on the knowledge of the system experts presently available. Interviews do not require the use of test facilities. They may be conducted at a location remote from the test site. Table XIV shows several applications for the interview method. The following may be of help in conducting interviews.

a. The purpose of an interview is to uncover either objective facts related to the system about which the interviewee has some knowledge, or subjective information, such as perceptions, attitudes, or opinions about how the interviewee feels about some test aspect. The interview must be designed to obtain this information with as much clarity and accuracy as possible.

b. The interview achieves its greatest value from the relationship established between the interviewer and the respondent. In a properly conducted interview, where a genuine rapport is established between the interviewer and the interviewee, it is possible to obtain more detailed and reliable data than from a self-administered questionnaire.

c. One caution regarding the use of interviews is the possibility of bias on the part of the interviewer or interviewee. Ideally, during the interview, the interviewee will supply accurate information to the interviewer. However, bias can alter the results to such an extent that the answers are of little or no value in the final analysis. Also, the interviewer must be aware that, when a test participant becomes frustrated or pleased with one part of the system, the participant may develop a negative or positive feeling toward other parts of the system. This is termed the "halo effect." The best way to deal with potential halo effects is to ask factual questions and follow up on generalities. The interviewer may also bias the interview by tone of voice, by the way in which the questions are phrased, or even by facial expressions or other body language. These and other sources of bias can be greatly reduced through recognition of the problem and by proper training and experience.

d. Another caution regarding the use of interviews is that they cannot serve as a substitute for direct test observation. They should be used as one of several HE T&E methods.

8.7.9.4 Comparison to other methods. Table XIII compares the interview method to other T&E methods.

8.7.10 Questionnaire. The basic tool for obtaining subjective data is the questionnaire. Questionnaires provide a structured means of collecting information from system users. They usually consist of specific questions about the performance of the system and human interface. Of all the subjective methods, the questionnaire is the most frequently used and is invaluable in the expedient collection of HE data.

8.7.10.1 Description. The questionnaire provides a structured method for asking a series of predetermined questions to obtain measurable expressions of attitudes, preferences, and

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opinions. Skill and experience are required to design a questionnaire that will produce valid and reliable results. Unfortunately, questionnaire design and construction cannot be learned from books alone, since the requirements for each test vary somewhat and present new challenges. However, there are certain rules and principles of questionnaire design aimed at helping users avoid some of the more common pitfalls, such as faulty questions and inadequate instructions. The following paragraphs are intended to provide guidance in planning, designing, and administering questionnaires. Additional information on constructing and using questionnaires may be found in Babbit & Nystrom (1989), Sinclair (1990), Charlton (1993), and AFOTEC (1994). Information on computing the optimal sample size is presented in Krejcie & Morgan (1997).

8.7.10.2 Procedure. The method of questionnaire design applicable to the types of tests conducted by HE T&E personnel involves seven logical steps.

1. Preliminary planning (e.g., determining data needed, administration strategy, anticipated suspense dates, and type of analysis required)
2. Selection of question type
3. Wording of individual questions
4. Construction of the overall questionnaire
5. Pretesting
6. Questionnaire administration
7. Quantification and analysis of questionnaire data

Questionnaire preparation requires great care and a background knowledge of the system to be evaluated. The examiner must also be knowledgeable about the background of the personnel to whom the questionnaire will be administered, and the way in which the results will be analyzed. Too often a questionnaire is prepared with insufficient planning. The problems involved and the weaknesses in the design are frequently not recognized until the results are interpreted.

8.7.10.2.1 Question type. There are three basic types of question used in questionnaires: open-ended, closed-ended, and a combination of the two. Each type has several variants that are described in Table XV. No single question type is superior to the others in all cases. To select one type over another, the questionnaire designer must be aware of the merits and drawbacks of each and choose the type that best meets the needs of the particular test situation.

8.7.10.2.2 Wording. The most important, and also the most difficult, aspect of questionnaire construction is wording the questions. Most authorities agree that faulty or inappropriate question wording is the greatest source of error in the use of questionnaires. Misunderstanding and misinterpretation of questions by test participants often cause errors and distortions in the resulting data. Such misunderstanding is frequently due to improper vocabulary or ambiguous phrasing.

8.7.10.2.3 Other aspects. In addition to selecting the type of question and wording the questions properly, the questionnaire designer must also consider question sequence, presentation

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format, and data collection issues. All questions must be checked to ensure complete and accurate coverage of all data required by the test objectives and test critical issues.

8.7.10.2.4 Pretest. A questionnaire must not be assumed to be perfected until it has undergone a pretest. The pretest provides an opportunity to try out the questionnaire on a small sample of respondents who can give feedback on their interpretation of the items. The result of this trial may then be used to make revisions and improvements as necessary before test administration. The pretest provides the final, validating step in questionnaire construction.

8.7.10.3 Use. A questionnaire is a subjective measurement tool for systematically eliciting perceptions or attitudes from selected personnel. The function of the questionnaire is to organize feedback from test subjects regarding the tested system. When properly designed, the questionnaire also aids in the tabulation of data and analysis of results. The questionnaire is used to assess a wide variety of qualitative variables such as acceptance, ease of use, and preference. It may be administered to small groups of technical personnel, such as those involved in highly controlled engineering tests, or to larger representative cross-sections of service personnel. Table XIV shows some of the applications for questionnaires. The following should be considered in the use of this method:

a. Knowledge of individual or group perceptions or attitudes can provide valuable information regarding reactions to, feelings about, and preferences toward military systems. Questionnaire responses from a representative sample of the user population permit a reliable estimate of group reactions to systems in use. These results also may be used to anticipate and thereby avoid future developmental problems.

b. The questionnaire is appropriate for use in all types of tests. It should be used to obtain subjective data when objective measurement is not feasible and when qualitative data are needed to supplement objective measurements. It may be used to augment direct observation by collecting information on the perceptions of a wider group of personnel interacting with the system than can be personally observed by the HE tester. This representative sample can alert the HE practitioner to emerging problems so that the practitioner can focus on observing critical problem areas. However, the questionnaire should not be used in place of direct observation methods if observation is possible.

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TABLE XV. Question types and response strategies.

| Question Type | Response Strategy | Sample Question |
|---|---|---|
| *Open* | Fill in blank | Your Skill Specialty Code is _____ |
| | Free Response | In your own words, describe problems encountered in operating System A during the _____ mission phase. |
| *Closed* | Force Choice, Binary Option | Was the display helpful to understanding your situation? *(Circle your choice)* YES NO |
| | Forced Choice, Multiple Option | Circle the most appropriate response from the following:<br>a. . . .<br>b. . . .<br>c. . . .<br>d. . . . |
| | Selection | Check ( ✔ ) all avionics subsystems that you have maintained for more than one year.<br>❑ Fire control<br>❑ Electronic countermeasures<br>❑ Navigation<br>❑ . . . |
| | Ranking | Rank the following proposed features of the system by their importance to mission accomplishment. *(Assign 1 to the most important and 5 to the least important. Assign a different number to each option.)*<br>*RANK* *Feature*<br>___ a. . . .<br>___ b. . . .<br>___ c. . . .<br>___ d. . . .<br>___ e. . . . |
| | Rating | Rate your overall opinion of the system performance during this field exercise.<br>\|----------\|----------\|----------\|----------\|<br>Strongly Dislike Dislike Neutral Like Strongly Like |
| *Combined* | Use any of the above "closed" categories with an open-ended response | Was the display helpful to understanding your situation? *(Circle your choice)* YES NO<br>Explain:_____<br>_____ |

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c. One disadvantage of using questionnaires is that test participants may not respond in writing to the same extent they would in an oral response during an interview. The effort required to write responses to open-ended questions is greater than the effort required to talk. Another disadvantage of the questionnaire, compared to the interview, is the inability of the HE practitioner to pursue through follow-up questions a participant response that is unexpected but might prove fruitful.

d. One of the most difficult problems to overcome in questionnaire design is the misunderstanding about what a questionnaire is and how it should be used. Some believe that anyone who can write reasonably well and who uses a little common sense can construct a good questionnaire. The seriousness of this faulty assumption can be seen from the fact that an improperly designed and poorly worded questionnaire can still yield data in the form of numbers, for example, frequencies or percentages. These numbers are amenable to statistical analysis and may even produce statistically significant findings. The real mistake is that these erroneous findings may be used to draw false conclusions that, in turn, contribute to faulty critical decisions regarding the utility of an item.

8.7.10.4 Comparison to other methods. The questionnaire method has many similarities with the interview method in terms of uses and procedures. Both the questionnaire and the interview should be carried out within a few hours of the test for best results. Both methods may be conducted away from the test area. Although the questionnaire must be more structured than the interview, the questionnaire may still include open-ended questions. One difference between these two methods is that the HE practitioner need not be present while the questionnaire is being filled out. Also, the questionnaire is inherently easier to use in evaluating or analyzing the participant responses. However, interviews provide a personal touch that may elicit more complete responses, and allow follow-up questions to be asked immediately so that relevant issues can be pursued. Table XIII shows a comparison between questionnaires and other HE T&E methods.

8.7.11 Motion pictures. This method is similar to the use of video recordings (see 8.7.13). It is the process of filming participant performance as a part of a system test. This method can be beneficial to the HE practitioner because it allows the practitioner to view the system's process repeatedly without having to revisit the system's location, or further interrupt the users of the system.

8.7.11.1 Procedure. As with videotapes, actual prototype hardware or sophisticated mockups should be available to justify the use of this method. Less sophisticated mockups imply more uncertainty in design, and therefore a greater risk in expending a picture effort on unsuccessful concepts. Permission to use cameras in secure areas must be obtained and the camera equipment and cameraman properly scheduled. Trained test participants must be available for observation of their appropriate tasks. The cameraman, and particularly the HE practitioner, should be familiar with the test operation being performed. The knowledge of when to take close-in footage of a particular critical task is important. As in the case with video cameras, a dry run is recommended to ensure the filming is properly performed. Consultation with all personnel familiar

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with the anticipated test events is advised. The following equipment is necessary to implement this method:

- camera and (film),
- lens,
- lights,
- projector,
- screen, and
- a tripod may be required, depending on the test situation.

8.7.11.2 Use. This method was comparatively more useful before the development of videotapes. Videotapes are now popular for that type of T&E process. However, when compared to all other methods, motion pictures still offer some advantages, such as

- permanent precise records of observed events,
- repeated observations of the same event,
- slow and fast motion study of real-time events,
- use in hazardous areas, and
- record of task activities as well as the related background situation.

The data gathered may be presented to large groups of people. The disadvantages are in the cost and effort to provide the proper equipment, particularly for processing and viewing the film. Skilled technicians are generally required for the filming of motion pictures. Motion pictures are not as useful as videotapes in that they must be processed to be viewed.

8.7.12 Sound recording. Sound tapes or audio tapes are recordings of the events of operating or maintaining the system. Sound tables are being replaced by videotapes since so much more can be gained by seeing as well as hearing the test process. Sound tapes are attractive to HE practitioners because they provide a permanent record of events to the practitioner, and they are inexpensive and portable.

8.7.12.1 Description. They are used extensively for tasks other than formal test observation. Test observers commonly use sound tape recorders to maintain a complete record of test conversation and events. Test notes may be verbally entered by the observers themselves. The recorders may also be used to record participant interview comments. The recorder may be linked into the intercommunication system if such is used as a part of a large-scale multi-operator test. The use of both sound tape and videotapes together is frequently valuable.

8.7.12.2 Use. Sound tapes are now a well used test/evaluation method. Their use is extremely easy and inexpensive. They have the same advantages as the videotapes in that they are a permanent record of events (audio), they may be repeatedly reviewed, and they may be used with time tags if desired. In addition to this, sound tape recordings negate the need for detailed handwritten notes. One disadvantage to the use of the recordings is in the quality of the reproduction if a high ambient noise is present near the test data being recorded. Another possible disadvantage is if the test participant becomes self-conscious due to the use of the recorder. This would be more noticeable during an interview. There is also the problem of loss of data due to

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weak or dead batteries and time required to change tapes. If the tape recorders are not used, good note taking becomes much more important.

8.7.13 Video recording. Videotapes are an outstanding means of recording events for system evaluation because of the simultaneous recording of sound and live action. Video is advantageous because it allows the HE practitioners to view a system's functions as a still picture, slow moving picture, an audio event, or a real-time audio/visual event.

8.7.13.1 Description. This T&E method is the use of video cameras and related equipment to make videotape recording for detailed review and evaluation of operator and maintenance personnel tasks. The following may be of help in considering videotape methods.

8.7.13.1.1 Videotape. The proliferation of inexpensive home video equipment and its usage has led to the capability for easy data gathering and analysis. This home equipment usually has between a 40 to 100 mm lens, about a 12 to 1 zoom ratio, and ever smaller cameras and recorders.

8.7.13.1.2 Recording events. As with any of the other methods, amateur operators should observe several cautions. To obtain the best record of an event (i.e., test), operators should enlist the cooperation of the test conductor. In addition they should establish which portions of the test can be rerun or interrupted to aid in the taping. A script, or list of events, should be used so that the cameraman will know the sequence and timing of events. To obtain a good record of the event, the video taping is just as important as the test itself. Tape is cheap so several angles and views should be recorded if possible. Most amateur operators do not let the tape run long enough; they should start taping approximately 20 seconds before a sequence begins and let the tape run 20 seconds after a sequence finishes. This will ensure everything is captured on tape. In preparing the camera, the cameraman should set the lens filter and then adjust the white set on the camera to allow for the available light color temperature. Then the electronic iris should be set to balance the blue and red, if these features are available on the model being used. Trained test participants should be available for HE practitioners; observation of their appropriate tasks. The camera operator(s) and particularly the HE practitioner coordinating the video data recording should be reasonably familiar with the test operation being performed. The knowledge of when to use the zoom lens to home in on a particular critical task is important. To be sure all the more critical tasks are properly recorded, dry (or test) runs of the test may be advisable. Consultation with all personnel familiar with the anticipated test event is recommended.

8.7.13.1.3 Equipment. The following equipment is necessary to implement this method:

- Videotape recorder
- VCR portable camera
- Zoom lens
- Monitor
- Portable lights

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Additional lenses, monitors, and tripods may be desired depending on the complexity of the test. Additional sound recording equipment may also be desired. Problems associated with the use of video recordings involve

- the logistics of transporting the equipment to the test site;
- the security of the equipment;
- permission to record any occurrences in secure areas (e.g., restricted, or classified areas); and
- request to perform recording on a possible test interference basis.

8.7.13.2 Use. There is little doubt that given the videotapes and proper display equipment, the use of this method is of notable value. However, the cost effectiveness of the method must be considered to be dependent upon the complexity of the test needing evaluation. Possible transportation and setup problems should also be considered before commitment to the use of this method. The following considerations also apply.

a. Careful review of tape playbacks can reveal human errors, and excessive task times not previously capable of being detected. The application of maintenance crew teamwork may be examined. Improper procedures may be thoroughly evaluated. Improper malfunction determinations may be traced back to the point of the original mistake. Technical publications and training can be methodically evaluated. The adequacy and proper use of tools may be verified.

b. Depending on how they are used, videotapes may account for less test interference than direct test observation alone. This would be true for an equal amount of test data gathered as a result of a relatively complex test. Once recorded, the data record is permanent and may be presented for use to numerous persons including the performing organization and requiring organization alike. The tapes may be easily stopped, started, and backtracked for repeated observation. Each task may be thoroughly examined step by step. Test sequences that may not be properly recorded may be easily reviewed and retaken. Further advantages include the fact that observer errors are reduced; the observation can be recorded and observed remotely from what might be a hazardous or congested area. The tapes may have considerable use as training aids. They require no time to process, but motion picture films do. The tape itself is reclaimable; it may be used over and over again for different tests. A record of time tags recorded along with the video is also possible.

8.7.13.3 Comparison to other methods. Table XIII provides a comparison between videotapes and other T&E methods.

8.7.14 Still photography. Still photography is, very simply, the process of taking photographs of tasks, objects, or events that are pertinent to the HE effort. Still photography is valuable to the HE practitioner because it is capable of high resolution, and establishes a permanent record of critical system events. Video cameras are now starting to approach the resolution of still cameras, and have the advantage of instantaneously available photographs that can be electronically transferred.

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8.7.14.1 Description. This method is perhaps too simple to be considered as such and should be described rather as a HE T&E tool. As in the case of the video records, actual prototype hardware or mockups must be available to justify the use of the tool. HE test operators must be familiar with the test to know when the critical tasks or events require the visual record. In addition to the camera, a tripod and special lighting may be required. Flash attachments are easily used. Depending on facility and agency requirements, a photographic pass may be required. The location of the test may restrict the use of cameras. Instant film type cameras are convenient in that they provide an instant picture for evaluation as to the need for additional pictures. However, the quality of the instant picture cameras tends to be inferior to those that produce the large 8 x 10 shots. The results of the photography generally are appropriate for inclusion in test reports or other HE T&E reporting forms.

8.7.14.2 Use. Naturally, photography is a well used HE T&E tool. It is easy to use and may be done quickly. The particular advantages gained in using this method are similar to some of those for the videotapes and motion pictures, e.g., the photograph is a permanent record which may be reviewed, it may be used as a training aid, and decreases observer errors about what really happened. Photographs are used extensively in HE testing for analysis of anthropometric interface problems. Table XIV shows many of the general applications of the photography methods.

8.7.14.3 Comparison to other methods. Table XIII provides a comparison between photography and other T&E methods. The obvious disadvantage associated with the use of this T&E tool is in the single frame static picture rather than the dynamic picture created by motion pictures or videotapes. A small problem may be created by the logistics of obtaining the photographic equipment and or camera personnel and the permission to use the equipment in the test area. Alternatives to photography are the more expensive videotapes or motion pictures or possibly a good fast-sketch artist assigned the duties of the HE test observer. In a few instances, a large number of descriptive words written in the test reports may substitute for a photograph of the situation or equipment that they are describing, but these descriptions are seldom completely satisfactory.

8.7.15 Event recording. Event recording is a method or combination of methods for recording real time test situation or event times. The equipment involved in the use of this method varies in complexity from the stopwatch to complete systems that record multiple inputs simultaneously. This method is valuable to the HE practitioner in establishing the big picture of the system.

8.7.15.1 Description. The more complex event recorder systems might include:

- an event recorder,
- battery pack,
- event control box,
- a signal cable, and
- data bus.

The event recorder itself should be capable of recording on several channels; the battery pack is to give portability to the operation; the control box is used to actuate the various channels in the

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recorder; and the signal cable is to electrically tie the control box to the recorder. Other recording systems are provided which combine these units into one easily portable package.

8.7.15.2 Procedure. The sequence of events that might occur with the use of this method may be as follows:

a. HE practitioners who are to observe the particular test first become familiar with the planned test events. They estimate what tasks are more critical and should be recorded in terms of time performance. If the tasks to be monitored are particularly critical they may even perform a dry run of the test or plan to run multiple replications of the same critical task.

b. The total test may be divided into several functional tasks and each such assignment allocated to a separate channel. Examples of such task functions are reading technical publications, actuating controls, reading displays, and making adjustments.

c. The channel controls are easily activated for each of the task functions as they start and stop. It may be necessary to write start labels for each event on each of the channels plotted on the recorder chart paper roll.

For several years recording equipment has been available that does not require the use of the paper role for a record of events. The test observer simply presses combinations of keys to note task functions as they occur. Data entries record in a solid-state memory in a computer program format. The data are later transmitted to the computer by connecting the device via a simple connecting cable. In this manner, computer written reports may be written in minutes. This device includes a space for written notes on an integral note pad. The direct outputs of each of these event recording methods varies from handwritten notes to complete computer printouts of evaluated data. The eventual outputs are verification of task time data.

8.7.15.3 Use. Most HE T&E efforts will require the use of one of the following but previously indicated event recording methods or some variation thereof:

- event recorder and separate control,
- combined function solid state memory data collector, and
- stopwatch.

When critical test events must be recorded and evaluated, these methods prove valuable for determining system/user time performance capabilities. Two of these methods allow several task functions to be recorded at once. The observer may thereby direct more of his attention to the other aspects of the test. The stopwatch is, of course, by far the cheapest method of the three for recording time. It may, upon occasion, be the most cost effective. It is, however, more error prone than the other methods. The recordings made from the other two methods can be used for timeline, task loading, and time sharing analysis.

In general, all recording methods will measure objectively human performance and provide useful data for the test as a whole. The methods can be used with very little test interference, The training required to use the method equipment varies with the equipment complexity but is

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generally uncomplicated. The data are applicable for time to accomplish tasks, evaluation and optimization of tasks involving teamwork, and the isolation of specific points that degrade turn-around times, loading times, and launch times. The method may not be used for evaluation per se, but further analysis must be made of the data using other methods.

8.7.15.4 Comparison to other methods. Table XIII provides a comparison between event recording and other T&E methods.

8.7.16 Secondary task monitoring. Secondary task monitoring is a method of measuring mental workload in which the operator is required to perform two tasks concurrently—the primary task of interest and another (related or unrelated) task. The operator's performance on the secondary task is used to estimate primary task workload. The method of secondary task monitoring is an important tool to help the HE practitioner assess mental workload so that especially stressful tasks can be identified and redesigned or re-allocated.

8.7.16.1 Description. For the purpose of determining crew workload, test participants are given both an operational task and a secondary task to perform. The secondary task may or may not be meaningless in relation to the rest of the test. However, it is in no way necessary to the operational task being tested. The secondary task is performed using prototype hardware, hot mockups, or simulators instrumented through hardware or telemetry to record crew performance.

8.7.16.2 Procedure. The participant is usually instructed to perform the primary task free from error, and the secondary task when not occupied in performing the primary operational task. The time taken to perform the secondary task is recorded and subtracted from the total time available. Crew workload in performing the operational task is then inferred from the measured time (or effort) not spent doing that operation. (For additional information, see Boff, Kaufman, Thomas (1986), *Handbook of Perception and Human Performance [Vol. II*, Section 42-22-4]).

8.7.16.3 Use. Secondary task monitoring is a useful method for measuring crew workload, especially when it is not feasible to monitor the operational performance parameters directly. Because workload can be measured quantitatively using this method, it can be estimated more accurately than with many other workload evaluation methods. The cost and effort to implement this method are relatively high compared with those for several other HE T&E methods if the secondary task data are recorded automatically. However, the cost is inherently lower than monitoring operator performance on each of the operational controls (and, ideally, displays). There are two different types of secondary task monitoring. The first type uses secondary tasks that are completely unrelated to the system operational tasks. These are make-work tasks. The second, more sophisticated type uses secondary tasks that are essentially the same as the required operational tasks. Test participants seem to have greater motivation to perform more realistic secondary tasks than to perform make-work tasks. Table XIV lists some general applications for the secondary task method.

8.7.16.4 Comparison to other methods. Table XIII provides a comparison of secondary task monitoring with other T&E methods.

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8.7.17 Physiological instrumentation. Physiological instrumentation is a method of gathering data related to physical events of a test participant, such as electroencephalogram (EEG), electrocardiogram (EKG), skin temperature, etc. This method is valuable because of its reliance on hard, non-subjective data in the measurement of user workload.

8.7.17.1 Description. The process of measuring test participant physiological data is generally quite rigorous. In addition to all the setup procedures required for the test itself, it requires several important tasks that must be performed just for the physiological instrumentation.

a. Physiological instrumentation requires more commitment from the test participants. The purpose of the instrumentation may be to monitor physiological parameters to ensure that the participant remains in a safe range of performance. The implication of this is that there is a possible unsafe range of performance and therefore more commitment required on the part of the test participant. Even if this is not the case, the encumbrances of the test sensors on the participant are generally somewhat annoying.

b. When conducting tests with human subjects, one must comply with the applicable human use and informed consent requirements and regulations. The proposed test must be explained to the test subjects (i.e., nature, duration, and purpose of the test, etc.). In addition all reasonably foreseeable risks (i.e., injury, death, inconvenience, and discomfort, etc.) must be disclosed. The identity of the test subject will not be made available to the public without the participant's approval. All tests must be approved by the appropriate agency's human use committee and have participants informed consent before collecting data.

8.7.17.2 Procedure. Medical personnel must approve the test. Generally, they should perform the test setup of the instrumentation system. This would involve the attachment of the sensors in a manner to minimize their effect on the total test. Medical personnel must also be present during the test if any participant risk is involved. Electronics technicians may also be required to adjust the test instruments. In addition to the individual parameter sensors located on the participant, wire leads must be provided. Attached to the leads would be the appropriate transmitters (if telemetered), receivers, and amplifiers. Instruments for displaying parameter values and chart recorders will also be required. Parameters that might be monitored are as follows:

- heart rate, blood pressure,
- respiration rate and volume,
- galvanic skin response (GSR),
- EEG,
- EKG,
- body temperature, and
- body movement, including eye blink.

Upon completion of the test, medical personnel are required for analysis and evaluation of the resulting test physiological data.

8.7.17.3 Use. Physiological measurement is performed much more for research testing than for operational or field type testing. It is also used when there is a possibility of risk involved, for example, centrifuge runs. Physiological testing is seldom intended to measure total system

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performance, let alone the more normally monitored operator performance parameters of time and errors.

8.7.17.4 Comparison to other methods. The cost to perform this type of testing is relatively high and the effort involved by HE, medical, and technical personnel is considerable. Because of the nature of the test itself, which would require the use of physiological instrumentation for safety, the testing must be considered to be performed on an interference basis. When physiologic monitoring is really needed, there is no substitute method that may be used to obtain the necessary data. The only alternative of constantly stopping the test to take time out for the required measurements is unacceptable. By use of radio transmitters, the method may be monitored remotely away from the test area. Notable use of this method has been in manned space programs, Army system portability testing , and Navy and Air Force new aircraft flight tests.

8.7.18 Physical measurement. This method is the process of measuring what the test participant can do in terms of physical performance or cognitive performance. This method discloses to the HE practitioner the proportion of capability the system is extracting from the test participant, allowing the HE practitioner to ascertain the physical demands of the system on the user. From this information, the HE practitioner can then determine if the system is too demanding for specific tasks, such as sustained operations.

8.7.18.1 Description. Three different types of physical measurement are presented in this section. The first, anthropometry, deals with potential test participant physical dimensions, proportions, and body composition. The other two, oculometry and voice monitoring, pertain to measurement of the participant’s physical and cognitive processes.

8.7.18.1.1 Anthropometry. Anthropometric measurements may be made of each of the test subjects to be used in a hardware prototype mockup test. These measurements are taken on the assumption that the test will indicate various areas of work space or work access verification. If problems are indicated, rather than designs verified, then detailed measurements are taken as to exactly how much of a work space problem exists. If much of the test is to hinge on the ability of the test participants to fit the equipment (e.g., vehicle egress), the subjects may be specially screened and chosen to fit the worst case (larger) population percentiles (95th or 98th percentile). If a subject with 98th percentile buttock-knee length and 98th percentile shoulder breadth can successfully egress with the given vehicle dimensions, then it may be assumed that most operators will be able to do the same at least in terms of egress space.

8.7.18.1.2 Oculometry. This method measures the test participant's eye movement while the participant is seated at (in) a mockup or prototype hardware of the system being tested. The oculometer is used to view the participant's eye movement in terms of deflection rate and amount. The instrument and associated equipment are capable of recording the links between controls and displays, the dwell times on each, the total number of eye contacts, and the probability of next contact. The oculometer performance is at a half degree at 30 inches from the eye within an envelope 30 deg. up, 10 deg. down, and 60 deg. horizontal. Once these data are recorded, panel layout adequacy is verified by the quantity, location, and rate of eye movements. Physical

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measurements may also include participant muscular strength, body weight, limb coordination, visual and auditory acuity, and kinesthetic response.

8.7.18.2 Use. The use and value of these physical measurement methods are as follows:

8.7.18.2.1 Anthropometry use. It is relatively easy to measure test participants to determine their anthropometric dimensions. The fact that these subjects either did or did not fit the particular mockup or prototype is also easy to note and record. The difficulty in the use of this method is if and when particular anthropometric dimensions are required as test subjects. It is very difficult for HE observers to go out and find particular anthropometric dimensional subjects, particularly for combinations of measurements and for the extremes of the population (e.g. greater than 90th percentile and less than 10th percentile). The real value in using anthropometric measurements is in the knowledge of how close the design, as represented by the mockup or prototype, comes to the specified user anthropometry. The disadvantage is the effort in finding subjects who properly represent the required population. If this method is not used and work space clearances are critical to the test conduct, the HE observer runs a high risk in only guessing the anthropometric characteristics of the test participants.

8.7.18.2.2 Oculometry use. The oculometer method is relatively complex and expensive to use. It cannot be run on a noninterference basis. It requires trained HE observers to use. The use of the method is still somewhat experimental. The advantage in the use of the method is that it is the ideal way to perform or verify console panel link analysis data. If not used, questionnaires or interviews may be used to determine subject reaction to panel layout adequacy.

8.7.19 Online interactive simulation. Previous HE T&E method paragraphs have described methods that rely heavily on prototype hardware or mockups. Also included in this guide are several methods that do not use either mockups or hardware, but are instead computer program simulations of both the operator and equipment in the man-machine interface. The general method described in this section pertains to the use of real time computer program simulations and actual test participant operators. Like other simulations, online interactive programs are used to evaluate and demonstrate application of specific procedures and equipment to specific operations. It is often difficult to make a sharp distinction between some computer simulation setups and functional mockups. The emphasis in the functional mockup is on an accurate representation of spatial dimensions and arrangements.

8.7.19.1 Description. The most important requirement of an online interactive simulation is that it be an accurate representation of some portion of the proposed system. Critical variables in the proposed system should be properly duplicated in the simulation. In some cases, simulators must actually provide deliberate distortions of certain parameters to yield operator responses that will be valid for the real world. The use of distortions is risky but often necessary to compensate for some parameter that cannot be provided for properly. Online interactive simulation presumes the use of a sophisticated computer and software. Test participant consoles must also be provided in a manner similar to the system consoles being simulated. The preparation of test participant operator procedures is a first step toward the complex job of constructing the real time interactive software. Online operation requires the construction of numerous operator controls in response to

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numerous displays and display formats. Operator and system performance outputs must also be provided for in terms of lists and time plots of events versus actions, errors, and reaction times.

8.7.19.2 Use. The reason for using online simulation is because of the ability to find out what might occur: to manipulate, to study, and to measure the model instead of the real world. There are several advantages to using online simulation as compared to other methods of T&E:

- Simulations are frequently cheaper, faster, and easier to construct than the systems or prototype hardware they simulate;
- Simulators can be instrumented to collect data that would be difficult or impossible to obtain from real systems and the data may be quickly reduced to usable form;
- Simulators are extremely useful as training aids;
- Simulators are easier to manipulate than the systems they represent;
- Simulators may be used to perform tasks that would otherwise be hazardous to the test participants (e.g., crash landings);
- Once the simulation program has been provided, alternative procedures or tactics may be easily manipulated;
- A record of data may be kept for later playback.

The disadvantages in the use of online simulation as compared with other T&E methods are as follows:

- Simulation tends to invite over-generalization;
- Simulations may be wrong because of incorrect relationships that have been made to hold between variables, or assumed constraints may be in error;
- Simulators may add ingredients of their own that will not be found in the real world system;
- Simulators, in general, are more expensive than the use of interview, questionnaire or other empirical data-gathering methods.

8.7.19.3 Comparison to other methods. The time to use online simulation is generally before the construction of the hardware (and software) that it is to simulate. If this is not done, there is little point in the expenditure of the time and effort for the simulation. There are essentially two alternatives to the use of online interactive simulation. One simulation method is the use of man model programs. The other alternative is the use of all the T&E methods that utilize the direct or indirect data obtained from the actual prototype system hardware. Table XI shows a comparison of this type of method to other methods.

8.7.20 Statistical analysis. Statistical analysis is the method by which the HE practitioner can summarize, describe, and draw inference from data collected form test participants. Statistical analysis is paramount to the HE practitioner because it allows the practitioner to quantify differences between groups of test participants, and allows the HE practitioner to infer the significance and cause of those differences.

8.7.20.1 Description. This section on statistical analysis methods is applicable to both system analysis and evaluation. To maintain consistency between this section and other HE methods sections, the details of the numerous statistical methods cannot possibly be provided

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herein. However, a few of the more commonly used methods are briefly presented along with their use. These methods have been grossly categorized into the two areas of statistical comparisons, and user population selection.

8.7.20.1.1 Statistical comparisons. Statistical comparisons may deal with the parametric performance of two or more hardware items under consideration for use in the system design. Comparisons may also be made between different parameters to draw a conclusion or develop new and useful data. System trade studies often include performance data comparisons such as reliability statistics. The mean or average reliability for one hardware item being considered is compared to another hardware item. Additional factors such as standard deviations from the mean and item population are necessary to make a proper performance comparison. The confidence limit or level of the results of the statistical analysis are very important. These are obtained from the standard errors, which are, in turn, a measure of the sampling uncertainty (e.g., sample size). Statistically derived data are of little value without an associated confidence limit (eg., 95%).

8.7.20.1.2 User populations. User population selection deals with the selection of a sample from the total population. It is generally impossible to test or measure all items (or users) in a population set from which data are to be obtained and analyzed. Statistical methods exist for random or specific parameter (i.e., stratified) population sampling. Whether a total population or a sample of the population, the data obtained will be presented in distribution plots. These plots describe the frequency of occurrence of the individual parameter values in the sample tested. The form of the resulting distribution (e.g., Gaussian, Poisson, binomial) is important in selecting the appropriate statistical methods to be employed and in the conclusions to be drawn from the data. For example, a bimodal distribution generally indicates that the data sample was actually drawn from two distinct populations and the application of standard statistical methods may not produce the intended results. As a further illustration, recent trends in design criteria application require the combination of male and female population anthropometric data. This combination will produce bimodal distributions. In such situations, standard statistical methods for determining cost effective design criteria (e.g., choice of 5th through 95th Percentile) can be erroneous.

8.7.20.2 Procedure. It is not the intent of this guide to provide the procedure for each of the many statistical analysis methods. If the HE practitioner has questions concerning data analysis and interpretation, consultation with a statistical specialist should be employed. This consultation should occur during the early planning stages. Errors in sample selection or data collection procedures cannot be corrected in the analysis. Statistical analysis, which once was performed with the use of desktop mechanical calculators, is now quickly performed by computer/software methods. There are many personal computer statistical packages currently available. These packages, in conjunction with a good experimental design, will enable the HE practitioners to complete a complex statistical analysis. If possible, statistical data should be collected in machine-readable form at the test site.

8.7.20.3 Use. Although HE itself is a specialized field, there are persons within this discipline who specialize in HE statistical analysis. The majority of HE practitioners have little to do with the statistical analysis, both because of relative little need to do so and availability of a

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few well-qualified persons who can perform the statistical analysis when needed. The following aspects of statistical analysis should be considered.

a. Comparisons or correlations between parametric data are useful to extrapolate from limited databases. For example, if based on comparisons between evaluator's judgments of operator task reliability and actual empirical data, and a high correlation seems to be evidenced, then this correlation can be quantified by the use of scatter diagram plots, regression curves, and correlation coefficients. The quantified correlation can be used, with some caution, to extrapolate to operator task reliability estimates that have not been field-tested. Correlation data showing the relationship between anthropometric measurements can also be very useful.

b. Statistical methods are not used as often as they should be to evaluate parametric data used to perform trade studies. Often hardware selection between various brands and systems is made on the basis of quoted or derived performance data that are not statistically reliable (significant) or accurate.

c. Just as statistics can be of great value to the HE analysis and evaluation process, they can also cause problems. If the statistical analysis is attempted by persons with limited experience, it is easy to make mistakes both in the choice of particular statistical methods and in the application of the methods. At the same time, skilled but unscrupulous practitioners have been known to purposely misuse statistics to “prove” an item of performance data which does not actually hold true. A thorough analysis should be made of any data which are crucial to a design decision and which could be suspect.

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9.0 Notes.

9.1 Intended use. This handbook is intended to provide guidance on human engineering program tasks, procedures and preferred practices, and methods for application to system acquisition. The program processes appear in Section 4 supporting information for involved government and contractor participants appears in Sections 5 – 7, and methods and tools applicable to the processes appear in Section 8. The handbook has been written to address the human engineering effort, as a part of HIS initiatives and integrated with system engineering; however, its content has been kept sufficiently generic so that it may be used for other acquisitions. The handbook is intended for guidance only and should not be cited as a requirement. If it is, the contractor does not have to comply.

9.2 Subject term (key work) listing.

Acquisition
Analysis
Design
Development
Evaluation
Methods
Planning
Reviews
Test
Tools

9.3 Tailoring guidance. The tailoring guidance in Appendix A is not provided for the traditional purpose of excluding unnecessary requirements from invitation for bids or requests for proposals since the handbook contains no requirements. Accordingly, the tailoring guidance is provided only to indicate when the recommended processes and procedures are best considered as a function of human roles in the system and acquisition phase involved.

9.4 Changes from previous issue. Marginal notations are not used in this revision to identify changes with respect of the previous issue due to the extent of the changes.

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# APPENDIX A
# APPLICATION AND TAILORING OF SECTION 4

## A.1 SCOPE

### A.1.1 Scope.

This appendix provides guidance and criteria for (a) the procuring activity's selection and use of this handbook for contract reference and, when used, (b) the tailoring of program task guidelines in Section 4.

### A.1.2 Purpose.

The purpose of this appendix is to limit program tasks to minimum essential needs. Stating such minimum essential needs in the solicitation gives the offeror a basis for providing information on the proposed HE program. This appendix also provides users of the handbook with guidance regarding applicability of the program task guidelines and, as a result, the sections covering HE procedures, methods, and tools.

## A.2 APPLICABLE DOCUMENTS

### A.2.1 General.

The documents listed below are not necessarily all the documents referenced herein, but are the ones needed to fully understand the information provided by this appendix.

### A.2.2 Government documents.

A.2.2.1 Specifications, standards, and handbooks. The following standard and handbook form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the latest issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplements thereto.

HANDBOOK

DEPARTMENT OF DEFENSE

MIL-HDBK-280 - Definitions of Item Levels, Item Inter-changeability, Models, and Related Terms

MIL-HDBK-1908 - Definitions of Human Factors Terms

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(Unless otherwise indicated, copies of Federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

A.2.2.2 Other Government documents, drawings, and publications. The following document forms a part of this appendix to the extent specified:

AD-1410 - Aeronautical Data Design for Maintainer Program Requirements

(Application for copies should be addressed to Commander, Naval Air Systems Command, Code AIR 4.6, Patuxent River, MD 20670.)

## A.3 DEFINITIONS

Terms are defined in accordance with MIL-HDBK-1908.

## A.4 APPLICATION OF SECTION 4, PROGRAM TASKS

### A.4.1 General.

Selection of Section 4 for citation in solicitations depends on the nature of the materiel in terms of operational and mission maintenance and support functions, the degree to which human interface is involved with materiel, including software, and the acquisition phase involved. Selection of Section 4 is generally independent of system complexity, branch of military service involved, equipment duty cycles, and, within practical limits, contract type, cost, and duration, and size of production lots.

### A.4.2 Selection for use.

The procuring activity should first decide whether to cite MIL-HDBK-46855 in the solicitation by considering the following provisions, as shown in the selection process guide of Figure A-1.

A.4.2.1 Nature of the materiel. Selection of MIL-HDBK-46855 for a specific contract is dependent upon the nature of the end item, materiel, or system in terms of its ability to perform operational and mission maintenance and support functions. Generally, the guide

- should not be considered for use in contracts for parts, subassemblies, or units as defined in MIL-STD-280,
- should be considered for use in contracts for sets, subsystems, and systems, as defined in MIL-STD-280, and for facilities.

The rationale for this initial screening is that parts, subassemblies, assemblies, and units typically are not produced to perform an operational function, but can be used as elements of different sets, subsystems, etc., that perform different desired operational functions. The contractor furnishing such items (e.g., transformers, wheel bearings, amplifiers) has no control over the diverse uses to

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which they will be applied or knowledge of the human performance requirements implicit in such uses. Accordingly, it is not generally reasonable to invoke MIL-HDBK-46855 for parts, subassemblies, assemblies, or units.

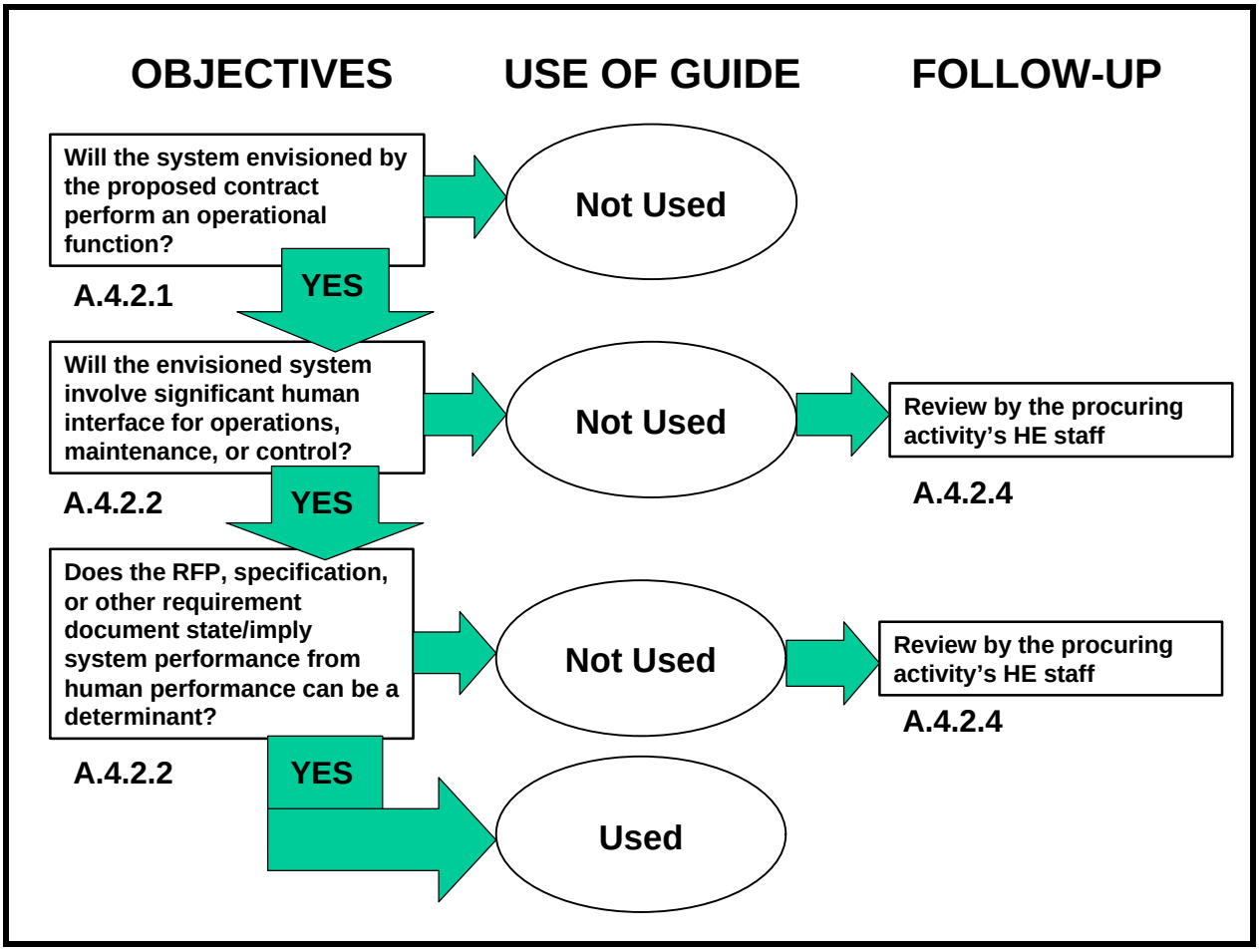


FIGURE A-1. Selection process guide.

A.4.2.2 Extent of human interface involved. Selection of MIL-HDBK-46855 for reference in a specific contract is sensitive to the extent of human involvement or interface for operation, maintenance, control, transport, or shelter. Generally, the handbook should not be considered for use in contracts for materiel where human involvement or interface is not anticipated or is obviously insignificant.

A.4.2.3 Nature of stated performance requirements. If, for a specific solicitation, MIL-HDBK-46855 has survived the tests of A4.2.1 and A4.2.2, its selection should be based on stated or implied performance requirements. If the solicitation, specification, or other requirement document states or implies performance requirements or goals, such as time and error, for which human performance can reasonably be considered a determinant or contributor, MIL-HDBK-46855 should be cited in the solicitation.

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A.4.2.4 Selection review. At this point, citation of the handbook has been tentatively determined. If the procuring activity's HE practitioners (human factors, human factors engineering, Human Systems Integration [HSI], crew systems integration, or equivalent personnel) have not already been involved in this decision-making process, they should be consulted to ensure that MIL-HDBK-46855 is not erroneously cited or rejected. Should results of this review disclose that the handbook should not be used, the process is complete; however, if results of this review conclude that the handbook should be cited, the tailoring process of A.5 should be pursued. The offeror may further tailor the guidelines.

## A.5 TAILORING SECTION 4, PROGRAM TASKS.

### A.5.1 General.

The primary purpose of HE program tasks and, therefore, Section 4, is to influence the design of the system, equipment, and facility—not to generate documentation. Accordingly, with the exception of validation efforts, tasks or documents that do not contribute to design or that emerge after design cannot be changed should be avoided because they are wasteful and drain resources from accomplishment of needed effort. Every HE task must focus on influencing design and testing, consistent with the nature of the procurement and the acquisition phase involved.

### A.5.2 Tailoring.

Table A-I provides guidance to facilitate the tailoring of Section 4 of this handbook. The sections covering procedures and techniques need not be tailored, since their applicability is driven by Section 4. Use of the tailoring matrix should be consistent with the following explanations and guidelines.

### A.5.3 Contractual applicability.

A.5.3.1 Contractor use. Unless otherwise specified by the procuring activity, contractors should use the tailored version of Section 4 (and therefore other applicable sections of this handbook) as a baseline for preparing solicitation responses and HE program planning information. Further tailoring by offerors is expected.

A.5.3.2 Evolutionary development. For evolutionary development of older or existing systems, equipment, software, and facilities, Section 4 should generally apply only to new designs and procedures involving human interfaces and to old designs, procedures, and interfaces that may be impacted thereby. When old systems undergo improvement through evolutionary means, the guide should generally not be applied to components that are retained and are not affected by such evolutionary development techniques. It is important to understand that there may be exceptions to this general rule; therefore, evaluation by the HE staff is considered extremely advisable.

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TABLE A-I. Tailoring guidelines.

| PARAGRAPH NUMBER | MODIFICATION |
|---|---|
| 4.1.1.1 Analysis | Phase I: Delete the first three sentences. Change the fourth sentence to: "Each task that must be performed to accomplish allocated functions should be analyzed to determine the human...." In the last line, change "design" to "validation."<br><br>Phase II: Same as for Phase I above. |
| 4.1.1.2 Design and development | Phase 0: Revise the title to "Preliminary design and development." Insert "Preliminary" at the beginning of the first sentence. In the fourth line, change "detail" to "preliminary." |
| 4.1.2 HE program planning | Phase 0: In lines 1-2, change "equipment specification" to "mission need."<br><br>Phase I: In lines 1-2, change "equipment specification" to "overall program objectives." |
| 4.1.6.1 Traceability | Phase 0: In lines 3-4, delete from "design and development" to the end of the sentence and insert "concept submission."<br><br>Phase I: In line 2, insert "preliminary" after "through." In lines 3-4, delete from "the verification" to the end of the sentence and insert "validation and demonstration." |
| 4.2.1.1.2 Estimates of potential user processing capabilities | Phase 0: In sentence 5, delete "design." |
| 4.2.1.2 Equipment selection | Phase 0: In line 2, change "design requirements" to "concepts." In line 3, change "configuration" to "concept." |
| 4.2.1.3.5 Timeliness and availability | Phase 0: In line 2, change "design" to "conceptual."<br><br>Phase I: In line 2, change "design" to "validation." |
| 4.2.1.4 Preliminary system and subsystem design | Phase 0: In line 2, change "designs" to "concept documentation" and delete the rest of the sentence.<br><br>Phase I: In line 6, put a full stop after "MIL-STD-1472" and delete the rest of the sentence. |
| 4.2.2.3 Work environment, crew station, and facilities design | Phase 0: Delete the first two sentences. Delete "Design of" from the beginning of the third sentence and add "concepts" after "facilities." |
| 4.2.3 HE in test and evaluation | Phase I: In the first sentence, change (1) to read "demonstrate that human performance technical risks have been identified and that solutions are defined." |

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| | |
|---|---|
| 4.2.3.1 Planning | Phase I: In the first sentence, change "into engineering design and development tests" to "into validation and demonstration test planning" and delete "contractor demonstrations, flight tests, acceptance tests." |
| Acquisition Phase 0: Concept Exploration<br>I: Program Definition & Risk Reduction<br>II: Engineering & Manufacturing Development<br>III: Production, Fielding/Deployment, & Operational Support<br><br>(See A.5.3.4 for tailoring guidelines) | |

A.5.3.3 Product improvement. Recognizing that product improvement actions may occur during more than one acquisition phase and that product improvements can involve concept exploration, program definition and risk reduction, or engineering and manufacturing development tasks, or a combination of these, the procuring activity should tailor applicable portions of Section 4 of this handbook to the specific performance objectives of the product improvement program.

A.5.3.4 Production, fielding/deployment, and operational support phase. Design changes affecting human performance during the production, fielding/deployment, and operational support phase can, like product improvement actions, involve concept exploration, program definition and risk reduction, or engineering and manufacturing development HE tasks. Therefore, the procuring activity should tailor applicable portions of the matrix to the specific performance objectives of the design changes. Particular attention should be directed toward failure analysis, quality assurance, drawing review, and software considerations.

A.5.3.5 Nondevelopmental item (NDI). Where an NDI is being acquired, applicable provisions of Section 4 may be used to guide government in-house efforts (see 6.1). Paragraph 4.2.1.2 should be considered to ensure that MIL-STD-1472 or other applicable HE design criteria will be a part of the selection criteria for determining the suitability of the item; 4.2.3 and its subparagraphs should be considered, as applicable, to verify human-system integration. In addition, the nature of the NDI program will influence tailored, in-house use of the guide. Where an item requires minor modification to meet the requirements of the procuring activity, and where the modification is driven by human performance or will result in significant human performance effects, applicable analysis tasks of 4.2.1, 4.2.2, and their subparagraphs may be used for identifying and implementing the modification.

A.5.3.6 Application of AD-1410. For Naval aviation systems and equipment design for integration within Naval aircraft, design for maintainer analyses and data review processes comply with AD-1410, where applicable.

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A.5.4 HE review.

Procuring activities are responsible for ensuring that the selected tailoring of Section 4 has been subjected to HE review for consistency of the tailored requirements with human performance requirements pursuant to the nature of the objectives of the contract.

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# APPENDIX B
# TASK ANALYSIS

## B.1 SCOPE

### B.1.1 Purpose.

This appendix provides guidelines for performing a task inventory and task analysis as part of the development and acquisition of military systems, equipment, and facilities. These guidelines include the work to be performed by the contractor in conducting a task inventory and task analysis during all phases of system development. They are the basis for addressing task inventory and task analysis during equipment design, test and evaluation (T&E) preparation, training requirements preparation, manning and workload assessment, development of training and maintenance manuals, and preparation of other documentation and reports. Finally, this appendix describes the task analysis product that the contractor submits to the procuring activity if required by the contract.

### B.1.2 Applicability.

This appendix can be applied to all military systems, equipment, and facility acquisition programs, major modification programs, and applicable research and development projects through all phases of the development and acquisition cycle. This appendix is for use by both contractor and government activities performing a task inventory and task analysis on systems, equipment, and facilities to which this handbook applies. This appendix is intended for use by the procuring activity and users of the task inventory and task analysis results to define for the contractor the requirements and output.

### B.1.3 Tailoring the task inventory and task analysis.

The task inventory and task analysis guidelines contained herein may not all be applicable to every program or program phase. Accordingly, the government should tailor this appendix to specific programs and the milestone phase of the program within the overall life cycle. This tailoring should consist of the selection of a task inventory and task analysis by phase of system, equipment, or facility development so that the guidelines are limited to minimum essential needs to preclude unnecessary and unreasonable program costs. Guidance for the selection of a task inventory and task analysis by the procuring activity is contained herein.

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## B.2 APPLICABLE DOCUMENTS

### B.2.1 General

The document listed below is not necessarily the only documents referenced herein, but is needed to fully understand the information provided by this appendix.

### B.2.2 Government documents

B.2.2.1 Handbook. The following handbook forms a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the latest issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto.

HANDBOOK

DEPARTMENT OF DEFENSE

MIL-HDBK-1908 - Definitions of Human Factors Terms

(Unless otherwise indicated, copies of the above specifications, standards, and handbooks are available from the Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

## B.3 DEFINITIONS

Terms are defined in accordance with MIL-HDBK-1908.

## B.4 GENERAL GUIDELINES

### B.4.1 General.

A task inventory and task analysis should be performed and documented to ensure effective human-machine and human-human interface design, to facilitate effective training program development and T&E, and to provide information for manning and workload studies. These activities should begin in the early stages of the design phase of system development and should be carried throughout system development and acquisition.

### B.4.2 Task inventory.

A task inventory should be prepared to list all the tasks that operator, maintainer, and support personnel are to perform. The task inventory should include a list of the tasks required to perform operator, maintainer, and support personnel functions, as well as a description of each task in behavioral terms. The tasks should be organized or grouped according to logical criteria such as purpose and function. The level of detail in the task inventory (e.g., duty, task, subtask, task element) should be as specified by the procuring activity using the tailoring recommendations herein.

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B.4.3 Task analysis.

Critical tasks should be subjected to a task analysis. In addition, other tasks should be analyzed as specified by the procuring activity. A set of data relevant to each task (critical or other) should be collected and analyzed. For each critical task, the minimum data collected and analyzed should be:

- Equipment acted upon
- Consequence of the action
- Feedback information resulting from the action
- Criterion of task accomplishment
- Estimate of probability of error
- Estimate of the time to perform the task successfully
- Relation of the time and error rate associated with each critical task to the performance time and error rate for the overall system.

Additional task data to be collected and analyses to be performed by the contractor should be specified by the procuring activity using the tailoring recommendations herein.

B.4.4 Level of detail and accuracy.

The level of detail in the task inventory and task analysis may be dependent upon the phase of system development and the task analysis application. The level of detail may be less in the early stages of system development than in later stages because of the lack of information. As the system develops and hardware and software specifications become solidified, the level of detail should increase. A greater level of detail normally is required as the system develops and matures. When feasible, the lack of detail in the early stages can be offset by an Early Comparability Analysis in which systems, equipment, or facilities similar to those being developed are examined to determine useful task information. The procuring activity should specify the level of detail using the tailoring recommendations herein. As a system develops, the precision of the task inventory and task analysis will improve and become more reliable.

B.4.5 Continuity.

As a system develops, changes are made and aspects of previous task inventories and task analyses become obsolete. Thus, they should be updated periodically to remain current. Currency should be maintained in the task inventory and task analysis throughout system development and acquisition. A task inventory and task analysis should build on previous task inventories and task analyses, with necessary changes and updates. Thus, there should be a continuity across the task inventories and task analyses performed during system development and acquisition.

B.4.6 Data base.

A data base of task inventory and task analysis information should be maintained and updated throughout system development and acquisition. This data base activity should be developed and

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updated as the contractor produces task inventory output and performs the task analysis. As information from these activities is produced through an iterative process, as stated in B.4.5, the data base should be updated in a continuous manner. For large or complex systems, the data base should be computerized. However, task inventory and task analysis data for simple systems may be adequately represented in printed or graphic form.

## B.5 SPECIFIC GUIDELINES

### B.5.1 Task inventory.

A task inventory should be prepared for the military system, equipment, or facility being acquired. This task inventory should consist of a list of all tasks that operators, maintainers, or support personnel must perform. Mission analyses, scenarios and conditions, and functional analyses should have been completed and documented prior to the task inventory and task analysis efforts. The task inventory is then developed by examining each system function allocated to personnel and determining what operator, maintainer, or support personnel tasks are involved in the completion of each system function. The inventory should be organized in terms of system functions, jobs, duties, tasks, subtasks, and task elements, as reflected in the task taxonomy given in B.5.1.1.3 through B.5.1.1.8. The task inventory is composed of task statements, each of which consists of (a) an action verb that identifies what is to be accomplished in the task, (b) an object that identifies what is to be acted upon in the task, and (c) qualifying phrases needed to distinguish the task from related or similar tasks. A task statement should exhibit the properties of clarity, completeness, conciseness, and relevance. Clarity is enhanced when easily understood wording is used, when the task statement is precise enough that it means the same thing to all intended users, and when vague statements of activities, skill, knowledge, or responsibility are avoided. A complete task statement contains sufficient detail to meet the needs of all intended users of such data. Concise task statements are brief, begin with an action verb (the subject I or you is understood), and employ commonly used and well understood terminology, abbreviations, and acronyms. Finally, a relevant task statement contains only information germane to describing the task (not the qualifications of the operator, maintainer, or support personnel; necessary tools or job aids; etc.).

B.5.1.1 Task inventory taxonomy. The task inventory and subsequent task analysis should be developed for the operator, maintainer, and support personnel involved with the system hardware, equipment, or facility under development. The level of detail in the task inventory should be specified by the procuring activity. The required level of detail should be specified in terms of the following taxonomy:

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B.5.1.1.1 Mission. What the system is supposed to accomplish, for example, combat reconnaissance.

B.5.1.1.2 Scenarios and conditions. Categories of factors for constraints under which the system will be expected to operate and be maintained, for example, day and night, all weather, all terrain operation.

B.5.1.1.3 Function. A broad category of activity performed by a system, for example, transportation.

B.5.1.1.4 Job. The combination of all human performance required for operation and maintenance of one personnel position in a system, for example, driver.

B.5.1.1.5 Duty. A set of operationally related tasks within a job, for example, emergency repair.

B.5.1.1.6 Task. A composite of related activities (perceptions, decisions, and responses) performed for an immediate purpose, for example, change a tire.

B.5.1.1.7 Subtask. Activities (perceptions, decisions, and responses) that fulfill a portion of the immediate purpose within a task, for example, remove lug nuts.

B.5.1.1.8 Task element. The smallest logically and reasonably definable unit of behavior required in completing a task or subtask, for example, apply counterclockwise torque to lug nut with lug wrench.

In addition to the task taxonomy given above, a consistent verb taxonomy should be used in the task statements. All verbs should be unambiguously defined within the taxonomy and used consistently throughout the task inventory. Some systems, equipment, and facilities will be developed with job categories well defined from the start of the task analysis activity. In this case, the task inventory should be organized by jobs and duties within jobs. New systems, equipment, and facilities under development may not have identifiable job categories, especially early in system development. In this case, the task analysis activity will be driven by the system functional analysis. As the task inventory and task analysis activity progresses, job positions will be identified by logically related sequences of tasks (duties).

B.5.2 Task analysis.

The task analysis process is one by which tasks are described in terms of the perceptual, cognitive, and manual behavior required of an operator, maintainer, or support person; the skills and information required to complete the task; equipment requirements; the task setting; time and accuracy requirements; and the probable human errors and consequences of these errors. It is not always necessary or cost effective to analyze all tasks in the task inventory. However, critical tasks should always be subjected to a task analysis. Tasks in the task inventory that reflect possible unsafe practices or that show the potential for improvements in operating efficiency should also be analyzed further, with the approval of the procuring activity. Finally, the

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procuring activity may require the contractor to analyze other tasks not covered in the above categories, for example, frequently performed tasks.

B.5.2.1 Specific task analysis parameters. The task analysis should contain information detailed enough to support ongoing HE, training, T&E, manning, or workload activities, as specified by the procuring activity. The analysis of a task may include, but is not limited to, the following:

a. Input parameters
   (1) Information required
   (2) Information available
   (3) Initiating cues
   (4) Data display format

b. Central processing parameters
   (1) Decision or evaluation processes
   (2) Decisions reached after evaluation
   (3) Job knowledge required
   (4) System knowledge required
   (5) Academic knowledge required
   (6) Significant memorization required

c. Response parameters
   (1) Actions taken
   (2) Body movements required by action taken
   (3) Workspace envelope required by actions taken
   (4) Workspace envelope available for actions taken
   (5) Physical skills required
   (6) Frequency or interval of actions
   (7) Tolerances of actions
   (8) Tools and job aids used
   (9) Support and test equipment
   (10) Power required
   (11) Spares or parts required
   (12) Adequacy of space support
   (13) Controls used
   (14) Control location
   (15) Instrumentation, displays, and signals used
   (16) Instrumentation, display, and signal location

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d. Feedback parameters

(1) Feedback required
(2) Feedback available
(3) Cues indicating task completion
(4) Rate of feedback update
(5) Format of feedback

e. Environmental parameters

(1) Workspace available
(2) Workspace envelope required
(3) Workplace arrangement
(4) Environment contamination level
(5) Climate
(6) Noise
(7) Shock, vibration, motion
(8) Lighting
(9) Workspace accessibility
(10) Workplace accessibility
(11) Life support and protective gear

f. Safety parameters

(1) Types and locations of safety hazards
(2) Cause of safety hazard
(3) Frequency of safety hazard
(4) Consequences of safety hazard
(5) Safety procedures
(6) Recommendation to eliminate or minimize safety hazard

g. Health parameters

(1) Mechanical forces

(a) Impulse noise and blast overpressure
(b) Steady-state noise
(c) Ultrasound
(d) Vibration and motion
(e) Acceleration and deceleration
(f) Impact, shock, and recoil
(g) Windblast
(h) Pressure fluctuations
(i) Weight and force loadings

(2) Temperature extremes

(a) Ambient and radiant heat
(b) Surface heat
(c) Flame and fire
(d) Ambient cold

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(e) Surface cold

(3) Electromagnetic radiation

(a) Laser radiation
(b) Microwave and radio-frequency radiation
(c) Ultraviolet radiation
(d) Intense visible light
(e) Ionizing radiation
(f) Particle beams
(g) Magnetic fields

(4) Toxic substances

(a) Fumes, vapors, and aerosols
(b) Smoke
(c) Liquids
(d) Solids
(e) Dust and particulates
(f) Chemical warfare agents, biological warfare agents, and antidotes

(5) Psychological stress

(a) Confined spaces
(b) Isolation
(c) Sensory and cognitive overload
(d) Visual illusions and disturbances
(e) Bodily disorientation (vestibular and kinesthetic)
(f) Sustained high-intensity operations

(6) Other

(a) Caustic chemicals
(b) Oxygen deficiencies (airborne and terrestrial)
(c) Restricted nutrition
(d) Restricted water availability
(e) Excessive water, moisture, or humidity
(f) Human waste elimination constraints
(g) Pests (insects and rodents)
(h) Broken glass, shrapnel, and missiles
(i) Skin or eye contact
(j) Electric shock
(k) Bacteria, viruses, and fungi

h. Performance standards and workload parameters

(1) Accuracy requirements
(2) Consequences of errors
(3) Subjective assessment by operator, maintainer, or support personnel of the reasons for their errors
(4) Description of each possible human-initiated error
(5) Performance under stress
(6) Subjective assessment of task workload

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(7) Subjective assessment of equipment design adequacy for task performance
(8) Subjective assessment of sufficiency of training and experience for task performance
(9) Physiological workload assessment
(10) Cognitive workload assessment
(11) Criteria for successful performance
(12) Error sources
(13) Allocated elapsed time or time budget
(14) Allocated work hours
(15) Predicted elapsed time
(16) Predicted work hours
(17) Task schedule or time line
(18) Elapsed time required to accomplish the task

i. Social and organizational parameters

(1) Task interdependence of crewmembers
(2) Number of personnel required to perform task
(3) Specialty and experience requirements
(4) Division of labor or responsibility
(5) Communications employed

j. Housekeeping parameters

(1) Task, subtask, task element title or statement
(2) Task, subtask, task element number
(3) Methodology used to generate task analysis results
(4) Data sources used
(5) Date
(6) Name of task analyst
(7) System mission and function
(8) Position title and duty (of position being analyzed)
(9) Position or skill specialty code (MOS/AFSC/NEC)
(10) Activities preceding the task
(11) Concurrent tasks
(12) Additional comments
(13) Validation and quality control (especially of critical tasks)

k. Other parameters (not listed above)

B.5.2.2 Graphic representation of task analysis. The task analysis should be presented in narrative form and may be supplemented by graphic portrayal. In graphic form, the task analysis can be represented in a time-line chart, operational sequence diagram, flow chart, or other appropriate graphics. Time-line charts indicate the interrelationships among tasks as a function of time. Operational sequence diagrams depict the activities of human and machine systems components and the interrelations among these components over time. Flow charts represent the

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functional dependencies among tasks. The principal advantage of the graphic format is that the sequential and simultaneous relationships among tasks are evident. Each task represented in the graphic form should be keyed to the narrative form of the task analysis. (See Section 8.3 for task analysis methods.)

B.5.3 Level of detail and precision.

The level of detail and precision used in the task analysis is determined by (a) the current phase of system development, and (b) the specifications of the procuring activity. The analysis may follow the system development cycle in a hierarchical fashion, so that tasks are defined early in system development, and then subtasks and task elements are described later in system development. The level of description ultimately used in the task analysis should be that level sufficient to meet the most detailed requirements specified by the procuring activity.

B.5.4 Continuity.

Task analysis activities should be carried on to remain current with the design effort during each phase of system development. The application of task analysis is to be considered iterative and evolutionary. To facilitate an orderly transition between system development phases, continuity among task analysis efforts should be ensured by (1) moving from the general to the specific as system development permits; (2) maintaining consistent and clearly defined terminology applicable to the system, equipment, or facility; (3) providing sufficient detail, relative to the phase of system development, to meet the most stringent information needs of a particular application; and (4) building upon previous task analysis efforts rather than starting anew each time the system undergoes some modification.

B.5.5 Data base requirements.

To be useful for the purposes intended by the procuring activity, a task inventory and task analysis data base should exhibit the following attributes:

B.5.5.1 Traceability. Data base inputs should be traceable. To provide accountability, the contractor should document the task analysis effort from the initial identification of functions, jobs, duties, tasks, subtasks, and task elements pertinent to system or job functions through the task analysis of tasks.

B.5.5.2 Data base media. For large, complex systems, task inventory and task analysis data should reside in a computer. However, for relatively simple systems, printed forms, supplemented with graphic materials, will suffice.

B.5.5.3 Accommodation of expansion and updating. The data base media should accommodate expansion and updating.

B.5.5.4 Relevance. The data base should not contain irrelevant data.

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## B.6 ADDITIONAL SOURCES OF INFORMATION

Balcom, J., Mannie, T., Jr., et al. (September, 1982). Estimating the manpower, personnel, and training requirements of the Army's Corps Support Weapon System using the HARDMAN methodology (Technical Report No. 564). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD-A134037)

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Burgy, D., Lempges, C., Miller, A., Schroeder, L., Van Cott, H., & Paramore, B. (September 1983). Task analysis of nuclear-power-plant control-room crews. Project approach methodology (Technical Report No. NUREG/CR–3371-Vol. 1). Washington, D.C.: Nuclear Regulatory Commission. (AD-A8310-031133)

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DeVries, P. B., & Eschenbrenner, A. J. (1979). Task analysis handbook (Technical Report No. AFHRL-TR-79-45[11]). Brooks AFB, TX: Air Force Human Resources Laboratory. (AD-0A087711)

Guidelines for job and task analysis for DOE nuclear facilities (Report No. DOE/EP- 0095). (June, 1983). North Stonington, CT: Analysis and Technology, Inc.; prepared for the Department of Energy.

Lobel, A. E., & Mulligan, J. F. (January, 1980). Maintenance task identification and analysis: Organizational and intermediate maintenance (Technical Report No. AFHRL-TR79-50). Wright-Patterson AFB, OH: Air Force Human Resources Laboratory. (AD-A083685)

McCormick, E. J. (1979). Job Analysis: Methods and applications. New York: AMACOM American Management Association.

Meister, D. (1985). Behavioral analysis and measurement methods. New York: John Wiley & Sons.

Meyer, R., Leveson, J., & Pape, G. (September, 1978). Development and application of a task taxonomy for tactical flying (Technical Report No. AFHRL-TR-78-42[1]). Williams AFB, AZ: Air Force Human Resources Laboratory. (AD-A79061387)

MIL-HDBK-1379, Guidance for acquisition of training data products and services (1997).Washington, D.C.: Department of Defense.

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Pew, R. W., Woods, W. A., Stevens, A. L., & Weene, P. (1978). Identifying information system requirements for decision-making (Report No. ESD-TR-78-169). Cambridge, MA: Bolt, Beranek, and Newman. (AD-B031705L)

Price, H., Maisano, R., & Van Cott, H. (June, 1982). Allocation of functions in man-machine systems: A perspective and literature review (Technical Report No. NUREG/CR–2623). Washington, D.C.: Nuclear Regulatory Commission. (AD-A8207-023193)

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# APPENDIX C
# HE DATA ITEM DESCRIPTIONS (DIDS)

HE Data Item Descriptions (DIDs) are presented on the following pages in this order:

HE Simulation Concept (HESC) (DI-HFAC-80742B)
HE Test Plan (HETP) (DI-HFAC-80743B)
HE Test Report (HETR) (DI-HFAC-80744B)
HE System Analysis Report (HESAR) (DI-HFAC-80745B)
HE Design Approach Document-Operator (HEDAD-O) (DI-HFAC-80746B)
HE Design Approach Document-Maintainer (HEDAD-M) (DI-HFAC-80747B)
Critical Task Analysis Report (CTAR) (DI-DI-HFAC-81399A)

(Note: When this handbook was prepared, the Army Materiel Command, OPR for DI-HFAC-80742 through DI HFAC-80747, approved those DIDs only through January 1999. Those HE DIDs, not transferred to Navy or Air Force OPR(s) by that time will be cancelled. Accordingly, the latest issue of DOD 5010.12-L should be consulted to identify current human engineering DIDs.)

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| 1.TITLE | 2. IDENTIFICATION NUMBER |
|---|---|
| Human Engineering Progress Report | DI-HFAC-80741B |

3. DESCRIPTION/PURPOSE

The Human Engineering Progress Report describes the status of the contractor's human engineering program and reports progress, problems, and plans for each succeeding reporting period. These reports provide evidence that human engineering considerations are reflected in system design and development and indicate compliance with contractual requirements for human engineering.

a. This data item description (DID) contains the format and content preparation instructions for a Human Engineering Progress Report resulting from applicable tasks delineated in the SOW.

b. This DID supersedes DI-HFAC-80741A.

| 4. APPROVAL DATE *(YYMMDD)* | 5. OFFICE OF PRIMARY RESPONSIBILITY (OPR) | 6a. DTIC APPLICABLE | 6b. GIDEP APPLICABLE |
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7. APPLICATION/INTERRELATIONSHIP

| 8. APPROVAL LIMITATION | 9a. APPLICABLE FORMS | 9b. AMSC NUMBER |
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| | | |

9. PREPARATION INSTRUCTIONS

Requirements:

1. General. The Human Engineering Progress Report shall describe progress and activity in sufficient detail to demonstrate that human engineering considerations are reflected in systems analyses (or systems engineering analyses where required), system design and development, and system test and evaluation. Progress reports shall be concise and shall not unnecessarily repeat previously reported material. Changes may be indicated by reference to past reports rather than by duplication of an entire set of data, information, or plans. Where detailed data are furnished by other reporting media, they shall be referenced by, rather than included in the progress report; however, general summary information, reflecting results of efforts germane to reported progress, shall be included.

2. Format. The Human Engineering Progress Report format shall include the following separate sections:

a. Work accomplished this reporting period. This section shall address tasks begun, completed, or in progress; significant results of completed tasks; end item products completed and available for review; and unusual conclusions that may portend modification to future activities.

b. Work planned for next reporting period. This section shall address tasks that shall be started or completed.

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FIGURE C-1. HE progress report (HEPR) (DI-HFAC-80741B).

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DI-HFAC-80741B HE Progress Report (HEPR)

Continuation of 9.0 PREPARATION INSTRUCTIONS

c. Problems. This section shall identify specific problems that occurred during the reporting period or are anticipated to occur during the next reporting period. Effects of problems on other tasks, schedules, costs or program scope shall be indicated. Proposed solutions shall be presented.

d. Actions required of the procuring activity. This section shall identify special considerations or problems requiring procuring activity assistance.

e. Appendix. This section shall present reports, project notes, drawings, or other documentation required to ensure completeness of the progress report.

3. Content. The Human Engineering Progress Report shall contain the following:

a. Summary and current status of human engineering activity.

b. Summary and status of significant human engineering design recommendations and action teams.

c. Summary of human engineering participation in major technical/subsystem reviews, other design reviews, and program reviews.

d. Summary results of human engineering analyses, studies, experiments, mock-up evaluations, simulation activities, tests, and demonstrations.

e. Results of projects, which involved human engineering participation (e.g., trade-off studies).

f. Other documentation reflecting changes to system design which affect human system interface (appended to the report as needed).

4. End of DI-HFAC-80741B

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| 1.TITLE | 2. IDENTIFICATION NUMBER |
|---|---|
| Human Engineering Simulation Concept | DI-HFAC-80742B |

3. DESCRIPTION/PURPOSE

The Human Engineering Simulation Concept describes the contractor's intended use of mockups and simulators in support of human engineering analysis, design support, and test and evaluation.

a. This data item description (DID) contains the format and content preparation instructions for the Human Engineering Simulation concept resulting from applicable tasks delineated in the SOW.

b. This DID is related to DI-HFAC-80741B, "Human Engineering Progress Report." This document may be used by the procuring activity to assist in and assess simulation approaches when there is a need to resolve potential critical human performance problems, particularly where government facilities, models, data or participants are required.

c. This DID supersedes DI-HFAC-80742A.

| 4. APPROVAL DATE (YYMMDD) | 5. OFFICE OF PRIMARY RESPONSIBILITY (OPR) | 6a. DTIC APPLICABLE | 6b. GIDEP APPLICABLE |
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7. APPLICATION/INTERRELATIONSHIP

| 8. APPROVAL LIMITATION | 9a. APPLICABLE FORMS | 9b. AMSC NUMBER |
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| | | |

9. PREPARATION INSTRUCTIONS

Requirements:

1. Format. The Human Engineering Simulation Concept format shall be contractor selected. Unless effective presentation would be degraded, the initially used format arrangement shall be used for all subsequent submissions.

2. Content. The Human Engineering Simulation Concept shall contain the following information:

a. Rationale and general description. The need for a mockup or simulation program shall be described. The overall simulation concept shall be described. Benefits to be derived shall be stated. The interrelationships between mockups, simulators, and other human engineering analysis, design support, and test and evaluation techniques shall be described.

b. Techniques. Each simulation technique and procedure proposed by the contractor shall be fully described. Rationale for the selection of techniques shall be given. The specific contributions of each technique to human engineering analysis, design support, and test and evaluation shall be stated. Previous efforts conducted by the contractor or others to validate each proposed technique shall be described, including a discussion of results.

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FIGURE C-2. HE simulation concept (HESC) (DI-HFAC-80742B).

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DI-HFAC-80742B HE Simulation Concept (HESC)

Continuation of 9.0 PREPARATION INSTRUCTIONS

c. Intended use. The intended use of each simulation technique shall be described with regard to each of the following:

(1) Human performance and workload analysis, test, and demonstration.
(2) System design development, test, and demonstration.
(3) System effectiveness studies, tactics development, and verification.
(4) Development and verification of operator skill, knowledge, and other training data.
(5) Operator procedures development and verification, including degraded mode and emergency procedures.
(6) Training equipment design and verification studies.
(7) Development and verification of technical publications.

d. Schedule. A detailed schedule shall be identified. Compatibility between the simulation schedule and the release of program analyses, design, and test products for each area of utilization described in paragraph 2c. above, shall be described.

e. Facilities and special requirements. Simulation facilities shall be described. Any requirements to utilize government facilities, models, data, or other government property shall be identified. If the contractor requires participation by government personnel (e.g., as subjects in simulation studies), appropriate information shall be provided, such as number and qualifications of personnel, desired level of participation, and schedule of participation.

f. Scenarios and mission descriptions. The scenarios and missions to be simulated shall be described. Information on mission objectives, geography, threats, weather conditions, or any other data relevant to system simulation shall be presented.

3. End of DI-HFAC-80742B

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| 1.TITLE | 2. IDENTIFICATION NUMBER |
|---|---|
| Human Engineering Test Plan | DI-HFAC-80743B |

3. DESCRIPTION/PURPOSE

The Human Engineering Test Plan details the proposed testing to demonstrate that the personnel-equipment/software combination can accomplish the intended operation and maintenance functions in accordance with system specifications. This plan serves as the principal means of planning for validating human performance requirements, accuracy of personnel selection criteria, adequacy of training, and acceptability of design of the personnel-equipment/software interface.

a. This data item description (DID) contains the format and content preparation instructions for a Human Engineering Test Plan resulting from applicable tasks delineated in the SOW.

b. This DID is related to DI-HFAC-80744B, "Human Engineering Test Report". This plan serves as the principal means of planning for validating human performance requirements, accuracy of personnel selection criteria, adequacy of training, and acceptability of design of the personnel-equipment/software interface.

c. This DID supersedes DI-HFAC-80743A.

| 4. APPROVAL DATE *(YYMMDD)* | 5. OFFICE OF PRIMARY RESPONSIBILITY (OPR) | 6a. DTIC APPLICABLE | 6b. GIDEP APPLICABLE |
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7. APPLICATION/INTERRELATIONSHIP

| 8. APPROVAL LIMITATION | 9a. APPLICABLE FORMS | 9b. AMSC NUMBER |
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| | | |

10. PREPARATION INSTRUCTIONS

Requirements:

1. General. The Human Engineering Test Plan shall detail the contractor's plan for gathering and analyzing data to show that the system, when fielded, will satisfy four criteria:

a. All human performance requirements for operations and maintenance can be performed to an acceptable level or standard under conditions of expected use.

b. The human performance requirements for operations and maintenance can be performed reliably by personnel reasonably representative of the military personnel who will ultimately perform them.

c. Both the cost (in terms of all resources required) and some measure (based on human performance time and error data) of prospective effectiveness of the contractor's training program for operations and maintenance are known.

d. The design of system hardware and software facilitates efficient, safe, and accurate human performance.

2. Format. The Human Engineering Test Plan format shall be contractor selected. Unless effective presentation would be degraded, the initially used format arrangement shall be used for all subsequent submissions.

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FIGURE C-3. HE test plan (HETP) (DI-HFAC-80743B).

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DI-HFAC-80743B HE Test Plan (HETP)

Continuation of 9.0 PREPARATION INSTRUCTIONS

3. Content. The Human Engineering Test Plan shall contain the following:

a. Introductory information. Introductory information shall include the following:
(1) Title descriptive of each test to be conducted.
(2) Identification of equipment (or concept) being tested.
(3) Statement of the task groups (or portions thereof) being reported. (A list, in sequential order, of all the discrete performance tasks--with critical tasks identified--which will be required of each person in the system).
(4) Purpose of tests.
(5) Objective(s) of tests (if different from paragraph 3a-4).

b. Test design. Identification of test conditions, performance measures, sample sizes, and sequence of test events.

c. Test methods and controls. Description of procedures to be followed in conducting each test. Explanation of how environmental variables and other factors which could affect the performance measures will be controlled or described, including where relevant:
(1) Noise.
(2) Illumination level.
(3) Shock and vibration.
(4) Air temperature and humidity.
(5) Ventilation.
(6) Exposure to toxic or hazardous substances.

d. Test participants. General description of the personnel population from which test participants will be selected. Identification and justification of test participant selection criteria. Identification of methods by which data describing actual test participants will be gathered, including where relevant:
(1) Age.
(2) Weight.
(3) Sex.
(4) Body dimensions relevant to performance tasks.
(5) Visual acuity.
(6) Hearing level.
(7) Existence of physical disabilities.
(8) Educational and work experience.
(8) Prior experience relevant to performance tasks.

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DI-HFAC-80743B HE Test Plan (HETP)

Continuation of 9.0 PREPARATION INSTRUCTIONS

e. Training of test participants.

(1) Type and amount (in hours) of system-specific pre-test training planned for test participants.
(2) Any end-of-training comprehension test administered to test participants before test data-gathering begins.

f. Equipment involved.

(1) Description of mockup or equipment on which tests will be conducted (including material to be used and type of fabrication, dimensions, and cross-reference to drawings or sketches).
(2) Identification of other, non-system equipment involved in tests (including all equipment to be worn, or carried or otherwise borne on the body of test participants such as weapon, communications equipment, headgear, survival equipment, protective mask and night vision equipment).

g. Data collection. Detailed description of the instrumentation or other means which will be used to obtain raw data on each of the performance measures. Identification of forms, if any, that will be used for recording data. Description of the frequency and means by which data on environmental variables and other extraneous factors will be collected.

h. Data reduction. Detailed descriptions of techniques to be used for transformation and combination of raw data, statistical techniques to be employed and assumptions pertaining to the use of each (e.g., normally distributed), and confidence levels selected.

i. Data analysis. Explanation of how the data collected will be used in:
(1) Human performance error analysis (e.g., “calculating operator error rate for mission-critical tasks”).
(2) Identifying incompatibilities among human performance and equipment.
(3) System safety analysis.
(4) Logistics and maintainability assessment(s).
(5) Calculating system reliability, availability, and effectiveness.

j. Test reporting. Identification of tests for which a “Human Engineering Test Report”, DI-HFAC-80744, is planned and tentative date(s) of initial submission.

4. End of DI-HFAC-80743B

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| 1.TITLE | 2. IDENTIFICATION NUMBER |
|---|---|
| Human Engineering Test Report | DI-HFAC-80744B |

**3. DESCRIPTION/PURPOSE**

The Human Engineering Test Report provides evidence that the human-system interface requirements for the operation, maintenance, and support of the system have been met. This report serves as the principal means of assessing the compatibility of the human performance requirements, personnel selection criteria, training program, and design of the human-equipment/software interfaces. This report will be used to determine whether and to what level or standard(s) each trained individual can perform in the specified sequence all assigned systems tasks, to determine whether and to what extent each individual's performance is affected by equipment configuration, the performance of other system personnel, or both; and to assess the impact of the measured human performance on the attainment of task, task group, and mission requirements.

a. This data item description (DID) contains the format and content preparation instructions for a Human Engineering Test Report resulting from the work task delineated in the SOW.

b. This DID is related to DI-HFAC-80743A, "Human Engineering Test Plan".

c. This DID supersedes DI-HFAC-80744A.

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**7. APPLICATION/INTERRELATIONSHIP**

| 8. APPROVAL LIMITATION | 9a. APPLICABLE FORMS | 9b. AMSC NUMBER |
|---|---|---|
| | | |

**10. PREPARATION INSTRUCTIONS**

Requirements:

1. General. The Human Engineering Test Report shall be prepared for each personnel position in the system being developed. All of the operations and maintenance tasks required of the individual assigned to a personnel position shall be referred to as the "task group" of the position.

2. Format. The Human Engineering Test Report format shall be contractor selected. Unless effective presentation would be degraded, the initially used format arrangement shall be used for all subsequent submissions.

3. Content. The Human Engineering Test Report shall contain the following:

a. Introductory information.

(1) Specific title of test.

(2) Identification of equipment or concept being tested.

(3) Specific purpose of this test.

(4) Objectives of this test (if appropriate, stated in terms of hypothesis to be tested).

(5) Date(s), location(s), names(s) of individuals present and supervising the conduct of the test.

(6) For each task group or portion thereof reported, a list of all the discrete tasks and a brief description of the operational environment in which they are to be performed when the system is deployed.

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FIGURE C-4. HE test report (HETR) (DI-HFAC-80744B).

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DI-HFAC-80744B HE Test Report (HETR)

Continuation of 9.0 PREPARATION INSTRUCTIONS

b. Description of test methods and controls. The following test methods and controls shall be described.

(1) Human performance standards. State or reference any human performance standards (e.g., "0.9 probability of operator launching missile within 10 seconds after detecting target") or assumed contribution to error (e.g., "aiming error less than 3 mils") contained in system development documents. If none, so state.

(2) Environment. Describe the environment at each distinct location of human performance. (Include noise and illumination levels, shock and vibration, air temperature and humidity, and ventilation. Also, state the concentration of, and test participant exposure time to any toxic or hazardous substances, and state whether that exposure was or was not within the applicable safety limits for each substance).

(3) Test participants. Describe test participants. For each participant, where relevant, state age, weight, body dimensions applicable to performance tasks, visual acuity and hearing levels, any known physical disabilities, and educational and work experience.

(4) Individual clothing and equipment. Describe individual clothing and equipment (including all clothing and equipment worn, carried or otherwise borne on the body, such weapon, communications equipment, headgear and protective mask).

(5) Pre-test training. Describe type and amount (in hours) of system-specific pre-test training (differentiating "hands on" practice from other training) given to test participants; and type, content and results of training used. Also, state time intervals between end of training, training assessment, and start of tests being reported.

(6) Mockup or equipment. Describe the mockup or equipment on which test is conducted (including material used and type of fabrication, dimensions, and cross-reference to blueprints, drawings or sketches).

(7) Deviations. Identify deviation(s) during the test from conditions of expected use (see paragraph 3a(6) above); narrative explanation of reason(s) for deviation(s), and presumed effect(s) of such deviation(s) on the validity of generalizations from test data.

c. Data collection and use. The following shall be identified or described, as indicated:

(1) Identification of the quantitative and qualitative measures of both human and system performance.

(2) Description of methods, procedures, and instrumentation used in data collection.

(3) Description of techniques used for data reduction, statistical techniques employed, and confidence levels selected.

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DI-HFAC-80744B HE Test Report (HETR)

Continuation of 9.0 PREPARATION INSTRUCTIONS

d. Results. The following results shall be summarized:

(1) Quantitative human and system performance data.
(2) Qualitative data (including questionnaires, interviews, and checklists).

e. Human performance errors. The following considerations of human performance shall be described:

(1) Each error (narrative description, with photograph(s) if appropriate) and frequency of occurrence.
(2) Consequence (brief statement of the immediate effect of the error on system operation).
(3) Causes (isolation of the immediate cause of each actual performance error and identification of the events, conditions, operator workload, environmental factors, and equipment configurations which may have contributed to it).
(4) Explanation by participants making errors of the reasons for the errors.
(5) Recommended solutions (stated in terms of equipment redesign, alteration of tasks, personnel selection, training, or a combination of these) and rationale.

f. Incompatibilities among human performance and equipment.

(1) Identification. The following incompatibilities encountered during the test, shall be identified:

(a) The tasks of one task group that interfered with the performance of tasks of another task group. (Identify both the interfering and affected tasks.) If none, so state.
(b) The human performance that was adversely affected by equipment configuration or characteristics. (Identify the human performance, equipment involved, and controls or displays needed but not present.) If no adverse effects on human performance were encountered, so state.

(2) Recommend solutions. Recommend solutions (stated in terms of equipment redesign, alteration of tasks, personnel selection, and training). Provide rationale.

g. Observed safety hazards. Descriptions of each safety hazard encountered during the test shall include the information below. If none were encountered, so state.

(1) Narrative description, with photograph(s) if appropriate.

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DI-HFAC-80744B HE Test Report (HETR)

Continuation of 9.0 PREPARATION INSTRUCTIONS

(2) Frequency of occurrence.
(3) Severity and consequences.
(4) Recommended action to eliminate or minimize hazard. (State in terms of equipment redesign, alteration of tasks, personnel selection, training, or a combination of these, and provide rationale).

h. Analysis of impact of human performance on attainment of system performance goals. This analysis shall include a:

(1) Statement of (or reference to) system performance goals.
(2) Narrative explanation of reasons why any human performance tasks required by present equipment design are not feasible, or why any standards presently set for specific performance tasks are unattainable. (if all human performance requirements are feasible and any standards set appear to have been met, so state).
(3) Narrative explanation of how measured human performance times and errors in operations and maintenance can affect system reliability and availability.
(4) Narrative explanation of how measured human performance times and error frequencies and magnitudes can affect system effectiveness.
(5) Narrative explanation of how system performance goals would be affected by implementing the solutions recommended in paragraphs, 3e, 3f, and 3g above.

i. Conclusions. Conclusions shall include:

(1) Summary of major findings from test,
(2) Implications of major findings (including anticipated effects on system reliability, availability, and effectiveness).

j. Recommended changes. List of recommended changes to equipment configuration, human performance tasks, personnel selection and training (in order of decreasing importance) with indication of government or contractor organization responsible for implementing recommended actions.

4. End of DI-HFAC-80744B

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| 1.TITLE | 2. IDENTIFICATION NUMBER |
|---|---|
| Human Engineering System Analysis Report | DI-HFAC-80745B |

3. DESCRIPTION/PURPOSE

The Human Engineering System Analysis report describes the human engineering efforts conducted as part of system analysis and presents results. The data are used by the procuring activity to evaluate the appropriateness and feasibility of system functions and roles allocated to operators and maintainers.

a. This data item description (DID) contains the format and content preparation instructions for the Human Engineering System Analysis Report resulting from applicable tasks delineated in the SOW.

b. This DID supersedes DI-HFAC-80745A.

| 4. APPROVAL DATE (YYMMDD) | 5. OFFICE OF PRIMARY RESPONSIBILITY (OPR) | 6a. DTIC APPLICABLE | 6b. GIDEP APPLICABLE |
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7. APPLICATION/INTERRELATIONSHIP

| 8. APPROVAL LIMITATION | 9a. APPLICABLE FORMS | 9b. AMSC NUMBER |
|---|---|---|
| | | |

9. PREPARATION INSTRUCTIONS

Requirements:

1. Format. The Human Engineering System Analysis Report format shall be contractor selected. Unless effective presentation would be degraded, the initially used format arrangement shall be used for all subsequent submissions.

2. Content. The Human Engineering System Analysis Report shall contain the following:

a. System objective(s). In accordance with information provided by the procuring activity or contractor studies, the system objective(s) shall be described. If the objective(s) are to be met by the system operating in conjunction with other systems not within the scope of the contract, the following shall also be described.

(1) The overall (or higher level) objective(s) to be met through combined operation of systems.
(2) The sub-objective(s) to be met by the system being developed under the contract.
(3) Interactions required between systems to meet the objective(s).

b. System missions(s). In accordance with information provided by the procuring activity or based upon contractor studies, the system mission(s) shall be described. The mission description(s) shall describe the context(s) within which the system will meet its objective(s); e.g., geography, mission time constraints, weather, day/night, humidity, sea state, terrain roughness, vegetation density, enemy force concentration, enemy weapons/countermeasures capabilities, enemy order of battle, presence or absence of other cooperating systems.

10. DISTRIBUTION STATEMENT

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FIGURE C-5. HE system analysis report (HESAR) (DI-HFAC-80745B).

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DI-HFAC-80745B HE System Analysis Report (HESAR)

Continuation of 9.0 PREPARATION INSTRUCTIONS

c. System functions. In accordance with information provided by the procuring activity or based on contractor studies, or both, the system functions (which must be performed to meet the system objective(s) within the mission context(s) shall be described.

d. Allocation of system functions. Allocation of system functions shall be described. Specifically, the following analyses and the results of these analyses shall be presented:

(1) Information flow and processing.
(2) Estimates of potential operator/maintainer processing capabilities.
(3) Allocation of functions.

e. Equipment identification. In accordance with information provided by the procuring activity and based upon contractor studies conducted to identify equipment, the selected design configuration shall be described.

3. End of DI-HFAC-80745B

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| 1.TITLE | 2. IDENTIFICATION NUMBER |
|---|---|
| Human Engineering Design Approach Document-Operator | DI-HFAC-80746B |

3. DESCRIPTION/PURPOSE

The Human Engineering Design Approach Document - Operator (HEDAD-O) describes equipment which interfaces with operators. This document provides a source of data to evaluate the extent to which equipment having an interface with operators meets human performance requirements and human engineering criteria.
a. This data item description (DID) contains the format and content preparation instructions for HEDAD-O resulting from applicable tasks delineated in the SOW.
b. This DID supersedes DI-HFAC-80746A.

| 4. APPROVAL DATE (YYMMDD) | 5. OFFICE OF PRIMARY RESPONSIBILITY (OPR) | 6a. DTIC APPLICABLE | 6b. GIDEP APPLICABLE |
|---|---|---|---|
| Draft | A/AMCOM | | |

7. APPLICATION/INTERRELATIONSHIP

| 8. APPROVAL LIMITATION | 9a. APPLICABLE FORMS | 9b. AMSC NUMBER |
|---|---|---|
| | | |

10. PREPARATION INSTRUCTIONS

Requirements:

1. Reference documents. The applicable issue of the documents cited herein, including their approval dates and dates of any applicable amendments, notices, and revisions shall be as cited in the current issue of the DODISS at the time of the solicitation.
2. General. The HEDAD-O shall describe the layout, detail design, and arrangement of crew station equipment having an operator interface; it shall also describe operator tasks (see below) associated with equipment. The HEDAD-O shall describe the extent to which human performance requirements and applicable human engineering design criteria (e.g., MIL-STD-1472) have been incorporated into the layout, design, and arrangement of equipment having an operator interface. Findings from analysis of operator tasks shall be presented as part of the rationale supporting the layout, design, and integration of crew station equipment.
3. Format. The HEDAD-O format shall be contractor selected. Unless effective presentation would be degraded, the initially used format arrangement shall be used for all subsequent submissions.
4. Content. The HEDAD-O shall contain the following crew station and operator-related information:
   a. Equipment List. A list of each item of equipment having an operator interface and a brief statement of the purpose of each item of equipment. Separate lists shall be provided for each operator's station.

10. DISTRIBUTION STATEMENT

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FIGURE C-6. HE design approach document–operator (HEDAD-O) (DI-HFAC-80746B).

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DI-HFAC-80746B HE Design Approach Document-Operator (HEDAD-O)

Continuation of 9.0 PREPARATION INSTRUCTIONS

b. Specification and drawing list. A list of specifications and drawings, approved by human engineering at the time of HEDAD-O preparation. When contractually required to prepare and submit the HEDAD-O early in the development process, the list shall also address documents where human engineering approval is planned.

c. Crew station description. Description(s) of the crew station(s), emphasizing human engineering design features. The following aspects of each crew station shall be described:

(1) Layout and arrangement. One sketch, drawing, or photograph of each crew station. These sketches, drawings, or photographs shall contain operator and equipment-related reference points (e.g., operator eye position, seat reference point) and scale. One sketch, drawing, or photograph of each item of crew station equipment shall also be provided; the point of reference shall be normal to the item of equipment and scale shall be indicated.

(2) Controls and displays. The layout and detail design of each control/display panel (or control/display areas independent of panels) shall be described (e.g., phospher type, brightness, resolution, contrast, color or other coding, control/display ratio, control force, and range characteristics). Display symbology, display formats, and control/display operation logic shall be described with regard to intended use by the operator(s).

(3) Operator vision. Operator vision to crew station items of equipment shall be described using the operator's normal eye position(s) as the point of reference. When applicable, operator external vision shall also be described using the operator's normal eye position(s) as the point of reference; extent of external vision shall be related to system mission requirements.

(4) Environmental factors. Operator life support systems, protective clothing and equipment, noise, vibration, radiation, temperature, ambient illumination, climatic effects, and other relevant environmental parameters.

(5) Ingress/egress. Normal and emergency ingress and egress provisions and procedures.

(6) Crew station lighting. Crew station lighting characteristics and lighting control systems.

DI-HFAC-80746B HE Design Approach Document-Operator (HEDAD-O)

Continuation of 9.0 PREPARATION INSTRUCTIONS

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(7) Crew station signals. Crew station signals including warning, caution, and advisory signals shall be described with regard to signal characteristics, signal meaning, signal consequences, operator procedures, cause of signal activation, and crew control over signal characteristics.

(8) Operator posture control. Operator posture control including seating, restraint systems, and other postural control techniques.

(9) Communication systems. Communication systems and communication systems control.

(10) Special design. Special design, layout, or arrangement features if required by mission or system environment.

(11) Multiple operator stations. Multiple operator station design, shall be described where applicable. Rationale for number of operators, arrangement of operators, and allocation of functions to the operators shall also be described.

d. Crew station geometry. Crew station geometry shall be described using the seat reference point or operator's eye position(s) as a reference point. The position of each control, display, panel, etc., shall be described in terms of three-dimensional space (X,Y,Z coordinates); operator eye position shall be described in terms of system design coordinates or as zero (X), zero (Y), and zero (Z). The center of each panel, display, control, etc., shall be used as the equipment point of reference. True angle to vision to each item of equipment shall also be shown.

e. Human engineering design rationale. Rationale for human engineering design, layout, and arrangement of each item of crew station equipment having an operator interface shall be described. The specific considerations of system mission (or system function); equipment operation; operator selection, training, and skill requirements; operator task performance requirements; and limitations imposed on designs by the procuring activity or state-of-the-art shall be described. The basis for reaching specific design, layout, and arrangement decisions shall be presented (e.g., MIL-STD-1472 criteria, human engineering requirements or guidelines specified in the contract, system engineering analyses, systems analyses, human engineering studies, trade-off analyses, mock-up results, simulation results, and human engineering results).

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DI-HFAC-80746B HE Design Approach Document-Operator (HEDAD-O)

Continuation of 9.0 PREPARATION INSTRUCTIONS

f. Analysis of operator tasks. Results from analysis of operator tasks (see critical tasks in MIL-HDBK-1908) shall be presented as part of the rationale for crew station design, integration, and layout. The following shall also be described: methodology used to generate task analysis results (e.g., paper and pencil, computer-based simulation, dynamic simulation); system-mission(s), function(s), or other exogenous information used to "drive" the task analysis; human performance data (e.g., time and error) against which task analysis results are compared; and operator assumptions (e.g., level of skill, training). Critical tasks (see MIL-HDBK-1908) shall be clearly identified. If the program has progressed to the point where the required data are available through other reporting media, such as a task inventory or task analysis, they shall not be duplicated, but shall be referenced or appended to the HEDAD-M along with appropriate supplementary information fulfilling the intent of this provision.

g. Alternatives to baseline design. Sketch, drawing, or photograph of each item of equipment being considered as alternatives or changes to the selected (baseline) crew station design.

h. Design changes. Design, arrangement, or layout changes made since the last HEDAD-O preparation.

5. End of DI-HFAC-80746B

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| 1.TITLE | 2. IDENTIFICATION NUMBER |
|---|---|
| Human Engineering Design Approach Document-Maintainer | DI-HFAC-80747B |

**3. DESCRIPTION/PURPOSE**

The Human Engineering Design Approach Document-Maintainer (HEDAD-M) describes equipment which interface with maintainers. This document provides a source of data to evaluate the extent to which equipment having an interface with maintainers meets human performance requirements and human engineering criteria.

a. This data item description (DID) contains the format and content preparation instructions for HEDAD-M resulting from applicable tasks delineated by the SOW.

b. This DID supersedes DI-HFAC-80747A.

| 4. APPROVAL DATE *(YYMMDD)* | 5. OFFICE OF PRIMARY RESPONSIBILITY (OPR) | 6a. DTIC APPLICABLE | 6b. GIDEP APPLICABLE |
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| Draft | A/AMCOM | | |

**7. APPLICATION/INTERRELATIONSHIP**

| 8. APPROVAL LIMITATION | 9a. APPLICABLE FORMS | 9b. AMSC NUMBER |
|---|---|---|
| | | |

**10. PREPARATION INSTRUCTIONS**

Requirements:

1. Reference documents. The applicable issue of the documents cited herein, including their approval dates and dates of any applicable amendments, notices, and revisions shall be as cited in the current issue of the DODISS at the time of the solicitation.

2. General. The HEDAD-M shall describe the characteristics, layout, and installation of all equipment having a maintainer interface (excluding depot level maintenance actions); it shall also describe maintainer tasks associated with the equipment. The HEDAD-M shall describe the extent to which the requirements and applicable human engineering design criteria (e.g., MIL-STD-1472) have been incorporated into the design, layout, and installation of equipment having a maintainer interface. Results from analysis of maintainer tasks shall be presented as part of the rationale supporting the layout, design, and installation of the equipment. The requirement for this information is predicated on the assumption that as analytic and study information, it is developed sufficiently early to influence the formulation of other system data, such as maintenance allocation, special repair parts, tool lists, and other logistic support data. If a task inventory or task analysis exists, it shall be referenced or appended to the HEDAD-M along with appropriate supplementary information fulfilling the intent of this provision.

**10. DISTRIBUTION STATEMENT**

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FIGURE C-7. HE design approach document–maintainer (HEDAD-M) (DI-HFAC-80747B).

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DI-HFAC-80747B HE Design Approach Document-Maintainer (HEDAD-O)

Continuation of 9.0 PREPARATION INSTRUCTIONS

3. Format. The HEDAD-M format shall be contractor selected. Unless effective presentation would be degraded, the initially used format arrangement shall be used for all subsequent submissions. The HEDAD-M format shall present the information in two major parts:

a. Information pertaining to maintenance actions performed at the organizational level.
b. Information pertaining to maintenance actions performed at the Field/Intermediate Maintenance Activity (IMA) level.

4. Content. The HEDAD-M shall contain the following:

a. Equipment List. A list of each item of equipment having a maintainer interface at the organizational and Field/IMA level, and a brief statement of the purpose of each item of equipment and types of maintenance required on each item of equipment (e.g., troubleshoot, remove, inspect, test, repair.)
b. Specification and drawing list. A list of specifications and drawings, approved by human engineering at the time of HEDAD-M preparation. The list shall also address documents where human engineering approval is planned.
c. System equipment description. Description(s) of system equipment, emphasizing human engineering design features. The following aspects of each crew station shall be described.

(1) Layout and arrangement. The location and layout of all system equipment requiring maintenance with emphasis on human engineering features which facilitate maintenance. Equipment located in areas assessed through common doors, panels, openings, etc., shall be indicated. The location of each item of equipment shall also be noted in terms of three-dimensional space (e.g., X,Y, and Z coordinates); the reference point for each item of equipment shall be its center as viewed by the maintainer while gaining access to the equipment.
(2) Design of equipment. The design of each item of equipment with emphasis on human engineering features which facilitate maintenance, such as handles, self-test capability, labeling, connector spacing, and keying.
(3) Installation of equipment. The installation of each item of equipment with emphasis on human engineering features which facilitate maintenance such as fasteners, clearances, relationship between accessibility and failure rate (or scheduled maintenance frequency) of each item of equipment, and visual access afforded.

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DI-HFAC-80747B HE Design Approach Document-Maintainer (HEDAD-O)

Continuation of 9.0 PREPARATION INSTRUCTIONS

d. Rationale. The specific consideration of equipment maintenance requirements (e.g., frequency, criticality, equipment failure rate), maintainer requirements (e.g., personnel selection, training, and skills), maintainer tasks requirements, environmental considerations, safety, and limitations imposed by the procuring activity or state-of-the-art. The basis for reaching specific design, layout, and installation decisions shall also be presented (e.g., MIL-STD-1472 criteria, human engineering requirements or guidelines specified in the contract, human engineering studies, trade-off analyses, mock-up results, and human engineering test results).

e. Special tools, support equipment, and aids. A list of special tools, support equipment, and job aids/devices required for maintenance of each item of equipment.

f. Analysis of maintainer tasks. Results from analysis of maintainer tasks (see critical tasks in MIL-HDBK-1908) shall be presented as part of the rationale supporting layout, design, and installation of items of equipment. Analysis of maintainer tasks analyses shall consist of the following: task number, task title, task frequency (for scheduled maintenance actions) or estimated task frequency (based on equipment mean-time-between-failure for unscheduled maintenance actions), data source used (e.g., drawing number, sketch number, development hardware, actual production equipment, detailed task sequence [see task analysis in MIL-HDBK-1908], support equipment required, tools required, job aids required, estimated task time, estimated personnel requirements [e.g., number of personnel required, skills and knowledge required] and human engineering considerations which reflect specific human engineering requirements incorporated into the design [e.g., maintainer fatigue, potential hazards, safety or protective clothing/equipment required or recommended, access problems, maintainer communication requirements, special task sequence requirements, labeling]). As applicable, the following types of maintainer tasks shall be addressed by the analyses of maintainer tasks; remove/replace, troubleshoot (fault location), repair, adjust, inspect, service, and test. Critical tasks (see MIL-HDBK-1908) shall be clearly identified.

g. Maintainer interface depictions. A sketch, drawing, or photograph of each item of equipment having a maintainer interface. Each item of equipment shall be depicted:

(a) by itself from top, front, and side (three-view trimetric or exploded trimetric view) and
(b) installed as the maintainer would normally view it during maintenance.

h. Alternative installations or layouts. A sketch, drawing, or photograph of each item of equipment being considered as an alternative to the selected, or baseline design. A sketch, drawing, or photograph of alternative equipment installations or layouts which exist at the time of HEDAD-M preparation shall also be provided.

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DI-HFAC-80747B HE Design Approach Document-Maintainer (HEDAD-O)

Continuation of 9.0 PREPARATION INSTRUCTIONS

i. Design changes. Design, installation, or layout changes which have been made since the last HEDAD-M preparation, shall be described.

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| 1.TITLE | 2. IDENTIFICATION NUMBER |
|---|---|
| Critical Task Analysis Report | DI-HFAC-81399A |

**3. DESCRIPTION/PURPOSE**

The Critical Task Analysis Report describes the results of analyses of critical tasks performed by the contractor to provide a basis for evaluation of the design of the system, equipment, or facility. The evaluation will verify that human engineering technical risks have been minimized and solutions are in hand.

a. This data item description (DID) contains the format and content preparation instructions for the data product generated by the specific and discrete task requirement as delineated in the contract.

b. This DID supersedes DI-HFAC-81399.

| 4. APPROVAL DATE (YYMMDD) | 5. OFFICE OF PRIMARY RESPONSIBILITY (OPR) | 6a. DTIC APPLICABLE | 6b. GIDEP APPLICABLE |
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**7. APPLICATION/INTERRELATIONSHIP**

| 8. APPROVAL LIMITATION | 9a. APPLICABLE FORMS | 9b. AMSC NUMBER |
|---|---|---|
| | | |

**10. PREPARATION INSTRUCTIONS**

1. Format. The Critical Task Analysis Report format shall be contractor selected. Unless effective presentation would be degraded, the initially used format arrangement shall be used for all subsequent submissions.

2. Content. The Critical Task Analysis Report shall describe and analyze each critical task including:

a. Information required by and available to personnel which is relevant to the critical task assigned to them.

b. Actions which each performer shall complete to accomplish the critical task, including responses to specific information, responses to combinations of information, and self-initiated responses.

c. The functional consequences of each operator or maintainer critical task with respect to the effects upon both the immediate subsystem functions and the overall system mission.

d. All affected missions and phases including degraded modes of operation. Information on each critical task shall be provided to a level sufficient to identify operator and maintainer problem areas that can adversely affect mission accomplishment and to evaluate proposed corrective action.

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FIGURE C-8. Critical task analysis report (CTAR) (DI- DI-HFAC-81399A).

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DI-HFAC-81399A Critical Task Analysis Report (CTAR)

Continuation of 9.0 PREPARATION INSTRUCTIONS

For each critical task, identify the:

(1) Information required by operator/maintainer, including cues for task initiation.
(2) Information available to operator/maintainer.
(3) Evaluation process.
(4) Decision reached after evaluation.
(5) Action Taken.
(6) Body movements required by action taken
(7) Workspace envelope required by action taken.
(8) Workspace available.
(9) Location and condition of the work environment.
(10) Frequency and tolerances of action.
(11) Time base.
(12) Feedback informing operator/maintainer of the adequacy of actions taken.
(13) Tools and equipment required.
(14) Number of personnel required, their specialties, and experience.
(15) Job aids, training, or references required.
(16) Communications required, including type of communication.
(17) Special hazards involved.
(18) Operator interaction where more than one crew member is involved.
(19) Performance limits of personnel.
(20) Operational limits of machine and software.

3. End of DI-HFAC-81399A

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Navy - AS
AF-11

Preparing Activity:
Army - MI
(Project HFAC-0086)

Review activities:
Army - AR, AT, AV, CR, EA, GL, MD, MR, PT, TE, TM
Navy - CG, EC, MC, ND, OS, PE, SH, TD
Air Force - 01, 10, 13, 19, 31
OSD - HS, SE
DLS - DH
DISA - DC2
NIMA - MP
NSA - NS

Industry associations and professional societies:
AAMI
AIA
ASTM
EIA
HFES
SAE

Civil Agency Coordinating Activities:
NASA - AE
NHTSA - OST
DOT - FAA