Acquisition Directorate

Research & Development Center

Report No. CG-D-04-09

Survey of Human Systems Integration (HSI) Tools for USCG Acquisitions

Distribution Statement:

This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.

April 2009

Homeland Security

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
APR 2009	**N/A**	**-**

4. TITLE AND SUBTITLE
Survey of Human Systems Integration (HSI) Tools for USCG Acquisitions

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Coast Guard Research and Development Center 1 Chelsea Street New London, CT 06320

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**178**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

NOTICE

This document is disseminated under the sponsorship of the Department of Homeland Security in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report does not constitute a standard, specification, or regulation.

Mr. Bert N. Macesker
AMS Branch Chief
United States Coast Guard
Research & Development Center
1 Chelsea Street
New London, CT 06320

1. Report No. CG-D-04-09	**2. Government Accession Number** Government Accession # (to be filled in by R&DC)	**3. Recipient's Catalog No.** N/A
4. Title and Subtitle Survey of Human Systems Integration (HSI) Tools for USCG Acquisitions		**5. Report Date** April 2009
		6. Performing Organization Code Project No. 9361
7. Author(s) Dr. Christopher Hale, Ms. Cindy Ching, Mr. Bryan Brett, and Dr. Anita Rothblum		**8. Performing Organization Report No.** R&DC UDI No. 848
9. Performing Organization Name and Address U.S. Coast Guard Research and Development Center 1 Chelsea Street New London, CT 06320	SAIC 23 Clara Drive, Suite 206 Mystic, CT 06355-1959	**10. Work Unit No. (TRAIS)** N/A
		11. Contract or Grant No. Contract HSCG32-05-D-R00010/ Task Order HSCG32-07-J-100029
12. Sponsoring Organization Name and Address U.S. Department of Homeland Security United States Coast Guard Human Resources Directorate Washington, DC 20593-0001		**13. Type of Report & Period Covered** Final
		14. Sponsoring Agency Code Commandant (CG-1B3) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

The R&D Center's technical point of contact is Dr. Anita M. Rothblum, 860-441-2847, email: anita.m.rothblum@uscg.mil.

16. Abstract (MAXIMUM 200 WORDS)

Human Systems Integration (HSI) is a collection of policies, processes, methods, and tools that are applied in the system acquisition process to ensure people are incorporated into new systems in ways that provide for their health and safety and that support system performance goals. The United States Coast Guard (USCG) uses competitive acquisition contracts to develop many types of products including aircraft, cutters, small boats, communications equipment, surveillance equipment, software suites, weapons, and personal protective equipment. The inclusion of HSI tools and methods in the acquisition process ensures the roles and needs of human operators are addressed concurrently with system development.

Because of the diversity of available tools, it can be daunting for system developers to locate and select the right tools for each acquisition phase. This report presents a compendium of HSI tools organized to help you select the right tool for your specific needs. The appendices provide reviews of 34 HSI tools and methods to support requirements and CONOPS development; manning and personnel analysis; workload and situation assessment analysis; and workstation and cockpit design. Eight of these tools and methods have been recommended as a "starter kit" for USCG acquisition use. Elements of this toolset can be used over the entire USCG major acquisition process and can contribute to a wide variety of HSI development activities.

17. Key Words acquisition HFE HSI human factors engineering	human performance human systems integration modeling total system performance	**18. Distribution Statement** Document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.	
19. Security Class (This Report) UNCLASSIFIED	**20. Security Class (This Page)** UNCLASSIFIED	**21. No of Pages**	**22. Price**

(This page intentionally left blank.)

EXECUTIVE SUMMARY

Human Systems Integration (HSI) is a collection of policies, processes, methods, and tools that are applied in the system acquisition process to ensure people are incorporated into new systems in ways that provide for their health and safety and that support system performance goals. The United States Coast Guard (USCG) develops many types of products including aircraft, cutters, small boats, communications equipment, surveillance equipment, software suites, weapons, and personal protective equipment. Other government agencies have found great benefits in mission performance and cost savings by including HSI activities all along the development/acquisition process. The USCG has become interested in a more methodical and integrated approach to HSI and recently stood up CG-1B3 as its Technical Authority for HSI. The technical authority will need to oversee/execute a variety of HSI activities during an acquisition. There are a number of HSI tools and methods that can be employed (by the USCG and-or its contractors) to perform HSI activities and analyses. This report presents a survey of 34 HSI tools and methods.

The report begins with an overview of HSI within the context of Coast Guard acquisition processes. We define the domains of HSI and discuss the importance of human operators as components of complex systems. We also discuss the importance of considering work content and variability in the operational environment as determinants of both the likely human performance envelope and the system's adaptive requirements during operations.

A foundational methodology for application of HSI to the acquisition and system engineering process then is briefly discussed. We identify ten system development processes in which HSI considerations play prominent roles, and which are critical to successful system development outcomes. These processes are mapped to the six major phases of Coast Guard system acquisition.* Their contributions to each phase are discussed.

We close the introductory section of the report with consideration of a small set of tools ("starter kit") within the context of a notional acquisition example. The purpose of this example is to illustrate how this tool subset can be used, in combination, to address many of the HSI challenges that arise during the design and development of a new system. This starter tool kit was chosen to have broad applicability across many of the development phases identified in earlier sections of the report (see Table ES-1, below).

HSI tools and methodologies falling into four categories are then surveyed against a number of criteria in the areas of content, communication, trade-off support, and traceability. The presentation of tools follows a discussion of the USCG acquisition process, HSI domains and activities, and a short example showing how some of these tools could be used to improve acquisition and systems engineering processes.

* In November 2008, the Department of Homeland Security (DHS) published interim Acquisition Directive 102-01 (see https://dhsonline.dhs.gov/portal/jhtml/tracking/viewdoc2.jhtml?doid=4658001). It describes a number of changes to DHS acquisition policy, including new names for the acquisition phases: Need; Analyze/Select; Obtain; and Produce/Deploy/Support. While the names have changed, the development objectives of each phase remain essentially the same, as do the potential contributions of HSI to each phase.

Table ES-1. Mapping of HSI "starter kit" tools to CG acquisition phases.

HSI Tool / Method	USCG Acquisition Phase					
	Project Identification	Project Initiation	Concept & Technology Development	Capability Development & Demonstration	Production & Deployment	Operations & Support
Concept mapping	✓	✓	✓			
Cognitive Function Analysis (CFA)		✓	✓	✓		
Information and Functional Flow Analysis (IFFA)		✓	✓	✓		
IMPRINT Pro			✓	✓		
Jack			✓	✓		
Job Assessment Software System (JASS)			✓	✓		
Advisor 3.5			✓	✓	✓	
Technique for Human Error Rate Prediction (THERP)				✓	✓	✓

The tools included in this survey should help acquisition managers, program managers, and system designers in two important ways. First, by providing ways to articulate and document HSI issues, the tools can be used to inform the overall acquisition process. Second, these tools support examination of the HSI issues whose resolution is crucial to system performance and the satisfaction of user needs. These tools will enhance and strengthen Coast Guard system acquisition effectiveness, efficiency, and operational outcomes by providing designers with the means to:

- understand the requirements associated with operations, critical decisions, and workflow;
- identify and properly allocate functions between human operators and systems;
- understand errors and their likely consequences; and
- carry out the trades required to optimize system effectiveness.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS/ABBREVIATIONS

3DSSPP	3D Static Strength Prediction Program
ACTA	Applied Cognitive Task Analysis
ACT-R	Adaptive Control of Thought – Rational
AVOSCET	Autonomous Vehicle Operator Span of Control Evaluation Tool
C&TD	Concept and Technology Development
C2	Command and Control
CD&D	Capability Development and Demonstration
CFA	Cognitive Function Analysis
CG	Coast Guard
CG-1B3	USCG Office of Human Resources, HSI Staff
CLS	Contractor Logistics Support
CONOPS	Concept of Operations
COTS	Commercial Off-the-Shelf
CREAM	Cognitive Reliability and Error Analysis Method
CSE	Cognitive Systems Engineering
DAGR	Defense Advanced GPS Receiver
DeSAT	Designer's Situation Awareness Tool
DoD	Department of Defense
DT&E	Developmental Test & Evaluation
EEPP	Energy Expenditure Prediction Program
GOMS	Goals, Operators, Methods and Selection Rules
GOTS	Government Off-the-Shelf
HFE	Human Factors Engineering
HPM	Human Performance Model
HSI	Human Systems Integration
IFFA	Information and Functional Flow Analysis
IMPRINT	Improved Performance Research Integration Tool
JASS	Job Assessment Software System
JBPDS	Joint Biological Point Detection Systems
LRU	Line Replaceable Unit
MANPRINT	Manpower & Personnel Integration
MAPS	Manpower Analysis and Prediction System
MIDAS	Man-Machine Integration Design and Analysis System
MMH	Manual Materials Handling
MPT	Manpower, Personnel, and Training
NASA	National Aeronautics and Space Administration
NIOSH	National Institute for Occupational Safety and Health
NMRS	Navy Manpower Requirements System
NSC	National Security Cutter
OPAREA	Operational Area
ORD	Operational Requirements Document

LIST OF ACRONYMS/ABBREVIATIONS (Continued)

OT&E	Operational Test & Evaluation
RDC	Research & Development Center
RULA	Rapid Upper Limb Assessment
SA	Situation Assessment
SAIC	Science Applications International Corporation
SHAPE	System Human Systems Integration for Affordability and Performance Engineering
T&E	Test and Evaluation
THERP	Technique for Human Error Rate Prediction
UAS	Unmanned Aerial Systems
UEA	Upper Extremity Assessment
USCG	United States Coast Guard
WMSM	Maritime Security Cutter Medium

(This page intentionally left blank.)

1 INTRODUCTION

The United States Coast Guard (USCG) uses competitive acquisition contracts to develop many types of products, including cutters, small boats, aircraft, communications equipment, surveillance equipment, software suites, weapons, and personal protective equipment. The complexity of many of the systems being acquired has increased dramatically, due in some measure to the complexity and performance demands of the USCG's new homeland security role. More sophisticated and complex systems require more sophisticated acquisition policies, organizations, personnel, and processes. The USCG is actively working to improve all of these aspects of their acquisition environment. Human systems integration (HSI) has been identified as an acquisition element that has not been incorporated into the process as efficiently as it might. HSI is a collection of policies, processes, methods, and tools that are applied in the system acquisition process to ensure people are incorporated into new systems in ways that provide for their health and safety and support system performance goals. The methodical incorporation of HSI into a system acquisition can result in substantial improvements in mission performance, as well as reduced cost (Rothblum, 2007).

1.1 Overview of the "HSI for Coast Guard Acquisitions" Task

In October 2007, USCG Office of Human Resources, HSI Staff (CG-1B3), was made the Technical Authority for HSI in all Coast Guard (CG) acquisitions. To assist both CG-1B3 and the Acquisition Directorate (CG-9), the USCG Research and Development Center (RDC) initiated a task [*] to identify HSI policies, processes, and tools which could improve the application of HSI within USCG acquisitions. The government-contractor HSI Team created the following products:

1) **HSI information brochure:** HSI is a relatively new concept for the USCG acquisition community. Two products were developed to educate and inform the community about HSI. The first product was a brochure (U.S. Coast Guard R&D Center, 2007, unpublished) that summarized the goals, areas of interest and analysis, processes, tools, and benefits of HSI to overall system development efforts. The brochure also illustrated how HSI can contribute to every phase of the CG's Major Acquisition Process.

2) **HSI support for CONOPS and ORD development:** The second product was an annotated briefing describing how HSI can be applied in Concept of Operations (CONOPS) and Operational Requirements Document (ORD) development (U.S. Coast Guard R&D Center, 2008b). A clear and effective statement of system requirements is essential to the development of mission-capable systems. The CONOPS and ORD are key requirements documents for expressing the CG's needs, requirements, and intended use of a new system. Consequently, it is imperative that HSI considerations be incorporated into these documents. The annotated briefing provides an overview of HSI, discusses HSI activities that can be performed in support of CONOPS and ORD development, and provides examples of methods and tools.

3) **HSI programs in other agencies:** Within the USCG and other Government organizations, the acquisition process is driven by formal policy documents such as regulations, directives, and instructions. Some organizations have promulgated specific policy in an effort to ensure that HSI is routinely and consistently incorporated into the acquisition process. These HSI-specific policies address

[*] The task order, "*Human Systems Integration for Coast Guard Acquisitions*," was performed by Science Applications International Corporation (SAIC) under contract number HSCG32-05-D-R00010, "*U.S. Coast Guard Research and Development Center Technical Support Services*."

factors such as how HSI organizations are structured, how HSI activities are incorporated into larger system acquisition efforts, and how the services define and implement the technical authority associated with HSI. The HSI Team addressed these questions by interviewing HSI representatives of three Department of Defense (DoD) services (Army, Navy, and Air Force) and the National Aeronautics and Space Administration (NASA), acquiring and analyzing technical instructions and other documents related to HSI definitions and program implementation, and by attending an inter-service workshop devoted to this topic. The HSI Team then produced an annotated briefing that documented these agencies' HSI organization, management, technical processes, and technical authority policies, and then made HSI policy and process recommendations for similar inclusion of HSI into the USCG acquisition process (U.S. Coast Guard R&D Center, 2008a).

4) **HSI tools survey and recommendations:** HSI encompasses a number of technical domains and a diverse set of activities. Methods and tools have been developed that enhance the focus and effectiveness of HSI analyses, design, and other activities and reduce the effort required. The HSI Team identified HSI tools that can be used to enhance USCG acquisition and system development processes. The tools surveyed included both (1) processes and methodologies and (2) software products that would be of value during the concept design, development, and evaluation phases of USCG acquisitions. This report is the product of that analysis.

1.2 The Organization of the Report

The body of this report provides overview information, while specific information on the tools has been included in the appendices. Section 2 discusses what HSI is, its role in the acquisition process, and the benefits that accrue from applying HSI. Section 3 provides introductory material on HSI tools: where they fit within the acquisition process; plus recommendations for an HSI tools "starter kit" for CG applications. A command and control (C2) system acquisition example is provided to show how the HSI "starter kit" could be applied throughout the acquisition process. Included is a brief discussion of human performance modeling as a specialized class of HSI tools that can provide quantitative, performance-based insights into a number of HSI domains across multiple acquisition phases. The discussion of human performance modeling also introduces an example (presented in more detail in Appendix F) of how the technology is applied. Section 3 ends with a summary of the survey.

Detailed information on the tools survey is provided in the appendices. Appendix A describes how the tool survey was performed, including the criteria used for the selection of tools. The next four appendices present the surveys of tools within four general classes: simulation and analysis tools for CONOPS and ORD development (Appendix B); tools to estimate manning and personnel qualifications (Appendix C); workload and situation assessment tools (Appendix D); and workstation and cockpit design tools (Appendix E). The last appendix (Appendix F) describes human performance modeling and how it can be applied to CG acquisitions, using the Unmanned Aerial Systems (UAS) as an example.

The survey of HSI tools was conducted in the context of well defined and generally-accepted HSI practice overlaid on the USCG acquisition process. Understanding the survey methodology and results requires some familiarity with both areas. We assume that readers are generally familiar with the USCG acquisition process, but recognize that HSI will be a new concept to many. Consequently, Section 2 provides an overview of HSI and situates HSI activities in the context of the USCG acquisition process. The discussion of the tools survey then follows.

2 OVERVIEW OF HSI AND THE USCG ACQUISITION PROCESS

As depicted in Figure 1, modern systems can be enormously complex. While mission needs are key factors shaping system design, there are other important factors as well. Regulatory or legal constraints can establish physical or other operating bounds (e.g., airspace restrictions on the operation of unmanned aerial vehicles). The operating environment itself will impose constraints and requirements that must be considered in system design. Operations in the arctic, for example, pose requirements for operating in extreme cold and stormy weather conditions. Drug interdiction missions require the ability to apprehend armed vessels while defending the ship. Refugee interdiction/assistance requires the ability to conduct both rescue operations, as required, as well as detention functions. While many people think of systems in terms of a ship or an aircraft (called a *platform* in Figure 1), there can be a number of components of a system. These include command and control nodes and the logistics subsystem. *Logistics* includes providing the base or port from which the system operates, and sustaining system operation by replenishing consumables, maintaining and repairing equipment, and providing trained personnel. System operating concepts are a key, but sometimes overlooked, aspect of a system. Doctrine and tactics, location of bases, and mission duration have impacts on how a system is employed to accomplish a mission along with other attributes such as the number of people needed (e.g., multiple crews for endurance missions).

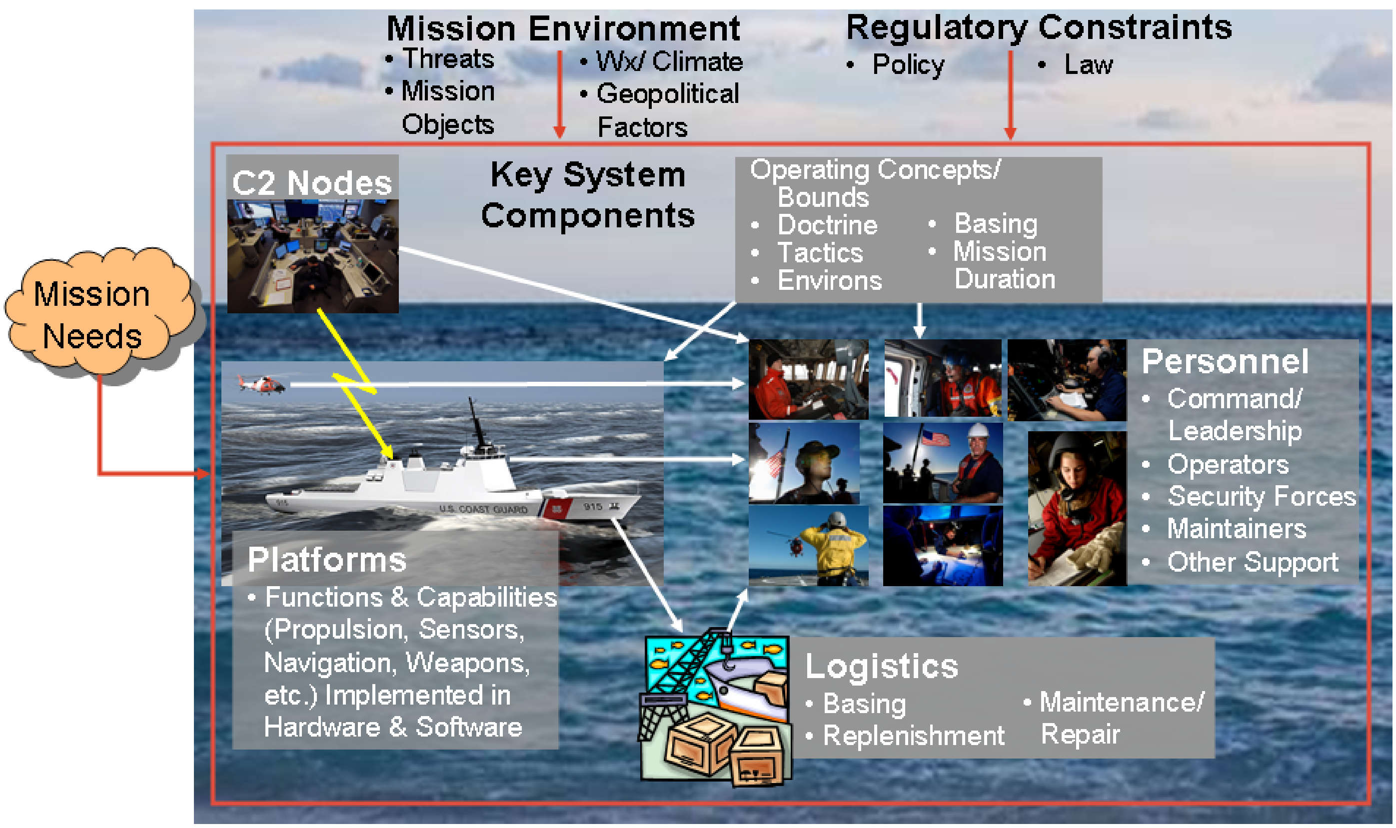


Figure 1. Personnel are a key element of the total system.

People are a system component that intersects with all others. They operate the platform; maintain and replenish it; and operate the C2 node that directs and tasks the platform. The number, types, jobs, skills, and abilities of personnel required in a system can vary significantly. Failure of individuals and teams to perform their duties can significantly impact system and mission performance. Because people are so key to system success, disciplines, processes, methods, and tools have been developed to help incorporate people into systems in ways that enhance system and mission performance and system and personnel safety and health. This is the work of HSI.

2.1 HSI Defined

Army Regulation 602-2[*] defines HSI as "a comprehensive management and technical strategy, initiated early in the acquisition process, to ensure that human performance, the burden the design imposes on manpower, personnel, and training (MPT), and safety and health aspects are considered throughout the system design and development processes." The Army has done more than any other service or organization to implement HSI as a formal, policy-driven set of activities within the acquisition process. Consequently, Army documents are the source of much HSI thinking being applied by other organizations.

There are several significant elements of the definition. The first is that HSI is both a management and a technical strategy. It is a management strategy because it organizes HSI activities in conjunction with broader system management processes (e.g., requirements development, requirements and design reviews, etc.). It is a technical strategy because methods, tools, and processes are applied to develop knowledge about human performance in a system. This knowledge can provide insight into human performance issues that need to be resolved so the system can meet its mission performance objectives.

A particularly important aspect of HSI is understanding the capabilities and limitations of the different personnel involved in a system. This recognizes that while people can be a critical enabling component of a system, they do have limits. When system demands exceed the capacity of personnel to meet those demands, system performance can be affected negatively (and bad things can happen). Understanding the limits of personnel in a system helps us design systems that exploit human abilities and avoid limitations.

As suggested in the definition, enabling human performance in the system is a key goal of HSI. There are a number of domains within which human performance can be affected. These include MPT, safety and health, and human factors engineering (HFE). Slightly different lists of domains are used by the different DoD services. A good core set of domains are described briefly below.

- **Manpower:** The number of personnel (both military and civilian) required, authorized, and potentially available to train, operate, maintain, and support a system.
- **Personnel:** The human aptitudes, skills, and capabilities required to operate, maintain, and support a system.
- **Training:** The instruction and resources required to provide personnel with requisite knowledge, skills, and abilities to properly operate, maintain, and support the system.
- **HFE:** The comprehensive integration of human capabilities and limitations into system definition, design, development, and evaluation to promote effective human-machine integration for optimal total system performance.
- **System safety:** The design and operational characteristics of a system that minimize the possibilities for accidents or mishaps caused by human error or system failure.
- **Health hazards:** The systematic application of biomedical knowledge to identify, assess, and minimize health hazards associated with the system's operation, maintenance, repair or storage, such as: acoustic energy, toxic substances (biological and chemical), oxygen deficiency, radiation energy, shock, temperature extremes, trauma, and vibration.

[*] AR 602-2, MANPRINT in the System Acquisition Process.

- **Personnel survivability:** The characteristics of a system that reduce fratricide as well as reduce detectability of personnel, prevent attack if detected, prevent damage if attacked, minimize medical injury if wounded or otherwise injured, and minimize physical and mental fatigue.

While the domains are distinct, they are not independent. It is important to understand that HSI domains are all parts of the same whole: human performance in a system. There is interaction across the domains. For example, a personnel strategy that assumes personnel with higher aptitudes will be used to operate a system can result in reduced training time and cost because the personnel will acquire job proficiency faster. Manpower can be negatively affected, however, because there are fewer high-aptitude candidates in the general population, and competition is stiff for those people. As a result, it might be impossible to acquire and retain enough personnel to operate the system, or the cost of those personnel might be too high. The point here is that HSI domains should be treated as an integrated trade space so that all aspects of the human component of the larger system can be shaped to most cost-effectively address system requirements.

2.2 Analysis of Work Content and Environments: The Fundamental Focus of HSI

Simply put, the role of HSI is to understand the work that people do in a system and use that knowledge to design “people”-related system components and capabilities that help ensure mission success of the complete system. Figure 2 provides an overview of how HSI professionals accomplish this. It begins with a description of the larger system. This can be a high-level description like a CONOPS or something more detailed like an ORD. In Figure 2 (left panel), a notional mission analysis of the Maritime Security Cutter Medium (WMSM) is used as a point of departure. HSI professionals would review the WMSM system analysis to identify system components and functions that explicitly or implicitly require people to operate or support (maintain, repair) them. In the figure, for example, the need for a helmsman to support the steering function is identified. By accumulating these “work requirements” across the system, HSI professionals construct a body of knowledge that describes the “people work content” for the system. People work content is described in terms of the functions and tasks (work elements) that people perform (Figure 2, center box). These work elements are further described in terms of features and factors such as equipment items used (points of interaction with the platform), broader mission processes supported, and the environment in which the work is performed (with an eye toward hazards or extreme conditions).

HSI professionals then analyze the people work content to identify important attributes of the work that have implications for the different HSI domains (Figure 2, bottom right table). Tasks, for example, will be evaluated to determine how often they must be performed; the nature of performance demands (e.g., how quickly or well they must be performed, physical strength requirements, etc.); the impact of task failure on mission performance (task criticality); the content of the skills and knowledge that enable task performance; the aptitudes (e.g., abstract thinking, math ability, language skills) needed to learn and perform the task; and the hazards associated with task performance (in terms of equipment, materials, threats, weather, etc.) that can affect the performer. This general body of work or task analysis data then is used to support more detailed assessments within the individual HSI domains (Figure 2, right center table). In these assessments, domain experts focus on work or task attributes that are most relevant to that domain (for example, skills and aptitudes necessary to use the new system). These assessments identify potential issues within a domain (e.g., insufficient numbers of personnel with required skills) and offer solutions and recommendations for resolving them. HSI leadership is responsible for reviewing results across domains, identifying the trade-offs that are available (e.g., changes in the HFE interface design may accommodate less skilled personnel), and using that information to generate requirements for the complete human component of the system and to participate in the cross-component trade-offs that occur at the system level.

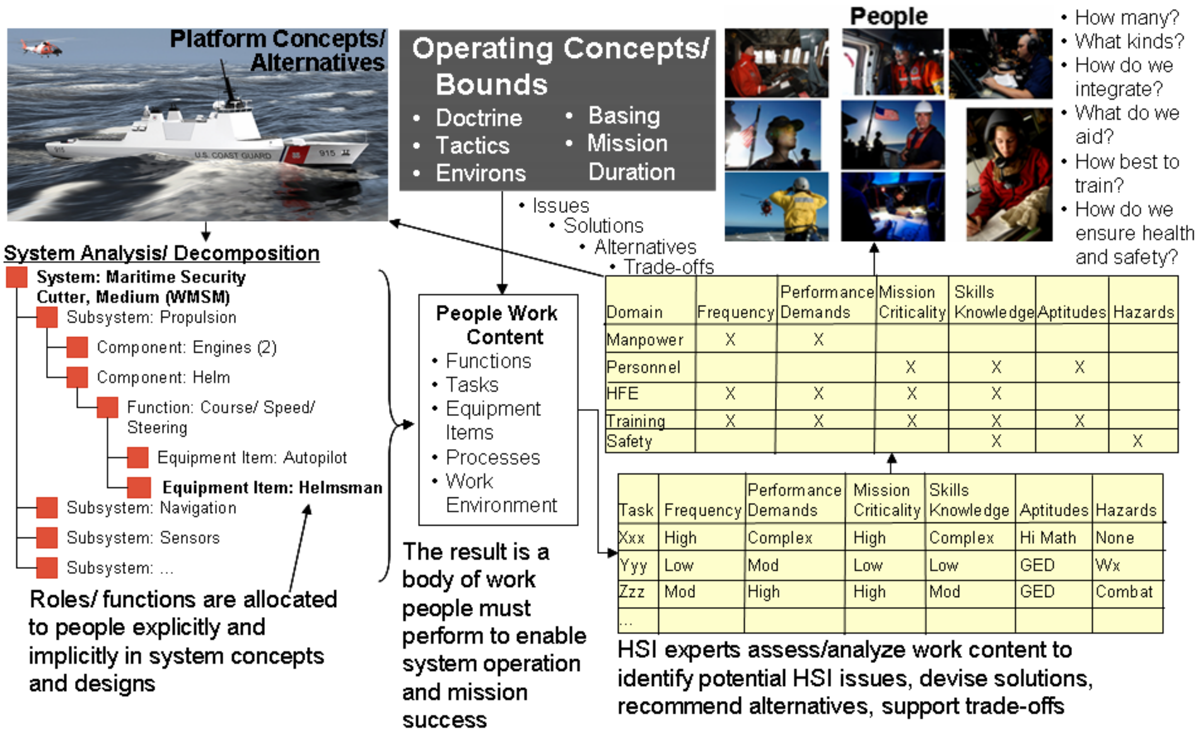


Figure 2. HSI is about understanding and supporting the work people do in a system to ensure mission success.

2.3 Integration of HSI into the Acquisition Process

Specifying HSI requirements is only one of a number of ways that work content data are applied. The data are used throughout the acquisition process. Work content data provide the basis for design, selection, and development of user-related system components. These include user interfaces (controls and displays) and work spaces; tools and aids; protective gear; training systems and capabilities; and operating procedures, tactics, and guidelines. Work content data also are used to create test regimens that assess the performance of user-related system components during developmental and operational testing. The work data help testers identify critical performances that need to be assessed and fashion measures and methods to conduct the assessment. One of the important functions of the tools discussed later in this report is to help HSI professionals frame, translate, or otherwise process work data to obtain insights into the effective design of user components.

From the point of view of HSI, there is a "standard" set of development activities that are carried out in support of system development (Haskins, et al., 2007; Meister & Enderwick, 2001; Sheridan, 2002). These are shown in Table 1 and defined in the bulleted list that follows.

Table 1. "Standard" HSI development activities.

• Concept definition	• Performance, workload, and training estimation
• Requirements analysis	• Requirements review
• Function analysis and function allocation	• Personnel selection
• Task design	• Training development
• Interface and team development	• Performance assurance (Test & Evaluation (T&E))

- **Concept definition** is a process of specifying the operational need for a new or modified system, the general nature of the needed system, a high-level system CONOPS, and operating parameters and constraints for the to-be-acquired system.
- **Requirements analysis** is a process of reviewing, assessing, prioritizing, and balancing the needs and constraints of all stakeholders pertinent in a system acquisition effort; defining a set of requirements based on these activities; and transforming those requirements into functional and technical descriptions that will satisfy stakeholder needs. Requirements analysis typically is segmented into three general activities: eliciting, analyzing, and recording requirements.
- **Function analysis** and **function allocation** typically take place as coordinated and interdependent activities. They involve examination of defined functions so as to identify all sub-functions necessary to accomplish each target function. Sub-functions will normally be arrayed in a functional architecture to show their relationships to one another and to other system elements, as well as to internal and external interfaces. Within the functional architecture, requirements at higher levels will often flow down to allocations at lower levels. Task analysis, a typical early design stage activity of human factors engineers, is a form of function analysis.
- **Task design** is a process of structuring and organizing the activities of human operators to (1) satisfy the operational requirements of the system, (2) satisfy the constraints present in the system, and (3) exhibit adaptive capabilities in the face of a dynamic environment.
- **Interface and team development** are interdependent activities, since the interface design will depend on the needs of the team. Interface development involves creating artifacts and procedures that allow user control of the system; provide data, information, and other feedback about system state; and allow manipulation, analysis, and storage of newly created data and knowledge structures. Team development involves creating artifacts and procedures that define organizations and processes to be used by both defined and ad-hoc teams when carrying out operational functions. Both interface and team development represent instantiations of the foregoing task design.
- **Performance, workload, and training estimation** are analytical processes that focus on estimating the levels of performance, effectiveness, and proficiency attainable with the task designs, interfaces, and team processes defined in the previous stages, discussed above. It is important to note that complete estimates of performance should include a consideration of both ideal and degraded environmental, physical, and psychological dimensions. Measurements should include both macro-scale (e.g., decisions made by commanders and operator situation awareness) and micro-scale (e.g., recognition accuracy, tracking accuracy, and reaction times) items.
- **Requirements review** is the process of ensuring that task design, interface and team development, and performance, workload, and training estimations all can be justified against the system and subsystem requirements developed in the early phases of system acquisition. In essence, the goal of this activity is to develop some means of tracing the design commitments of later phases to originating and system requirements of earlier phases. This is a challenge in and of itself, made more difficult by the lack of methods or tools in either the systems engineering or HSI communities.
- **Personnel selection** involves selecting operators and other personnel based on the knowledge, skills, and abilities – along with the cognitive and physical capabilities – required to fulfill the roles that each person will play in interacting with the system. These roles include operating, maintaining, supporting, and managing the system in all environments and operating conditions envisioned by the system originators.
- **Training development** encompasses: (1) the design, specification, and implementation of the instruction and resources that (2) will be required to bring to, and maintain, "proficiency" of (3) those personnel who will interact with (operate, maintain, support, and manage) the system throughout its lifespan and to maintain that proficiency at a defined level. Note that a crucial facet of training development includes defining "proficiency" for each of the roles just mentioned.
- **Performance assurance (T&E)** is an evaluative process. It encompasses all tests and evaluations that will be carried out over the course of system development. Developmental T&E (DT&E) and operational T&E (OT&E) are included under this activity, as are earlier and less formal performance assurance activities such as formative evaluations and usability evaluations.

Each of these activities can be overlaid on the Coast Guard acquisition phases in the manner shown in Figure 3.* As suggested by this figure, the HSI development activities are both overlapping and fairly loosely defined in terms of their extent across acquisition phases. The figure also suggests that these activities are linear. While some activities will tend to follow others, there are many points of feedback and other interdependencies between activities. Primarily, this is because outputs of earlier activities often will serve as inputs to later activities; but, as mentioned earlier, some activities are performed in parallel, and the interaction between them is important to their maturation/optimization. The main point to be made is that the range of HSI activities supports most acquisition phases. Most of these activities tend to cluster in the Concept & Technology Development (C&TD) and Capability Development & Demonstration (CD&D) phases. However, successful application of HSI in these phases is enabled by HSI involvement in Project Initiation. The presence of tools across most of the acquisition phases enables a consideration of HSI throughout the system development.

Within the context of a specific acquisition, HSI planning activities are conducted early in the acquisition to specify the processes, methods, and tools that will be applied within the different HSI development activities. The goal here is to fashion an approach to the HSI portion of the acquisition that is consistent with factors such as complexity, mission criticality, and risk associated with the system being acquired and the time and resources available for the HSI activities. To be most effective, HSI planning activities should be conducted by experienced professionals who are knowledgeable of the broad range of HSI processes, methods, and tools available. Experienced HSI professionals can create an integrated HSI approach that will focus on the most critical domains and human performance issues and will maximize the reuse of products and data across HSI development activities.

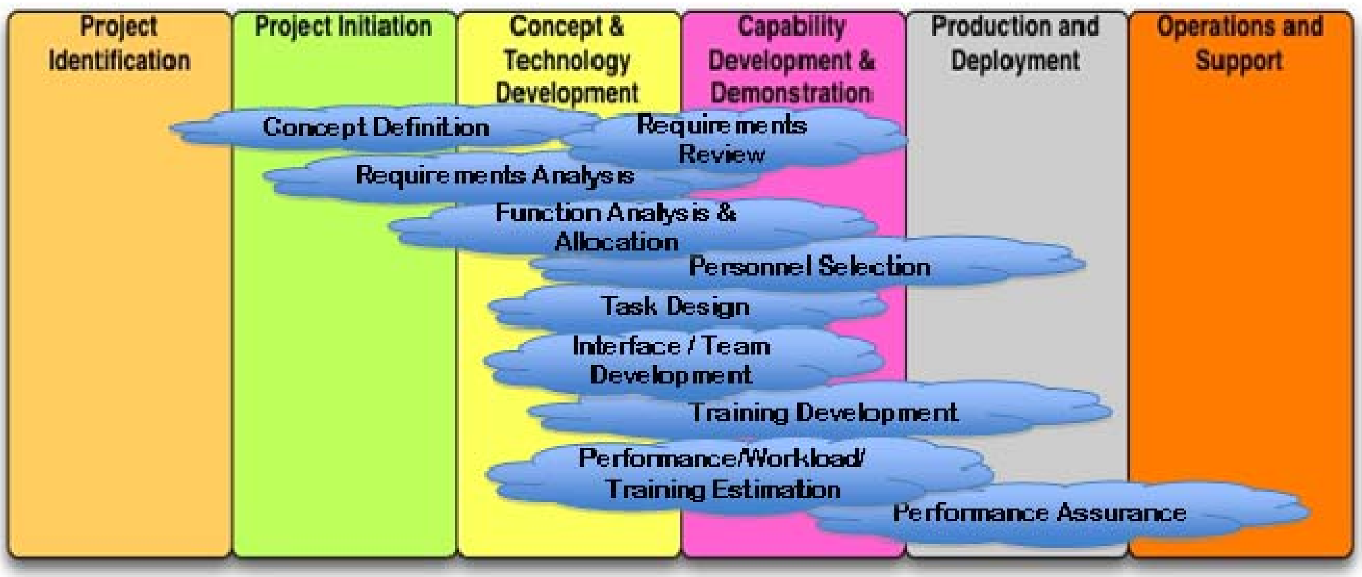


Figure 3. HSI development activities mapped to Coast Guard acquisition phases.

* In November 2008, the Department of Homeland Security (DHS) published interim Acquisition Directive 102-01 (see https://dhsonline.dhs.gov/portal/jhtml/tracking/viewdoc2.jhtml?doid=4658001). It describes a number of changes to DHS acquisition policy, including new names for the acquisition phases: Need; Analyze/Select; Obtain; and Produce/Deploy/Support. While the names have changed, the development objectives of each phase remain essentially the same, as do the potential contributions of HSI to each phase.

2.4 HSI Benefits

Up to this point, the discussion has been more about what HSI is and what it does. This section concludes the overview of HSI with a brief discussion of the benefits of HSI to acquisition programs that apply it. Some of the key benefits include:

- **Risk reduction:** Perhaps one of the greatest benefits of HSI is that it reduces risk associated with what often is the most expensive and complex portion of a system: the people. By helping the systems engineering team identify and resolve people-related risks early in the acquisition process, HSI professionals can help the team avoid costly surprises and re-designs later in the program.
- **Cost management and reduction:** Cost is always a big factor in system acquisition. By establishing clear, human-component requirements early in the acquisition process, HSI professionals help the acquisition team to create a more realistic trade space for evaluating system alternatives and to develop more realistic expectations of system cost. HSI professionals also can help lower system acquisition costs by avoiding design decisions that later have to be revisited and corrected and by developing the most cost-effective solutions for manning, personnel selection, training, and safety. In acquisitions where HSI has *not* been incorporated, serious design flaws can result which significantly degrade human and total system performance. Correcting these deficiencies late in the development can incur huge costs, as high as a factor of 100 times the original cost (Haskins, et al., 2007, based on a Defense Acquisition University statistical analysis).
- **Improved mission performance:** An “intangible” cost of not properly considering HSI factors shows up in the loss of effectiveness and efficiency when a fielded system contains errors or sub-optimal interfaces introduced in design. This has the added cost of increasing overall life-cycle costs because of the extra training needed to attain and maintain effective performance levels. In some cases, poorly-designed systems create so much user frustration that they lead to personnel attrition – offsetting personnel loss can be a huge cost to the organization. By helping design a more balanced, effective integration of people, hardware, and software, HSI professionals help ensure the system meets its mission performance objectives in a cost-effective manner.
- **Safety and hazard reduction:** Given the hazards of CG missions and the environments within which CG systems operate, safety is a particularly important consideration. Safer systems not only mean fewer deaths and injuries to personnel, it also means fewer accidents that result in damage to CG systems and equipment and to property in their operating environment. Generally, safety issues accrue from errors in design. Many, if not most, accidents evolve from a long chain of errors and-or sub-optimal system behaviors (i.e., “an accident waiting to happen”). HSI methods and tools make it possible to discover these causal chains at an early stage of design so they can be corrected, or at least rendered non-catastrophic.

A previous survey on the uses of HSI processes in the DoD services indicated that a number of cost savings and positive returns on investment accrue to those who integrate human-system considerations in their system development efforts. One of the most important advantages is in the area of cost savings. As stated above, allowing design “mistakes” to propagate through a development effort and into the fielded system can be very expensive in terms of (1) corrections to hardware and-or software (a monetary dimension), (2) additional and more frequent training required to achieve and maintain proficiency (a time dimension), and (3) degradation of system performance (a performance dimension). Simply stated, cost is multidimensional and often intangible. Much of the cost associated with a system will be associated with its human components: operators, maintainers, trainers, and so on. Opportunity costs, as well as monetary costs, are relevant. Including human considerations early in development as an integral part of the larger development process provides the opportunity to identify and eliminate design “mistakes” before they become costly in one or more of the dimensions discussed above.

Achieving cost savings through HSI can be realized by following seven general tenets, as outlined below (Haskins, et al., 2007).

1) Initiate HSI into development systems engineering early.
2) Identify HSI issues and plan appropriate analyses that are program-specific and issue-oriented.
3) Inject HSI considerations into system requirements development.
4) Make HSI a factor in source selection.
5) Execute integrated HSI technical processes throughout the program by developing an HSI integrated architecture and including HSI considerations in each planning/engineering document.
6) Conduct proactive HSI trade-off analyses.
7) Conduct HSI assessments throughout the development process.

These tenets, based on the experience of DoD service-specific acquisition programs, underlie a number of system development success stories. Conversely, when these HSI tenets are *not* applied properly, it generally leads to costly systems which fail to attain the hoped-for level of mission performance. Table 2 summarizes a few of the success stories and illustrates the diverse ways that HSI can positively affect program and system success factors.

Table 2. Some HSI success stories.

Maintenance Analysis for Joint Biological Point Detection Systems (JBPDS). Army Manpower & Personnel Integration (MANPRINT) analysts determined the operator and direct support-level maintenance manpower requirements and spare line replaceable units (LRUs) needed for the JBPDS. A comparison was performed between the cost of standard army maintenance using 35F Special Electronics Repair personnel and Contractor Logistics Support (CLS). Results demonstrated a $270k savings per year per biological detection company for CLS for wartime requirements.
Mine Clearing Training for Improved Detection. Army training experts developed a specific training regimen with the AN/PSS-12 Hand-held Mine Detector to transfer expert detection skills to soldiers; designed a training site that could efficiently enable soldiers to develop the required skills (and could be practically constructed by field units); and validated low-metal mine simulants for use in training. Results of tests employing these improvements showed significant increases in the probability of detection in relatively little training time. Repeatedly, results showed increases in probability of detection from less than 20% using standard techniques to 75% (less than 1 hour of training) to 98% (about 15 hours of training) using the expert techniques.
Hand-held GPS Receiver Operator Performance. Army MANPRINT experts evaluated dismounted soldiers using the Defense Advanced GPS Receiver (DAGR) in the field and observed the presence of a fratricide issue: 38% of the soldiers (6 out of 16) incorrectly reported their present position rather than the target's position during a simulated Call for Fire Scenario. The MANPRINT experts recommended use of a pop-up warning message (which was incorporated by the contractor) and, in the retest, none of the soldiers (13 out of 13) incorrectly reported their present position.
C-17 Cargo Aircraft. Air transportability and loading issues were resolved for joint delivery, complex ground refueling operations, the number of people required for complex operations, training time, down time/maintenance time, and reduction of number of flight crew positions. Crew systems, human factors, manpower, personnel, and training efforts were credited with saving 2916 manpower positions over predecessor systems. Life-cycle cost savings were estimated in excess of $300M.
F-22 RAPTOR. Human performance HSI challenges for the F-22 included the management of manpower allocations and specialty codes, maintenance manpower compressions, repair of low observable coatings, servicing advance oxygen generating systems, control and display integration, and net-centric warfare display integration. An integrated training system also was required. Development of this aircraft involved a major shift from system status orientation to tactical warfighter-centric displays. The Program Manager elevated eight Crew Systems and HSI-related issues to the Work Breakdown Structure III-level for the first time ever. A detailed MPT analysis ($2M investment) led to $700M in life-cycle cost avoidance. The eventual manpower implementation for the F-22 (2005-2006) has been credited with $3B in life-cycle cost savings.

3 HSI TOOLS SURVEY

As noted above, HSI covers a diverse set of human performance-related domains and development activities. Over time, HSI researchers and practitioners have created methods and tools that support the conduct of key activities. A wide variety of tools exist, potentially allowing HSI analysts and designers to contribute to many phases of development. However, because of the diversity of the available tools, it can be daunting for those involved in system development to locate and select tools for optimal application at each phase, or during specific processes, of a development effort. The existence of a tool compendium should make the selection and acquisition of the "best tool for today's need" more tractable. Through this report, we hope to provide the HSI Technical Authority (CG-1B3) and other members of the USCG acquisition community with a categorized list of resources, indexed according to a tool's relevance and contribution to system development. By using this off-the-shelf resource, one can quickly locate the right tool for the right task during each phase of development. A basic question that can be asked at every phase of system development is "are we doing the right things, and are we doing things right?" With respect to HSI, the existence of a tools survey helps address this question.

All of the tools in the survey are available as either commercial off-the-shelf (COTS) or Government off-the-shelf (GOTS). The goal of the survey was to identify useful HSI tools that can either be used by the CG or can be required of acquisition contractors during system development efforts. Contractors would use these tools, in conjunction with other methods and processes, to conduct HSI analyses for injection into system development processes.

The HSI tools survey presented in this report is not exhaustive. All available tools and methodologies have not been included in the survey. We included only those tools that were relevant to development in a Coast Guard environment and that were easily available either commercially or through DoD or other Government channels. We have included contact information for each tool included in the survey to simplify tool acquisition. Similarly, the surveys of individual tools are not exhaustive. Each survey contains only the information that the reviewers felt was relevant to the needs of the Coast Guard acquisition process. This information has been organized into four broad categories, each of which will be discussed in detail in Appendix A. Briefly, these categories address: (1) the content produced by each tool; (2) the means by which the tool communicates its output to the larger system development process; (3) methods by which the tool can be used to estimate and predict human performance "errors" and conduct trade-off analyses within and across HSI domains; and (4) the degree to which each tool provides traceability between originating requirements and design commitments.

Many HSI tools tend to be domain-specific, which can be a limitation. As discussed in Section 2.1, HSI consists of the domains of manpower, personnel, training, HFE, system safety, health hazards, and personnel survivability. The issues considered by each domain often will serve as drivers of acquisition-related research and analysis efforts. It is also necessary to manage trade-offs and risks among the different HSI domains, as well as between HSI and other engineering disciplines. Consider, for example, a system designed for expert users, which therefore has stringent selection criteria for specific knowledge and skills (drawn from the HFE domain (Folds, 2007)). This issue leads to a need to trade off human factors considerations (typically focused on performance) against personnel qualifications (typically focused on aptitudes and preparation) and manpower (the number of people available with the required qualifications). Trade-offs against other aspects of the system design will be needed (perhaps the requirement for an expert user came from a COTS component that was less expensive than a custom design with a simpler user interface – need to trade off component costs against costs of training and increased manpower). Ideally, tools for HSI should allow these trades to be made. Few, however, support this ability.

Table 3 lists the tools surveyed and summarizes the distribution of HSI domain coverage for the tools. Tool names are shown at the left of the table and HSI domains are shown across the top. Table cells contain both a letter code and a number code. The letter code indicates the acquisition phase within which the tool can best be applied. These are the acquisition phases used in the USCG acquisition process. The number code indicates the survey category, taken from the statement of work, to which each tool applies. (Note: Because other CG organizations already deal with the issues of safety, survivability, and habitability, these were not focus areas for the tools survey.) An additional code following each tool name designates tool type and breadth of applicability across HSI domains. Each tool was categorized as one of three types: software, analysis technique, or methodology. Software tools are self-explanatory. Analysis techniques provide specific, stepwise procedures for exploration and analysis of particular topics relevant to system development. They usually make explicit assumptions about the nature of the issue under analysis (e.g., errors arise probabilistically and are causally associated, or strongly correlated, with system failures). Technique of Human Error Rate Prediction (THERP) is an example of an analysis technique. Methodologies provide broad ways of carrying out analyses in support of system development; however, they are neither as specific nor do they provide the programmed, stepwise procedures that analytical techniques do. They might be based on theoretical positions but these often are high-level "world views" rather than specific, rigorous theoretical statements. Therefore, they leave much of the specific technique up to the individual analyst, subject to an individual analysis problem. Most of the cognitive systems engineering methods fall into this category. Each tool was also categorized according to the number of HSI domains it addressed. Tools that addressed only one or two HSI domains were considered "restricted;" those that addressed three or more domains were considered "broad." For example, Improved Performance Research Integration Tool (IMPRINT) is considered to be a software tool with broad applicability (code = SB) because it can be used to address questions in four HSI domains, whereas Advisor 3.5 is a software tool with restricted applicability (code = SR) because it applies to a single HSI domain.

As can be seen in Table 3, all domains received coverage across the tools surveyed. However, this coverage was not uniform. Due to the focus of this project, four of the seven HSI domains received the most coverage from the tool set included in this survey. These four were HFE, training, manpower, and personnel. All 34 tools address at least one of these four domains, and most address two or more domains. Ten of the tools also address one or more of the remaining three domains (safety, survivability, and habitability). About two-thirds of the tools in the survey are software applications; the rest are specific techniques and methodologies. About half of the tools are general-purpose tools, while the others are more specialized.

Full surveys of each tool shown in Table 3 are contained in Appendix B through Appendix E. Explanations of the criteria used in the surveys are contained in Appendix A. Both the structure of the surveys and the selection of the tools reviewed follow from our consideration of the USCG acquisition process and the state-of-the-art in HSI theory and tools.

Table 3. HSI tools coverage. (Key to abbreviations at end of table.)

Tool and Category	HSI Domains						
	HFE	Training	Safety	Survivability	Habitability	Manpower	Personnel
3D Static Strength Prediction Program (3DSSPP)			C,D 2,4		C,D 2,4	C,D 2,4	C,D 2,4
Abstraction-Decomposition Hierarchy (MB)	C,D 1,4	C,D 1,4	C,D 1,4				C,D 1
Adaptive Control of Thought – Rational (ACT-R) (SB)	C 1,3	C 1,3					C,1,2
Advisor 3.5* (SR)		C,D,E 2					
Applied Cognitive Task Analysis (ACTA) (MB)	C,D 1,3	C,D 1,3					C 1
Anthropometric Accommodation in Aircraft Cockpits (--)			C,D 2,4		C,D 2,4		C,D 2,4
Autonomous Vehicle Operator Span of Control Evaluation Tool (AVOSCET) (SB)	C 1,3		C 1,3			C 1,3	
C3TRACE (SR)							C,1,2
Cognitive Function Analysis* (CFA) (MR)	B,C,D 1,3,4	B,C,D 1,2,4					
Cognitive Reliability and Error Analysis Method (CREAM) (TR)	C 1		C 1				
Concept Mapping* (SB)	A,B,C 1,3	C 1,2	C 1	C 1	C 1	C 1,2	C 1,2
Critical Decision Method (MR)	C 1,3,4	C 1,3,4					
Designer's Situation Awareness Tool (DeSAT) (SR)	C,D 1,3,4	C,D 1,3,4					
Energy Expenditure Prediction Program (EEPP)			C,D 2,4		C,D 2,4	C,D 2,4	
ErgoIntelligence Upper Extremity Assessment (UEA)			C,D 2,4		C,D 2,4		C,D 2,4
ErgoIntelligence Manual Materials Handling (MMH)			C,D 2,4				C,D 2,4
Goals, Operators, Methods and Selection Rules (GOMS) (MR)	C 1,4	C 1					

Table 3. HSI tools coverage (continued).

Tool and Category	HSI Domains						
	HFE	Training	Safety	Survivability	Habitability	Manpower	Personnel
Human Factors Workbench (SB)	C 1,3,4	C 1,3,4	C 1,3,4				
IMPRINT Pro/MicroSAINT* (SB)	C,D 1,3,4	C,D 2,4				C,D 1,2,4	C,D 2,4
iGEN (SB)	C,D 1,3,4	C,D 2,4				C,D 1,2,4	C,D 2,4
Informal System Evaluation Methods (MB)	B,C,D 1,2,3,4	B,C,D 1,2,3,4	B,C,D 1,2,3,4	B,C,D 1,2,3,4	B,C,D 1,2,3,4	B,C,D 1,2,3,4	B,C,D 1,2,3,4
Information and Functional Flow Analysis* (IFFA) (MB)	B,C,D 1	B,C,D 1				C 1,2	
Jack* (SB)	C,D 1,4				C,D 1,4		C,D 1,4
Job Assessment Software System* (JASS) (SB)	C,D 1,2	C,D 1,2				D 1,2	D 1,2
Liberty Mutual Tables (--)			C,D,2,4				C,D,2,4
LOCATE (SR)	C,D 1,4						
Man-Machine Integration Design and Analysis System (MIDAS) (SR)	C,D 1,3,4	C,D,F 2,4					
Manpower Analysis and Prediction System (MAPS) (SR)						C,D 2	C,D 2
Navy Manpower Requirements System (NMRS) (SR)						C,D 2	C,D 2
National Institute for Occupational Safety and Health (NIOSH) Lift Equation			C,D 2,4				
Risk Management Toolkit (MB)	B,C 1	B,C 1	B,C 1,2,3	B,C 1,2,3	B,C 1,2,3	B,C 1,2	B,C 1,2
Rapid Upper Limb Assessment (RULA)			C,D 2,4		C,D 2,4		C,D 2,4
Ship-System Human Systems Integration for Affordability and Performance Engineering (Ship-SHAPE) Tool Set (SB)	B,C 1,3,4	B,C 1,2	B,C 1			B,C 1,2	B,C 1,2
Technique for Human Error Rate Prediction* (THERP) (TR)	D,E,F 1		D,E,F 1				

* Tools included in the "starter kit" (see Sec. 3.1).

Key to codes shown in Table 3.

Tool Type and Coverage Codes	Coast Guard Acquisition Phases	Tool Categories
MB = Methodology Broad HSI Domain Coverage	A – Project Identification	1 – Simulation & Analysis Tools for CONOPS and Requirements Development
MR = Methodology Restricted HSI Domain Coverage	B – Project Initiation	2 – Manning and Personnel Qualifications
SB = Software Broad HSI Domain Coverage	C – Concept and Technology Development	3 – Workload and Situation Assessment (SA)
SR = Software Restricted HSI Domain Coverage	D – Capability Development and Demonstration	4 – Workstation and Cockpit Design
TB = Analysis Technique Broad HSI Domain Coverage	E – Production and Deployment	
TR = Analysis Technique Restricted HSI Domain Coverage	F – Operations and Support	

3.1 A Recommended HSI Tools "Starter Kit" for the USCG

Because the USCG's HSI Technical Authority is a fledgling program, it would be useful to consider what tools might be particularly helpful as CG-1B3 establishes its acquisition processes. Given the tools shown in Table 3, what would a starter kit of tools for HSI in acquisition consist of? One way to answer this question is to create a matrix of HSI development activities against acquisition phases. Useful tools can then be placed in appropriate cells of the matrix. One goal would be to minimize the number of tools needed, while maximizing the number of HSI domains that the tools allow analysts to address. Using these criteria, we have formulated a minimum HSI tool set shown in Table 4.

Table 4 presents HSI development activities down the left and the CG acquisition phases across the top. The blue shading shows the acquisition phases in which the different HSI development activities occur. Tools from the starter set which support a specific development activity in a specific acquisition phase are shown in the cells of the table. The first thing to note in Table 4 is that most of the tools in the starter kit fall into the middle two phases of acquisition. The second noteworthy item in Table 4 is that the kit consists of both software tools and methodologies. The third item of note is that the starter kit tools cover almost all of the HSI development activities in each phase: for those few exceptions, analysts will have to fall back on good engineering practice until acceptable tools are developed to support those activities.

The selected tools allow analysis across a range of HSI domains, thereby demonstrating a general utility for development and acquisition. For example, the concept mapping tool can be used to carry out analysis and represent both findings and issues in all of the HSI domains. Likewise, IMPRINT, IFFA, Jack, and JASS can each be used to conduct analyses related to three or four of the seven HSI domains. Two special-purpose tools, THERP and Advisor 3.5, are useful in rounding out coverage of the above tools by adding narrowly defined, but highly specific, capabilities. THERP allows analysts to identify likely errors caused by proposed system designs and estimate system failure probabilities associated with those errors, thereby allowing enhanced analysis in the HFE and safety domains. Advisor 3.5 is a software product focused exclusively on issues of training. This tool allows analysts to estimate the time commitments and costs of specific training strategies for evolving designs. The starter tool kit provided here should serve HSI analysts well across many acquisition phases and most development activities.

Most of the tools in this survey address multiple development activities. The collection of tools in the starter kit address all but one of the "standard" HSI development activities identified earlier. Furthermore, since five of the eight tools selected for the starter tool kit are broad in scope, they should allow HSI analysts to address a wide range of issues likely to arise in system development. Thus, the presence of these tools, as well as their breadth of coverage, provides a pathway by which HSI considerations can be integrated with other design and development disciplines.

The manner in which this can be accomplished is through (1) an integration of HSI considerations with evolving system requirements; (2) carrying these integrated requirements into the conceptual system modeling stages of design; (3) basing initial specifications of task structure, interfaces, and team processes on the findings of HSI analyses and doing so in a way that links the specifications explicitly to the requirements developed for the overall system; (4) providing a means of evaluating the evolving system with respect to the effectiveness of the system and indexed back to the originating requirements; and (5) providing a means to ensure that performance rises to the level required by the operating domain. Tools that did not contribute to the accomplishment of one or more of these objectives were not included in the starter kit.

Table 4. "Starter kit" of HSI tools.

Development Activity	Coast Guard Acquisition Phase					
	Project Identification	Project Initiation	Concept & Technology Development	Capability Development & Demonstration	Production & Deployment	Operations & Support
Concept Definition	Concept mapping	Concept mapping, CFA	Concept mapping, CFA			
Requirements Analysis		Concept mapping, CFA, IFFA	Concept mapping, CFA, IFFA			
Function Analysis & Allocation			CFA, IFFA IMPRINT	CFA, IFFA, IMPRINT		
Task Design			Jack, CFA, IMPRINT	Jack, IMPRINT		
Interface/Team Development			CFA	CFA		
Performance/Workload/ Training Estimation			IMPRINT	IMPRINT		
Requirements Review						
Personnel Selection			JASS	JASS		
Training Development			Advisor 3.5	Advisor 3.5	Advisor 3.5	
Performance Assurance (T&E)				THERP	THERP	THERP

Note: Blue shading in body of table indicates HSI development activity coverage over USCG acquisition phases. Colored cells with no tool designation indicate a lack of available tools to support the development activities in these phases.

3.2 A Notional Example of How the HSI Tools Starter Kit Could Be Applied to Support an Acquisition

We now present an example of how the HSI tools starter kit might be used as part of a fictional USCG system development project in order to illustrate the integration methodology outlined above. Assume that the following need has been identified in the Project Initiation phase of an acquisition.

- The system will allow C2 of diverse USCG resources operating in a range of environments;
- The C2 system will provide dynamic tracking of USCG and port partner asset positions and status;
- The C2 system will rely on a database that is populated automatically by data from remote sensors and manually by C2 system operators;
- The C2 system will operate at tactical (i.e., data fusion and interpretation) and operational (i.e., evaluation, based on tactical results, of progress toward the operational plan) levels, and
- The C2 system will be responsible for producing plans, assessments, and recommendations that can inform command decision makers concerned with tactical and strategic operations.

Given these high-level statements of need, the first concern of the HSI analyst would be to understand the purposes and constraints associated with the use of the system. The analyst probably would begin by carrying out a Cognitive Systems Engineering (CSE) analysis. The CSE analysis might focus on several categories of information that can be used to document the work domain, the work itself, and the opportunities and constraints that will be important in carrying out the work. Specific categories in the analysis might include information about the work domain, control tasks, strategies, organizational entities, socio-technical factors, and worker competencies and limitations. Analysts also would focus on relationships among specific items of information in each of these categories. The concept mapping software tool would be used to capture and archive this information, as shown in the example in Figure 4.

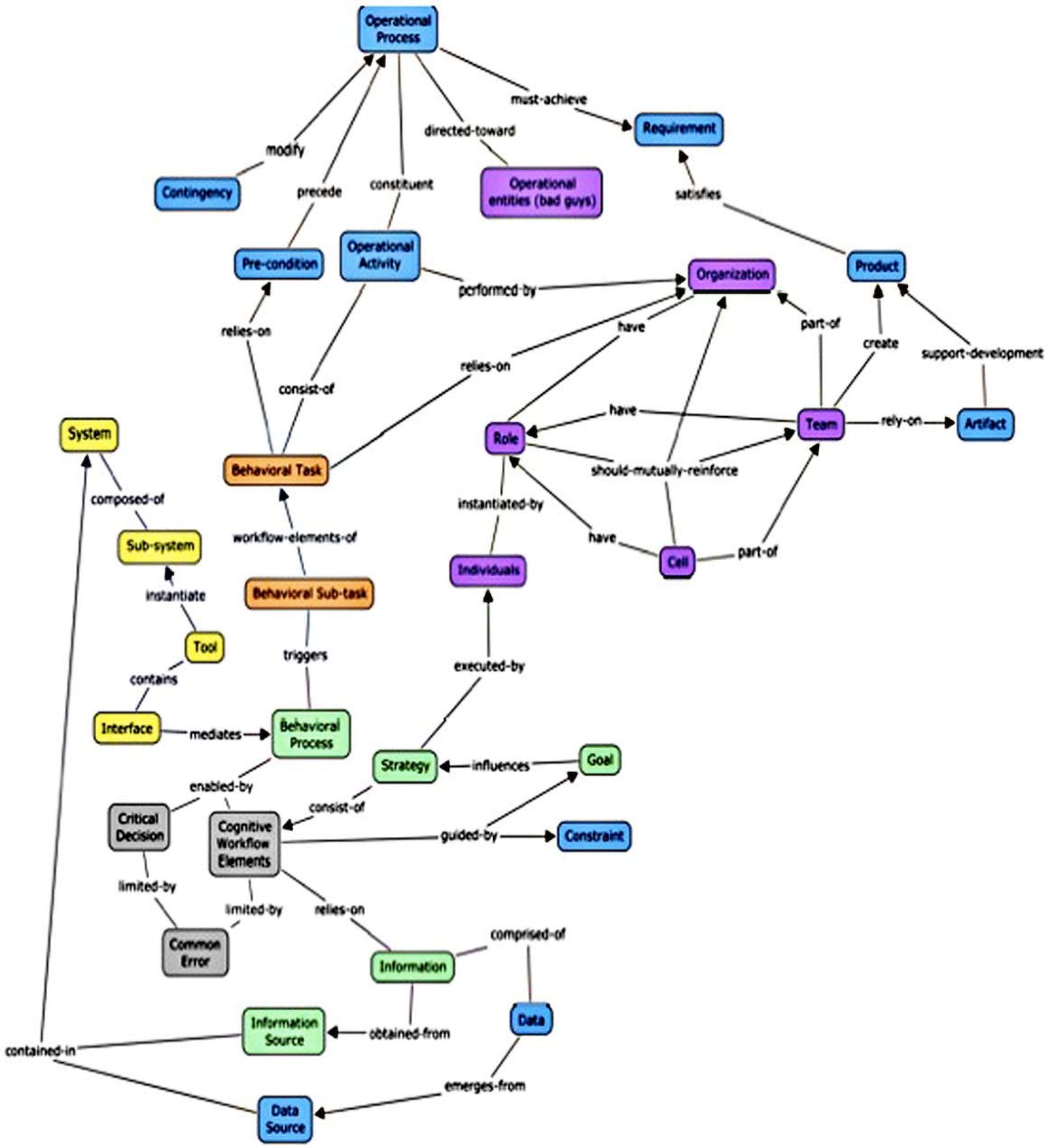


Figure 4. A concept mapping template for capturing CSE data in the C2 example.

As the information in the concept maps is successively refined through increasing levels of analysis, it will be possible for the analyst to identify requirements in each of the HSI domains. These HSI requirements can then be integrated with those from other engineering disciplines to form the systems engineering requirements for the C2 system. One way to accomplish this is to follow the integration methodology summarized in Figure 5. This methodology maps information gathered during CSE analysis to the various types of system engineering analyses conducted early in system development. Note that the HSI/CSE data influence almost all the systems engineering analyses.

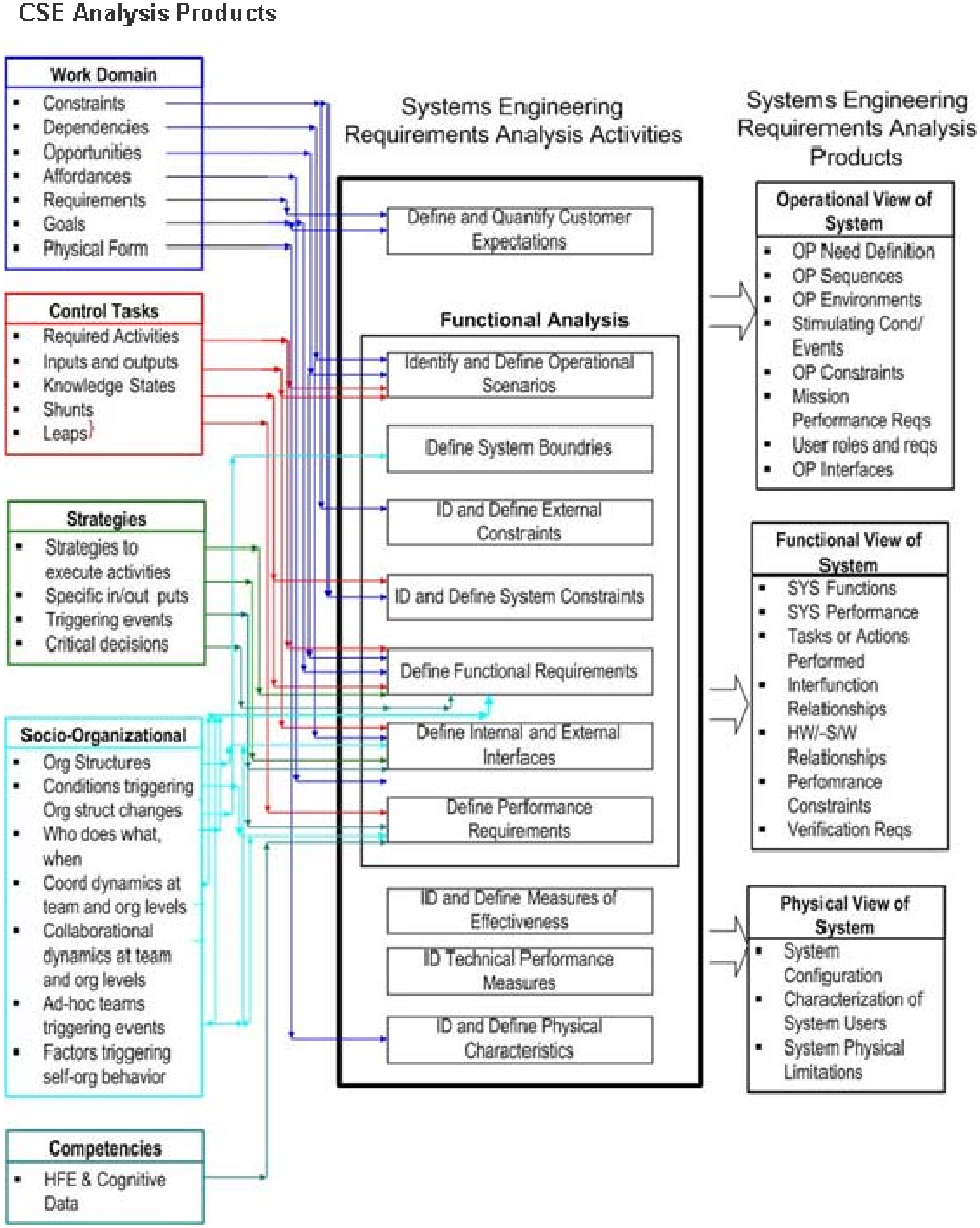


Figure 5. A methodology to integrate CSE analysis results with other systems engineering analyses.

As the initial CSE analysis proceeds into the C&TD acquisition phase, information about required system operator skills and aptitudes will begin to emerge. The JASS tool will facilitate the capture and further definition of this information. An example of a JASS information capture screen is shown in Figure 6.

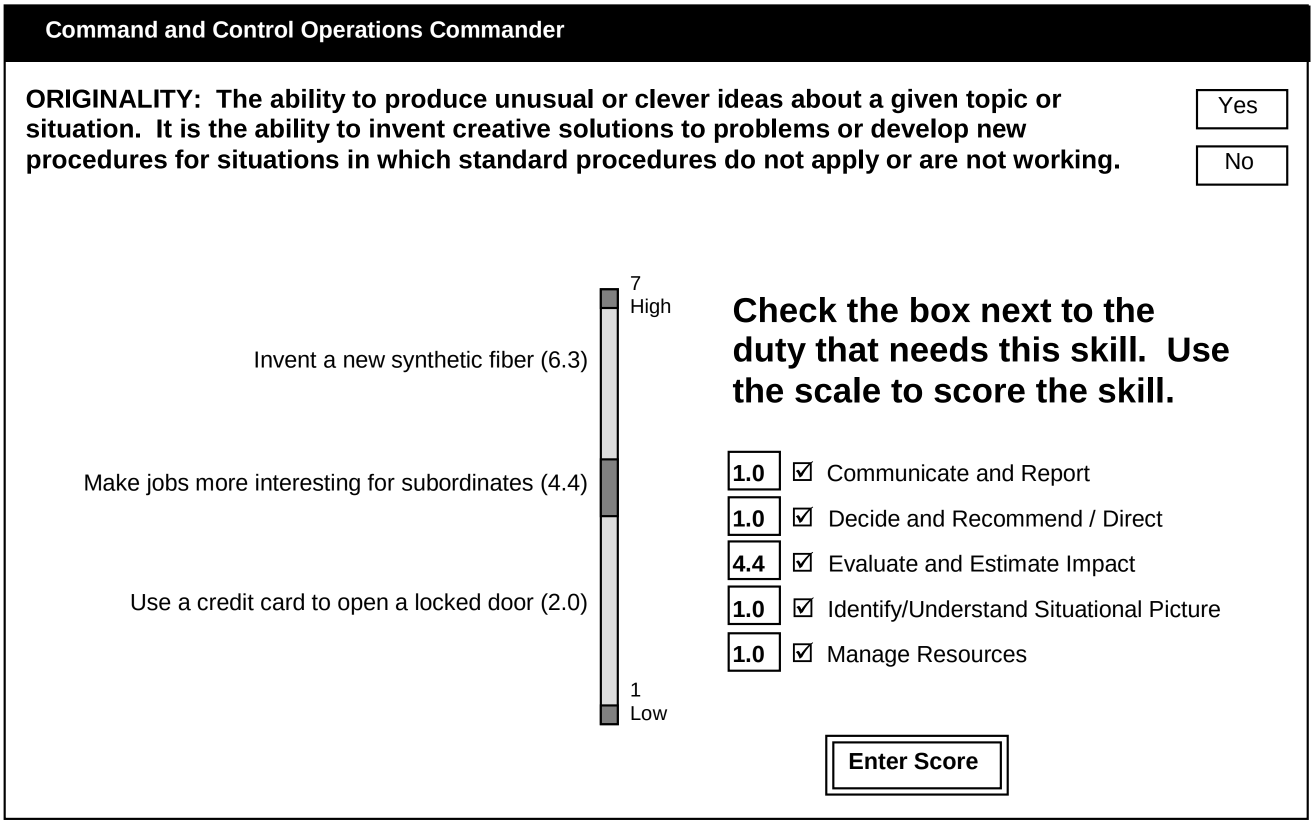


Figure 6. Information capture in JASS allows analysts to specify the range of skills needed for critical tasks in a new system.

The JASS tool is based on accepted descriptions of knowledge categories, skills, and aptitudes. Use of this tool, therefore, would allow HSI analysts to translate information from the concept maps into a form that can be used by the MPT community to specify required attributes for operators of the C2 system. The output of the JASS tool would be a specification of the knowledge, skills, and aptitudes of system operators that can be used for personnel selection. This information also will be invaluable as input into the development and implementation of a training plan. As this personnel and aptitude information is being specified for input into JASS, analysts also could develop IMPRINT models to study the broad effects of staff sizes and configurations on high-level system effectiveness.

Several other tools also will be useful for the C&TD phase. For example, CFA can be used to organize information from the concept maps into a form that will allow analysts to identify functions, develop logical functional groupings, and formally define the functions that operators and other system users will be expected to perform. The CFA can be supplemented with an IFFA to allow specification of the information requirements for each function, information interdependencies between functions, and how the functions "fit together" to define the workflow of the system.

This is a crucial, and often-overlooked, aspect of system design. In the absence of a designed, coherent workflow, users will develop a workflow that they can use to accomplish their goals and required tasks. If workflow organization is not carefully considered during system design, users often will develop idiosyncratic methods that decrease system effectiveness and can introduce safety issues.

Use of CFA and IFFA by HSI analysts can prevent many of these issues from arising later, after the system has been fielded. Of course, when these types of system models have been defined using these methodological tools, they should then be used to estimate system effectiveness and support trade studies so that design commitments can be narrowed to those most likely to lead to "optimal" design outcomes. IMPRINT will be particularly useful for this purpose, and should be a tool of choice at this point in the acquisition cycle.

Physical task design also becomes prominent during the C&TD phase. One of the best tools available to HSI analysts for addressing the issues in this area is the Jack bio-mechanical modeling environment. Jack is useful for analysis and design of the physical workspace. It can be used to conduct link and reach analyses, strength assessments, and anthropometric analysis, as exemplified by Figure 7. Jack will allow HSI analysts to conduct trade studies and address areas of physical fit, fatigue, and comfort, and safety issues associated with the evolving system design.

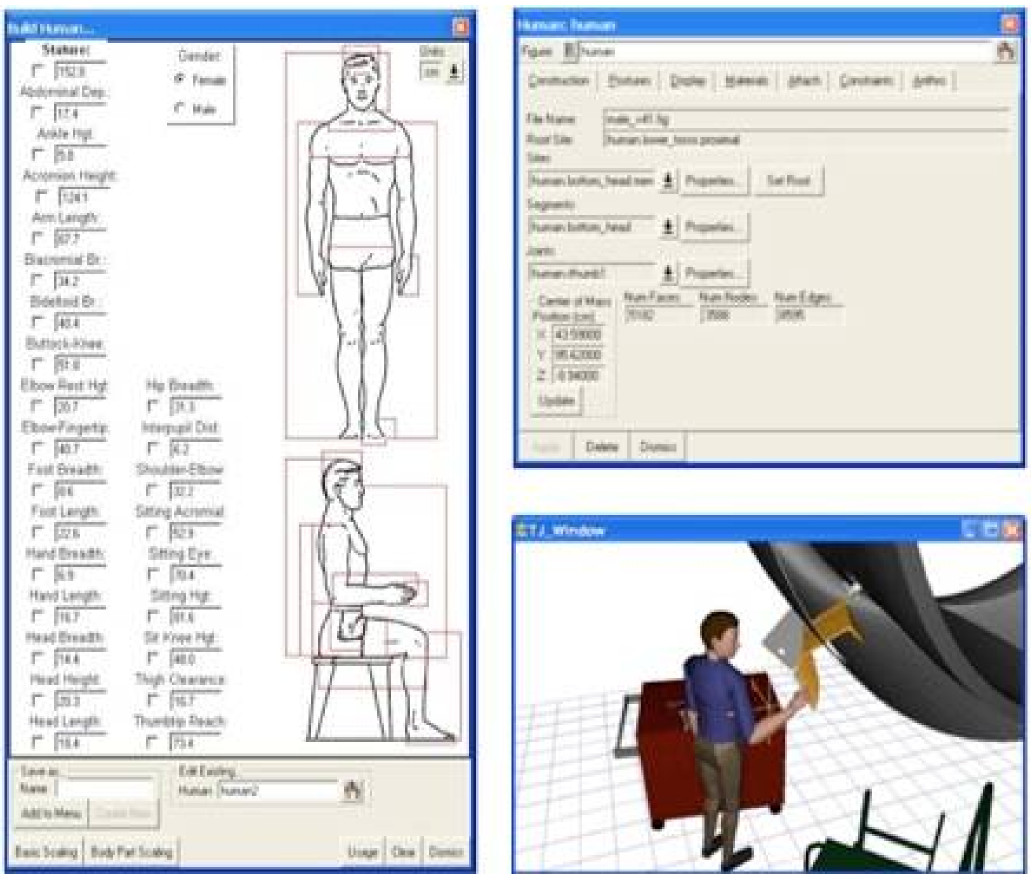


Figure 7. Jack allows bio-mechanical modeling for workspace task design.

IMPRINT also allows HSI analysts to conduct design and trade studies in the task design arena. Its focus, however, is on areas of human performance. Figure 8 shows how HSI analysts can develop specific task and workflow structures. These then can be executed to assess the resulting effects on system performance, thereby enabling trade studies of potential work alternatives. Analysts can also conduct analyses of the workload associated with alternative task structures and the performance changes associated with these workload variations. Effects on performance and time to proficiency of various training alternatives also can be evaluated.

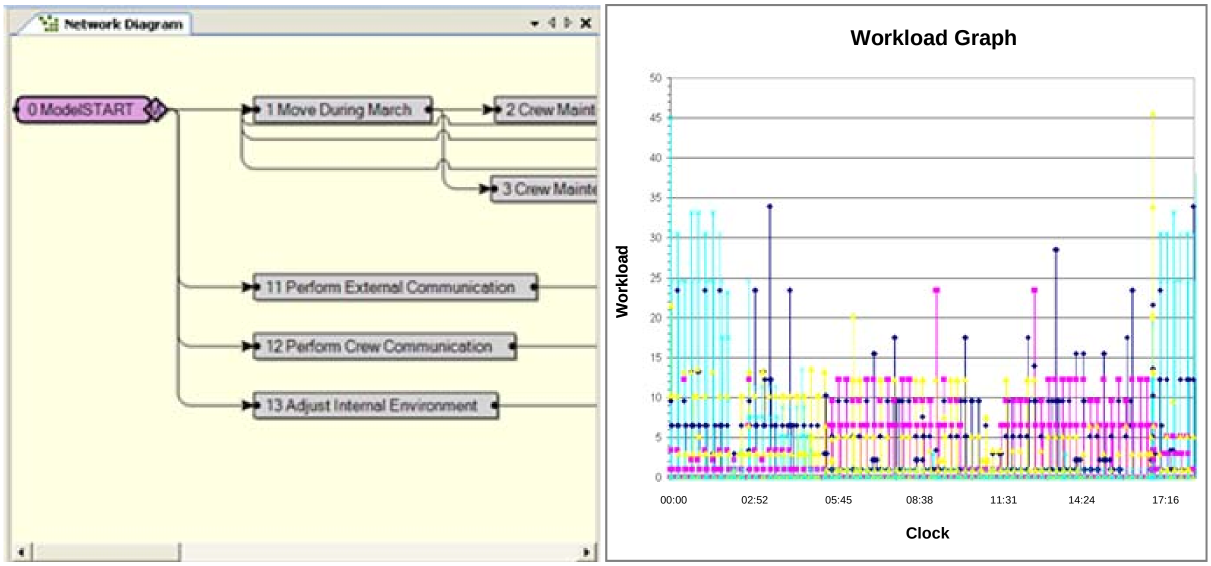


Figure 8. IMPRINT supports human performance trade studies for task design and workload analysis.

The outputs of the Jack and IMPRINT tools can serve as inputs to Advisor 3.5, enabling HSI analysts to develop and manage specific training designs. Using these outputs to specify particular training designs, the Advisor 3.5 tool (Figure 9) will allow training designers to determine the most cost-effective ways to deliver training by estimating the effectiveness and cost of alternative methods, estimating the time required to develop materials associated with different training alternatives, and computing a return on investment for alternative methods.

Figure 9. Advisor 3.5 allows analysts to determine timelines, levels of effort, and cost associated with specific training alternatives.

Another tool that will be useful during the CD&D phase will be THERP. As the system design evolves, it will become possible to identify likely errors that operators might make during operations. Using THERP, HSI analysts can categorize the errors, estimate their probabilities of occurrence, and predict the likely consequences of each error on system effectiveness, safety, and other aspects of performance. System designers can use this information to identify design alternatives that should be dropped from consideration due to these system effectiveness, safety, training, or other issues. A highly simplified example of a THERP fault tree is shown in Figure 10.

The information from all of these tools accomplishes several goals. They allow analysis of specific aspects of an evolving design from an HSI point of view. They do so in ways that ensure the findings and analysis results can be integrated with other engineering information needed to arrive at an effective system design. They allow HSI analysts to conduct critical trade studies, needed by the systems engineering community, that will inform the evolving design. That is, they help "point the design team in the right direction" with respect to design commitments. They help to identify likely errors and estimate the impact of each type of error on system safety and effectiveness. They help HSI analysts to define and integrate task and workflow design specifications into the overall system definition and design process. Therefore, they provide invaluable assistance in enabling HSI within the overall engineering of new systems.

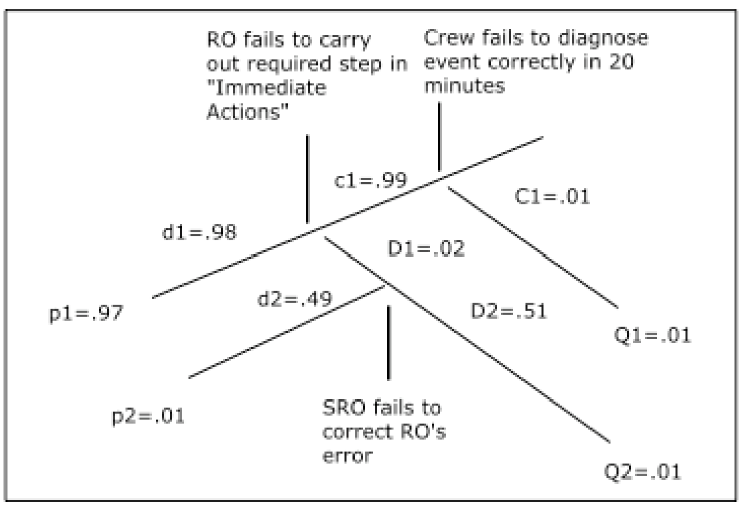


Figure 10. A simple THERP fault tree.

3.3 Human Performance Modeling: Specialized HSI Tools

As the USCG acquires more complex and sophisticated systems, more sophisticated HSI methods and tools are needed to ensure that the people in those systems support and enable successful mission performance by the system. Human performance models (HPMs) are an example of a sophisticated tool that helps HSI practitioners better understand human performance issues in complex systems and address those issues with effective HSI solutions. This section provides a brief overview of human performance modeling and introduces a notional example (presented in Appendix F) of how the technology could be applied to help the USCG evaluate the addition of Unmanned Aerial Systems (UAS) to the National Security Cutter (NSC).

As noted in the discussion of HSI, understanding the work requirements of people in a system is fundamental to the HSI process. This is challenging because work requirements in complex systems are dynamic, driven by the moment-to-moment demands of the mission environment and the hardware and software components of the system. Human performance modeling provides a computational means for representing these dynamics and gaining insights into human performance issues such as numbers and types of personnel required, levels of performance proficiency required for mission success, and difficult and mission-critical performances that require special attention in terms of HFE and training factors.

There are a number of human performance modeling tools available to HSI practitioners but the one most widely used is IMPRINT, developed by the Army Research Laboratory. Figure 11 shows a portion of an IMPRINT HPM. IMPRINT uses task network modeling to represent human performance. As the name implies, task networks use a flowchart type format to specify detailed task sequences, decision points, and branches. Task networks are organized under higher-level functions; and functions are organized under goal states. Goals states are a concept from cognitive psychology: goals provide an executive function that organizes and controls behavior. Goals are triggered by conditions in the mission environment that the performer needs to maintain within certain limits. For example, a navigation goal state would be triggered in a pilot when he/she determines the aircraft is off course. Once the goal state triggers, lower-level functions and tasks would be activated to bring the airplane back on course (restore performance within desired limits).

Modeling environments such as IMPRINT generally have two major components. The first is a model development module. In IMPRINT, this is a graphical interface (Figure 11) in which the user specifies goals, functions, and tasks and arranges their organization and sequences. The user also enters data that control how the goals, functions, and tasks execute. These data include trigger (start) criteria, task performance times and variances, task output and effects data, and behavioral process algorithms (e.g., visual detection and identification, information processing, etc.). These data are obtained from a variety of sources that include the human factors and behavioral science literature on human performance, observation of performance in operational and laboratory environments, and interviews with subject matter experts. The second component is a runtime module. This module actually executes the model (i.e., simulates the sequence of tasks), manages time, generates and collects data, and manages any interfaces to other models and simulations.

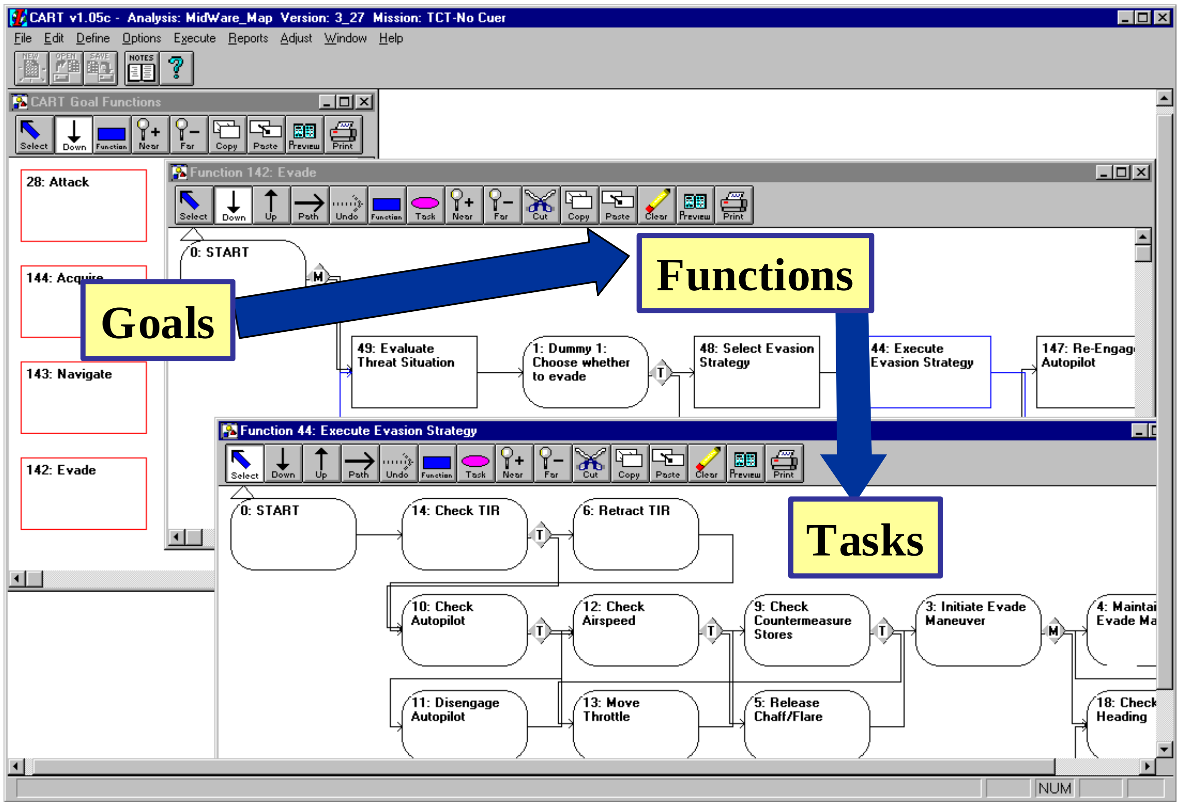


Figure 11. Sample IMPRINT model screen.

To generate the dynamic performance effects of interest to HSI practitioners, events are incorporated into an HPM that represents the dynamic demands of the mission environment and the system hardware and software components. Environments like IMPRINT provide ways for modelers to create these events, but the most preferred method is to integrate the HPM with simulations of the system hardware and software components and the mission environment. Modeling and simulation are often employed in the development of complex systems so system and mission environment simulations are often available. When the HPM is integrated with the system and mission environment simulations, the result is a complete representations of the system of interest. More importantly, these “complete system” simulations provide more realistic representation of the performance demands that stimulate the HPM. Consequently, performance effects observed in the output of the HPM are more realistic and predictive of what can be expected in the real system.

The ultimate product of HPM, and indeed all models and simulations, is data that informs decision making. Typically, multi-level performance measure schemes are employed that systematically assess mission outcomes, key system functions, and enabling operating components. The enabling operating components include people modeled in the HPM. The multi-level performance measurement schemes help decision-makers understand how the performance of human and other system components propagate through the system and, ultimately, affect mission outcomes. By systematically manipulating capabilities, performance levels, and other factors and observing mission impacts, acquisition decision-makers can converge on a set of objective system requirements that have been demonstrated to support desired levels of mission performance.

There are a variety of factors that HSI modeling experts can manipulate within HPMs. These include the numbers of personnel that perform work activities, the allocation of functions and tasks across those personnel, and the levels of performance generated by the personnel. The levels-of-performance-generated-by-personnel is a particularly important factor. In this assessment, performance levels (e.g., task performance times, performance effects such as accuracies and errors) are manipulated systematically to determine the levels needed to enable desired levels of mission performance. Once performance level data are obtained, the data are reviewed to determine whether the levels are reasonable within the manpower and personnel concept being employed. The results might suggest that a different personnel mix (different numbers and types, different aptitudes and levels) is needed to generate the desired levels of performance. Alternatively, or in addition to, modifying manpower and-or personnel factors, the HSI team might explore HFE solutions that incorporate tools and aids that enhance human performance and-or advanced training concepts that generate and sustain the high levels of performance that are required. HSI modelers would adjust the HPM to represent these different approaches to HSI solutions and test them within the performance assessment framework of the total system simulation. When combined with the results of other HSI domain assessments (e.g., safety, habitability), evolving hardware and software capabilities, system cost estimates, and risk assessment, a clearer understanding of the best HSI solutions and their associated system requirements will emerge.

A final point to be made about human performance modeling is that, like other forms of modeling and simulation, it can be applied throughout the acquisition process. Early in the acquisition process, HPM can be used to support development of CONOPS for new systems. Modeling in support of CONOPS usually is conducted at a fairly high level because of the immaturity of the system concepts. Similarly, HPMs used to support CONOPS development are not very detailed but are important because they can begin to define and bound the requirements for human performance in the system. Issues such as key personnel roles and functions can be explored. Also, system operational doctrine and tactics can begin to be considered. This is particularly important for systems that are incorporating new technologies and capabilities. In these systems, an important question posed by acquisition decision-makers is “what kinds of performance gains can I expect from these new capabilities?” The answer lies not in the technologies themselves, but in how they are applied. The application of technologies in a new system is “human mediated,” based on operating rules, processes, tactics, etc. By incorporating human performance into the early modeling and simulation activities used to develop CONOPS, the engineering team has the opportunity to formulate operational concepts that maximize the benefit of new technologies and capabilities.

As the acquisition process evolves and system requirements and concepts become more detailed, the modeling and simulation environments become more detailed. This includes the human performance modeling environment. The evolutionary nature of the acquisition process allows modelers to focus the development and test efforts in ways that minimize cost and maximize information and knowledge gained. An HPM used to develop CONOPS, for example, might represent human performance simply, i.e., to ensure the new system concept provides key information needed to support decision-making. Subsequent extensions of the model might focus on representing key personnel and tasks in sufficient detail to resolve the numbers and types of personnel and the appropriate function and task allocation required to enable mission success. The next round of extensions might focus on very detailed representation of select, mission-critical tasks to better understand operator-system interface requirements, workload and situation awareness issues and mitigation strategies, and-or exceptional proficiency levels that training must generate and maintain. When designed properly, a high-level HPM developed early in the acquisition process should be extensible so that detail can be added selectively as the system concept evolves. This makes the application of human performance modeling technology much more cost effective.

To provide the reader with a more concrete example of how human performance modeling is applied, Appendix F presents an example using a notional study of potential surveillance mission performance gains obtained by adding UAS to the NSC. The example addresses the overall, notional mission context, the key system elements that would be involved in the study, the elements of human performance that would be modeled, performance measures that could be used, and possible results. Though notional, the example does highlight some key points about the use of human performance modeling, including:

1) Human performance modeling can be focused and scaled to address key human performance issues while controlling model development and test costs.
2) Smart approaches to modeling highlight similarities in model components that promote reuse and adaptation of model elements across components (e.g., elements that require modeling of visual identification of vessels can be reused across components that model different teams – such as a helicopter crew versus a UAS sensor operator performing visual identification).
3) When modeling human performance in detail, attributes of a situation can emerge that can be exploited in tactics and process development to improve overall mission performance. For instance, in the UAS example, it is recognized that the UAS speed and sensor range combine to ensure that vessels in the operational area (OPAREA) are detected multiple times. This provides multiple opportunities to correct target misidentifications made previously. Well-defined tactics and procedures will provide a means of exploiting this opportunity.

3.4 Survey of Specific HSI Tools

With the exception of Appendix F, as described above, the remainder of this report focuses on the HSI tools survey, including an introduction to the criteria used to evaluate the tools (Appendix A), followed by the surveys themselves (Appendix B through Appendix E).

We begin the survey discussion with an explanation of the criteria used in each tool review (Appendix A). These criteria are organized into four sections consisting of those focused on (1) content considerations of each tool; (2) the manner in which tool outputs are communicated to the larger system development process; (3) facilities provided by the tools for helping manage risks and trade-offs across HSI domains and between HSI and other system development considerations; and (4) the manner in which a tool allows HSI analysts to relate the form and function of artifacts to the requirements of the artifact. Each survey consists of several specific items in each focal area upon which the tool is reviewed. See Appendix A for detailed definitions of these items.

As was shown in Table 3, we surveyed 34 tools that addressed one or more domains of HSI. The tool surveys are presented in four appendices designed to organize them into sets addressing the major HSI concerns within a system acquisition.

Appendix B presents simulation and analysis tools for CONOPS and requirements development, including:

- Abstraction-Decomposition Hierarchy
- ACT-R
- Critical Decision Method
- Cognitive Function Analysis
- Concept Mapping
- MIDAS
- GOMS
- iGen

- Information and Functional Flow Analysis
- Applied Cognitive Task Analysis
- AVOSCET

Appendix C presents tools for determining manning and personnel qualifications, including:

- Advisor 3.5
- Job Assessment Software System
- Manpower Analysis and Prediction System
- Navy Manpower Requirements System
- C3TRACE

Tools under Appendix D are for workload and situation assessment, and include:

- CART/IMPRINT Pro
- Designer's Situation Awareness Tool
- Cognitive Reliability and Error Analysis Method
- THERP

Workstation and cockpit design tools are in Appendix E, including:

- 3D Static Strength Prediction Program
- Energy Expenditure Prediction Program
- LOCATE
- Liberty Mutual manual material handling tables
- NIOSH lift equation
- informal system evaluation methods
- Human Factors Workbench
- Rapid Upper Limb Assessment
- Ship-SHAPE Tool Set
- Risk Management Toolkit
- Jack
- ErgoIntelligence Upper Extremity Assessment
- ErgoIntelligence Manual Material Handling
- Anthropometric Accommodation in Aircraft Cockpits

In order to use this survey to identify a tool for use during acquisition and development, first consult Table 3 in order to identify candidates that might satisfy your analysis needs for the acquisition phases and tool categories of interest. When candidates have been identified from Table 3, analysts can locate them in one of the four appendices shown in the "tool categories" designation. Reviewing the surveys in the appropriate appendix will indicate what system development activities each tool addresses, along with other information about the nature of the tool. The "best" tool should then be selected based on these survey criteria.

4 REFERENCES

Brett, B.E. (2008). Human System Integration Support for the CONOPS Development Process. United States Coast Guard Report.

Folds, D.J. (2007). Human-systems Integration. Presented to the 2007 INCOSE HSI Workshop. San Diego, CA.

Haskins, C., Forsberg, K. and Kruger, M. (2007). Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities: Vol. 3.1. INCOSE-TP-2003-002-03.1. San Diego, CA: International Council on Systems Engineering (INCOSE).

Meister, D. and Enderwick, T. P. (2001). Human Factors in System Design, Development, and Testing. Boca Raton, FL: CRC Press.

Rothblum, A.M. (2007). Human Factors Engineering and User-Centered Design for USCG Acquisitions, http://cgcentral.uscg.mil/mycg/portal/ep/contentView.do?pageTypeId=1610622343&channelId=-1610629179&programId=1614122125&contentId=1621583238&contentType=EDITORIAL

Sheridan, T.B. (2002). Humans and Automation: System Design and Research Issues. Santa Monica, CA: Human Factors and Ergonomics Society.

U.S. Coast Guard R&D Center (2007, unpublished). Human Systems Integration Services for USCG Acquisitions. (Brochure)

U.S. Coast Guard R&D Center (2008a). HSI Programs in Other Agencies and recommendations for USCG HSI. (Annotated PowerPoint presentation) USCG R&D Center UDI #914. Groton, CT: Author.

U.S. Coast Guard R&D Center (2008b). Human Systems Integration Support for the CONOPS and ORD Development Process. (Annotated PowerPoint presentation) USCG R&D Center UDI #845. Groton, CT: Author.

APPENDIX A. SURVEY CRITERIA FOR HSI TOOLS

The tools included in the survey were evaluated along four broad criteria that, we feel, must be addressed in order for HSI considerations to be satisfactorily integrated into the Coast Guard system acquisition process.

Criterion 1: Content. The first criterion is that of the content produced by the tool. In order to be useful along this dimension, a tool should produce information bearing on design, rather than producing information in the service of theory testing. The output also should be articulated at a level of fidelity that matches the mission-oriented considerations of system design. The content produced by the tool should be actionable, that is, it should support the derivation of design commitments. It also should produce content that can be used to support trade-offs that will have to be made during the course of the development effort. Finally, good tools should support designers in understanding how adaptive behavior at one level influences of constrains behavior at other levels throughout the operating range of the system.

The content of each tool was assessed with respect to a number of measures.

a. *Theoretical assumptions*. These are the assumptions about the structure and organization of basic processes that both shapes and constrains the types of analyses the tool can be used to conduct, the terminology and conventions a tool adopts and the mechanisms by which analyses are carried out. For example, a software tool might be described as “a theory of cognitive functioning embodied as a computer model.” The assumptions made by the theory about, say, memory dynamics would influence any simulations of operator performance within the context of specific system designs.
b. *HSI domains addressed*. This is an enumeration of the domains that each tool addresses, either directly or indirectly. All tools address at least one domain directly, that is, the tool is designed to permit analyses or design activities in the target domain explicitly. For example, a human reliability tool would directly address the safety domain through its analysis of error probabilities and probabilities of system failures arising from the errors. Tools also can address domains indirectly by providing analyses or information that can be used to make design decisions related to those domains. A simulation environment that produces output regarding workload under different conditions of stress indirectly addresses safety by providing information that can be used in an error and reliability analysis.
c. *Questions addressed*. Each tool addresses certain questions with respect to the activities involved in system design, aspects of HSI domains, and phases of Coast Guard acquisition. We attempted to keep all three of these areas in mind as we reviewed each tool. Broadly speaking these questions tended to cluster into six categories: work structure, effectiveness, performance, optimization, management, and cost and return on investment.
d. *Content modeled*. The specific HSI content, in each HSI domain, addressed by the tool.
e. *Granularity*. Different tools carry out their analyses and produce their outputs at differing levels of granularity. Whereas one tool might allow only identification of broad categories of processes (e.g., engage checklist), another tool might allow detailed description of the process (e.g., a detailed task network of checklist use) in conjunction with completion time estimates of each process step. Clearly, these two tools will support different design activities, and at different levels of fidelity. The tools in this survey ranged across many of levels of granularity. We assessed the granularity of a tool as either low of high. This assessment does not reflect a rigorous or precise measure of tool granularity; rather, we applied subjective judgments to each tool based on either direct experience or the description provided by the tool vendor.

Criterion 2: Communication. A closely related criterion is that of communication. The challenge here is to communicate information to the other developmental disciplines in a way that facilitates their use of the information for their own design activities. Although there are several "models" of interdisciplinary communication between the HSI and system development communities, the one we favor places the responsibility for effective communication on the HSI community. Accordingly, the content of tool output produced by the HSI community should be stated in language, and use conventions, that are conducive to easy incorporation by other developers. When HSI tools use language and conventions to communicate effectively, they will facilitate integration of HSI considerations into acquisition activities and will improve the chances that HSI practitioners can become full, contributing members of interdisciplinary development teams.

The communication effectiveness of each tool was surveyed with respect to several indexes.

a. *Form of output, terminology, and taxonomic conventions*. This area addresses the manner in which content produced by a tool is expressed. In most cases, the tools falling into HSI domains render their output as text, statistical analysis results, graphical representations and so on. These renderings must be "translated" into other forms for direct use by the systems engineering and development functions. Ideally, HSI analysis output would be rendered in a manner that could be directly input to engineering analysis. Since this is not the case currently, we judge the "better" HSI tools to be those that approximate renderings appropriate to engineering modeling and analysis needs. Terminology, definitions, and taxonomic conventions address the specific language used in the output of tool content. Once again, the degree of approximation to engineering analysis needs is a critical consideration. Some tools speak only in the language of the tool: Cognitive processes, workload, situation awareness, and so on. The information produced by these tools will not often be used by the "engineering process" because engineers are not sure how to use the terminology, definitions and conventions as data for engineering analysis and design. Thus, a tool that produces data about human visual detection performance with a terminology based only on detection probabilities, degrees of visual angle, foveal attention, and iconic persistence is not likely to be useful to a process that needs this information presented in terms of system effectiveness.

b. *Methods of integration with system development processes*. Results from HSI analyses can be integrated in several ways.
    i. Provide data that can be used by engineering analyses. These data might address aspects of human performance, capabilities, or limitations that will be important in designing the system and-or performing the trade-offs that will inevitably be required during system development. Another way in which HSI analyses can be used directly by engineering analyses is by supporting the modeling of some aspect of human work that will be important in development of the system.
    ii. Identify important parameters or other factors affecting the performance of a system. HSI analyses might, for example, identify the parameters that must be considered in designing a system for single operator control of multiple uninhabited vehicles.
    iii. Provide design guidance regarding some aspect of the overall system design. Principles based on archival data might be used to provide guidance in the design of feedback lags in a system, for example.

iv. Provide specifications that define a system or subsystem. HSI analyses often are used to develop specifications for the interface in a system, or more recently, to develop specifications for advanced visualizations to be used in a system. Specifications regarding system safety, habitability and other areas also are commonly developed based on HSI analyses.

v. Provide methods for evaluation of a system or subsystem. Several of the tools discussed below are designed to provide ways of evaluating aspects of systems informally and formally, and in formative and engineering phases of development. To the extent that these tools are used in an integrated manner across the course of system development, they can help to keep the development "on course" by spotting problems and resolving uncertainties.

c. *Language and interface support*. This area addresses the computer language, if any, used by each tool in the survey. We also address here the degree and type of interface support provided by the tool. In some cases, this will be an integrated part of the tool, as in the case of a simulation environment or custom computer-based tool. In other cases, there might be no interface support, as in the case of a methodology or analysis technique. A third possibility is that a tool might rely on third-party interfaces such as MS Office applications or statistical packages.

Criterion 3: Risk and Trade-offs. The third criterion used in our tool survey was that of risk assessment and trade-off management. An effective tool should allow analysts to identify, quantify, and assess the likely consequences of risks associated with specific issues arising across HSI domains. The most useful tools will allow analysts to identify risks associated with various HSI considerations, quantify their likelihoods of occurrence, and estimate/mitigate their potential detrimental consequences. One way this can be done is to provide information needed to avoid developing incomplete or inaccurate requirements. This is, in fact, a strength of many of the tools included in this survey, albeit at a qualitative level. Some of the tools even go beyond this by supporting analysts in developing quantitative estimates of errors and their consequences.

Risk management and trade-off support was assessed according to the following factors.

a. *Assumptions regarding risk*. This item addresses whether the tool makes any assumptions about the nature of risk and, if so, what those assumptions are. Most tools do not address this area. Only those tools designed to be used as human reliability instruments explicitly address this area. A few tools that address other HSI domains will also address risk, perhaps indirectly. Examples of such tools would be those concerned with workload or those supporting simulation of human performance.
b. *Error/Risk definitions and taxonomy*. If risk is addressed by a tool, this category will address the taxonomy used in supporting the risk assessments.
c. *Risk computation/mitigation methodology*. For tools that explicitly address risk, this category discusses the analysis and computation methods used to measure the risk, assess the consequences of the risk, and develop mitigation strategies.

Criterion 4: Traceability. The fourth criterion used in the survey, traceability, is concerned with linking developed artifacts to originating requirements. Tools that are maximally useful should provide ways of accomplishing this linkage. Unfortunately, this criterion is, arguably, the most difficult one for HSI tools to satisfy. Reasons for this stem, in part, from inadequacies related to the other criteria. For example, if a tool does not support production of the type of content needed to establish the linkages that constitute traceability, then the traceability criterion will not be met. Likewise, if a tool does not communicate in a manner conducive to the establishment of traceability, then this criterion will not be met.

Three areas were used to survey the traceability provided by each tool.

a. *Output categories and relationships to acquisition requirements*. Output categories include the categories of information that the tool produces. These can include data, descriptions, specifications, analysis results, evaluations, requirements, and models. These can be related to acquisition requirements by contributing directly to acquisition control documents such as the MNS, PORD, ORD and so on; by serving as criteria in milestone decision-making such as decisions to proceed to subsequent analysis phases; by contributing to the development of design specifications; and by serving as input to program reviews.
b. *Development steps supported*. This will be a listing of the design and development activities that a tool supports.
c. *Method of mapping system requirements to HSI work requirements*. This addresses the question of whether the tool provides an explicit way of relating system requirements to HSI requirements. A critical element in the notion of traceability is whether design commitments in HSI domains can be traced back to related system requirements. It should be stated that, in most cases, the tools surveyed here do not provide an explicit means of doing that. In some cases, however, a tool will support the development of a method to carry out this traceability.

In addition to the four criteria outlined above, the review of each tool concludes with a section on the learning curve to become proficient with the tool, general information regarding tool support, and contact information.

The information on learning curve has been included as a general guide to the estimated time that would be required to develop sufficient facility with the tool to use it profitably in development projects. Three levels are used to estimate learning curves. Tools with shallow curves are assumed to be “learnable” within 1 week. The content and assumptions associated with these tools are assumed to be easy to understand. There are no special skills needed to begin using the tool profitably and the tool is assumed to require little experience to apply to design challenges. Tools with moderate learning curves are estimated to require about 2 weeks to “master.” These tools have content and assumptions that require users to engage in some amount of learning, and perhaps some background research, prior to being able to apply the tool. Some special skills might be required of users, perhaps some acquisition of (minimal) programming skills. Background experience will be useful in learning to use the tool. Some minimal training might be needed. Tools with steep learning curves will require more than 2 weeks to proficiency. Substantial learning will be required to master the content and assumptions of the tool. Special skills are required to use to the tool competently. Users will be required to either receive substantial training or participate in substantial practice before being able to use the tool to solve design problems.

Readers will note that some HSI categories are only sparsely represented in this survey. In particular, survivability and habitability have few tools representing them. These domains fall outside the scope of the survey requested by the CG R&D Center because other CG organizations already deal with these issues. The wealth of tools that address these categories, therefore, were not included here.

APPENDIX B. SIMULATION AND ANALYSIS TOOLS FOR CONOPS AND REQUIREMENTS DEVELOPMENT

TABLE OF CONTENTS – APPENDIX B

B.1 Abstraction-Decomposition Hierarchy

Description
Hierarchical description of system operations that relates system purpose to physical form through five levels of decomposition.

Tool/Method Content
Theoretical Assumptions:
- Environment is a primary determining factor in system behavior/effectiveness
- Systems are teleological (goal-seeking) artifacts
- Each level of abstraction in a system must be related to other levels for the system to achieve resilience in the face of environmental complexity

HSI Domains Addressed:
- HFE
- Training
- Safety
- Personnel

Questions Addressed:
- System behavior under environmental variation
- Control tasks
- Adaptive strategies

Content Modeled:
- Functional purpose
- Abstract function
- Generalized function
- Physical function
- Physical form

Model Granularity:
Extends from high level functional purpose to low level physical form.

Communication
Form of Output, Terminology, and Taxonomic Conventions:
- Abstraction - decomposition hierarchy
- Control tasks
- Strategies for carrying out control tasks

Methods used to Integrate with SE and Other Environments:
No explicit points of integration. Often proposed as a replacement for conventional Systems Engineering (SE) process, though this approach is not feasible. Best integration point is in early analysis as an input to system requirements analysis and modeling. No explicit methods. Technique is analytical only. Can be integrated, in principle, with any environment.

Computer Language and Interface Support:
None, this is an analytical technique only. “Interface” is left up to the analyst.

Risk and Trade-off Management
Assumptions Regarding Risk:
Not explicitly part of this tool.

Error Definitions/Taxonomy:
Systems are under development to include error analysis in the general scope of the tool. These are not likely to be a formal tool.

Risk Computation/Mitigation Methodology:
None at this time. Erik Hollnagel has developed a methodology for error estimation. Not currently integrated.

Traceability
Output Categories and Relationships to Acquisition Requirements:
Output categories include

- System purpose
- Constraints
- General laws that apply to system operations
- Physical functions used to realize system purpose
- Physical forms (interfaces)

Methodology allows designers to identify environmental factors affecting system behavior & effectiveness, and relate these to human operator work strategies and performance competencies.

Development Steps Supported:

- Cognitive work analysis
- System requirements analysis

How Tool Maps System Requirements to HSI Requirements:
Allows analysis that will help identify requirements in each HSI domain.

Other Evaluation Criteria
Learning curve: Shallow

Reliability, Validity, and Platform Requirements:
N/A

Analysis Utilities and Interface Support:
N/A

Availability, Cost, and Contact Information:
Vicente, K. (1999). *Cognitive Work Analysis*. Erlbaum: Hillsdale, NJ.

B.2 Adaptive Control of Thought – Rational (ACT-R)

Description

ACT-R is a "hybrid" cognitive architecture that aspires to provide an integrated account of many aspects of human cognition. It is a successor to the previous ACT production-system theories, with emphasis on activation-based processing as the mechanism for relating a production system to a declarative memory.

ACT-R as originally developed was a model of higher-level cognition. That model has been applied to modeling domains such as Tower of Hanoi, mathematical problem solving in the classroom, navigation in a computer maze, computer programming, human memory, learning, and other tasks.

ACT-R is a cognitive architecture: a theory about how human cognition works. On the exterior, ACT-R looks like a programming language; however, its constructs reflect assumptions about human cognition. These assumptions are based on numerous facts derived from psychology experiments.

Like a programming language, ACT-R is a framework: for different tasks (e.g., planning tasks, memory for text or for list of words, language comprehension, communication, aircraft controlling), researchers create models (a.k.a. programs) that are written in ACT-R and that, beside incorporating the ACT-R's view of cognition, add their own assumptions about the particular task. These assumptions can be tested by comparing the results of the model with the results of people doing the same tasks. By "results" we mean the traditional measures of cognitive psychology:

- Time to perform the task,
- Accuracy in the task, and,
- Neurological data such as those obtained from Functional Magnetic Resonance Imagery (fMRI).

Tool/Method Content

Theoretical Assumptions:

In general, ACT-R adheres to the assumptions inherent in the ACT, with the minor exception that all processors, including the motor processors, communicate through the contents of working memory, and not directly from cognition.

ACT-R assumes that there are two types of knowledge—declarative and procedural—and that these are architecturally distinct. Declarative knowledge is represented in terms of chunks, which are schema-like structures consisting of an *isa* pointer specifying their category and some number of additional pointers encoding their contents. Procedural knowledge is represented in production rules. ACT-R's pattern matching facility allows partial matches between the conditions of productions and chunks in declarative memory.

Both declarative and procedural knowledge exist permanently in long-term memory. Working memory is the portion of declarative knowledge that is currently active. Thus, the limitation on working memory capacity in ACT-R concerns access to declarative knowledge, not the capacity of declarative knowledge.

HSI Domains Addressed:

- HFE
- Personnel
- Training

Questions Addressed:

ACT-R has been used in

- Human-computer interaction (HCI) to produce user models that can assess different computer interfaces,
- Education (cognitive tutoring systems) to “guess” the difficulties that students may have and provide focused help,
- Computer-generated forces to provide cognitive agents that inhabit training environments,
- Neuropsychology, to interpret FMRI data.

Content Modeled:

Like a programming language, ACT-R is a framework: for different tasks (e.g., Tower of Hanoi, memory for text or for list of words, language comprehension, communication, aircraft controlling), researchers create models. These models reflect the modelers’ assumptions about the task within the ACT-R view of cognition. The model might then be run.

Running a model automatically produces a step-by-step simulation of human behavior which specifies each individual cognitive operation (i.e., memory encoding and retrieval, visual and auditory encoding, motor programming and execution, mental imagery manipulation). Each step is associated with quantitative predictions of latencies and accuracies. The model can be tested by comparing its results with the data collected in behavioral experiments.

Model Granularity: Very high. Processes can be modeled down to the neurological level.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Modules. There are two types of modules:

- perceptual-motor modules, which interface with a simulation of the real world. The most well-developed perceptual-motor modules in ACT-R are the visual and the manual modules.
- memory modules. There are two kinds of memory modules in ACT-R:
    - declarative memory, consisting of facts such as Washington, D.C. is the capital of United States, France is a country in Europe, or 2+3=5, and
    - procedural memory, made of productions. Productions represent knowledge about how we do things: for instance, knowledge about how to type the letter “Q” on a keyboard, about how to drive, or about how to perform addition.

Buffers. ACT-R accesses its modules (except for the procedural-memory module) through buffers. For each module, a dedicated buffer serves as the interface with that module. The contents of the buffers at a given moment in time represents the state of ACT-R at that moment.

Pattern Matcher. The pattern matcher searches for a production that matches the current state of the buffers. Only one such production can be executed at a given moment. That production, when executed, can modify the buffers and thus change the state of the system. Thus, in ACT-R cognition unfolds as a succession of production firings.

Most existing ACT-R models stand alone; all of the action is cognitive, while perception and motor behavior are finessed. However, some models have been built that interact with an external world implemented in Macintosh Common Lisp or HyperCard™. The ACT-R models generally only interact with custom systems developed by the modeler, rather than with a commercially-available system.

Methods used to Integrate with SE and Other Environments:
None

Computer Language and Interface Support:
Written in Common Lisp and programmed for easy extensibility.

In addition to the fully functional and portable implementation of the ACT-R system, a number of tools are available. There is a graphical environment for the development of ACT-R models, including a structured editor; inspecting, tracing, and debugging tools; and built-in tutoring support for beginners. A perceptual/motor layer extending ACT-R's theory of cognition to perception and action is also available. This system, called ACT-R/PM, consists of a number of modules for visual and auditory perception, motor action, and speech production, which can be added in modular fashion to the basic ACT-R system. Both ACT-R and ACT-R/PM are currently available for the Macintosh, but there are plans to port them to the Windows platform or to some platform-independent format, such as CLIM.

Risk and Trade-off Management

Assumptions Regarding Risk: Treated through a process cost function, to be included as a constraint in model development.

Error Definitions/Taxonomy: No explicit error theory. Errors can be defined by model developers for use in individual models.

Risk Computation/Mitigation Methodology: No explicit treatment of this in the software.

Traceability

Output Categories and Relationships to Acquisition Requirements:

Development Steps Supported:
- Function analysis
- Function allocation
- Task design
- Interface and team development
- Performance/workload/training estimation

How Tool Maps System Requirements to HSI Requirements: very difficult to accomplish this mapping with the ACT-R system. The high degree of system granularity and its emphasis on purely theoretical cognitive-perceptual processes prevents easy translation to HSI or system requirements.

Other Evaluation Criteria

Learning curve: Steep

Reliability, Validity, and Platform Requirements:

ACT-R the theory is embodied in ACT-R the software, as a set of functions and algorithms implemented in Common Lisp. Since the ACT-R implementation lives in Lisp, the aspiring cognitive modeler must also have access to some Lisp environment, or use the standalone version of the ACT-R Environment.

Available on Windows, Mac (PowerPC), and Unix

Analysis Utilities and Interface Support: Support available via email and ACT-R user group. No formal support.

Availability, Cost, and Contact Information:

http://act-r.psy.cmu.edu/actr6/
http://en.wikipedia.org/wiki/ACT_(cognitive_model)

B.3 Critical Decision Method (CDM)

Description

Used to capture critical decisions needed in managing complex work domains, the environments in which decisions are made, decision dynamics and triggers, common errors, tools used to assist in decision-making (if any), and the outcomes of the decisions.

Tool/Method Content

Theoretical Assumptions:

- Decisions are recognition-primed, that is, they rely on complex recognition of conditions and constraints occurring in real time. They are not analytical and deliberate, as assumed by many classical models of decision-making.
- The ability to make rapid, recognition-based, effective decisions is a function of expertise and, therefore, arises after training and exposure to a range of operational situations.

HSI Domains Addressed:

- HFE
- Training
- Some implications for manpower can be derived indirectly from use of CDM methods.

Questions Addressed:

- Decisions required for successful performance/effectiveness
- Some notion of decision criticality
- Decision triggers (often expressed as perceptual patterns)
- Common errors for the types of decisions being made
- Common decision strategies

Content Modeled:

- Information, common errors and environmental factors triggering the decisions.

Model Granularity:

- Descriptive only. Provides a high-level description of the decision "space" and factors influencing decision effectiveness.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

- Output usually rendered as a spreadsheet with decisions and supporting/descriptive/forensic information. Another form of output consists of a detection-interpretation-control-feedback diagram that describes decision processes tracked through time-based or sequence-based stages. An example of such a diagram is shown below (Figure B-1).
- Most terminology taken from recognition-primed decision theory.
- Standard elements include decisions, triggers, common errors, information required for decision, perceptual patterns used in decision-making, strategies.

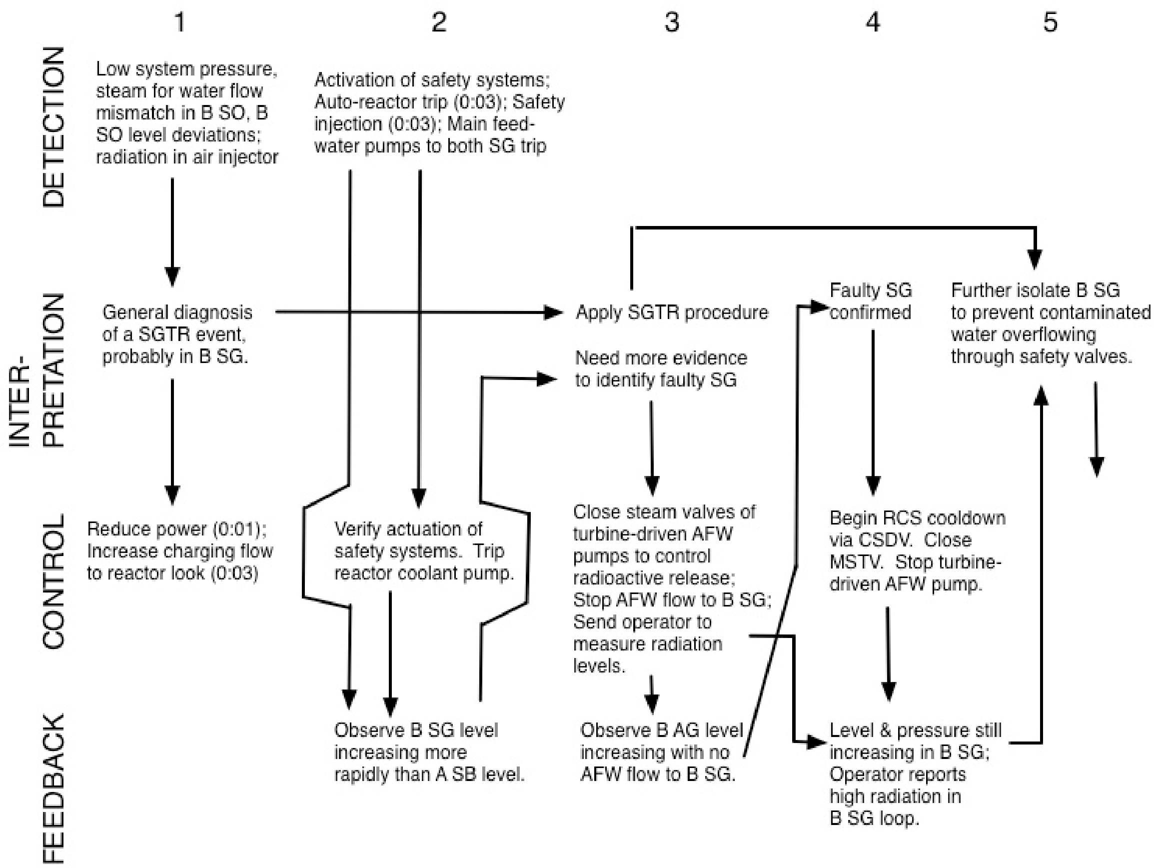


Figure B-1. Critical decision method diagram.

Methods used to Integrate with SE and Other Environments:

- No explicit discussion of using critical decision theory for systems engineering design. This tool most often used for training applications.
- Potential utility as an analytical tool contributing to requirements definition and analysis.

Computer Language and Interface Support:

- None

Risk and Trade-off Management

Assumptions Regarding Risk:

- No discussion of risk in the literature.

Error Definitions/Taxonomy:

- No standard or well-defined error taxonomy. Errors tend to be defined uniquely to the specific application under consideration.

Risk Computation/Mitigation Methodology:

- None

Traceability

Output Categories and Relationships to Acquisition Requirements:

- Training requirements
- Systems engineering requirements

Development Steps Supported:

- Concept definition
- Requirements analysis
- Function analysis
- Function allocation
- Task design

How Tool Maps System Requirements to HSI Requirements:

- Required and critical decisions can be captured in system requirements and mapped to HSI domains, primarily to HFE.

Other Evaluation Criteria

Learning curve: Shallow

Reliability, Validity, and Platform Requirements:

- N/A

Analysis Utilities and Interface Support:

- None

Availability, Cost, and Contact Information:

- Freely available
- Klein, G.A., Calderwood, R. & MacGregor, D. (1989). Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man and Cybernetics, 19(3).*

B.4 Cognitive Function Analysis (CFA)

Description

An integrated approach to human-centered system design. Cognitive functions are defined as a mapping from a task to an activity. Tasks are things that a system user is required to do. Activities are the actions workers perform to complete a task. The phases of this approach include design of a set of primitive cognitive functions through the use of participatory design and domain analysis, definition of evaluation criteria to guide the distribution of cognitive functions among agents, and incremental design and assessment of cognitive functions by designers, users, and usability specialists that are used to build active design documents. Active design documents (ADD) provide interactive and dynamic explanations about the way the system should be or actually is used, as well as a trace of the design rationale as a function of usability criteria. ADD include interaction descriptions, interface objects, and contextual links.

Tool/Method Content

Theoretical Assumptions:

(1) Notes a shift from energy-intensive to information-intensive interaction.
(2) Defines the AUTO pyramid: Artifact, User, Task, Organization. The axes connecting these four anchors indicate the information, challenges and design commitments that one must address in user-centered design.
(3) Distinction between artifact-based cognitive function transfer and task-based cognitive function transfer. The former refers to automation that enhances direct manipulation. The latter refers to automation enhancing task delegation to a software agent.

HSI Domains Addressed:

- HFE
- Training

Questions Addressed:

CFA is based on the cognitive systems engineering philosophy, accordingly, the questions addressed primarily are focused on task requirements in context, the role of the environment in shaping task requirements and strategies, constraints and adaptive responding.

Content Modeled:

Artifact, user, task, organization, procedure training, social issues, role and job analysis, task and user activities, information requirements, technological and human operator limitations, user and artificial cognition.

Model Granularity:

Low. Primarily a qualitative, "paper and pencil" method. No known computer-based development environment that would force careful, consistent definition of concepts or relationships. At best, the method seems to be a specification only.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Accomplished primarily through ADD. ADD are defined as having three components:

- Interaction descriptions: Symbolically conveys ideas and information, e.g., descriptions of procedures. The interaction descriptions define the task space.
- Interface objects: Constituents of interaction descriptions, these contain the "emotive aspects" of the design. They will include mockups of the interface being designed. Interface objects define the activity space.
- Contextual links: These are defined as the "connective tissue" between interaction descriptions and interface objects. Contextual links define the cognitive function space.

Methods used to Integrate with SE and Other Environments:

- CFA is an instance of participatory design.
- No explicit way to convert CFA results into system requirements.
- ADD "are shareable prototypes of the real artifacts being designed that can be used by real users to assess their usability." This statement places the ADD approach somewhat outside the traditional systems engineering requirements development process. Integration with system requirements would be an indirect effect of ADD development.
- Their use of ADDs exists more at the specification level than at the requirements development level. This carries the danger that the ADDs "jump over" the system requirements in their quest for specifications, thereby creating specs that can be disconnected or contradictory to the system requirements.

Computer Language and Interface Support:

No specific computer or interface support for CFA beyond the specifications and some structured paper and pencil artifacts.

Risk and Trade-off Management

Assumptions Regarding Risk:

- No explicit treatment of risk.
- This method contains the basis for some risk analysis associated with the specifications contained in the ADD. However, the literature contains no suggestion that this area has been developed.

Error Definitions/Taxonomy:

No defined error taxonomy.

Risk Computation/Mitigation Methodology:

- No explicit treatment of risk.
- This method contains the basis for some risk analysis associated with the specifications contained in the ADD. However, the literature contains no suggestion that this area has been developed.

Traceability

Output Categories and Relationships to Acquisition Requirements:

Traceability possible only with an explicit linking of CFA method to requirements analysis. This is possible in principle, however, no links have been defined in the literature.

Development Steps Supported:

- Concept definition
- Function analysis
- Function allocation
- Task design
- Interface and team development
- Training development

How Tool Maps System Requirements to HSI Requirements:
No explicit method for accomplishing this mapping.

Other Evaluation Criteria
Learning curve: Shallow

Reliability, Validity, and Platform Requirements:

- Paper and pencil method only.
- No known reliability or validity studies.
- No specific platform requirements.

Analysis Utilities and Interface Support:
N/A

Availability, Cost, and Contact Information:

- Freely available
- www.eurisco.org

References:

Boy, G. A. Cognitive Function Analysis., Stamford, CT: Ablex Publishing Corporation, 1998.

Boy, G. A. Active Design Documents as Software Agents that Mediate Participatory Design and Traceability. In Chipman, Shalin & Schraagen, Eds. Cognitive Task Analysis. New Jersey: Lawrence Erlbaum, 2000.

B.5 Concept Mapping

Description
Concepts and labeled links between concepts are formed into networks describing work, organizations, information flows, relationships and so on. Because the concept mapping is atheoretical and general in its taxonomic structure it can be used to describe almost any design problem. Typically, an ontology or taxonomy is developed for the particular application being addressed. For example, typical taxonomic categories for human interaction with complex systems might include tasks, activities, organizations, roles, products, artifacts, tools, interfaces, cognitive work elements, information, data, relationships and so on.

Tool/Method Content

Theoretical Assumptions:

This method is essentially atheoretical. Its only assumption is that the content of analysis will consist of concepts, represented as boxes, and relations, represented as links between concepts. Links can be unidirectional or bidirectional. Any theory is added by the analyst in the form of ontological definition.

HSI Domains Addressed:

Can potentially address any of the HSI domains due to the flexibility of the representational system. One must simply define a taxonomic system for the domain being analyzed.

Questions Addressed:

The open-ended nature of concept mapping allows analysts and designers to address most any question needed, assuming they can define an analysis system that can represented by a basic “boxes and arrows” system.

Content Modeled:

Any content needed.

Model Granularity:

Can be at whatever level the designer needs. Decomposition can be created for as many levels as desired.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Basic concepts and links between concepts. Taxonomic conventions are defined by the analyst. Links to external documents can be added to concepts or relations contained in the concept maps. Figure B-2 shows a master concept map supporting the design of a visualization-based decision support system for Air Force operational assessment. Node colors correspond to categories relevant to a cognitive system engineering analysis (operational processes, tasks and activities, products and artifacts, requirements and contingencies; systems, tools and interfaces; behavioral and decision processes and supporting information and data needs; organizations, teams, individuals and roles; cognitive and perceptual requirements, capabilities and limitations). Links between nodes express relationships. Analysts would use this master concept map (as a work ontology) to generate individual concept maps capturing all information important to the design and development of the system in question for the work to be supported in the domain of interest.

Methods used to Integrate with SE and Other Environments:

No integration method as part of the concept mapping methodology. Integration method is completely analyst-determined.

Computer Language and Interface Support:

Several concept mapping environments are available. For example:
http://www.inspiration.com
http://www.semanticresearch.com/products/semantica-pro.php
http://cmap.ihmc.us/

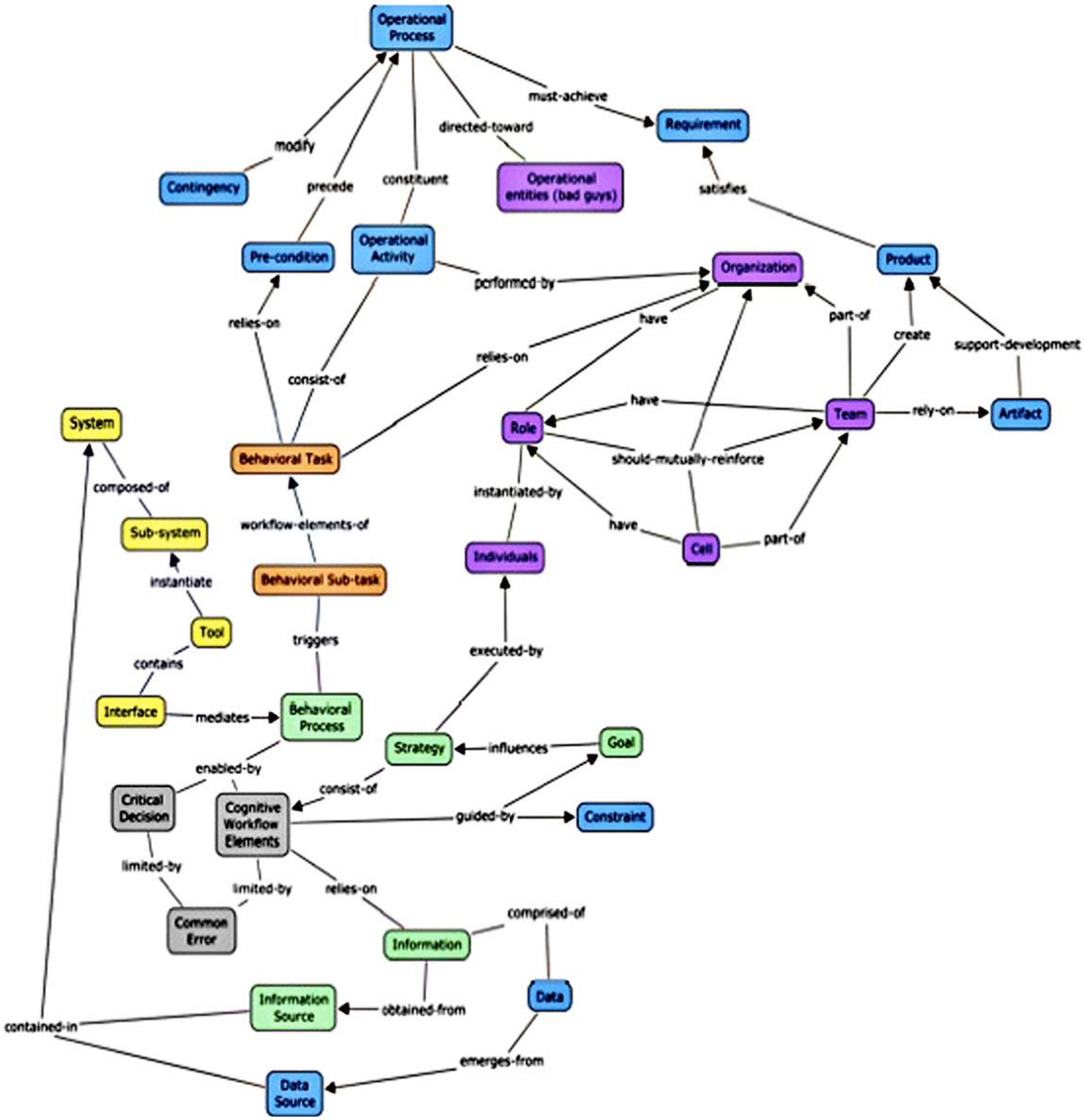


Figure B-2. Concept map.

Risk and Trade-off Management

Assumptions Regarding Risk:

None

Error Definitions/Taxonomy:

None

Risk Computation/Mitigation Methodology:

None

Traceability

Output Categories and Relationships to Acquisition Requirements:

Specific output categories are up to the designer and analyst. Concept maps can contribute to the development of CONOPS and early requirements documents. They can contribute to requirements analysis and development if a method for translating their content to a form compatible with requirements is available.

Development Steps Supported:

- Concept definition
- Requirements analysis
- Function analysis
- Function allocation
- Task design
- Requirements review
- Training development

How Tool Maps System Requirements to HSI Requirements:

Nothing inherent in these tools to do this. Mapping across these domains must be defined and implemented by the analyst.

Other Evaluation Criteria

Learning curve: Shallow

Reliability, Validity, and Platform Requirements:

- N/A
- There are concept mapping tools available for most common computing platforms.

Analysis Utilities and Interface Support:

- Varies by tool. Freeware tools have little or no support for tasks beyond the creation of concepts and links.
- Commercial tools often have some analysis tools included, particularly in the area of network analysis and, in some cases, some reasoning capability over the network.

Availability, Cost, and Contact Information:

Tools range from freeware to commercial tools. The best freeware tool available is the IHMC Cmap tools available from the Institute for Human and Machine Cognition at the University of West Florida. http://cmap.ihmc.us/

B.6 Goals, Operators, Methods, and Selection rules (GOMS)

Description

GOMS is an approach to human computer interaction (HCI) observation. Goals are what the user intends to accomplish. Operators are actions that are performed to get to the goal. Methods are sequences of operators that accomplish a goal. There can be more than one method available to accomplish a single goal, if this is the case than selection rules are used to describe when a user would select a certain method over the others.

Types of GOMS:

- Keystroke-Level Model (KLM) described by Card, Morgan, Newell. Contains several simplifying assumptions.
  - Uses pre-established keystroke-level primitive operator for predictions.
  - Specified method is limited to being in sequence form and containing only keystroke level primitive operators.
- GOMS developed by Card, Morgan, Newell (CMN-GOMS).
  - Slightly more specified than general GOMS
  - Hierarchical goal structure and methods in program form. Represented in pseudo-code-like notation that can include sub-methods and conditionals.
  - Each method consists of a series of steps executed in strictly sequential order.
  - One-to-one correlation of physical operator in CMN-GOMS with the K's (press Key or button) and P's (Pointing with a mouse) of KLM
  - Puts mental time in "verify" operators at end of sub-procedures.
- Natural GOMS Language (NGOMSL)
  - Provides well-defined, structured natural language
  - NGOMSL models are in program form
  - Uses breadth-first expansion of user's top-level goals into methods
  - Can be used to estimate learning time and execution time
  - Assumed knowledge of execution of operators
  - Has limitations -- assumes linear tasks
- Cognitive-Perceptual-Motor (Alternatively, Critical Path Method) (CPM-GOMS)
  - Based directly on the parallel multi-processor stage model of human information processing (Model Human Processor)
  - No human assumptions that operators are performed serially -- Perceptual, cognitive, and motor operators at the level of Model Human Processor, processor cycle times can be performed in parallel as the task demands
  - Begins with a CMN-GOMS model, and starts out serially then interleaved to take advantage of parallelism
  - Is overly detailed for serial tasks
  - Assumes that the user is experienced
  - Requires understanding of parallel processing and information-flow dependencies

Tool/Method Content

Theoretical Assumptions:

Skilled behavior is organized as a set of productions. All behavior is goal-directed. When a system reaches an impasse in its problem-solving behavior, it will decompose the substance of the impasse into smaller problem definitions and attempt to solve these smaller problems. Solutions will be integrated until the original problem has been solved.

HSI Domains Addressed:

- HFE
- Training

Questions Addressed:

Systems can be compared to one another to see how performance changes or is different. It can provide specific details about time to do tasks.

Content Modeled:

GOMS breaks down users interactions with a system into their most primitive actions. These actions can be physical, cognitive, or perceptual. Traditionally these actions are based around the use of a software interface.

Model Granularity:

Breaks tasks down into their smallest possible pieces. Granularity can be adjusted to capture what the evaluator wants to examine.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Output is expressed in terms of model elements (goals, operators, methods and selection rules), task specifications and performance data under varying task conditions. Taxonomic conventions are those of goal-directed processing, declarative and procedural knowledge, forms of learning that lead to creation of production rules, and model assumptions about performance dynamics associated with fundamental perceptual and cognitive processes. Figure B-3 shows a comparison of two cursor-control interfaces, with associated component completion times.

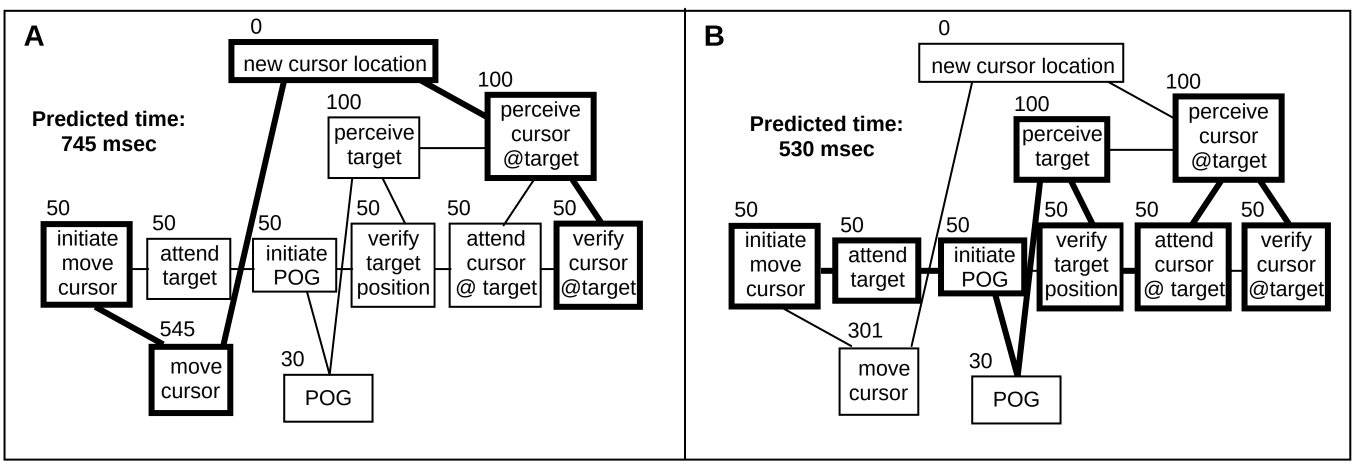


Figure B-3. Use of GOMS to compare two interfaces.

Methods used to Integrate with SE and Other Environments:

The primary method of integration is the input of human performance findings, for the system or subsystem under analysis, into an overall systems engineering analysis and design process.

Computer Language and Interface Support:

GOMS is primarily a theoretically motivated modeling and analysis methodology, with no particular supporting computer language. Several systems based on the GOMS framework have been developed. The interface support associated with these systems varies.

Risk and Trade-off Management

Assumptions Regarding Risk:

No explicit assumptions for risk. No explicit error model. These areas are left up to the definitions provided by the modeler for each specific application.

Error Definitions/Taxonomy:

None. See comment above.

Risk Computation/Mitigation Methodology:

None. See comment above.

Traceability

Output Categories and Relationships to Acquisition Requirements:

Development Steps Supported:

- Task design
- Interface development
- Performance/workload/training estimation

How Tool Maps System Requirements to HSI Requirements:

GOMS is designed to be used after requirements have been defined. Therefore, there is no method resident in the approach itself that addresses system to HSI requirements mapping.

Other Evaluation Criteria

Learning curve: Moderate

Reliability, Validity, and Platform Requirements:

GOMS is not a software application in of itself, but some groups have created software around the GOMS framework and concepts.

Analysis Utilities and Interface Support:

Most software resources have been created at academic institutions and are not warranted. Interface support is minimal.

Availability, Cost, and Contact Information:

All known software is free of charge.

http://www.cs.cmu.edu/~bej/cogtool/

B.7 iGEN

Description

iGEN is a Cognitive Agent Software Toolkit that allows you to develop your own applications in-house. Use iGEN to develop software solutions that emulate human decision-making and problem-solving skills. iGEN lets you build intelligence into your IT infrastructure and process automation, whether for training, performance support, or simulation. By emulating human decision-making processes and problem-solving skills, iGEN helps you capture knowledge in the terms your people understand and your systems use. iGEN allows you to put that knowledge into action, improving productivity and efficiency through better support and enhanced training.

iGEN is a complete Integrated Development Environment (IDE) for building embeddable cognitive agents.

The iGEN cognitive engine, called BATON, is an implementation of a broader framework for modeling human information processing. That framework is described in the research literature under the name COGNET.

Tool/Method Content

Theoretical Assumptions:

iGEN takes the idea that human beings are the best example of intelligence available to us, and applies the cognitive science research as the basis for tools to build cognitive agents. Intelligent human-like software programs that think like humans offer many potential advantages over traditional ‘dumb’ software or conventional AI:

- Their actions should be more human-like and understandable to the people that need to interact with them;
- The knowledge the agents need should be more readily obtainable from human experts in the same field of work; and
- The agent’s internal reasoning and thought processes should be easier to analyze and debug.

Openness and extensibility: The iGEN cognitive engine uses an architecture based on cognitive research, but the architecture minimizes the number of ‘built-in’ psychological theories. As a result, it has retained an open architecture, which allows different component-level theories (e.g., of vision, audition, grasp/reach, memory decay, and so on) to be built and inserted into specific applications as needed and desired by the end-user.

Scalability and compatibility with complex expertise: Unlike the highly constrained settings in which much basic cognitive research has been carried out, real-world cognitive agents must operate in large complex problem environments. They have to be able to incorporate the sophisticated strategies used by true human experts, such as those identified by research on naturalistic decision making. iGEN was deliberately designed to be compatible with these expert strategies, through its use of pattern-directed attention and highly chunked goal structures. This, in turn, has given iGEN cognitive agents an ability to scale up to very complex and dynamic applications that would be unapproachable by other methods.

Separation of competence and performance: There are many limitations of human cognition that an agent-builder won't want to replicate in a cognitive agent, such as limited processing speed, a propensity for errors, a memory which forgets information, and so on. iGEN differentiates between these limiting factors which model human performance and the overall unconstrained abilities which give rise to human competence. In applications such as decision support or intelligent tutoring, the cognitive agent developer typically wants the advisory or tutorial reasoning within the agent to be as competent as possible. On the other hand, when the cognitive agent is a simulation of a human (such as an equipment operator), then producing realistic human performance is paramount. The iGEN cognitive engine captures expertise in a way that allows unconstrained execution to model human competence, but also allows specific performance-constraining factors to be incorporated to create execution as a human performance model.

Support for multi-tasking and time-critical applications: Cognitive agent applications typically need to help (or simulate) people who need to make time-critical decisions and who are working on many tasks simultaneously (i.e., are multi-tasking). iGEN was designed to deal with competing demands for attention and a constantly-changing set of circumstances. The iGEN cognitive engine uses a memory-centric, situation-based attention process that allows the cognitive agent to be highly responsive to changing situations, to be able to interrupt itself when necessary, and to prioritize among many competing demands on the basis of the current context.

HSI Domains Addressed:

- HFE
- Manpower
- Personnel
- Training

Questions Addressed:

A significant problem for training individuals and teams is the expense associated with the time and resources required (e.g., support personnel, team members, instructors). iGEN(R) cognitive agents can be used in different ways to provide a better training environment.

Synthetic Teammates: iGEN(R) can be used to build agents that synthetically represent team members during team training. These synthetic teammates are capable of standing in for their human counterparts to support individual or partial-team training on teamwork skills.

Synthetic Instructors: Synthetic instructors use domain and task knowledge to provide context-based observations and assessments of trainee behavior. They can be designed to provide assessments that may be diagnostic at either the behavioral level (e.g., trainee did not perform a required procedure) or at the cognitive level (e.g., trainee did not understand the required procedure). These assessments may be presented to the trainee during the training exercise and-or after the exercise (i.e., after action review).

Simulating complex systems before they are built allows detailed non-destructive and low-cost analysis and testing. Often, though, the critical component of simulation is the human element. The most important questions can't be answered through simulation without a reasonable model of how the human operator, human team or human organization will behave. iGEN(R) human performance models (HPM) provide the modeling and simulation community with a powerful new tool to represent the human element in advanced simulation.

Content Modeled:

iGEN(R) HPM agents can be built to represent the knowledge-based work and decision processes of individuals (such as workstation operators), teams (such as command teams or control room teams), or even whole organizations (such as command and control nodes, enemy or competition organizations). iGEN(R) HPM agents incorporate the knowledge and work processes of the human element being simulated. The powerful iGEN(R) cognitive agent architecture applies these to simulate the desired range of behavior, including individual variability, errors, population variability, and some forms of learning. The result is dynamic and adaptive behavioral simulations that are robust and scenario-independent.

Model Granularity:

Because iGEN was designed to support as large a range of applications as possible, it does not have any 'least common denominator' of granularity for representing knowledge and-or cognitive processes. Unlike other architectures, which are tied to fixed cognitive cycle time (typically a small fraction of a second), the iGEN cognitive engine allows the cognitive agent builder to select a level of detail that is appropriate for the application at hand. This allows knowledge about the application domain to be programmed at the level most appropriate for the needs of the specific application.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Output includes task specifications, performance data and results, and information about errors during operations. Terminology includes standard discrete-event and task network terms, human information processing (HIP) terms, performance parameters associated with HIP dynamics.

Methods used to Integrate with SE and Other Environments:

iGEN has convenient implementation features that make it attractive for incorporation into your development environment:

- Workbench-based development approach—a collection of high level agent-building tools that facilitate engineering of intelligent applications

Computer Language and Interface Support:

- Visual programming interface—a graphical way of defining program logic and knowledge, for easier use by programmers and non-programmers, alike
- Well-structured Application Program Interface—permitting integration of iGEN cognitive agents with and within existing applications using standard languages (e.g., C/C++, Java) and protocols (COM, CORBA, HLA)

Risk and Trade-off Management

Assumptions Regarding Risk:

Risk can be modeled in iGEN by defining relationships between errors committed by operators and resulting consequences on system performance/effectiveness. Modelers define these relationships for the systems and operational contexts under consideration.

Error Definitions/Taxonomy:

iGEN does not contain error categories as part of the software package. HS analysts can define errors as needed for particular modeling applications.

Risk Computation/Mitigation Methodology:
No risk computation process included with the software. The system can be used to produce models that allow analyses of performance under various operating conditions, thereby producing data that inform separate risk analyses.

Traceability
Output Categories and Relationships to Acquisition Requirements:
Model output includes operator performance, efficiency estimates, error characteristics (if defined), and temporal dynamics (e.g., time to proficiency) that can be integrated with other acquisition and system requirements.

Development Steps Supported:

- Requirements analysis
- Function analysis
- Function allocation
- Task design
- Interface and team development
- Performance/workload/training estimation
- Requirements review
- Training development
- Performance assurance

How Tool Maps System Requirements to HSI Requirements:
No facilities within the tool to do this. However, because iGEN supports rigorous simulation of human performance levels and dynamics, HSI requirements can be derived from simulations. These then can be integrated with, or compared to, system requirements.

Other Evaluation Criteria
Learning curve: Steep

Reliability, Validity, and Platform Requirements:
iGEN IDE System Requirements (Version 2.0):

- Windows 95, 98, 2000, NT, XP
- We recommend at least 64 Mb RAM, recommend over 256 MB
- Build the required communication shell (API), using Microsoft Visual C++ 6.0, service pack 3 or greater for Windows applications, or gcc 3.2 or greater for Linux and other applications, including embedded systems.

Standalone Agent Requirements:

- Windows (95, 98, 2000, NT, XP), Unix (Linux (RedHat 6.1+), IRIX (6.5), Solaris (2.6))
- Recommend > 256 MB of RAM

Analysis Utilities and Interface Support:
Delivered as part of the standard software package and user support license.

Availability, Cost, and Contact Information:
http://www.chisystems.com
Jim Hicinbothom, iGEN(R) Product Manager / 858-618-1060
Email: jhicinbothom@chisystems.com or iGEN@chisystems.com

B.8 Information and Functional Flow Analysis

Description
In information flow analysis, a flowchart of the information and decisions required to satisfy the functions of a complex system is constructed. These charts describe information flow and highlight critical paths and bottlenecks as information flows among nodes in the system.

In functional flow analysis the system is decomposed into the functions it must support. Function-flow diagrams are constructed to show the sequential or information-flow relationships between system functions. Petri nets may be used as a modeling formalism to implement function-flow diagrams.

Tool/Method Content
Theoretical Assumptions:
In system dynamics, flows represent information, products and processes of interest. They alter the state of a system by altering component states of system constituents. Since flows are the rates at which system states change, they can be used to assess the performance levels of a system of interest by deriving measures such as capacity, flow amounts, flow rates and other properties.

HSI Domains Addressed:

- HFE
- Training
- Manpower

Normally, flow analysis is used in analysis and evaluation of issues involving HFE and training concerns in system development. However, because the theory underlying flow analysis is so flexible, the method can be used in any domain in which system states and flow dynamics can be consistently defined.

Questions Addressed:
Fundamentally, the questions addressed by all types of flow analysis involve the computation of system state as a function of the flow dynamics that apply to the system. Some examples of specific questions that can be addressed include:

- Performance levels as a function of information arrival rates,
- Performance as a function of information carrying or processing capacity,
- Performance as a function of average throughput in a system,
- Performance as a function of disequilibria involving information flow through a system.

Content Modeled:
Flow analyses model functions (or processes) and information in a system, along with the dynamics of these concepts. As stated above, dynamics can include capacities, rates, accumulations, delays, disequilibria, and other dynamics related to system performance and-or effectiveness. The specific content of a model or analysis will depend on the system under study and the questions being asked by the development team.

Model Granularity:

The models typically developed under flow analyses will exist at the system level. Because these model are functional in nature, we consider this to represent a mid-level of granularity. Detailed processes, such as those articulated by analysis systems like ACT-R, are not addressed with flow analysis.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Flow analysis uses the terminology of system dynamics: processes and flows (or some equivalent nomenclature), system state, transfer functions, accumulations (or integral notation), rates (or some other derivative notation), delays, and disequilibrium dynamics. The forms of output can be either descriptive or formal. For purposes of system acquisition and development the form of output can be stated in terms of requirements and system performance constraints.

Methods used to Integrate with SE and Other Environments:

The system orientation of flow analysis can be used to integrate with other systems engineering activities during the early stages of system design and development. In general, flow analysis can be integrated with any other development activity which relies on the language of system dynamics in solving design and development problems.

Computer Language and Interface Support:

There seem to be very few tools available that are specifically devoted to flow analysis applied to HSI domain issues. One tool formerly available was the Information Flow Analysis Software Tool (IFAST), in development for a time by Aptima and Micro-Analysis and Design (now a division of Alion Science and Technology). This was to be a model-driven software tool to represent and analyze information flow in complex systems. IFAST was a simulation-based software tool to analyze information flow, highlight critical paths and bottlenecks, and answer "what-if" questions regarding complex human-machine systems. It included the capability to represent the human decision maker, resulting in more representative information flow metrics for analyses relevant to HSI concerns. IFAST produced metrics of information flow by providing users with a simulation capability tailored towards the flow of messages. This tool apparently is no longer available.

Risk and Trade-off Management

Assumptions Regarding Risk:

All risk assumptions in flow analysis are developed by the analyst, tailored to the needs of the specific system under development.

Error Definitions/Taxonomy:

No explicit error definition taxonomy. Derivative taxonomies can be developed based on the system dynamics concepts of the flow analysis methodology.

Risk Computation/Mitigation Methodology:

No explicit risk computation method. Derivative methods can be developed based on the system dynamics concepts of the flow analysis methodology.

Traceability

Output Categories and Relationships to Acquisition Requirements:

Outputs consist of system states and information flow dynamics. This information is useful in requirements and function analysis. It also informs functional allocation decisions, task design and performance estimation.

Development Steps Supported:

- Requirements analysis
- Function analysis
- Function allocation
- Task design
- Performance/workload/training estimation

How Tool Maps System Requirements to HSI Requirements:

The system representations provided by the flow analysis methodology of these tools provides a way to represent needed system dynamics, as articulated in the system requirements, against the capabilities and limitations of human components of the system. This allows analysts to model the system specified by these requirements and evaluate its effectiveness, attributing shortfalls to human and non-human system components. In cases in which shortfalls can be attributed to humans, appropriate HSI requirements can be defined or modified.

Other Evaluation Criteria

Learning curve: Shallow

Reliability, Validity, and Platform Requirements:

The flow analysis methodology has been shown to be both valid and reliable across a wide range of applications. There are no particular platform requirements for the use of this methodology.

Analysis Utilities and Interface Support:

No analysis utilities other than those associated with general system theory and analysis. There are no software tools for flow analysis known at this time, therefore, no interface support.

Availability, Cost, and Contact Information:

The flow analysis methodology is widely available from many sources

Davis, J. G., Subrahmanian, E., Konda, S., Granger, H., Collins, M., & Westerberg, A. W. Creating Shared Information Spaces to Support Collaborative Design Work.

Meister, D. (1989). Conceptual Aspects of Human Factors. Baltimore, MD: The Johns Hopkins University Press.

Randel, J. M., Pugh, L. H., & Wyman, B. G. Methods for Conducting Cognitive Task Analysis for a Decision Making Task. Navy Personnel Research and Development Center (1996). The Critical Incident Method, Interviewing, and Information Flow Modeling are used to study a decision making task.

Kirwan, B. & Ainsworth, L. K. A Guide to Task Analysis. London: Taylor and Francis, 1992. A text book of various task analysis techniques and their use in the systems engineering process.

B.9 Applied Cognitive Task Analysis (ACTA)

Description
A method for performing Cognitive Task Analysis. The method consists of three structured interviews. The first interview generates a Task Diagram, which provides a broad overview of the task and highlights difficult cognitive portions of the task that should be probed further. This is followed by a Knowledge Audit, which surveys the aspects of expertise required for a specific task or subtask. Finally, in the Simulation Interview step, the cognitive processes of experts are probed within the context of a specific scenario. The output of the process is a Cognitive Demands Table, which presents the results so they can be applied to a specific project.

ACTA is an instructional software tool that is designed to assist practitioners in identifying cognitive skills, or mental demands, that are needed to perform a task. These skills/demands include: critical cues and patterns of cues; assessment, problem solving, and decision-making strategies; why these are difficult for novices; and common novice errors. ACTA provides a means for practitioners to elicit this kind of information and incorporate it into instructional design interventions.

Tool/Method Content
Theoretical Assumptions:

(1) Experts are able to articulate task structure, cognitive requirements and critical decisions in ways that allow designers to collect the information needed to inform system design.
(2) Expertise is expressed as a focused recognition of critical information and patterns accompanied by an application of strategic behaviors in the service of goal attainment.
(3) Knowledge categories critical to the definition and development of systems include diagnosing and predicting, situation awareness, perceptual skills, developing and knowing when to apply specific strategies, improvising, recognizing anomalies, and compensating for equipment limitations. Experts are able to describe their task requirements in terms of these categories.
(4) Probes can be developed to carry out audits of the knowledge needed to execute critical tasks in the design problem of interest.

HSI Domains Addressed:

- HFE
- Training.
- Personnel

Some of the information acquired by this method can be used in safety analyses, although this use would be primarily tangential.

Content Modeled:

- Operational task structure
- Strategic performance in dynamic task circumstances
- Critical decisions and the task contexts in which these arise
- Cognitive content in task performance
- Common errors committed during task performance

Model Granularity:

To the extent that models are developed based on the information gathered with ACTA, granularity is considered to be low. Most of the techniques used under the ACTA framework are paper and pencil, and interview, techniques. The procedures used here are intentionally high-level so as to avoid intractability and a reliance on "degenerating into a search for everything in a person's head."

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Output exists primarily in the form of tabular and survey text gathered according to the methodology shown below.

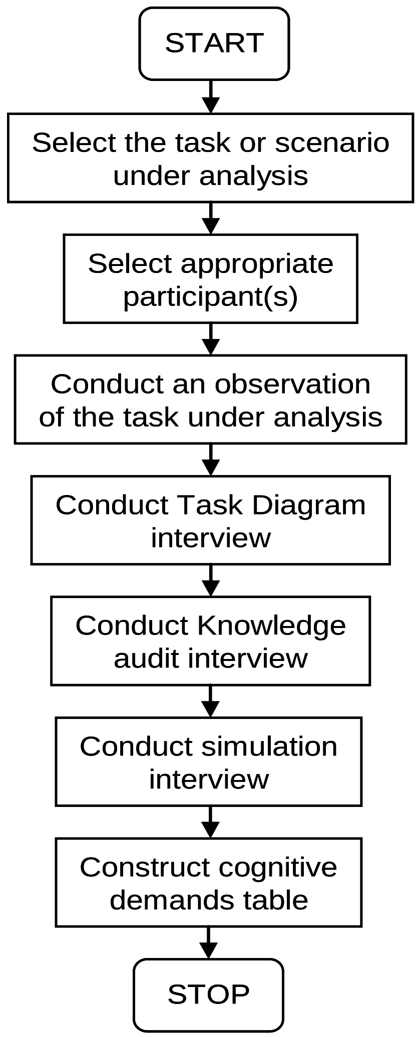


Figure B-4. Method for applied cognitive task analysis.

Some Likert-type data can be collected, if desired, but these data will be subjective in nature. Output terminology follows standard cognitive systems engineering conventions. There have been no standard taxonomic conventions developed for this tool. Typical output is shown in the tables below.

Table B-1. Example simulation interview table. (Source: Militello and Hutton, 2000.)

Events	Actions	Assessment	Critical Cues	Potential Errors
On scene arrival	Account for people (names) Ask neighbours Must knock on or knock down doors to make sure people aren't there	It's a cold night; need to find place for people who have been evacuated	Night time Cold > 15° Dead space Add on floor Poor materials, metal girders Common attic in whole building	Not keeping track of people (could be looking for people who are not there)
Initial attack	Watch for signs of building collapse If signs of building collapse, evacuate and throw water on it from outside	Faulty construction; building may collapse	Signs of building collapse include: What walls are doing: cracking What floors are doing: groaning What metal girders are doing: clicking, popping Cable in old buildings hold walls together	Ventilating the attic; this draws the fire up and spreads it through the pipes and electrical system

Table B-2. Example cognitive demands table. (Source: Militello and Hutton, 2000.)

Difficult cognitive element	Why difficult?	Common errors	Cues and strategies used
Knowing where to search after an explosion	Novices may not be trained in dealing with explosions. Other training suggests you should start at the source and work outward.	Novice would be likely to start at the source of the explosion. Starting at the source is a rule of thumb for most other kinds of incidents.	Start where you are most likely to find victims, keeping in mind safety considerations. Refer to material data sheets to determine where dangerous chemicals are likely to be. Consider the type of structure and where victims are likely to be. Consider the likelihood of further explosions. Keep in mind the safety of your crew.
Finding victims in a burning building	There are lots of distracting noises. If you are nervous or tired, your own breathing makes it hard to hear anything else.	Novices sometimes don't recognise their own breathing sounds; they mistakenly think they hear a victim breathing.	Both you and your partner stop, hold your breath and listen. Listen for crying, victims talking to themselves, victims knocking things over, etc.

Methods used to Integrate with SE and Other Environments:

There are no specific integration methods inherent in this tool. The primary method of integration is the presence of the cognitive systems engineer with other members of the design team. ACTA is designed to produce information that can be incorporated into ongoing system requirements development. Successful incorporation will depend, however, on satisfactory translation of the cognitive task analysis information into systems engineering and requirements language.

Computer Language and Interface Support:

Interface support will consist of commonly available office support tools and databases.

Risk and Trade-off Management

Assumptions Regarding Risk:

No explicit assumptions regarding risk.

Error Definitions/Taxonomy:
No standard error taxonomy. Error definitions are left up to the individual analyst.

Risk Computation/Mitigation Methodology:
No standard risk computation or mitigation methodology. The analyst can define these concepts as part of the ACTA process and can develop risk computations, although this is not typically done.

Traceability
Output Categories and Relationships to Acquisition Requirements:
Output categories are primarily focused on cognitive strategies, decisions, cognitive errors. This information is important for requirements development and interface/interaction specifications. Much of the information produced by this tool is relevant to work design, error identification and training. Some information might be related to safety and personnel selection considerations, although these are not explicitly treated by the tool methodology.

Development Steps Supported:

- Concept definition
- Requirements analysis
- Function analysis
- Function allocation
- Task design
- Interface and team development
- Training development

How Tool Maps System Requirements to HSI Requirements:
No explicit mapping. The information produced by the tool can be used to relate system requirements to HFE and training requirements. The method of doing this will be the responsibility of the individual analyst.

Other Evaluation Criteria
Learning curve: Shallow

Reliability, Validity, and Platform Requirements:
The ACTA tool was validated in a series of studies carried out by Militello, et al. (1997). The reliability of the tool has not been established across multiple domains or with multiple analysts. There are no platform requirements associated with this tool other than those needed for office and database support.

Analysis Utilities and Interface Support:
Interface support will consist of commonly available office support tools and databases.

Availability, Cost, and Contact Information:
Militello, L.G., Hutton, R.J.B., Pliske, R.M., Knight, B.J., & Klein, G. (1997), "Applied Cognitive Task Analysis (ACTA) Methodology," Fairborn, OH: Klein Associates, Inc. Final Technical Report prepared for the Navy Personnel Research and Development Center under Contract No. N66001-94-C-7034.

B.10 Autonomous Vehicle Operator Span of Control Evaluation Tool (AVOSCET)

Description
AVOSCET is a trade-off analysis tool specifically designed to help analysts determine how many autonomous systems an operator or a crew can control under a variety of conditions.

Tool/Method Content
Theoretical Assumptions:
Human performance can be described as a set of networked tasks, modified by specifications of capabilities and limitations describing operator competencies. When situated in a description of system dynamics, operator performance can be used to moderate overall system effectiveness.

HSI Domains Addressed:
- HFE
- Safety
- Manpower

Questions Addressed:
This tool is focused on the question of how many autonomous vehicles a single operator can control concurrently.
Content Modeled:
Task structure, vehicle dynamics, environmental conditions, performance moderators and stressors, temporal requirements and characteristics.

Model Granularity:
This system has a moderate to high level of granularity. Operators can be modeled in detail using task performance specifications and information on capabilities and limitations. Environmental and task stressors and other moderators can be included in analyses. It is not possible to model individual processes in this system.

Communication
Form of Output, Terminology, and Taxonomic Conventions:
The system presents a network graph of critical tasks, as shown in Figure B-5. Momentary workload levels as a function of many inputs, operator performance as a function of time, stressors, and environmental/vehicle characteristics are then computed based on the task network and associated specifications, as shown in Figure B-6.

Methods used to Integrate with SE and Other Environments:
Integration is accomplished primarily through the production of analysis results that can be input to other systems engineering design and analysis activities. There is no direct means of integrating into other systems engineering tools.

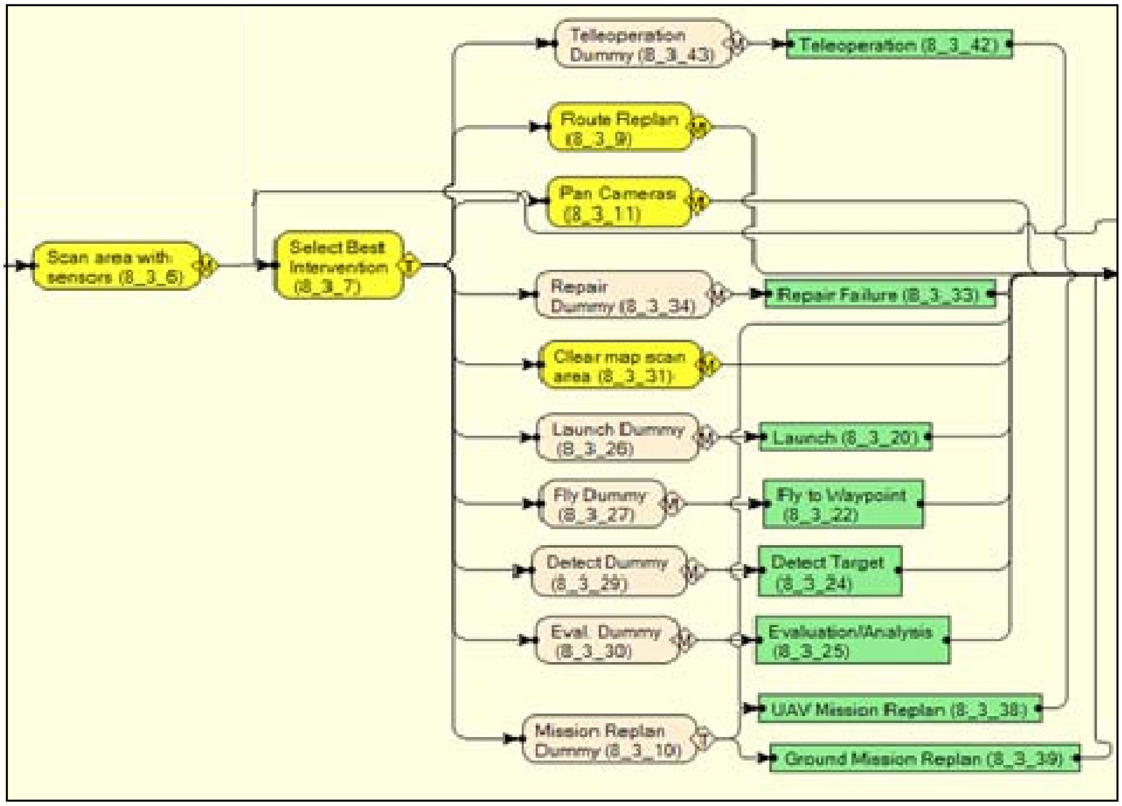


Figure B-5. Part of an AVOSCET task network.
(from www.maad.com)

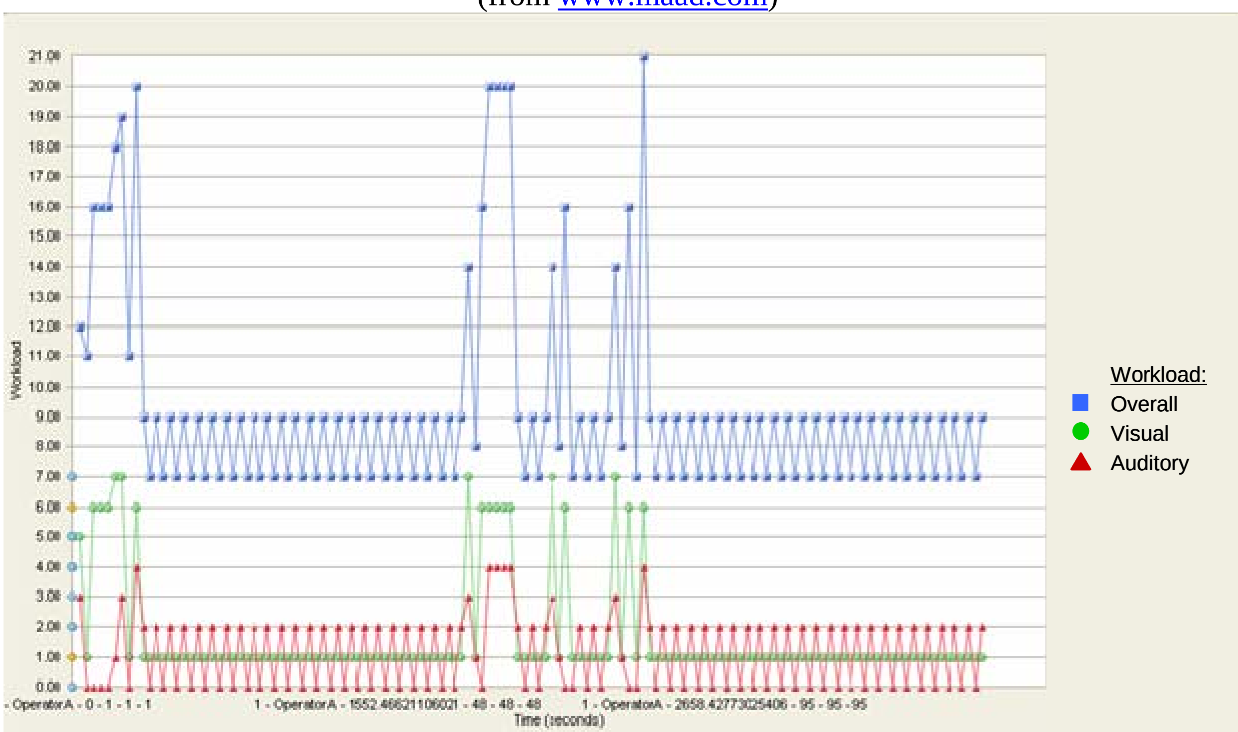


Figure B-6. AVOSCET workload analysis display.
(from www.maad.com)

Computer Language and Interface Support:
AVOSCET is based on the MicroSAINT discrete event simulation package. That environment is based on C#.

Risk and Trade-off Management
Assumptions Regarding Risk:
No explicit risk assumptions. Any risk analyses or trade-offs are based on the specifications built into the simulation by the analyst.

Error Definitions/Taxonomy:
AVOSCET contains no error terminology.

Risk Computation/Mitigation Methodology:
The system contains no risk computation or mitigation support.

Traceability
Output Categories and Relationships to Acquisition Requirements:
AVOSCET outputs information on overall operator task performance, overall effectiveness within the defined operational envelope, and workload estimates.

Development Steps Supported:

- Function analysis
- Function allocation
- Task design
- Interface and team development
- Performance/workload/training estimation

How Tool Maps System Requirements to HSI Requirements:
Analyses can be used to constrain system requirements in the areas of workload; overall task performance; dynamic task performance as a function of stressors, moderators, environmental and system characteristics; and manpower.

Other Evaluation Criteria
Learning curve: Steep

Reliability, Validity, and Platform Requirements:
No data have been found regarding reliability and validity. Platform requirements for this tool will be based on those for the MicroSAINT simulation environment, i.e., Windows platform.

Analysis Utilities and Interface Support:
The tool has analysis support for task network modeling and performance-based analyses of human control and decision making.

Availability, Cost, and Contact Information:
This tool is commercially available. Cost depends on the number of licenses. AVOSCET was developed by Micro Analysis and Design, which is now part of Alion Science and Technology Corp.

Alion MA&D Operation
Corporate Headquarters
4949 Pearl E. Circle, Suite 300
Boulder, CO 80301
303-442-6947
www.maad.com
Stacey Quesada, squesada@alionscience.com

B.11 Man-Machine Integrated Design and Analysis System (MIDAS)

Description
The Man-machine Integration Design and Analysis System (MIDAS) is a three-dimensional rapid prototyping human performance modeling and simulation environment that facilitates the design, visualization, and computational evaluation of complex man-machine system concepts in simulated operational environments.

MIDAS combines graphical equipment prototyping, dynamic simulation, and human performance modeling with the aim to reduce design cycle time, support quantitative predictions of human-system effectiveness, and improve the design of crew stations and their associated operating procedures.

MIDAS links a virtual human, comprised of a physical anthropometric character, to a computational cognitive structure that represents human capabilities and limitations. The cognitive component is made up of a perceptual mechanism (visual and auditory), memory, a decision maker and a response selection architecture (MicroSAINT Sharp). The complex interplay among bottom-up and top-down processes enables the emergence of unforeseen, and non-programmed behaviors.

MIDAS outputs include dynamic visual representations of the simulation environment, timelines, task lists, cognitive loads along six resource channels, actual/perceived situation awareness, and human error vulnerability and human performance quality.

Tool/Method Content
Theoretical Assumptions:
MIDAS assumes that the human operator can perform multiple, concurrent tasks, subject to available perceptual, cognitive, and motor resources. MIDAS is an integrative, versatile model with much detail. Its sub-models are often based on current psychological can psychomotor theory and data. Its task loading model is consistent with multiple resource theory. MIDAS explicitly models communication. Much modeling attention has been given to situation awareness with respect to the updateable world representation.

HSI Domains Addressed:
- HFE
- Training

Questions Addressed:
Over its history, NASA's MIDAS has compared human performance in the nuclear power plant, emergency control room response to 911 calls, suit design, helicopter, aviation, and space domains.

Content Modeled:

The overall architecture of MIDAS is comprised of a user interface, an anthropometric model of the human operator, symbolic operator models, and a world model. MIDAS is an object-oriented system consisting of objects (grouped by classes). Objects perform processing by sending messages to each other.

There are two types of physical component agents in MIDAS: equipment agents are the displays and controls with which the human operator interacts; physical world agents include terrain and aeronautical equipment (such as helicopters). Physical component agents are represented as finite-state machines, or they can be time-script-driven or stimulus-response-driven. Their behaviors are represented using Lisp methods and associated functions.

The human operator agents are the human performance representations in MIDAS — cognitive, perceptual, and motor. The MIDAS physical agent is Jack™, an animated mannequin. MIDAS uses Jack to address workstation geometry issues, such as the placement of displays and controls. Jack models the operator's hands, eye, and feet, though in the MIDAS version, Jack cannot walk.

The visual perception agent computes eye movements, what is imaged on the retina, peripheral and foveal fields of view, what is in and out of focus relative to the fixation plane, preattentional phenomena (such a color and flashing), detected peripheral stimuli (such as color), and detailed information perception.

Model Granularity: Unknown

Communication

Form of Output, Terminology, and Taxonomic Conventions:

In a MIDAS simulation, declarative and procedural information about the mission and equipment is held in the updatable world representation. Information from the external world is filtered by perception, and the updatable world representation is updated. Mission goals are decomposed into lower-level activities or tasks, and these activities are scheduled. As the activities are performed, information is passed to Jack, whose actions affect cockpit equipment. The external world is updated, and the process continues.

MIDAS outputs include dynamic visual representations of the simulation environment, timelines, task lists, cognitive loads along 6 resource channels, actual/perceived situation awareness, and human error vulnerability and human performance quality.

Methods used to Integrate with SE and Other Environments:

Unknown

Computer Language and Interface Support:

MIDAS is written in the Lisp C, C++ programming languages and runs on Silicon Graphics, Inc., workstations. It consists of approximately 350,000 lines of code and requires one or more workstations to run on. It is 30 to 40 times slower than real time, but can be simplified so it can run at nearly real time.

The user interface consists of an input side (an interactive Graphical User Interface (GUI)), a cockpit design editor, an equipment editor, a vehicle route editor, and an activity editor. On the output side there's display animation software, run-time data graphical displays, summary data graphical displays, and 3D graphical displays.

Risk and Trade-off Management

Assumptions Regarding Risk:

Many MIDAS behaviors, such as operator errors, are not emergent features of the model, but must be explicitly programmed. The Z-Scheduler makes assumptions that are somewhat controversial. The scale-up of the original MIDAS to multi-operator systems would appear to be quite difficult. MIDAS is also too big and too slow for most military simulation applications. In addition, it is very labor-intensive, and it contains many details and features not needed in military simulations.

Nevertheless, MIDAS has a great deal of potential for use in military simulations. The MIDAS architecture would provide a good base for a human behavior representation. Components of MIDAS could be used selectively and simplified to provide the level of detail and performance required. Furthermore, MIDAS would be a good test-bed for behavioral representation research.

Error Definitions/Taxonomy:

No data.

Risk Computation/Mitigation Methodology:

No data.

Traceability

Output Categories and Relationships to Acquisition Requirements:

Primary output category is operator performance. MIDAS supports operator requirements analysis and workload/performance/training estimation.

Development Steps Supported:

- Concept definition
- Function analysis
- Function allocation
- Task design
- Performance/workload/training estimation
- Training development

How Tool Maps System Requirements to HSI Requirements:

Mapping achieved by showing relationships between operator performance and system effectiveness.

Other Evaluation Criteria

Learning curve: Steep

Reliability, Validity, and Platform Requirements:

MIDAS is written in the Lisp, C, and C++ programming languages and runs on Silicon Graphics, Inc., workstations.

The original version of MIDAS has been validated in at least one experiment involving human subjects. MIDAS was programmed to model the flight crew of a Boeing 757 aircraft as they responded to descent clearances from air traffic control: the task was to decide whether or not to accept the clearance and if so, when to start the descent. The model was exercised for a variety of scenarios. The experimenters then collected simulator data with four two-pilot crews. The behavior of the model was comparable to that of the human pilots.

Analysis Utilities and Interface Support:

The MIDAS support environment has editors and browsers for creating and changing system and equipment specifications, and operator procedures and tools for viewing and analyzing simulation results. Currently much specialized knowledge is required to use these tools to create models, but it is worth noting that a major thrust of the MIDAS redesign is to develop a more self-evident GUI that will allow nonprogrammers and users other than MIDAS development staff create new simulation experiments using MIDAS. In addition, this version will eventually include libraries of models for several of the more important domains of MIDAS application (rotorcraft and fixed-wing commercial aircraft).

Availability, Cost, and Contact Information:

NASA AMES
http://humansystems.arc.nasa.gov/groups/midas/

APPENDIX C. TOOLS FOR DETERMINING MANNING AND PERSONNEL QUALIFICATIONS

TABLE OF CONTENTS – APPENDIX C

C.1 Advisor 3.5

Description
A decision support tool to help manage training budgets and resources. Helps identify ways to conduct training programs more effectively. Comprised of four modules: Where training funds should be allocated, training effectiveness, training delivery, money/resources needed.

Tool/Method Content
Theoretical Assumptions:
Seems somewhat atheoretical. Job and skill analysis is a standard theory-free procedural analysis.

HSI Domains Addressed:
- Training

Questions Addressed:
- Determine most cost-effective way to deliver training
- Effectiveness/cost of alternate training methods
- Estimate time required to develop various training materials
- Return on investment (ROI) of alternate training methods

Content Modeled:
Feasibility and effectiveness of alternative training delivery methods. Computes & compares costs of alternative methods.

Model Granularity:
Unknown

Communication
Form of Output, Terminology, and Taxonomic Conventions:
- Costs associated with trainees, instructors, development, facilities, maintenance and hardware
- Training strategies
- Requirements
- ROI
- Cost and time required
- Optimize strategies, resources, cost, ROI

Methods used to Integrate with SE and Other Environments:
No explicit integration discussed. Acquisition team could use this system early in acquisition planning to evaluate alternatives emerging from CONOPS definition with respect to training costs, schedules, etc. No known integration with other environments.

Computer Language and Interface Support:
Interfaces provided with each analysis module to assist/guide analyst through the overall process. Interface examples, showing input support and analysis alternatives, are shown below.

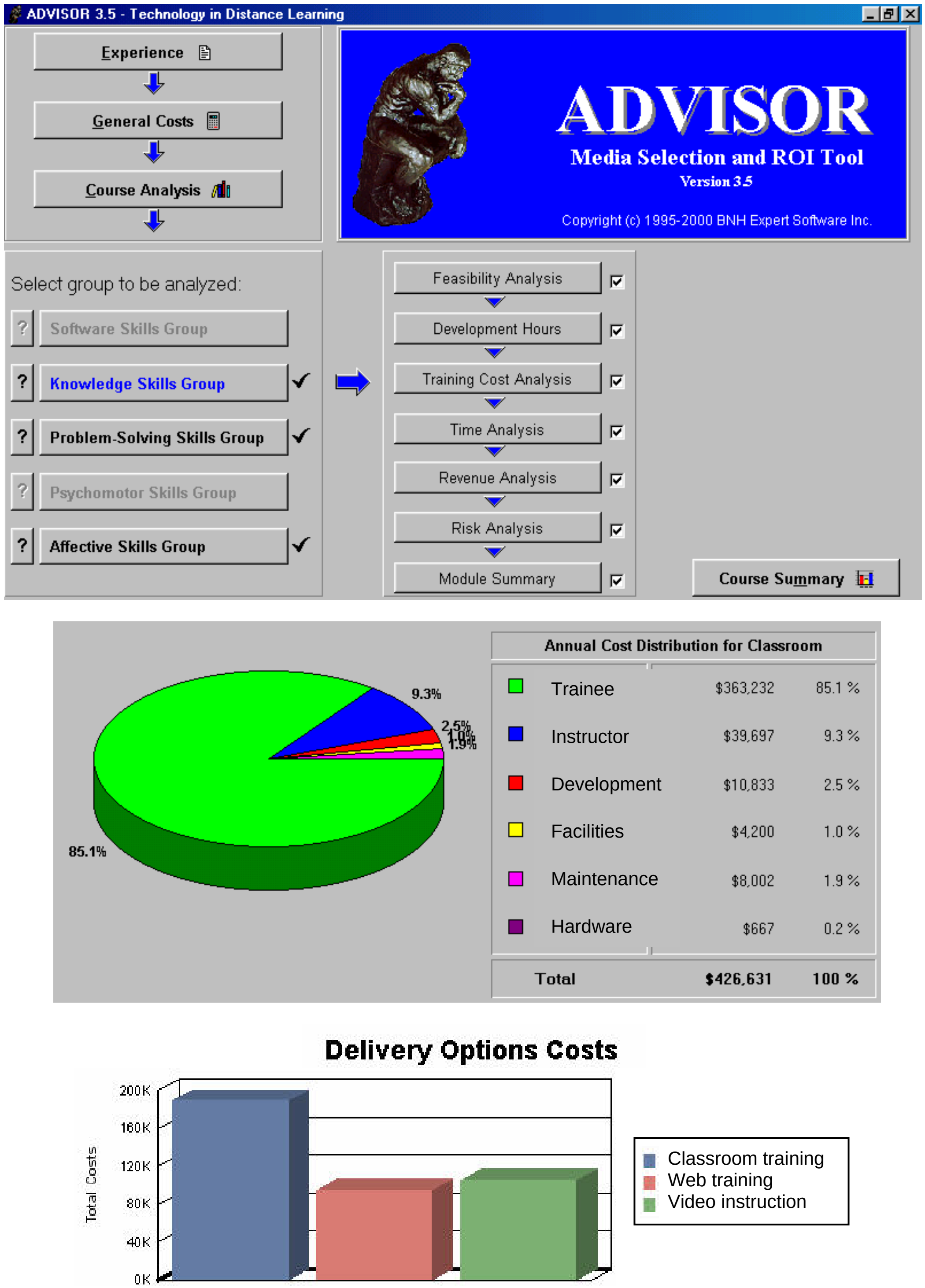


Figure C-1. Input and analysis screens from Advisor 3.5.

Risk and Trade-off Management

Assumptions Regarding Risk:

Conducts a cost and ROI analysis, given inputs of training strategies and delivery options.

Error Definitions/Taxonomy:
Training requirements based on the Difficulty, Importance, Frequency (DIF) model.

Risk Computation/Mitigation Methodology:
Addressed by cost and ROI analysis; training budgets and resources analysis. No mitigation methodology contained in system.

Traceability

Output Categories and Relationships to Acquisition Requirements:

- Training required
- Skill requirements by job
- Media
- Cost
- ROI analysis results
- Resource requirements
- Implementation requirements

Development Steps Supported:

- Training requirements analysis
- Identify re-training intervals
- Identify training costs, systems, ROI

How Tool Maps System Requirements to HSI Requirements:
System requirements map to training requirements through the Advisor module 1 requirements analysis. The content of this analysis should reflect system requirements arising from the SE requirements analysis.

Other Evaluation Criteria

Learning curve: Moderate

Reliability, Validity, and Platform Requirements:
System seems stable and has apparently be validated through numerous uses in many domains. Platform requirements include Intel processor, 32 MB RAM, 20 MB HD space, VGA or SVGA.

Analysis Utilities and Interface Support:
Interface support provided through GUI. Tech support available through BNH Software.

Availability, Cost, and Contact Information:
BNH Software, 4000 Steinberg Street
St. Laurent, QC, Canada H4R 2G7
Tel: (800)747-4010 (514)745-4010, Fax: (800)947-4010 (514)745-4011
E-mail: sales@bnhexpertsoft.com

C.2 C3TRACE

Description
Evaluate the effects of different personnel configurations and information technology on human performance as well as on overall system performance.

Tool/Method Content
Theoretical Assumptions:
Discrete event system based on micro-Saint. Makes the same theoretical assumptions.

HSI Domains Addressed:
- Personnel

Questions Addressed:
- Operator utilization
- Task completion results
- Message flow & success
- Utilization over time
- Operator performance
- Task summary/timeline

Content Modeled:
Operator, organizational performance and system effectiveness subject to operational conditions and constraints

Model Granularity:
Spans operator level to organizational level.

Communication
Form of Output, Terminology, and Taxonomic Conventions:
Unknown

Methods used to Integrate with SE and Other Environments:
Trade-off analysis of system alternatives. Potential integration with environment and system simulations. There are plans to integrate, at some level, with large-scale simulation environments and detailed cognitive modeling environments

Computer Language and Interface Support:
Proprietary language developed for IMPRINT. Interface for developing task networks, defining variables, parameterizing models.

Risk and Trade-off Management
Assumptions Regarding Risk:
Risk assumptions embedded in parameterization process.

Error Definitions/Taxonomy:
No explicit definition of any risk language.

Risk Computation/Mitigation Methodology:
Risk computations are implicit in the analyses of task networks and performance outcomes. Risk mitigation is accomplished through alternative designs and modifications of task dynamics

Traceability
Output Categories and Relationships to Acquisition Requirements:
Task performance times, task performance accuracies, system performance outcomes, errors

- System alternatives
- Effectiveness associated with varying strategies of work configurations

Development Steps Supported:

- Requirements analysis
- Analysis of alternatives

How Tool Maps System Requirements to HSI Requirements:
Reflected in the task networks developed for alternative system configurations.

Other Evaluation Criteria
Learning curve: Moderate
Reliability, Validity, and Platform Requirements:
No formal reliability or validity work yet. Validation is planned. Platform requirements include PC, windows, VGA, 100 MB hard drive space.

Analysis Utilities and Interface Support:
Task network definition, task parameterization, debugging

Availability, Cost, and Contact Information:
Patricia Kilduff
Army Research Lab
Aberdeen Proving Ground, MD
(410) 278-5874
pkilduff@arl.army.mil

C.3 Job Assessment Software System (JASS)

Description
Computer-based survey tool used to identify and rate the level of skills and abilities needed to perform jobs and job duties. Based on Fleishman's taxonomy.

Tool/Method Content
Theoretical Assumptions:
Fleishman taxonomy

HSI Domains Addressed:

- Training
- Personnel
- Manpower
- HFE

Questions Addressed:

- Skill requirements
- Skill levels
- Training retention intervals

Content Modeled:
Cognitive, perceptual, psycho-motor skills and abilities required for defined jobs

Model Granularity:
Individual skills by job

Communication
Form of Output, Terminology, and Taxonomic Conventions:
Scale scores written to an Access database, organized by skill. All definitions are based on Fleishman's 50 generic abilities.

Methods used to Integrate with SE and Other Environments:
Could be used with requirements analysis to estimate capacity for job accomplishment and training requirements for defined jobs

Computer Language and Interface Support:
No computer language. There is a GUI for survey creation and implementation of the skills/abilities index for each job (see Figure C-2).

Risk and Trade-off Management
Assumptions Regarding Risk:
Risk not addressed by this tool.

Error Definitions/Taxonomy:
Not addressed by this tool.

Risk Computation/Mitigation Methodology:
Not addressed by this tool.

Traceability
Output Categories and Relationships to Acquisition Requirements:
Indexes required skills & abilities for job assignments defined through system allocation activities.

Development Steps Supported:
Function analysis and allocation

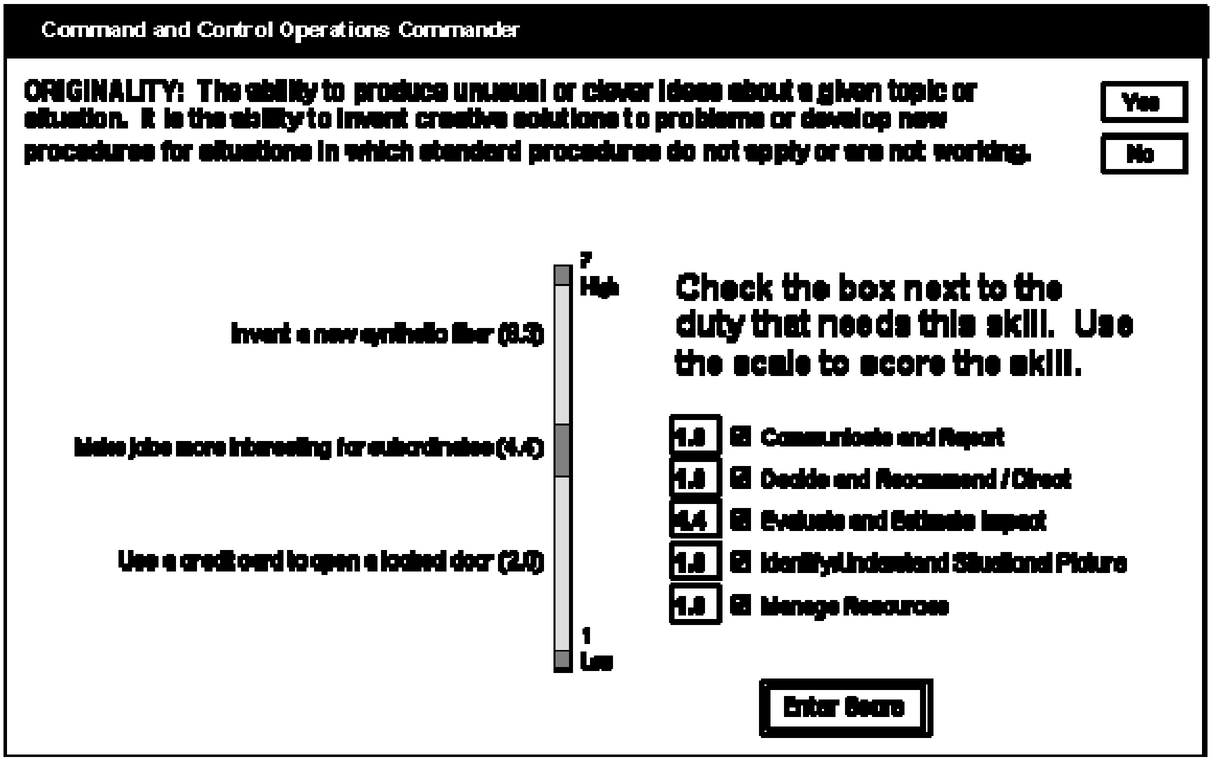


Figure C-2. JASS interface for identifying and rating skills and abilities needed to perform a job.

How Tool Maps System Requirements to HSI Requirements:
Relates requirements and allocation decisions to abilities and training requirements.

Other Evaluation Criteria
Learning curve: Moderate

Reliability, Validity, and Platform Requirements:
No information.

Analysis Utilities and Interface Support:

- GUI for development and implementation of surveys
- GUI for export into Access
- Output report displays mean and SD of scores for each skill

Availability, Cost, and Contact Information:
Barry Tillman
NASA Johnson Space Center
(281) 483-7131
barry.tillman-1@nasa.gov

C.4 Manpower Analysis and Prediction System (MAPS)

Description

MAPS is a simulation model developed at the Naval Surface Warfare Center, Carderock. It mimics the Navy Manpower Requirements System (NMRS) (using NMRS inputs as a baseline) but is simpler to use and provides valuable quick-response capability. Unlike NMRS, MAPS contains a billet-cost component, making it possible to predict costs. The costs in MAPS include all MPN and OMN cost of personnel – salaries, recruiting, training, housing, and medical expenses. It also creates linkages between the Required Operational Capability/ Projected Operational Environment (ROC/POE) and manpower requirements, which could prove useful to policymakers.

MAPS permits ship mission planners to evaluate billet and cost impacts before a final ROC is approved and published. Hardware design teams can research the manpower impact of proposals while in the concept phase.

Tool/Method Content

MAPS is a relational database based on functional data from existing ship classes. Within MAPS, this data has direct linkage to all applicable ROC elements. Billet calculations follow approved Navy standards. Various billet and cost reports are available from the system on demand. Because of the relational database configuration, rapid response to proposed changes is available. Changes to ROC, on-board equipment, operational stations, or ship compartments can be quickly assessed and processed. Selected functional areas can be isolated for in depth analysis. When specific billets are identified to the system, their relationship to functions, task, and ROC elements can be identified and evaluated. Multiple billet identities can be obtained, usually in real time and, if desired, complete with cost data.

The calculations performed by the system adhere to approved Navy standards for variables such as workweek, productivity allowance, make-ready / put away, etc.

HSI Domains Addressed:

This tool addresses the determination of manpower and personnel requirements.

Questions Addressed:

MAPS can identify associated personnel changes associated with system changes.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

The original MAPS program was developed in 1997-98. The latest version has been rewritten in Visual Basic 6.0 and the data structures have been modified to permit multiple baselines within the same application. MAPS is based on functional data from existing ship classes. Within MAPS, these data have direct linkages to all applicable ROC elements. Billet calculations follow approved Navy standards. Various billet and cost reports are available from the system on demand.

The following reports can be generated from the MAPS:
Summary Report: The Summary Report displays the manpower requirements calculated including rating, paygrade and Navy Enlisted Classification (NEC) and summarized by Division and Department. Cost information for the billets can also displayed and summarized. Cost data include No Cost Data, Total Cost, Direct Cost and Indirect Cost.
High Driver Report: The High Driver Report displays project calculated manpower requirements by rating and Division summed by the category of workload such as Preventive and Corrective Maintenance, Facilities Maintenance, Own Unit Support, Directed Requirements, and Watch Stations.
NEC Requirements Report: The purpose of this report is to identify those NEC's that are required within the project, along with the associated ratings and paygrades.
Project Task Report: The Project Task Report displays all project Workload Factors, e.g., Facilities Maintenance (FM), Preventive Maintenance (PM), Watch Stations (WS), etc., and all Task Identifications and Task Names within those Workload Factors.

Risk and Trade-off Management
This has yet to be identified.

Traceability
Development Steps Supported:

- Performance/workload/training estimation
- Personnel selection

Other Evaluation Criteria
Learning curve: Moderate

Analysis Utilities and Interface Support:
MAPS provides a complete interface to support all aspects of project creation, manpower specifications, and analysis. The screenshots presented below provide examples of MAPS project set-up and analysis selection support.

Availability, Cost, and Contact Information:

Multi-Media Communications, Inc
6610 Rockledge Drive, Suite 168
Bethesda, Maryland 20817
(301) 897-8777
postmaster@mmci.net

Mr. Bill Cheng
NSWC Carderock Division
West Bethesda, Maryland 20817
(301) 227-1926
chengh@navsea.navy.mil

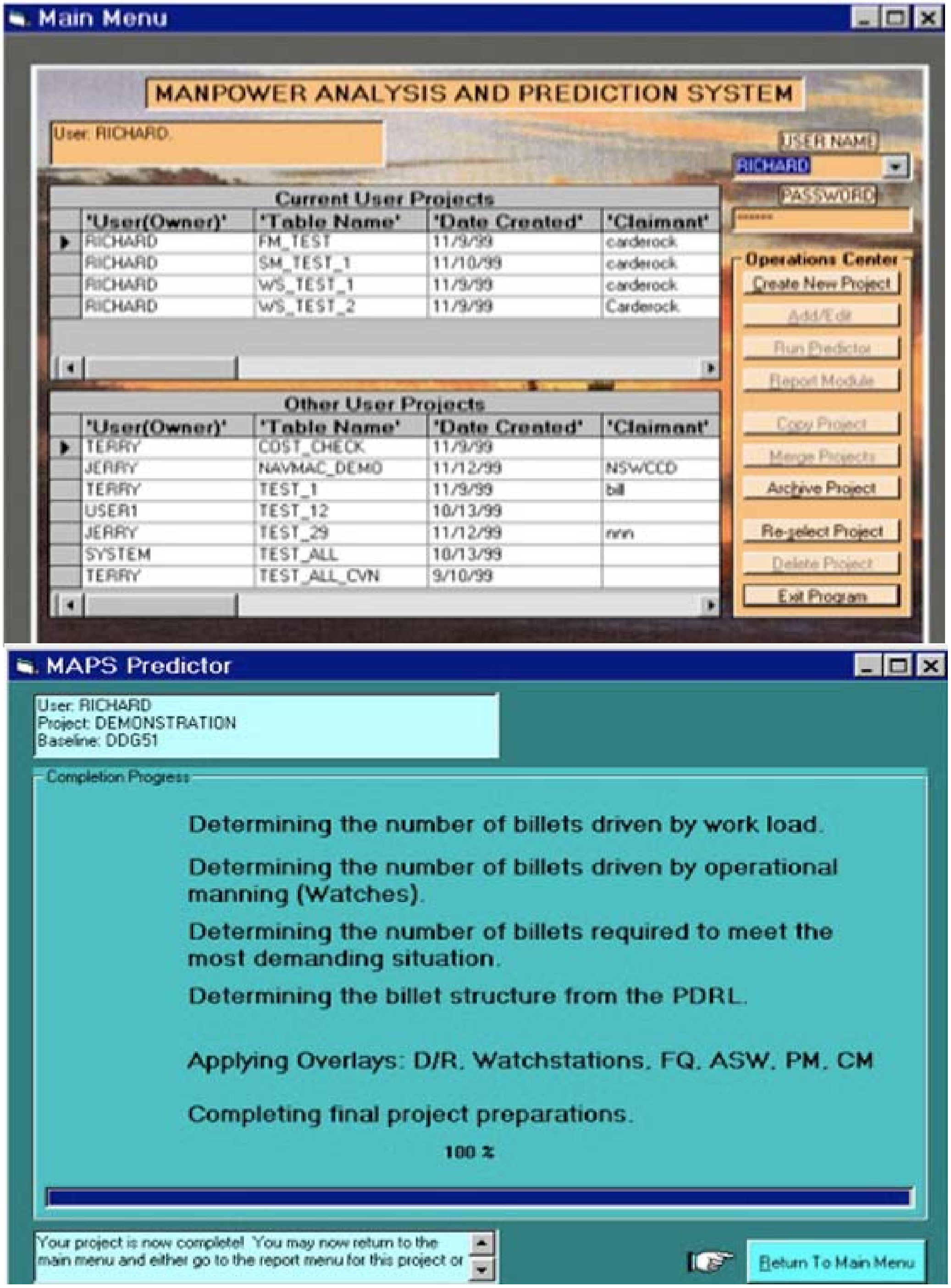


Figure C-3. Screens from Navy's manpower analysis and prediction system.

C.5 Navy Manpower Requirements System (NMRS)

Description
The Navy Manpower Requirements System (NMRS) is the process the Navy uses to determine the number of sailors it needs on board ships. This model computes billets from expected workload using certain assumptions about hours of work, paygrade, and workload allowances.

The NMRS is currently undergoing a major update. The Phase II system will be a Coast Guard owned and operated enterprise level application and will perhaps serve as a benchmark for the Navy's effort to update their MRD information system technologies.

Tool/Method Content
Theoretical Assumptions:

- Navy Standard Workweek,
- Staffing Tables from the Navy's *Standard Organization and Regulations Manual (SORM)*

HSI Domains Addressed:
This tool addresses the determination of manpower and personnel requirements.

Questions Addressed:

- How many personnel (minimum/maximum) are required to operate the system?
- What skills are required of the personnel?

Content Modeled:
In Phase II, The USCG is capturing the IT functional requirements for an MRD AIS based upon our knowledge and experience with other DOD methods/applications and practices and guidance from the leading Industrial Engineering Text (Maynard's).

A concurrent Analysis of Alternatives (AoA) will identify potential systems to assist with developing criterion for phase 3 (Development). Phase three may include Government-off-the-shelf technology, commercial-off-shelf technology, a combination, or development from scratch.

Model Granularity:
Low. Units of analysis are large work units and people assigned to complete work units.

Communication
Form of Output, Terminology, and Taxonomic Conventions:
NAV-MAC uses the NMRS generate the Ship Manpower Documents (SMDs), which give the number and type of billets needed to man a particular ship class. The SMDs are used to generate the Activity Manpower Documents (AMDs) which provide the same information but in more detail. They do not include recommendations for optimizing personnel or performance objectives.

Risk and Trade-off Management
There are a number of trade-offs associated with the system.

- The algorithm must be run by the Navy Manpower Analysis Center. The system is not opaque and the documentation is not readily accessible or processed.
- The NMRS billet-generation algorithm is based on assumptions that are decades old. The Navy Standard Workweek, paygrade tables, and workload allowances date from the 1960s and 1970s. As a result, they may be incompatible with today's technology, personnel policies, workforce, and business practices. The system, however, is in the midst of a large multi-phase overhaul to make the system user-friendly and perhaps web-enabled.
- The process does not adequately consider manning alternatives. In setting requirements, NAVMAC takes technology as given and uses decades-old assumptions about average hours of work and the paygrade mix of the crew. For example, it does not take into account any reductions in personnel gained by using technology.

Traceability
In its current form, the NMRS process is not transparent. The NMC works with the user to collect system inputs and NMC personnel use the NMRC to generate data on the user's behalf.

Development Steps Supported:

- Requirements analysis
- Performance/workload/training estimation
- Personnel selection

Other Evaluation Criteria
Learning curve: Moderate

Availability, Cost, and Contact Information:

CDR Troy S. Taylor (Troy.Taylor@navy.mil)
Coast Guard Human Resources Deepwater (CG-1B3)
CGLO to Navy Manpower Analysis Center (NAV-MAC)
Tel: 901-874-6233; Fax: 901-874-6448

This page intentionally left blank.

APPENDIX D. WORKLOAD AND SITUATION ASSESSMENT ANALYSIS AND DESIGN TOOLS

TABLE OF CONTENTS – APPENDIX D

D.1 CART/IMPRINT Pro

Description
Discrete event task network descriptions of mission outcomes, operator workload, taxon loadings.

Tool/Method Content
Theoretical Assumptions:
All complex activities can be expressed as task networks. System effectiveness is a function of task network dynamics. Human contribution to effectiveness affected by task goals and constraints, performance functions and parameters, and moderators.

HSI Domains Addressed:
- HFE
- Training
- Manpower
- Personnel

Questions Addressed:
- Task completion (Y/N)
- Task accuracy
- Task completion times
- VACP Workload
- Roles of performance multipliers

Content Modeled:
- Goals
- Procedures and tasks
- Behaviors
- Workload
- Performance multipliers
- Stressors
- Task variability

Model Granularity:
Moderate

Communication
Form of Output, Terminology, and Taxonomic Conventions:
- Task time
- Task accuracy
- All analysis done within the language of task networks
- Results presented in terms of times and accuracies
- Goals, functions, tasks
- Output related to system development cast in terms of system effectiveness
- All definitions are in terms of task networks, discrete event processes, human performance factors.

Methods used to Integrate with SE and Other Environments:

- Capture human component of system model
- Operationalize CTA
- Define human participation in CONOPS
- Communicate human component functionality to systems engineering
- Perform system effectiveness trade-offs with respect to human performance
- Model CWE for traceability
- HLA
- DIS

Computer Language and Interface Support:

C# used in latest version of MicroSaint engine supporting IMPRINT. Interface support includes:

- GUI support of task network construction
- Form-based support for task specifications, workload, crew features, taxons, decision paths

Risk and Trade-off Management

Assumptions Regarding Risk:

No special assumptions regarding risk. No adherence to any theoretical risk model.

Error Definitions/Taxonomy:

Modeler-defined

Risk Computation/Mitigation Methodology:

Stochastic outcomes based on modeler-defined assumptions and structure/specification of the task network under study.

Traceability

Output Categories and Relationships to Acquisition Requirements:

- Behaviors
- Time
- Accuracy
- Relates human performance considerations to overall system effectiveness.

Development Steps Supported:

- Cognitive work analysis
- System modeling & requirements analysis
- Risk analysis and management
- Workflow concept development

How Tool Maps System Requirements to HSI Requirements:

Allows modeler to represent relationships between system requirements and HFE, training, manpower, environment.

Other Evaluation Criteria

Learning curve: Moderate

Reliability, Validity, and Platform Requirements:

System is stable and considered reliable in its output. Verification testing of each version at Army Research Labs. Underlying structure passed VV&A in 1995.

Platform requirements include Windows XP or 2000, 512 MB RAM, 10 GB hard drive space 1280x1024 32 bit color display, Windows Installer 3.1

Analysis Utilities and Interface Support:

The CART/IMPRINT Pro/MicroSAINT family has extensive user and interface support extending across all aspects of model development, specification/parameterization and analysis. Figure D-1, which shows part of an analysis of an Army tank crew, addresses these human performance modeling stages. The upper right screen shows a task network in development. A specification interface (not shown) enables modelers to specify model parameters (such as time on task, workload, etc.). The middle screen shows the workload of one crew member in a tabular format. The final screen demonstrates a workload analysis of all four crew members.

Availability, Cost, and Contact Information:

Free but limited to US government agencies, US industry and universities with government contracts.

Charneta Samms
Army Research Lab
(410) 278-5877
imprint-info@arl.army.mil

Figure D-1. IMPRINT Pro model development and analysis screens.

D.2 Designer's Situation Awareness Tool (DeSAT)

Description

The Designer's Situation Awareness Toolkit (DeSAT) aids designers in creating systems that support situation awareness (SA). The SA-Oriented design approach involves three phases: an analysis of SA requirements, the application of SA-Oriented design principles, and the measurement of SA during design evaluation. DeSAT provides support to the designer for each phase of the SA-Oriented design process through both tutorials and application specific tools. The DeSAT tool suite includes several tools that support various phases of design. These include:

(1) Tools for SA requirements analysis. These tools; known as the Goal-directed Task Analysis (GDTA) tool, GDTA checklist tool and GDTA tutorial; support early design stages. The GDTA tool helps analysts create graphic representations of the task analyses done in the initial stages of a design effort by documenting operator goals, decisions and situation awareness requirements. The checklist tool helps analysts assess designs to ensure that requirements are met, as well creating a list of requirements missing from the design.

(2) Tools for situation awareness-based design. These include design guidelines tools consisting of checklists and design principles and a situation awareness-oriented design tutorial describing 50 design principles.

(3) Situation awareness measurement tools based on the SA Global Assessment Technique (SAGAT). SAGAT contains support for SA query creation, administration of the survey and results; and formatting support for export to statistical packages.

Tool/Method Content

Theoretical Assumptions:

SA consists of an awareness of what is happening around you and what implications information has for the future behavior of a system. There are typically thought to be 3 levels of SA: (1) perceiving critical factors in the environment, (2) understanding what those factors mean, particularly when integrated together in relation to the operator's goals, and (3) understanding what will happen with the system in the near future.

HSI Domains Addressed:

- HFE
- Training

The DeSAT is designed to address HSI domains that are sensitive to an awareness of information and situational dynamics, team processes, functional meaning with respect to task requirements and decision making. These include the domains of human factors engineering, training and, potentially, manpower and personnel in a derivative manner.

Questions Addressed:

- Information structuring, managing uncertainty & complexity
- Decision support
- Training requirements and estimates of training times
- Visual & Auditory displays
- Team operations
- Automation, controls, alarms and alerts
- Controls

Content Modeled:

This method makes assumptions about task structure and information dynamics, and attempts to identify and measure levels of awareness and understanding about these attributes. At level 1 SA the content modeled by the DeSAT system consists of domain specific elements such as aircraft type, heading, altitude and flight plan. Level 2 content consists of descriptions of the meaning of the level 1 elements, with respect to the goals that an operator has. Level 3 content is made up of predictions of "system" behavior that an operator generates based on the information at the lower levels. Because the tool relies on the existence of a goal-directed task analysis for the identification and measurement of SA, goals also must be explicitly modeled.

Model Granularity:

Processes and information can be described to as low a level as desired by analysts. However, levels of granularity are practically limited in that the theory is descriptive and non-quantitative.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Output comes in the form of design recommendations and specifications based on DeSAT analysis during the early portions of design. Terminology is that of standard situation analysis research. There are no specific taxonomic conventions with DeSAT, other than those associated with the three descriptive levels of SA theory.

Methods used to Integrate with SE and Other Environments:

There do not seem to be any formalized methods, contained within DeSAT, that can be used to integrate the methodology or tool output with environments in the systems engineering domain. In the absence of such methods, it is left up to the SA-oriented analyst to integrate DeSAT outputs into the overall system design process.

Computer Language and Interface Support:

The system requires installation of the MySQL database and WxPython GUI programming toolkit.

Risk and Trade-off Management

Assumptions Regarding Risk:

There are no specific facilities for defining or analyzing errors in DeSAT. Some attention to error is contained in the design principles contained in the design guidelines tool. These, however, are general rules of thumb for design rather than focused error or risk analysis tools.

Error Definitions/Taxonomy:

No specific error definitions or taxonomy.

Risk Computation/Mitigation Methodology:

None.

Traceability

The DeSAT system provides facilities that allow assessment of aspects of designs that satisfy requirements, as well as a method of documenting what requirements are missing from a design. This is done through a checklist mechanism contained in the GDTA checklist tool. Other than this checklist enumeration there seems to be no formal mechanism for design traceability. Furthermore, the satisfaction of requirements provided by the GDTA checklist tool seems to address only those "requirements" that are specific to SA. This limits the utility of the tool with respect to broader system requirements.

The DeSAT supports several development steps, although only partially. These include requirements analysis; function analysis and allocation; task design; interface and team development; and performance, workload and training estimation. The tool also can contribute to training development and performance assurance.

There are no explicit methods for mapping system requirements to HSI requirements. The DeSAT does not address any HSI domain other than HFE and training.

Other Evaluation Criteria

Learning curve: Moderate

Reliability, Validity, and Platform Requirements:

The SAGAT portion of DeSAT has been validated across a wide variety of analytical and design efforts. DeSAT requires 450 MB of memory for a full installation. The system runs on Windows platforms. MySQL and WxPython are required.

Analysis Utilities and Interface Support:

A comprehensive user manual is included with the system along with tutorial information for the specific modules. There is no mention of online or technical support on the tool website. Interface support is provided by GUI facilities for each of the tool components.

Availability, Cost, and Contact Information:

Cost depends on the number of copies purchased and ranges from $1400 for 5 or more individual copies to $20,000 for a site license. Contact information is shown below:
http://www.satechnologies.com/products/

D.3 Cognitive Reliability and Error Analysis Method (CREAM)

Description

A comprehensive approach to Human Reliability Analysis (HRA) that includes a method to conduct an analysis that can be used to both search for the causes of errors and predict performance, an error classification scheme that consists of a number of groups that describe person-related, technology-related, and organization-related errors, and an underlying model of operator cognition called COCOM (Contextual Control Model) that describes how actions are chosen based on the result of the interaction between competence and context.

Tool/Method Content

Theoretical Assumptions:

Human work can be characterized by a scale of "doing" to "thinking." Some tasks, such as manual skills and following a procedure, require much "doing" and little "thinking," while others, such as diagnosis, planning, and problem solving, require much "thinking" and little "doing." The development of modern technology has changed the nature of human work from being mostly manual skills to being mostly knowledge intensive functions (i.e., cognitive tasks). In present-day industrial environments the amount of "thinking" is increased while the amount of " doing" is reduced. This state of affairs has consequences for both system design and reliability analysis. In system design, for instance, conventional ergonomic aspects must be replaced by cognitive ergonomics. Similarly, in risk assessment and reliability analysis, first generation HRA must be replaced by a second generation, context-dependent cognitive reliability analysis.

HSI Domains Addressed:
This tool addresses the HFE and safety domains.

Questions Addressed:
1. Identify those parts of the work, as tasks or actions, that require or depend on human cognition, and which therefore may be affected by variations in cognitive reliability,
2. Determine the conditions under which the reliability of cognition may be reduced, and where therefore these tasks or actions may constitute a source of risk,
3. Provide an appraisal of the consequences of human performance on system safety which can be used in a PRA/PSA, and
4. Develop and specify modifications that improve these conditions, hence serve to increase the reliability of cognition and reduce the risk.

Content Modeled:
Errors, error probabilities, probabilities of system failures and relationships between these.

Model Granularity:
Variable. Errors, in particular, can be modeled at whatever level of granularity desired by analysts.

Communication
Form of Output, Terminology, and Taxonomic Conventions:
The primary form of output from a CREAM analysis is a qualitative and-or quantitative description of errors, causes and the relationships between the two. Error mitigation strategies normally take the form of recommendations for design changes within the context of the cognitive model underlying this method (Hollnagel, E. (1997). Context, cognition and control. In Y. Waern, (Ed.), *Cooperation in process management: Cognition and information technology*. London: Taylor and Francis.). See the section on Risk and Trade-off Management below for terminology and taxonomic conventions.

Methods used to Integrate with SE and Other Environments:
No specific methods are described for integrating this information with other system engineering processes or environments. However, this methodology is sufficiently robust that taking input and providing output for other system engineering activities should be straightforward. Specific integration methods to be used should be developed by the individual development team, tailored to the needs of each project.

Computer Language and Interface Support:
No specific computer language or interface support has been developed for this method. However, see the reference to an early CREAM analysis support system in the "Analysis Utilities and Interface Support" section below.

Risk and Trade-off Management

Assumptions Regarding Risk:

This approach assumes three major categories of causes that can lead to a loss of human-machine reliability, each category containing several specific manifestations as shown below:

- Person-related causes
  - Causes arising from specific cognitive functions
  - Causes based on temporary operator states
  - Causes based on permanent states of the operator
- Technology-related causes
  - Equipment malfunctions
  - Causes based on procedures
  - Causes based on temporary interactions between human and machine
  - Causes based on permanent interactions between human and machine (design flaws)
- Organization-related causes
  - Communication
  - Organization
  - Training
  - Ambient conditions
  - Working conditions

Error Definitions/Taxonomy:

Similar to causes, errors are organized into a quasi-hierarchical set of categories:

- Actions taken at the wrong time
  - Timing errors
  - Duration errors
- Actions of the wrong type
  - Force errors
  - Distance/magnitude errors
  - Speed errors
  - Direction errors
- Actions directed at the wrong object
  - Neighbor errors
  - Similar object errors
  - Unrelated object errors
- Actions in the wrong place
  - Omission errors
  - Jumping forward errors
  - Jumping backward errors
  - Repetition errors
  - Reversal errors

Risk Computation/Mitigation Methodology:

Risk mitigation strategies, by and large, consist of identifying error types, causes and probabilities that causes of each type will lead to errors of each type. This is carried out through some combination of retrospective analysis, qualitative and quantitative performance prediction. Designers then eliminate the problems through design changes.

Traceability

Output Categories and Relationships to Acquisition Requirements:

CREAM outputs errors, error probabilities and system failure probabilities associated with various error categories. These should be used to inform and constrain the specification of acquisition requirements. In cases where CREAM analysis indicates catastrophic system events, the associated acquisition requirements should be re-written to mitigate the events.

Development Steps Supported:

- Function analysis
- Function allocation
- Task design
- Interface and team development
- Performance/workload/training estimation
- Requirements review
- Training development
- Performance assurance

How Tool Maps System Requirements to HSI Requirements:

The error analysis provided by CREAM will produce data that can be mapped to system requirements in the form of constraints on system development, taking account of human reliability and error/safety information in the evolving system.

Other Evaluation Criteria

Learning curve: Moderate

Reliability, Validity, and Platform Requirements:

No systematic validity or reliability studies have been carried out, to date, for this tool. Most of the current work addressing the CREAM methodology is concerned with (1) applications of CREAM to issues of human reliability for specific systems or (2) research aimed at extending the theory and-or classification system of the tool. Studies of tool validity and-or reliability likely will be delayed by some time.

The CREAM tool is a methodology and, as such, has no platform requirements associated with it. The only existing software instantiation of CREAM is platform-independent.

Analysis Utilities and Interface Support:

Analysis utilities are provided within the CREAM methodology, as outlined in Hollnagel (1998). There is limited interface support at this time. A prototype software support system has been developed at the University of Illinois. This should, however, be considered early beta-level support. See http://www.ews.uiuc.edu/~serwy/cream/v0.6beta/ for the current version of the CREAM Navigator.

Availability, Cost, and Contact Information:
Hollnagel, E. Cognitive Reliability and Error Analysis Method. NY: Elsevier Science Inc., 1998.

D.4 Technique for Human Error Rate Prediction (THERP)

Description
THERP is a technique for human error rate prediction based on probabilistic risk analysis and fault tree task decomposition methods. It will allow analysts to predict human error probabilities and to evaluate the degradation of human-computer systems likely to be caused by human errors alone or in connection with equipment malfunctioning, operational procedures or other system and human characteristics that influence complex system behavior.

Tool/Method Content
Theoretical Assumptions:
This method assumes that the success or failure of operator actions are equivalent to that of a system or subsystem. Thus, operator reliability can be assessed in the same way as the reliability of non-human components. This is done by (1) identifying system functions that can be influenced by human errors, (2) decomposing human tasks through detailed task analysis, (3) estimating error probabilities for each task using a combination of expert judgment and data available on the effects of causal and moderating factors, (4) estimating the effects of the errors compiled in the task analysis on system failure.

HSI Domains Addressed:
THERP is primarily focused on the safety and HFE domains.

Questions Addressed:
Two major categories addressed by this tool are (1) the kinds and probabilities of errors associated with tasks that will be carried out by human operators and (2) the probabilities that the errors identified will lead to system failures, what the nature of the failures will be, and what mitigating strategies can be developed to prevent or recover from the errors.

Content Modeled:
THERP allows analysts and designers to consider tasks, error categories associated with tasks, probabilities of error occurrence for each task, and probabilities that errors in each category will lead to system failures.

Model Granularity:
Granularity will be determined by the analyst through the task decomposition, error definition and the manner in which errors are related to system failures. The tool situates analysis at the level of probabilities.

Communication
Form of Output, Terminology, and Taxonomic Conventions:
Output is in the form of probabilities of error and probabilities of system failures resulting from errors. Terminology and taxonomic conventions are largely the choice of the analyst, although much of the error taxonomy often is derived from Reason's (1990) error classification.

Methods used to Integrate with SE and Other Environments:

The primary method of integration is the existence of system failure probabilities based on the error analysis. There are no integration methods inherent in the tool itself. The output of a THERP analysis can serve as input to systems engineering tools in the safety and workstation design domains.

Computer Language and Interface Support:

Not applicable.

Risk and Trade-off Management

Assumptions Regarding Risk:

Risk is defined as a function of the probabilities of error occurrence and system failures as a result of the occurrence of errors. Risk will be expressed probabilistically. These often will be used to support a hazard analysis.

Error Definitions/Taxonomy:

Any error taxonomy can be defined for use in a THERP analysis. Common taxonomies include Reason (1990), Hollnagel (1998) and Endsley (1999). Error taxonomies, and relationships between errors, typically are organized into tabular and-or “fault tree” formats. Examples of these formats, for small fragments of an analysis, are shown below.

Table D-1. THERP error probability estimation.

Item	Checking Operation	Human Error Probability	Error Factor
1	Checking routing tasks using written manuals	0.1	5
2	Same as above but without manual	0.2	5
3	Special short-term, one-of-a-kind checking with alerting	0.05	5

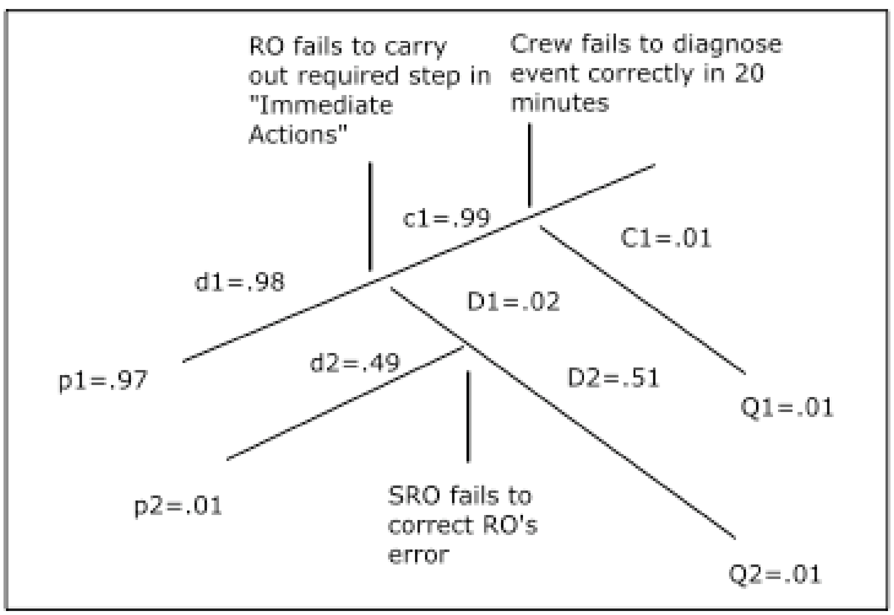


Figure D-2. THERP fault tree.

Risk Computation/Mitigation Methodology:

The THERP methodology involves five steps:

1. Define the system or process. This involves describing the system goals and functions and the consequences of not achieving them. It also requires identifying mission, personnel, and hardware/software characteristics.
2. Identify and list all the human operations performed and their relationships to the system or process tasks and functions. This requires an analysis of all operator and maintainer tasks.
3. Predict error rates for each human operation or group of operations. Errors likely to be made in each task or subtask must be identified. Errors that are not significant in terms of system operation are ignored. This step includes estimating the likelihood of each error occurring and the likelihood of an error not being detected.
4. Determine the effect of human errors on the system or process, including the consequences of the error not being detected. This requires the development of event trees. The left limbs of the event trees are success paths; the right limbs are failure paths. Probabilities are assigned to each path. The tree reflects the effects of task dependence. The relative effects of performance-shaping factors, e.g., stress and experience, are estimated.
5. Develop and recommend changes that will reduce the system or process failure rate. The recommended changes can be developed using sensitivity analyses, in which factors and values are varied and effects monitored. THERP makes no assumptions about the dependence or independence of personnel behaviors. Data are taken from available sources.

A key aspect of THERP is the determination of the probability that an error or class of errors will result in a system or process failure. This probability is assigned a value F_i. Branching trees are constructed to determine the paths to success and failure. The probability that an error will occur is given by P_i. F_iP_i is the joint probability that an error will occur and that the error will lead to system failure. 1- F_iP_i is the probability that an operation will be performed that does not lead to system failure. The probability that a class of errors will lead to system failure is given by:

$$Q_i = 1 - (1 - F_iP_i)^{ni}$$

Traceability

Output Categories and Relationships to Acquisition Requirements:

Output categories include error probabilities for tasks of interest, probabilities of system failures, joint probabilities that errors for selected tasks will cause certain system failures. This information will be useful in developing system requirements and in ORD development.

Development Steps Supported:

- Function analysis
- Task design
- Performance assurance

How Tool Maps System Requirements to HSI Requirements:

The error analysis carried out in THERP will contribute to relating overall system requirements and task organization to safety concerns involving human operators.

Other Evaluation Criteria
Learning curve: Moderate

Reliability, Validity, and Platform Requirements:
THERP is one of the most mature tools available for human reliability analysis. As such, it has been thoroughly validated across many operational domains. Its reliability has been demonstrated to be high.

There are no specific platform requirements for the use of THERP. Since the tool is an analytical method, rather than a specific software tool, the only platform requirements include a tool that will support task decomposition and a statistical analysis tool that will support estimation of error probabilities and system failures.

Analysis Utilities and Interface Support:
None.

Availability, Cost, and Contact Information:
References on THERP methodology are widely available:

Endsley, M.R. (1999). Situation Awareness and Human Error: Designing to Support Human Performance. Proceedings of the High Consequence Systems Surety Conference, Albuquerque.

Hollnagel, E. (1998). Cognitive Reliability and Error Analysis Method. Oxford, UK: Elsevier.

LaSala, K.P., RAC Publication. A Practical Guide to Developing Reliable Human- Machine Systems and Processes, January 2002.

Reason, J.T. (1990). Human Error. New York: Cambridge University Press.

Swain, A.D., “THERP,” SC-R-64-1338, Sandia National Laboratories, Albuquerque, NM, August 1964.

(This page intentionally left blank.)

APPENDIX E. WORKSTATION AND COCKPIT DESIGN TOOLS

TABLE OF CONTENTS – APPENDIX E

E.1 3D Static Strength Prediction Program ™ (3DSSPP) Version 5.0

Description
This is a job design/evaluation tool that can provide a wide variety of information and analyses ranging from predicted low back compression forces to population strength capability information.

Tool/Method Content
Theoretical Assumptions:
3DSSPP is most useful in the analysis of "slow" movements used in manual material handling tasks since the biomechanical computations assume that the effects of acceleration and momentum are negligible.

HSI Domains Addressed:
This tool addresses the safety domain; specifically Workstation Design, Physical Ergonomics, Manual Material Handling, and Task Analysis.

Questions Addressed:
- How much compression does the back feel?
- Where do the maximum forces occur during the task?
- What percentage of people are capable of performing this task?

Content Modeled:
- Tasks and task sequences

Model Granularity:
It is easy to enter coarse data. However, it is also possible to provide more detailed inputs (see below). The generated reports provide quite a bit of detail.

Communication
Form of Output, Terminology, and Taxonomic Conventions:
3DSSPP presents a number of reports including:
- Task Input Summary that provides information regarding body segment angles, hand locations, and hand force magnitude and direction,
- Analysis Summary which summarizes hand forces, L5/S1 disc compression, percent capable, balance, and coefficient of friction,
- Reports of Anthropometry, Posture, Joint Locations and Moments, and Strength Capabilities.

Methods used to Integrate with SE and Other Environments:
This software integrates with the Energy Expenditure Prediction Program (EEPP).

Computer Language and Interface Support:
Computer language is not an issue with these proprietary and self-contained tools. The tool set contains a full range of interfaces for data entry, analysis and reporting.

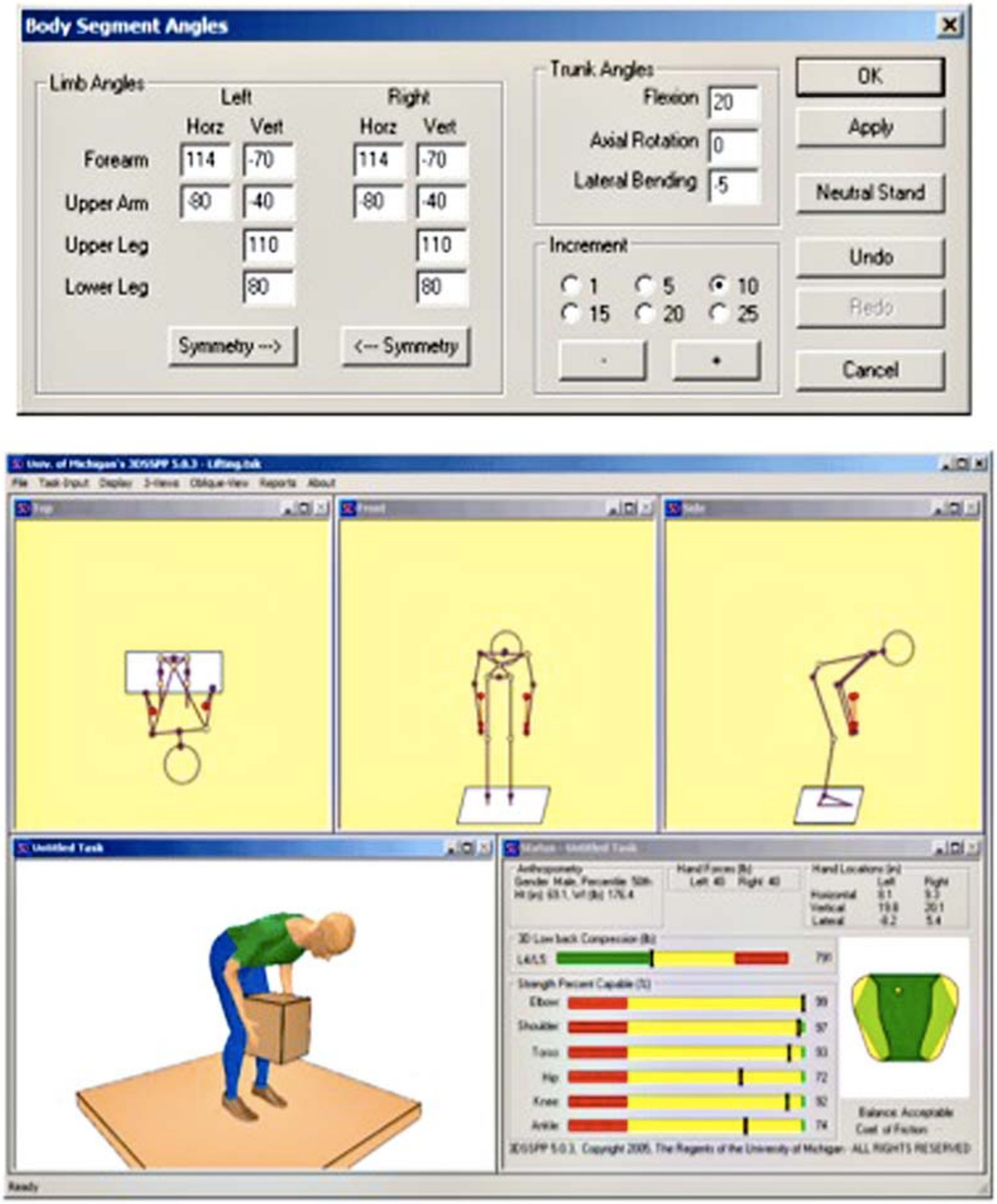


Figure E-1. Screens from 3D Static Strength Prediction Program.

Risk and Trade-off Management

Assumptions Regarding Risk:

This tool is to be used in conjunction with other analysis methods and should not be use alone to determine risk. Analysis summaries can be provided in either graphical format (as shown in bottom right screen in Figure E-1) or tabular format.

Traceability

The 3DSSPP identifies and quantifies the physical limits of a design.

Development Steps Supported:

- Function analysis
- Task design
- Performance/workload/training estimation

Other Evaluation Criteria
Learning curve: Moderate
Reliability, Validity, and Platform Requirements:
Platform requirements include Windows 2000 or XP with a minimum 128 MB RAM and 20 MB hard disk space.

Availability, Cost, and Contact Information:
The cost for a single 3DSSPP license is $1,495. Combined with the EEPP, a single license is $1,900. There are discount for larger quantities.
Distributed by:
University of Michigan Office of Technology Transfer
Center for Ergonomics
University of Michigan
1205 Beal Avenue, Ann Arbor, MI 48109-2117

E.2 Energy Expenditure Prediction Program™ (EEPP)

Description
This tool predicts metabolic energy expenditure rates by summing up the energy requirements of small, well-defined work tasks that comprise the entire job. It identifies specific work tasks that contribute heavily to an overall high job energy expenditure rate, which facilitates job redesign activities. The EEPP is useful in designing new jobs, comparing one job to another, and improving an existing job by identifying the particular tasks that require excess energy expenditure.

Tool/Method Content
Theoretical Assumptions:
This tool assumes that a job can be divided into simple tasks and that the average metabolic energy rate of the job can be predicted by knowing the energy expenditure of the simple tasks and the time duration of the task.

HSI Domains Addressed:

- Safety
- Habitability
- Manpower

Questions Addressed:

- Is the job/task acceptable?
- How can this job be redesigned?

Content Modeled:

- Tasks and task sequences. This information is entered into tabular formats provided by the system, as shown in Figure E-2. Detailed information for both tasks and task elements can be provided.

Model Granularity:

The model relies heavily on the quality of the task breakdown and input in to the analysis. The analysis is specific to the gender and body weight inputs to the model.

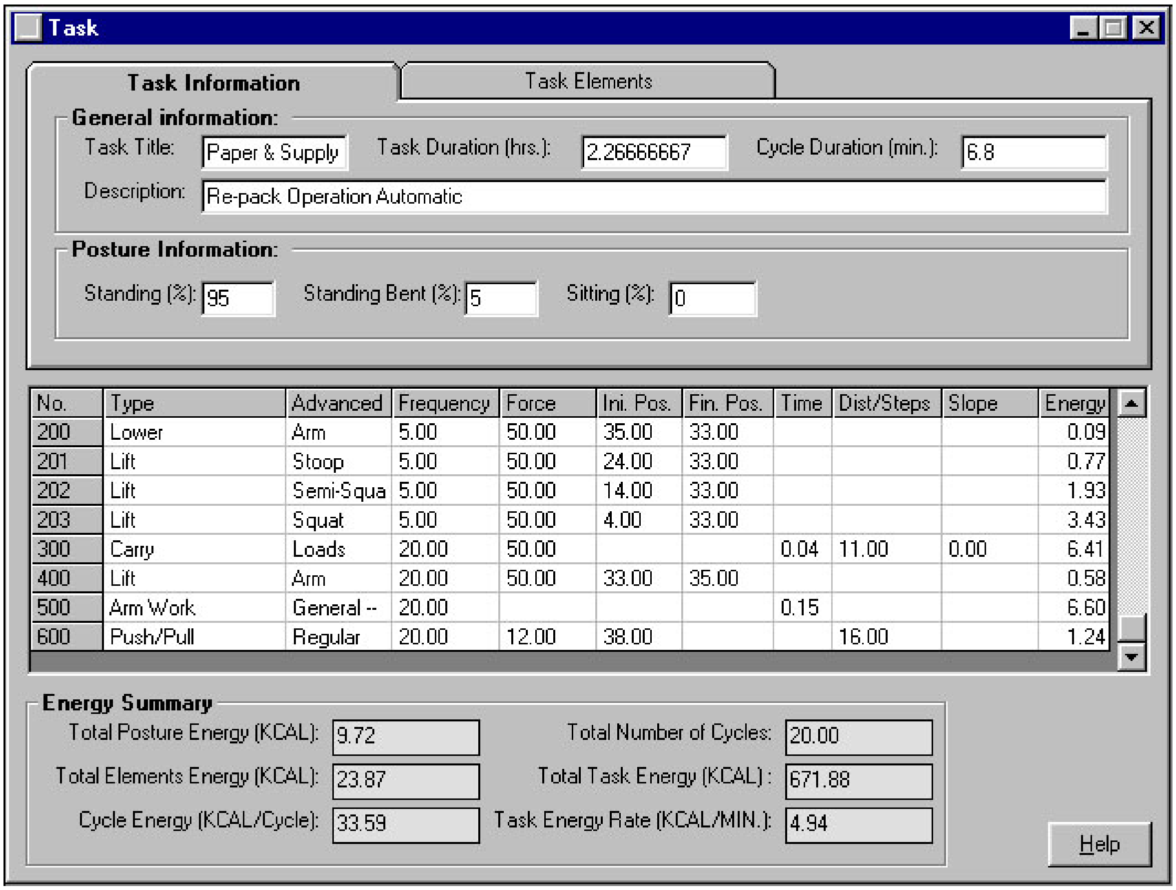


Figure E-2. Analyzing a manual task design with the Energy Expenditure Prediction Program. (from www.engin.umich.edu/dept/ioe/ENGEXP/)

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Graphical outputs suitable for reports are standard in this software package.

Methods used to Integrate with SE and Other Environments:

This software integrates with the 3D Static Strength Prediction Program

Computer Language and Interface Support:

Computer language is not an issue with these proprietary and self-contained tools. The tool set contains a full range of interfaces for data entry, analysis and reporting.

Risk and Trade-off Management
Assumptions Regarding Risk:
This tool is to be used in conjunction with other analysis methods and should not be use alone to determine risk.

Traceability
The EEPP identifies and quantifies the physical limits of a design.

Development Steps Supported:
- Function analysis
- Task design
- Performance/workload/training estimation

Other Evaluation Criteria
Learning curve: Moderate
Reliability, Validity, and Platform Requirements:
Platform requirements include Windows 2000 or XP with a minimum 32 MB RAM and 1 MB hard disk space.

Availability, Cost, and Contact Information:
The cost for a single EEPP license is $695. Combined with the 3DSSPP, a single license is $1,900. There are discount for larger quantities.

Distributed by:
University of Michigan Office of Technology Transfer
Center for Ergonomics
University of Michigan
1205 Beal Avenue, Ann Arbor, MI 48109-2117

E.3 LOCATE

Description
Computer-aided tool for analyzing communication in visual, auditory, tactile and movement domains in multi-operator machine workspace layout problems. Computes link strength for human-human, human-machine and machine-machine combinations. Rolls these up into a single cost function. Can be used to form matrices of component costs.

Tool/Method Content
Theoretical Assumptions:
None

HSI Domains Addressed:
- HFE

Questions Addressed:
Human-human, human-machine, machine-machine interface costs and effectiveness.

Content Modeled:
Communication paths between system components.

Model Granularity:
Individual human and machine components.

Communication
Form of Output, Terminology, and Taxonomic Conventions:
Layouts of multi-operator-machine workspaces. Can also produce panel design layouts. Output characterized in terms of components, links, communication channels, positions, angles.

Methods used to Integrate with SE and Other Environments:
Addresses workstation layout design, allocation, and system effectiveness.

Computer Language and Interface Support:
Uses a proprietary language. Contains a GUI for entering all data and conducting analyses. Information is entered via a tool palette and work area. Following entry of specifications the work environment can be either manipulated manually by the analyst to evaluate workstation layouts and communication efficiencies or analysts can choose to allow the system to optimize these.

Risk and Trade-off Management
Assumptions Regarding Risk:
Risk increases as an inverse function of the cost score computed by LOCATE's AIM algorithm.

Error Definitions/Taxonomy:
Described solely in terms of cost functions associated with communication in various workspace layouts

Risk Computation/Mitigation Methodology:
Uses optimization and cost function for risk computation. Mitigations expressed as reductions in cost.

Traceability
Output Categories and Relationships to Acquisition Requirements:
Single value of the cost associated with a particular configuration and incremental costs associated with each pairwise relationship between workstations in each communication domain. Seems to provide a good way to evaluate workstation layout alternatives.

Development Steps Supported:
Allocation, workspace layout, manpower estimates, workload estimates

How Tool Maps System Requirements to HSI Requirements:
Can inform design team about habitability, workload, system effectiveness as a function of workspace layout

Other Evaluation Criteria
Learning curve: Moderate

Reliability, Validity, and Platform Requirements:
Has been validity tested, system is stable. Platform requirements include Windows or Mac OS-X.

Analysis Utilities and Interface Support:
- Has complete interface support through GUI
- Analysis utilities offered through system GUI and AIM algorithm

Availability, Cost, and Contact Information:
http://www.sosproducts.ca/LocateVideoQT.html

E.4 Liberty Mutual Tables

Description
These are loss prevention tables that provide guidance on the percentage of the male and female population able to safely complete a manual material handling task. It recommends that tasks be able to be performed by 75% of the female population.

Theoretical Assumptions:
The tables focus on lifting aspects that contribute to a high risk of low back injury. The data is based on psychophysical methodologies that include measuring oxygen consumption, heart rate, and anthropometric characteristics.

HSI Domains Addressed:
This tool addresses the safety domain. More specifically, Workstation Design, Physical Ergonomics, and Manual Material Handling.

Questions Addressed:
- What population can safely complete this lift/push/pull/carry?
- How can the load or type of handling be modified to make it safe?

Content Modeled:
- Object weight
- Hand distance
- Initial/final hand height

Model Granularity:
There are tables for 20 different handling tasks (see example below). They are gender/load/parameter specific. For a greater numbers of input variables, and therefore greater detail, use the NIOSH lift equation instead. But since the NIOSH equation has many limitations on its application, the Liberty Mutual tables provide adequate detail.

Communication
Form of Output, Terminology, and Taxonomic Conventions:
The output of these lookup tables is the percentage of a gender-specific population that can perform the task.

Risk and Trade-off Management

Assumptions Regarding Risk:

Effective use of these tables requires basic level training in ergonomics and manual handling task analysis and evaluation. Users should be knowledgeable of biomechanical, physiological and psychophysical workload criteria and evaluation methods.

Traceability

The analysis can be conducted before and after an intervention to demonstrate that the intervention has worked to accommodate a larger percentage of the population.

Development Steps Supported:

- Function analysis
- Task design
- Performance/workload/training estimation

Other Evaluation Criteria

Learning curve: Shallow

Availability, Cost, and Contact Information:

Snook, SH and Ciriello, VM. "The design of manual handling tasks: revised tables of maximum acceptable weights and forces." *Ergonomics.* 34:9 1197-1213, 1991.
http://libertymmhtables.libertymutual.com/CM_LMTablesWeb/pdf/LibertyMutualTables.pdf
Liberty Mutual (2004). Manual Materials Handling Guidelines.

Table E-1. Liberty Mutual table: female population percentages for lifting tasks ending above shoulder height (>53”). (Source: From Liberty Mutual (2004).)

HAND DISTANCE		7 INCHES					10 INCHES					15 INCHES				
FREQUENCY ONE LIFT EVERY		15s	30 s	1m	5m	8h	15s	30 s	1m	5m	8h	15s	30 s	1m	5m	8h
OBJECT WEIGHT (POUNDS)	LIFTING DISTANCE (INCHES)															
40	30	-	-	-	-	13	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	26	-	-	-	-	12	-	-	-	-	-
	10	-	-	-	-	40	-	-	-	-	22	-	-	-	-	-
38	30	-	-	-	-	19		-	-	-	-	-	-	-	-	-
	20	-	-	-	-	33	-	-	-	-	17	-	-	-	-	-
	10	-	-	-	15	48	-	-	-	-	30	-	-	-	-	-
36	30	-	-	-	-	26	-	-	-	-	12	-	-	-	-	-
	20	-	-	-	11	41	-	-	-	-	24	-	-	-	-	-
	10	-	-	12	21	55	-	-	-	-	38	-	-	-	-	-
34	30	-	-	-	-	34	-	-	-	-	18	-	-	-	-	-
	20	-	-	-	18	50	-	-	-	-	32	-	-	-	-	-
	10	-	-	18	29	63	-	-	-	14	46	-	-	-	-	13
32	30	-	-	-	12	43	-	-	-	-	26	-	-	-	-	-
	20	-	-	15	24	59	-	-	-	-	41	-	-	-	-	-
	10	-	11	26	38	70	-	-	12	21	55	-	-	-	-	20
30	30	-	-	11	19	53	-	-	-	-	35	-	-	-	-	-
	20	11	14	22	33	67	-	-	-	17	51	-	-	-	-	17
	10	11	18	36	47	77	-	-	19	29	64	-	-	-	-	29
28	30	-	-	18	28	62	-	-	-	13	45	-	-	-	-	13
	20	18	22	32	44	74	-	-	16	26	60	-	-	-	-	25
	10	18	27	46	57	82	-	13	28	40	72	-	-	-	-	39
26	30	-	14	27	39	71	-	-	13	21	56	-	-	-	-	21
	20	28	33	43	54	81	13	17	25	37	69	-	-	-	-	36
	10	28	38	57	67	87	13	21	39	51	79	-	-	-	17	50
24	30	16	23	39	51	79	-	-	22	33	66	-	-	-	-	32
	20	40	45	55	65	86	23	27	37	49	77	-	-	-	15	48
	10	40	50	67	75	+	23	33	51	62	84	-	-	17	27	61
22	30	27	36	52	63	85	13	19	34	46	76	-	-	-	13	45
	20	53	58	66	74	+	35	40	50	61	84	-	-	16	26	60
	10	53	62	76	82	+	35	46	63	72	89	-	13	28	40	72
20	30	41	50	65	73	+	24	32	49	59	83	-	-	15	24	59
	20	65	69	76	82	+	49	54	63	72	89	16	20	28	40	72
	10	66	73	84	88	+	50	59	74	81	+	16	25	43	54	80
18	30	57	64	76	82	+	39	48	63	72	89	-	15	28	40	72
	20	76	79	84	88	+	64	68	75	81	+	30	35	44	55	81
	10	77	82	89	+	+	64	72	83	87	+	30	40	58	68	87
16	30	71	77	85	89	+	57	64	76	82	+	22	30	46	57	82
	20	85	87	+	+	+	76	79	84	88	+	48	52	61	70	88
	10	85	89	+	+	+	77	82	89	+	+	48	57	72	79	+
14	30	83	86	+	+	+	73	78	86	+	+	42	50	64	73	+
	20	+	+	+	+	+	86	88	+	+	+	66	70	76	82	+
	10	+	+	+	+	+	86	+	+	+	+	66	73	83	88	+
12	30	+	+	+	+	+	85	88	+	+	+	64	70	80	85	+
	20	+	+	+	+	+	+	+	+	+	+	81	83	87	+	+
	10	+	+	+	+	+	+	+	+	+	+	81	85	+	+	+
10	30	+	+	+	+	+	+	+	+	+	+	82	85	+	+	+
	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
8	30	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
6	30	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

+ = GREATER THAN 90%   - = LESS THAN 10%

E.5 Informal System Evaluation Methods

Descriptions

Ethnographic Observation:

These are techniques that stem from the anthropology and psychology communities that study how people interact with technology. Domain practitioners are observed and interviewed in their actual work environments as they perform regular work activities. There are also a host of "rapid ethnography" methods being developed by the HCI community with the goal of providing a reasonable understanding of workers and their activities given significant time pressure and limited time in the field. These methods can be useful in gathering user requirements, understanding and developing user models, and evaluating new systems and iterating their design.

Heuristic Evaluation:

A technique for assessing the usability of a computer interface that uses ten rules of thumb, such as "speak the user's language," "provide feedback," "be consistent," and "provide good error messages." In a heuristic evaluation, the analyst evaluates how well the proposed interface follows the rules of thumb and provides feedback as to how it could be improved.

Cognitive Walk-through:

In walk-throughs and talk-throughs, workers who know a system perform a task using an actual system or a realistic mock-up for analysis. When performing a talk-through, the user is removed from realistic surroundings and merely verbalizes the demonstration. Cognitive walk-throughs attempt to evaluate the state of the user's thought processes at each step of task performance, with emphasis on identifying aspects of the interface that are confusing.

Interface Evaluation Surveys:

These are a group of information collection methods which can be used to identify specific ergonomics problems or deficiencies in interfaces. They address issues such as the labeling and consistency of controls, how well the system works within its environment (e.g. is the environment too noisy for an auditory interface?), and whether operators have modified the system in some way to overcome a deficiency (e.g. are there post-it notes everywhere?). They are applied when a detailed design has been created. There are also a host of surveys, such as the Questionnaire for User Interaction Satisfaction (QUIS), which can be used to assess worker satisfaction with specific aspects of a human-computer interface.

Ergonomics Checklists:

Checklists that an analyst can use to ascertain whether particular ergonomic criteria are being met by a system. The items within these checklists can range from overall subjective opinions to very specific objective checks. They can be used to evaluate both existing and proposed systems.

Tool/Method Content

Theoretical Assumptions:

All of the informal system evaluation methods are essentially atheoretical in their approaches to HSI evaluation. Their emphasis is empirical and analytical.

HSI Domains Addressed:

These methods can potentially address all of the HSI domains. They have primarily been developed with the human factors domain in mind. However they also can be useful in surveying the other domains, if one can define criteria of satisfaction and performance in the domain of interest and measures or performance indexes to structure and guide the survey.

Questions Addressed:

The primary questions center on the acceptability of a system or subsystem as indexed against the criteria and performance measures developed by the analysis and evaluation team. These will vary with the HSI domain under evaluation. As an example of one area of concern in the human factors domain, a question that might be addressed with the cognitive walkthrough analysis could be:

Workflow: For new systems, are there any procedures in which the human operator is required to engage in contradictory, competing, or distracting workflow "paths?"

Thus, the area being addressed by the cognitive walkthrough is that of workflow. The question above is one instance of the workflow consideration. There would be others, as well as other areas to be addressed.

Content Modeled:

These analysis methods will address whatever content systems analysts believe are important to a thorough analysis of the system from the HSI point of view. Although there is no modeling of the content surveyed in these analyses, the methods typically are used to survey and analyze areas such as behavioral, operational and cognitive competencies required for proficient system performance; workflow structure, distractions, interruptions and other potential disruptions to proficient system performance; usability issues surrounding visual, auditory and psycho-motor interfaces in the system; safety issues; ergonomic and anthropometric issues and acceptability;

Model Granularity:

These tools exist at a low level of granularity, in that they consist of survey-level analyses of human interaction "checkpoints" with the system under analysis. Their emphasis is strictly on outcome measurements of interaction. They do not support any modeling or detailed analysis of process.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Form of tool output is survey data on interaction problems observed or inferred through analysis of the system. Analysis and output is communicated primarily through the language of interaction characteristics and errors. Taxonomic conventions are up to the analyst but usually consist of a combination of interaction styles, error taxonomy, actions taken by users of the system and a grading method used to rank the severity of findings. As an example, Hale (1998) developed an error taxonomy for use with HCI analyses that consisted of 11 cognitive error categories observed over a series of interactions with different types of software-based systems. These were communicated to software developers through ethnographic observations, interface evaluation surveys and formal usability evaluations. Error categories were ranked according to severity of impact on system functionality and usability.

Methods used to Integrate with SE and Other Environments:

Integration depends on the results of each analysis being communicated effectively to the systems engineering and software development functions in the acquisition process.

Computer Language and Interface Support:

These are paper and pencil tools with no explicit software or interface support, other than that available through standard office applications.

Risk and Trade-off Management

Assumptions Regarding Risk:

No explicit assumptions regarding risk. Any assumptions used must be developed by the analyst.

Error Definitions/Taxonomy:

N/A

Risk Computation/Mitigation Methodology:

N/A

Traceability

While there are no explicit relationships to acquisition requirements inherent in these tools, analysts can develop a traceability matrix that correlates findings to system requirements. This correlation would serve as a basis for the development of severity ratings to accompany the usability and error findings.

These tools are used in support of the performance assurance phase of development. In addition, if a traceability matrix is developed during analysis, this matrix can be used in support of requirements review.

Other Evaluation Criteria

Learning curve: Shallow

Reliability, Validity, and Platform Requirements:

Reliability estimates will be the responsibility of the analyst, as most tools in this category are somewhat custom developed. In general, the validity of these methods has been shown to be high over a large range of applications. The only platform requirement for the tools is that of general office applications to support development of the tools themselves and data compilation/analysis.

Analysis Utilities and Interface Support:

No analysis utilities specific to any of the tool categories. Descriptive statistics typically will be the only analyses carried out. Analyst-developed severity measures might be used to facilitate requirements review.

Availability, Cost, and Contact Information:

These tools are freely available at a number of sites accessible on the internet. Representative examples include:

http://coven.lancs.ac.uk/4/deliverables/del37e.pdf
http://swiki.cs.colorado.edu:3232/dlc-2002/uploads/6/dist-cogn-feb20.pdf
https://dspace.ucalgary.ca/bitstream/1880/46646/1/2008-904-17.pdf
http://human-factors.arc.nasa.gov/ihi/research_groups/air-ground-integration/publication_papers/Sm1999-CockpitWalk.pdf

E.6 NIOSH Lift Equation

Description

This calculation is used for lifting or lowering tasks done by one person without mechanical assistance. The product of the NIOSH lift equation is the Recommended Weight Limit (RWL). The RWL considers the horizontal parameters of the lift, the vertical height at the start of the lift, the vertical distance traveled during the lift, the angle traveled, lift frequency, and a qualifier for rating the comfort of the hand holds. The maximum RWL with all factors being optimal is 51 pounds.

Tool/Method Content

Theoretical Assumptions:

NIOSH assumes that lifting and lowering tasks carry the same risk of lower back injury. There are a number of limitations when using the NIOSH lift equation. The lift must be a two-handed lift and the work shift must be less than eight hours. The lift equation cannot be applied to a task in an environment that anticipates slips or falls, or environments with unfavorable temperature and humidity conditions. The lift task must be completed while standing. The equation cannot be applied if the lift occurs while the worker is seated or kneeling or in a workspace that restricts movement. The equation does not apply if the load is carried more than 2 steps, or is pushed/pulled/shoveled as in a wheelbarrow or dolly. If any of these conditions apply, the assumptions made my NIOSH in formulating the equation do not apply. There are other tools, Snook & Cirello tables for example, that can be used instead.

HSI Domains Addressed:

This tool addresses the safety domain.

Questions Addressed:

- Is the load too heavy for the parameters of this lift?
- If so, which parameter is causing the recommended weight limit to be low?
- How often can this lift be performed per minute/hour?

Content Modeled:

- Load weight, shape, handles
- Vertical height and horizontal distance of start and end points of the lift
- Frequency of lift
- Twisting while lifting

Model Granularity:

This tool is easy to use and can be done using worksheets and tables, or in an electronic spreadsheet. There are also COTS software packages that allow the user to use this with a GUI.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

The RWL is used to determine the Lift Index (LI) of the task. The LI is an estimate of physical stress given the actual load of the lift versus the RWL.

Risk and Trade-off Management
Assumptions Regarding Risk:
There are a number of limitations regarding the application of this lift. To apply this equation for a two-person lift, or a carry, for example, would invalidate the assumptions of the equation.

Traceability
Output categories of the HFW tool set include errors and their probabilities of occurrence, factors leading to the appearance of errors and estimates of the prominence of these factors in error production, mitigation strategies, and likely error consequences. This information can be used to assist in analysis of technology alternatives, trade-off analyses, and analyses of system effectiveness.

Development Steps Supported:

- Function analysis
- Task design
- Performance/workload/training estimation

Other Evaluation Criteria
Learning curve: Shallow

Availability, Cost, and Contact Information:
"Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks" Water, Putz-Anderson, Garg, and Fine, 1993.

E.7 Rapid Upper Limb Assessment (RULA)

Description
RULA is a survey method developed for use in ergonomic investigation of workplaces where work related upper limb disorders are reported. RULA is a screening tool that assesses biomechanical and postural load on the whole body with particular attention to the neck, trunk and upper limbs.

Tool/Method Content
Theoretical Assumptions:
Depending on the type of study, an analysis may be done on the longest held posture or what appears to be the work posture, or postures, adopted.

HSI Domains Addressed:
This tool addresses the Workstation Design and Physical Ergonomics domains.

Questions Addressed:

- Is the risk of upper body cumulative trauma disorders acceptable?

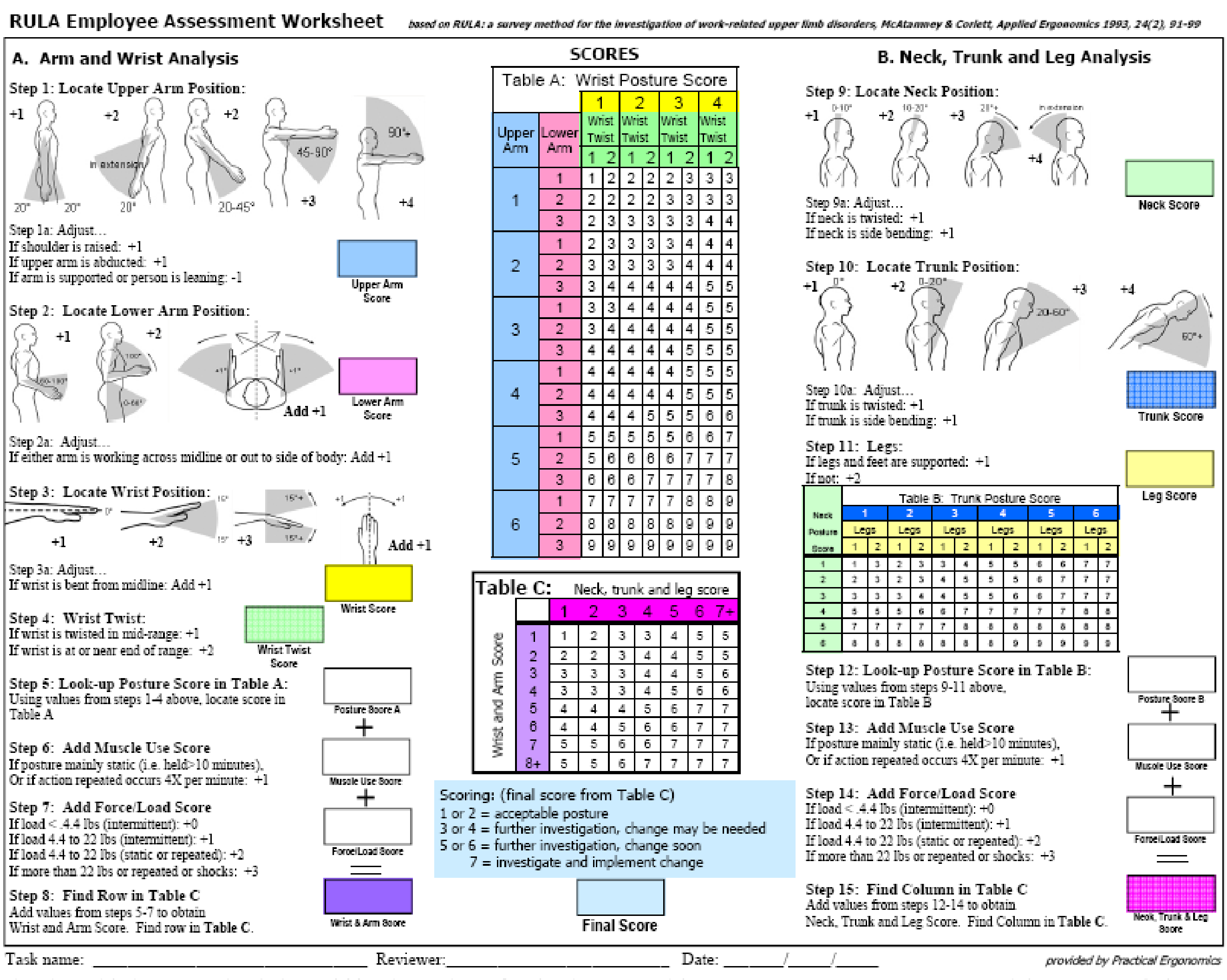
Content Modeled:

- Body postures (both upper limb and whole body)
- Static or repetitive motion
- Load size/force

An example of a RULA Employee Assessment Worksheet is shown below. Limb, trunk and muscle scores are mapped to a set of tables, which are combined to arrive at an acceptability score for the workplace in question.

Model Granularity:
The model relies heavily on the quality of the task breakdown and input in to the analysis.

Communication
Form of Output, Terminology, and Taxonomic Conventions:
RULA output is a single digit Final Score. However, in calculating the Final Score, individual body parts are given a score, as are muscle use and load size. These scores can be compared to provide a picture of relative risk.



RULA Employee Assessment Worksheet *based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99*

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:
Step 1a: Adjust…
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1
Upper Arm Score

Step 2: Locate Lower Arm Position:
Step 2a: Adjust…
If either arm is working across midline or out to side of body: Add +1
Lower Arm Score

Step 3: Locate Wrist Position:
Step 3a: Adjust…
If wrist is bent from midline: Add +1
Wrist Score

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2
Wrist Twist Score

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A
Posture Score A

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>10 minutes),
Or if action repeated occurs 4X per minute: +1
Muscle Use Score

Step 7: Add Force/Load Score
If load < 4.4 lbs (intermittent): +0
If load 4.4 to 22 lbs (intermittent): +1
If load 4.4 to 22 lbs (static or repeated): +2
If more than 22 lbs or repeated or shocks: +3
Force/Load Score

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in Table C.
Wrist & Arm Score

SCORES

Table A: Wrist Posture Score

Upper Arm	Lower Arm	1 Wrist Twist 1	1 Wrist Twist 2	2 Wrist Twist 1	2 Wrist Twist 2	3 Wrist Twist 1	3 Wrist Twist 2	4 Wrist Twist 1	4 Wrist Twist 2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C: Neck, trunk and leg score

Wrist and Arm Score	1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Scoring: (final score from Table C)
1 or 2 = acceptable posture
3 or 4 = further investigation, change may be needed
5 or 6 = further investigation, change soon
7 = investigate and implement change

Final Score

B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:
Step 9a: Adjust…
If neck is twisted: +1
If neck is side bending: +1
Neck Score

Step 10: Locate Trunk Position:
Step 10a: Adjust…
If trunk is twisted: +1
If trunk is side bending: +1
Trunk Score

Step 11: Legs:
If legs and feet are supported: +1
If not: +2
Leg Score

Table B: Trunk Posture Score

Neck Posture Score	1 Legs 1	1 Legs 2	2 Legs 1	2 Legs 2	3 Legs 1	3 Legs 2	4 Legs 1	4 Legs 2	5 Legs 1	5 Legs 2	6 Legs 1	6 Legs 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above, locate score in Table B
Posture Score B

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>10 minutes),
Or if action repeated occurs 4X per minute: +1
Muscle Use Score

Step 14: Add Force/Load Score
If load < 4.4 lbs (intermittent): +0
If load 4.4 to 22 lbs (intermittent): +1
If load 4.4 to 22 lbs (static or repeated): +2
If more than 22 lbs or repeated or shocks: +3
Force/Load Score

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain Neck, Trunk and Leg Score. Find Column in Table C.
Neck, Trunk & Leg Score

Task name: ____________ Reviewer: ____________ Date: ___/___/___ *provided by Practical Ergonomics*

This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in RULA. *© 2004 Neese Consulting, Inc* *rbarker@ergosmart.com (816) 444-1667*

Figure E-3. Rapid Upper Limb Assessment worksheet.
(http://personal.health.usf.edu/tbernard/HollowHills/RULA.pdf)

Risk and Trade-off Management
Assumptions Regarding Risk:
This tool is to be used in conjunction with other analysis methods and should not be use alone to determine risk.

Traceability
The analysis can be conducted before and after an intervention to demonstrate that the intervention has worked to lower the risk of injury.
Development Steps Supported:

- Concept definition
- Requirements analysis
- Task design

Other Evaluation Criteria
Learning curve: Shallow

Availability, Cost, and Contact Information:
McAtamney, L & Corlett. "RULA: a survey method for the investigation of work-related upper limb disorders." *Applied Ergonomics.*(24) 91-99. 1993.
Online RULA tool incorporated into: *ErgoIntelligence* by NexGen, *ErgoSure Pro* by Magnitude Inc. Also versions by COPE and Humanics are commercially available.

E.8 Ship System Human Systems Integration for Affordability and Performance Engineering (Ship-SHAPE) Tool Set

Description
Ship-SHAPE is an adaptation of the Integrated Decision/Engineering Aid (IDEA) tool set developed by Carlow for the Army's Human Research and Engineering Directorate, Naval Sea Systems Command, the Navy's Space and Warfare Systems Command (SPAWAR), and DARPA. Ship-SHAPE is a set of automated processes, tools, and data bases developed specifically to enable HSI analysts in the Navy and in the commercial ship building and maritime system arena to meet HSI requirements as contained in the DoD 5000 series, the Defense Acquisition Deskbook, Naval Sea Systems Command Instruction 3900.8, MIL-STD-1472, MIL-HDBK-46855, ASTM-1166 and ASTM-1337.

Ship-SHAPE Automated Human Systems Integration (HSI) tools include:

a) An HSI Process Tool;
b) A mission/function analysis tool and scenario generator (IMAGE);
c) Comparability Analysis (I-CAN) tool which supports the identification of high driver tasks/conditions and lessons learned from predecessor systems;
d) A function allocation tool to support investigation of alternate feasible roles of the human: Role of Man and Automation (ROMAN)
e) The HSI Assessment tool (ASSESS) for assessing technology, affordability and risk associated with design concepts;
f) A Task Analysis Tool (I-TASK) based on MIL-H-46855 and MIL-STD-1478;
g) A Simulation for Workload Assessment and Modeling (SIMWAM) tool for assessing multi-operator task network impacts on human performance and workload;

h) A tool which supports planning an HSI effort by tracking project tasks, personnel hours, task status, deliverables with due dates, called HSI Planning (I-PLAN);
i) A usability testing tool (CUTTER) to support all phases of usability testing. This tool consists of three modules: (1) a test preparation and planning support module (2) a data logging and data analysis module and (3) an interface evaluation guideline module;
k) An Integrated NDI Selection/Assessment Tool (INDI)

Tool/Method Content

Theoretical Assumptions:

The guiding principle behind the design of the Ship-SHAPE software is that the HSI analyst should have at his or her fingertips all of the guidance, instructions, processes, procedures, methods, tools, and data needed to conduct a timely and complete HSI effort. The elements of the Ship-SHAPE system are: the HFE process for ships; an integrated HFE information system; automated HFE tools; and a report generator for producing HFE plans and reports.

HSI Domains Addressed:

- HFE
- Training
- Manpower
- Personnel
- Safety

Questions Addressed:

These tools address planning and administrative issues involved in HSI, in addition to many of the technical issues in the HFE, personnel, manpower and safety domains. Cost issues also are addressed.

Content Modeled:

The tools allow modeling and analysis of task structure and organization, workload, allocation questions, design alternatives, teaming and team structure issues, performance levels, and error/risk concerns.

Model Granularity:

The granularity of these models seems to be moderate. Models developed under the support of most of the tools in this set are descriptive rather than quantitative or executable. Most descriptions will be at an operational, rather than at a process, level.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Output is available in a wide variety of forms, depending on the tool in use. The outputs include:

- Display of results of a mission function analysis in tabular or flowchart form;
- Guidelines on performance of specific HSI activities in the context of ship operations;
- Tasks that have a likelihood of significantly affecting operational effectiveness;
- Function allocations and roles of humans in the overall system;
- Comparative assessments of HSI design concepts and alternatives;
- Task analysis data for subsequent design and engineering analyses;
- Mission times, task completions, task start and end times, time spent per task per operator, and operator utilization;
- Project planning documents, status reports, hours and tasks by persons and by project month.

Terminology and taxonomic conventions are those of traditional human factors and HSI engineering.

Methods used to Integrate with SE and Other Environments:
It will be the responsibility of the HSI analyst to communicate these to the larger system development process.

Computer Language and Interface Support:
MS Office is required for most of these tools. Other language requirements include HyperCard, Filemaker Pro, and an internet browser.

Risk and Trade-off Management
Assumptions Regarding Risk:
Not known.

Error Definitions/Taxonomy:
No known.

Risk Computation/Mitigation Methodology:
Not known.

Traceability
Output Categories and Relationships to Acquisition Requirements:
The wide variety of outputs provided by these tools can be used to support several acquisition requirement categories: Analysis of technology alternatives, evaluations of system effectiveness, functional allocation, and CONOPS development. The administrative tools can support decision criteria definition and evaluation.

Development Steps Supported:
- Concept definition
- Requirements analysis
- Function analysis
- Function allocation
- Task design
- Performance/workload/training estimation
- Personnel selection
- Training development

Other Evaluation Criteria
Learning curve: Moderate

Reliability, Validity, and Platform Requirements:
All of the tools have been formally validated and have been used in a number of programs conducted by the US Navy. The tools will run on either Windows machines or Apple Macintosh platforms.

Analysis Utilities and Interface Support:

All of the tools contain analysis utilities within the tools themselves. Interface support is provided primarily by the Office software upon which each tool relies.

Availability, Cost, and Contact Information:

The Ship-SHAPE web site states that all tools are readily available. However, the platform requirement descriptions imply that these tools were developed some time ago.

Carlow International Incorporated
Thomas B. Malone, President
tbmalone@carlow.com
20856 Waterbeach Place
PO Box 650457
Potomac Falls, VA 20165 USA
703.444.4666
http://carlow.com/index.html

E.9 Risk Management Toolkit

Description

The risk management toolkit is a management and CMMI process tool set designed to allow development teams to define, track and mitigate project risks. In addition to the processes and procedures that have been defined as part of this tool kit, there are three software packages designed to assist program managers and development teams with system development.

RiskNav® is a well-tested tool developed by MITRE to facilitate the risk process and help program managers manage their risk space. RiskNav lets you collect, analyze, prioritize, monitor, and visualize risk information in a collaborative fashion. This tool provides three dimensions of information graphically (risk priority, probability, and the mitigation/management status).

RiskNav is a well-tested tool developed by MITRE to facilitate the risk process and help program managers manage their risk space. RiskNav lets you collect, analyze, prioritize, monitor, and visualize risk information in a collaborative fashion. This tool provides three dimensions of information graphically (risk priority, probability, and the mitigation/management status).

Risk Radar is a risk management database to help project managers identify, prioritize, and communicate project risks in a flexible and easy-to-use form. Risk Radar provides standard database functions to add and delete risks, as well as specialized functions for prioritizing and retiring project risks. Each risk can have a user-defined risk management plan and a log of historical events. A set of standard short- and long-form reports can be easily generated to share project risk information with all members of the development team. The number of risks in each probability/impact category by time frame can be displayed, which allows the user to drill down through the data to uncover increasing levels of detail. Risk Radar allows the user the flexibility of using automatic sorting in addition to manually moving risks up and down in setting priority rank.

Tool/Method Content

Theoretical Assumptions:

This is a management toolkit derived from the Carnegie-Mellon University Software Engineering Institute (SEI). As such, there are minimal theoretical assumptions in the development and use of the toolkit. What theoretical assumptions are present are based on the notion that human errors occupy the status of causal agents in analyses of system failures.

HSI Domains Addressed:

All domains are addressed by this toolkit. Some domains are addressed indirectly through a propagation of analysis results into systems engineering analysis and design activities.

Questions Addressed:

The toolkit addresses questions of acquisition management in the following areas:

- Acquisition
- Contracting
- Cost
- Environmental aspects
- Funding
- Health hazards
- Human factors
- Logistics planning
- Manpower
- Personnel
- Requirements
- Resources
- Safety
- Scheduling
- Software development
- Survivability
- Systems engineering
- Training

Content Modeled:

The primary content modeled by the toolkit, in each of the areas outlined above, includes determination of risk factors, the relationships of these factors to program outcomes and mitigation strategies that can be applied to the risks.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Output comes primarily in the form of risk factors and mitigation strategies.

Methods used to Integrate with SE and Other Environments:

This toolkit is intended to be a systems engineering method. The areas of interest in the HSI domain are included in the toolkit.

Computer Language and Interface Support:

Not applicable except in the case of the three tools outlined in the description section above. RiskNav® uses a weighted averaging model and tabular format to analyze program risks. Risk Matrix also uses a tabular interface based on Excel spreadsheets. Risk Radar uses a forms-based approach to capture information that is entered into a database for tracking and resolution.

Risk and Trade-off Management

Assumptions Regarding Risk:

Risks, in each of the areas outlined above, can be identified through a subjective, analytical process, tabulated and resolved through weighted averaging and other methods.

Error Definitions/Taxonomy:

This toolkit contains no standard error taxonomy.

Traceability

Output Categories and Relationships to Acquisition Requirements:

All output categories concern risks, probabilities of occurrence, severity associated with risk occurring, and mitigation strategies. Since this toolkit is a program management tool, the acquisition requirements addressed by the toolkit are enumerated in the above section on "questions addressed."

Development Steps Supported:

- Requirements analysis
- Requirements review

How Tool Maps System Requirements to HSI Requirements:

This toolkit should allow explicit mapping of system requirements to HSI requirements as an outgrowth of the scope and approach taken to risk analysis at the program level. However, the toolkit contains no explicit method of doing this other than providing the process and information to support this mapping. Actually making the mapping is the responsibility of the development team.

Other Evaluation Criteria

Learning curve: Moderate

Reliability, Validity, and Platform Requirements:

Reliability and validity information is unavailable. Platform requirements apparently include standard Windows and OS-X platforms running Office applications.

Analysis Utilities and Interface Support:

Analysis and interface support are provided in the three software packages mentioned above. Other support requirements are provided through tools contained on the platforms used to run the tools, e.g., Office applications.

Availability, Cost, and Contact Information:

Availability seems to come primarily through the Risk Management Toolkit website. The Risk Radar tool is a third-party development. Availability/cost information for this tool is not available. The toolkit can be accessed at: http://www.mitre.org/work/sepo/toolkits/risk/index.html

E.10 Jack™

Description

Jack is an ergonomics tool set allowing constructive simulation for workstation design and early trade-off studies. Areas addressed by this tool include reach, vision, injury risk, fatigue, comfort and strength assessments.

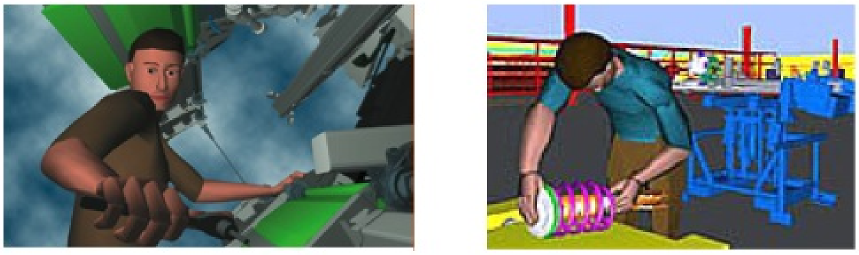


Figure E-4. Jack workstation design tool.

Tool/Method Content

Theoretical Assumptions:

There are no theoretical assumptions. Jack is a physical modeling environment.

HSI Domains Addressed:

- HFE
- Habitability
- Personnel

This tool set will allow HSI designers to address issues in ergonomics, workstation design and layout, and personnel (through its ability to inform designers regarding anthropometric and strength requirements).

Questions Addressed:

The tool set is focused almost exclusively in the areas of anthropometry, strength, and physical layout. Vision analyses also can be completed.

Content Modeled:

Posture predictions, 3D vision obscuration, reflection areas, visibility zones, strength limits, posture, injury risk, fatigue and task timing.

Model Granularity:

The tool set has a high degree of granularity in both modeling and analysis output.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

The output can include visual viewpoints from the model's point of view, "view cones" that illustrate a third-person perspective of what the model sees, distances between the model's eyes and any visual object in the modeled scene or system, eye-tracking trajectories, reach envelopes, hand-to-object distances, interactive distance measures, model-object collisions. Terminology and conventions are those of physical ergonomics. Examples of specification screens and a modeled environment are shown below.

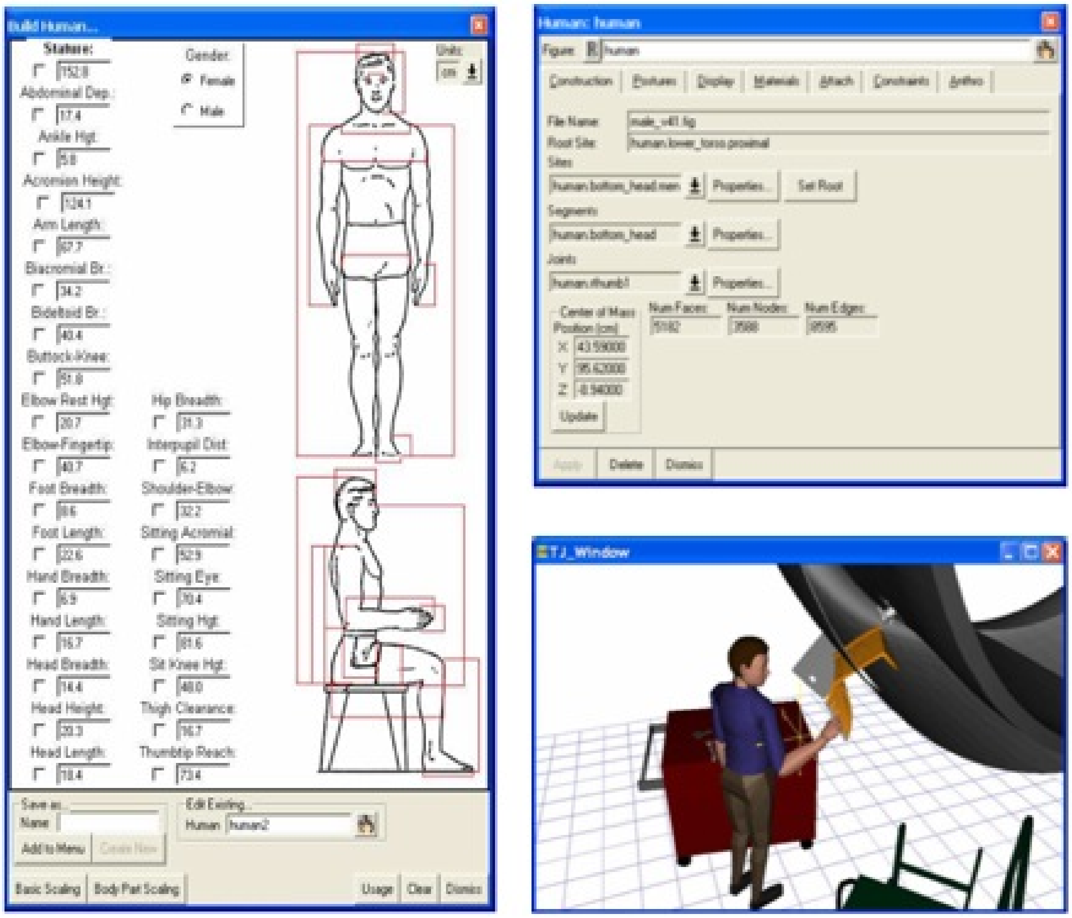


Figure E-5. Jack input and analysis screens.

Methods used to Integrate with SE and Other Environments:

Output results can be used as input to CAD systems, thereby integrating Jack output with other systems engineering tools.

Computer Language and Interface Support:

The system uses an internal language.

Risk and Trade-off Management

Assumptions Regarding Risk:

Risk is not addressed explicitly in this system. Any assumptions regarding risk will be implicit in the specification of anthropometric and other physical parameters of a given task or environment being modeled.

Error Definitions/Taxonomy:

None

Risk Computation/Mitigation Methodology:

None

Traceability

Output Categories and Relationships to Acquisition Requirements:

These include reach, anthropometry, strength and vision data. These data can be used in requirements analyses and other design analyses that are included in the development of PORDs and ORDs.

Development Steps Supported:

- Task design
- Personnel selection
- Performance assurance

Other Evaluation Criteria

Learning curve: Moderate

Reliability, Validity, and Platform Requirements:

The tool has been validated over a wide range of applications. Platform requirements include:
Windows 2000 or XP
Minimum 300 MHz processor
128 MB RAM
175 MB free disk space

Analysis Utilities and Interface Support:

Complete analysis utilities and user interface are included with the tool.

Availability, Cost, and Contact Information:

Siemens PLM Software
(800) 498-5351
www.siemens.com/plm

E.11 Human Factors Workbench (HFW)

Description

An integrated software package composed of five analytical tools that can be used independently or together. Among the tools in the set are the Predictive Human Error Analysis (PHEA) tool and the Measurement and Investigation Technique to Reduce Errors (MITRE) tool. The PHEA is used to predict potential human errors and their consequences. The MITRE tool allows analysts to assess factors influencing the likelihood of errors identified in the PHEA and to develop specific prevention strategies for mitigating the consequences of errors.

Tool/Method Content

Theoretical Assumptions:

An important theoretical assumption of these tools is that one can develop an exhaustive list of error modes and that these can be used to (1) identify (potential) errors across a wide range of operational situations, (2) estimate error probabilities, (3) relate the errors to causal factors. The critical assumption is that this process can be exhaustive, that is, that all error types and causes can be identified and related in a quantitative way.

HSI Domains Addressed:

- HFE
- Training
- Safety

Questions Addressed:

- What errors might be committed in the operational scenarios of interest
- What causal factors can be identified to "explain" the errors inherent in an operational scenario of interest
- What are the likelihoods of errors in each of the categories of interest
- What is the significance of each "causal factor" on each error category

Content Modeled:

- Tasks and task sequences
- Error types
- Causal factors influencing the probabilities of errors in each category
- Error probabilities
- Error commission consequences
- Error mitigation strategies

A task analysis screenshot and associated error taxonomy are shown in Figure E-6 and Figure E-7 (below). The system provides support for development of both of these design artifacts.

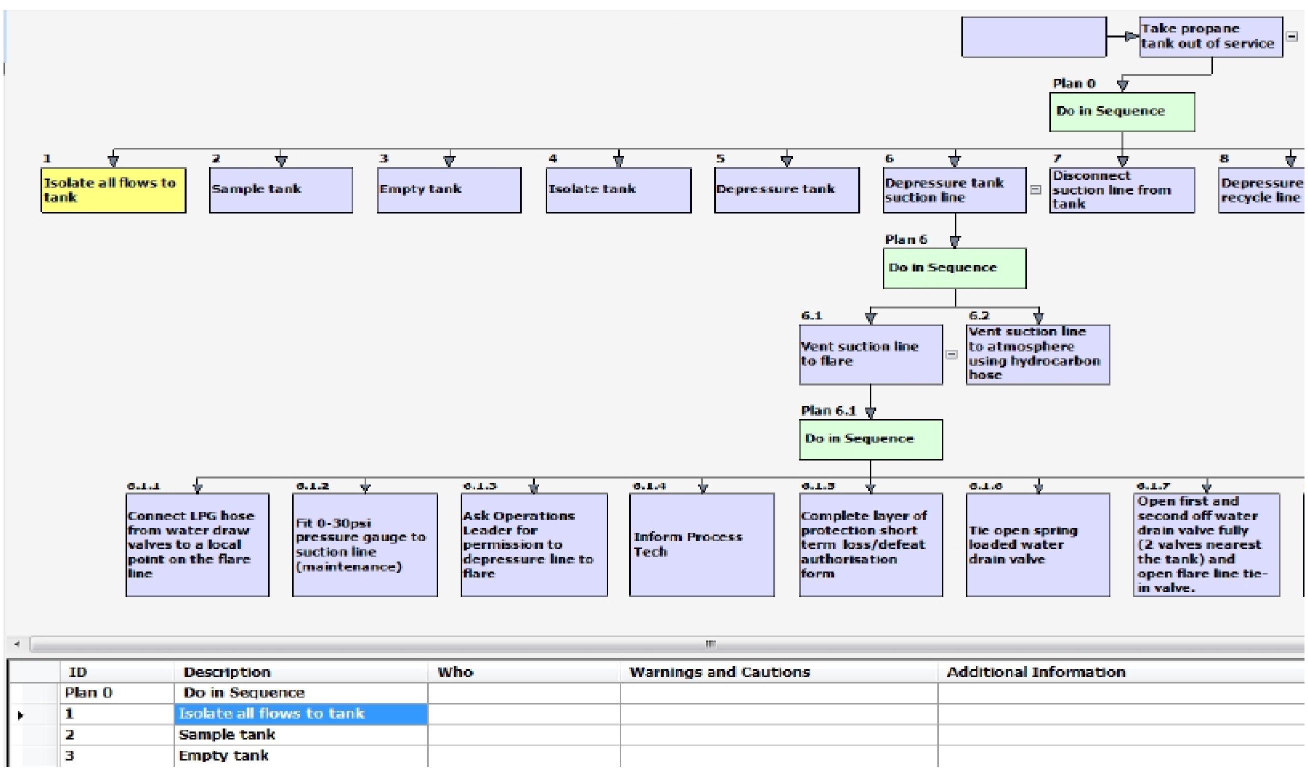


Figure E-6. Section of a Human Factors Workbench task analysis for taking a propane tank out of service. (from www.humanreliability.com)

Action Errors	
A1	Operation too long / short
A2	Operation mistimed
A3	Operation in wrong direction
A4	Operation too little / too much
A5	Operation too fast / too slow
A6	Misalign
A7	Right operation on wrong object
A8	Wrong operation on right object
A9	Operation omitted
A10	Operation incomplete
A11	Operation too early / late
A12	Operation in wrong order
A13	Misplacement

Checking Errors	
C1	Check omitted
C2	Check incomplete
C3	Right check on wrong object
C4	Wrong check on right object
C5	Check too early / late

Information Retrieval Errors	
R1	Information not obtained
R2	Wrong information obtained
R3	Information retrieval incomplete
R4	Information incorrectly interpreted

Information Communication Errors	
I1	Information not communicated
I2	Wrong information communicated
I3	Information communication incomplete
I4	Information communication unclear

Selection Errors	
S1	Selection omitted
S2	Wrong selection made

Planning Errors	
P1	Plan incorrect because of misdiagnosis
P2	Diagnosis correct but wrong action plan formulated

Figure E-7. Predictive human error analysis scheme used in Human Factors Workbench.

Model Granularity:

The PHEA tool provides an a priori classification of observable failure modes. The tool authors claim that this list is exhaustive. Currently, the list consists of 30 error modes, organized into six error categories. These error modes reside at a moderate level of granularity, stated operationally at a level allowing enumeration of individual “errors” but not allowing any insight into process or microscopic detail.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

These tools provide a variety of outputs that can be used in system development:

- PHEA analysis produces a spreadsheet output compiling errors, possible accident hazard consequences, risk control measures and performance influencing factors
- Based on an influence diagram model, MITRE outputs to the design team evaluation results of the factors affecting human errors in scenarios of interest. These include histograms relating error factors to overall failure assessment likelihoods
- Risk reduction strategies based on relative cost and effectiveness

- Overall “quality” of factors affecting error probabilities. The MITRE tool calculates an index assessing this “quality” and provides estimates of error probabilities under selected operating conditions. It is not clear from the literature available what is meant by the term “quality” in connection with these computations

The tools used in the HFW rely on the standard terminology of errors and error probabilities. Taxonomic conventions are those of standard accident investigation.

Methods used to Integrate with SE and Other Environments:

There are no explicit SE integration methods contained in this tool set. However, the use of standard accident investigation and error probability conventions should improve the ease with which these tools and their results can be integrated into larger SE trade-off processes.

Computer Language and Interface Support:

The tool set contains a full range of interfaces for data entry, analysis and reporting.

Risk and Trade-off Management

Assumptions Regarding Risk:

These tools are based on the following assumptions:

- Risk is an outcome of system failures resulting from errors committed by human operators,
- Errors are committed when factors are present that create the conditions under which the errors can arise,
- Factors leading to error generation result from system characteristics and design commitments that can be detected through analysis and corrected with proactive design decisions or retroactive changes to system operations, structure or organization,
- Error probabilities can be estimated, and mitigation strategies devised through an analysis process embodied in the HFW PHEA and MITRE tools.

Error Definitions/Taxonomy:

Definitions and taxonomies are contained in the HFW tool set and have been discussed in the review comments above.

Risk Computation/Mitigation Methodology:

For tasks of interest, potential errors and their consequences are identified and placed in a spreadsheet along with mitigation strategies and performance influencing factors. These factors are then assessed through a tool-supported questionnaire and rated to provide overall assessments of failure likelihoods at each level of a task tree. Alternative task reduction strategies are evaluated using available data on cost.

The overall results of the assessment of factors contributing to errors of interest can then be calculated. The tool calculates an index which indicates overall quality of factors in scenarios of interest. Estimates of error probabilities under the conditions of interest are calculated and can be displayed in a manner similar to that shown below (Figure E-8).

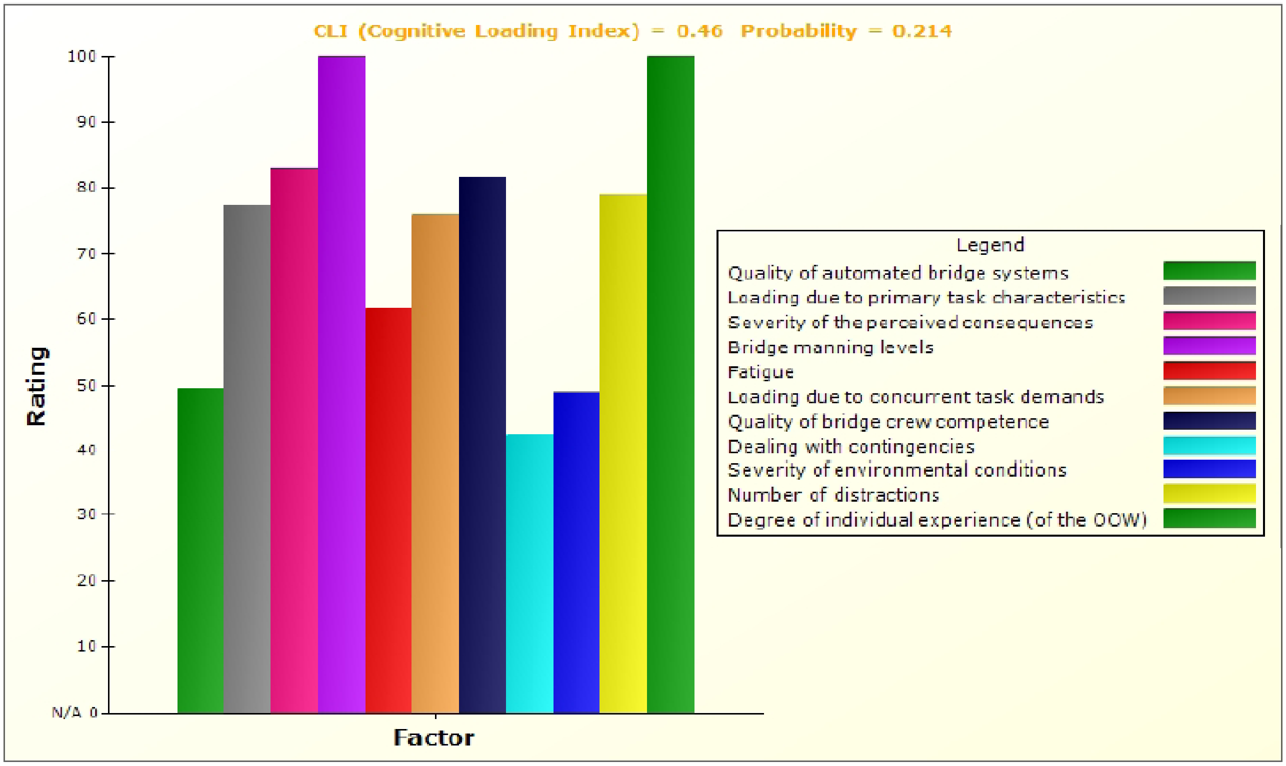


Figure E-8. Error probability estimates from Human Factors Workbench.
(from www.humanreliability.com)

Traceability
Output categories of the HFW tool set include errors and their probabilities of occurrence, factors leading to the appearance of errors and estimates of the prominence of these factors in error production, mitigation strategies, and likely error consequences. This information can be used to assist in analysis of technology alternatives, trade-off analyses, and analyses of system effectiveness.

Development Steps Supported:

- Function analysis
- Task design
- Performance/workload/training estimation

Other Evaluation Criteria
Learning curve: Moderate

Reliability, Validity, and Platform Requirements:
The HFW tool set has been used across a wide range of scenarios and error analysis contexts and has been shown to be both valid and reliable. Platform requirements include Windows XP or Vista.

Analysis Utilities and Interface Support:
Each individual module contains its own native analysis utilities and interface support.

Availability, Cost, and Contact Information:

The costs for the HFW modules are as follows:

- Hierarchical Task Analysis £250
- Predictive Human Error Analysis (PHES) £250
- Measurement and Investigation Technique for Reducing Error (MITRE) £250

Human Reliability
1 School House, Higher Lane
Dalton, Lancashire WN8 7RP
UK
contact@humanreliability.com

E.12 Anthropometric Accommodation in Aircraft Cockpits: Methodologies

Description

This is a series of techniques, focusing solely on accommodation, for examining aircraft cockpits for optimum aircraft operation. These techniques address the variability in body sizes and proportion of potential pilot populations. The most straightforward use of the accommodation data is to verify design specifications. If a cockpit is required to accommodate a given range of body sizes, the techniques make it possible to validate compliance. This is done by comparing the anthropometric dimensions in the specification to the results of the evaluations. Another use for these data is to predict the fit of a range of body sizes in a crew station. Data can also be sued to assess the effects of expanding the ranges of body sizes permitted to enter pilot training.

Tool/Method Content

Theoretical Assumptions:

The development of examination procedures was based on aircraft available between 1990 and 1995 including the USAF F-16A, C-141A, T-37B, T-38A, T-1A, and F-22A. Also the USN T-34C, T-44A, T-45A, and the TA-4J, the Enhanced Flight Screener (EFS) and the Joint Primary Aircraft Training System (JPATS).

HSI Domains Addressed:

This tool addresses the workstation and cockpit design of the safety domain.

Questions Addressed:

- Is the individual too large/small to fly the aircraft? Has the aircraft been designed to accommodate particular body sizes?
- Parameters considered: ejection, rudder throw, alternative seated eye height (the Frankfurt Plane), for example.

Content Modeled:

The approach relies heavily on the following measurements: maximum sitting height, vision from the cockpit to the outside and toward the instrument panel, static ejection clearances of the knee, leg, and torso with cockpit structures, operational leg clearances with the main instrument panel, operational leg clearance with the control stick/wheel motion envelope, rudder pedal operation, hand reach to and actuation of controls.

Model Granularity:

The model takes into account many of the body positions required to operate an aircraft. There are a number of human dimensions to record and compare against the norms. However, judgment should be applied as to the specific aircraft that the person is intended to operate.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

The analysis returns usually the maximum height/breadth/depth/etc of a body part that can safely operate the aircraft, maintain a visual field inside/outside the cockpit, or safely eject.. There are a number of separate analyses for many aspects of aircraft operation that need to be complete to provide a more complete picture of accommodation.

Risk and Trade-off Management

Assumptions Regarding Risk:

There are a number of limitations regarding the application of this lift. To apply this equation for a two-person lift, or a carry, for example, would invalidate the assumptions of the equation.

Traceability

We have only limited ability to predict the individual's level of accommodation. This is true of all measures but especially hand reaches to controls. When regression equations are used, they must be based on large samples. Such predictions produce "average" values expected for a population of individuals of that body size. There can be a good deal of variation around the average. If examination indicates some question regarding an individual's ability to safely operate the aircraft, a trial in the cockpit may be warranted.

Development Steps Supported:

Function analysis
Task design
Requirements review
Personnel selection

Other Evaluation Criteria

Learning curve: Shallow

Availability, Cost, and Contact Information:

- Zehner, GF and JA Hudson, Body Size Accommodation in USAF Aircraft, AFRL-HE-WP-TR-2002-0118, United States Air Force Research Laboratory, Human Effectiveness Directorate, Wright-Patterson AFB, OH.
- KW Kennedy, http://cockpiteval.home.att.net Accessed 24 February 2008.

E.13 ErgoIntelligence ™ Upper Extremity Assessment (UEA)

Description

The ErgoIntelligence™ Upper Extremity Assessment (UEA) suite of tools incorporates a variety of tools including RULA, REBA, Strain Index, Occupational Repetitive Actions Index (OCRA) and the Cumulative Trauma Disorders Risk Index.

Tool/Method Content

ErgoIntelligence combines accepted physical ergonomics tools focusing on the upper body into one integrated software package with a graphical user interface.

- RULA provides a rapid assessment of the musculoskeletal loads on workers due to posture, repetition and force. It accomplishes these goals by providing a “Grand Score” which can be compared to four Action Levels ranging from “that posture is acceptable” to “investigation and changes are required immediately.”
- REBA (Rapid Entire Body Assessment was specifically designed to assess various unpredictable working postures found in health care and other service industries. REBA provides a scoring system for muscle activity caused by static, dynamic, rapid changing or unstable postures. The final REBA score provides an action level with an indication of urgency.
- The Strain Index (SI) is a score value based on a multiple of six variables: intensity of exertion, duration of exertion, efforts per minute, hand/wrist posture, speed of work and duration of task. The output score determines whether a job has a high risk of distal upper extremity disorders.
- The Occupational Repetitive Actions Index (OCRA) is a measurement tool that quantifies the relationship between the daily number of actions actually performed by the upper limbs in repetitive tasks, and the corresponding number of recommended actions. OCRA indices >4 should be considered as a high-risk job; an index of 0.8 to 4 is an intermediate risk job.
- This cumulative trauma disorder risk assessment model (CTD Risk Index) for the upper extremities represents the predicted incidence rate for a cumulative trauma disorder. The model is unique in that it uses quantitative data such as hand motion frequencies and forces together to obtain a frequency factor score that is reflective of the strain imposed on the muscles and tendons of the wrist. Gross upper extremity postures are included in a posture factor score and various minor job stressors are included as a miscellaneous factor score.

HSI Domains Addressed:

This tool addresses the Workstation Design and Physical Ergonomics domains.

Questions Addressed:

- Is the job/task acceptable?
- How can this job be redesigned to warrant a lower risk score

Content Modeled:

- Tasks and task sequences

Model Granularity:

The model relies heavily on the quality of the task breakdown and input in to the analysis.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Graphical outputs suitable for reports are standard in this software package.

Methods used to Integrate with SE and Other Environments:

Computer Language and Interface Support:
Computer language is not an issue with these proprietary and self-contained tools. The tool set contains a full range of interfaces for data entry, analysis and reporting.

Risk and Trade-off Management
Assumptions Regarding Risk:
This tool is to be used in conjunction with other analysis methods and should not be use alone to determine risk.

Traceability
Development Steps Supported:
- Function analysis
- Task design
- Performance/workload/training estimation

Interface Support
ErgoIntelligence UEA interface support is typified by the screenshots shown below, used to specify trunk and upper limb positioning and stress.

Other Evaluation Criteria
Learning curve: Moderate

Reliability, Validity, and Platform Requirements:
ErgoIntelligence runs on Windows 2000/NT4 and Windows XP

Availability, Cost, and Contact Information:
6600 Trans Canada Highway
Suite 750
Pointe Claire (Montreal), Quebec
Canada
H9R 4S2
Telephone: (514) 685-8593
Fax: (514) 685-8687

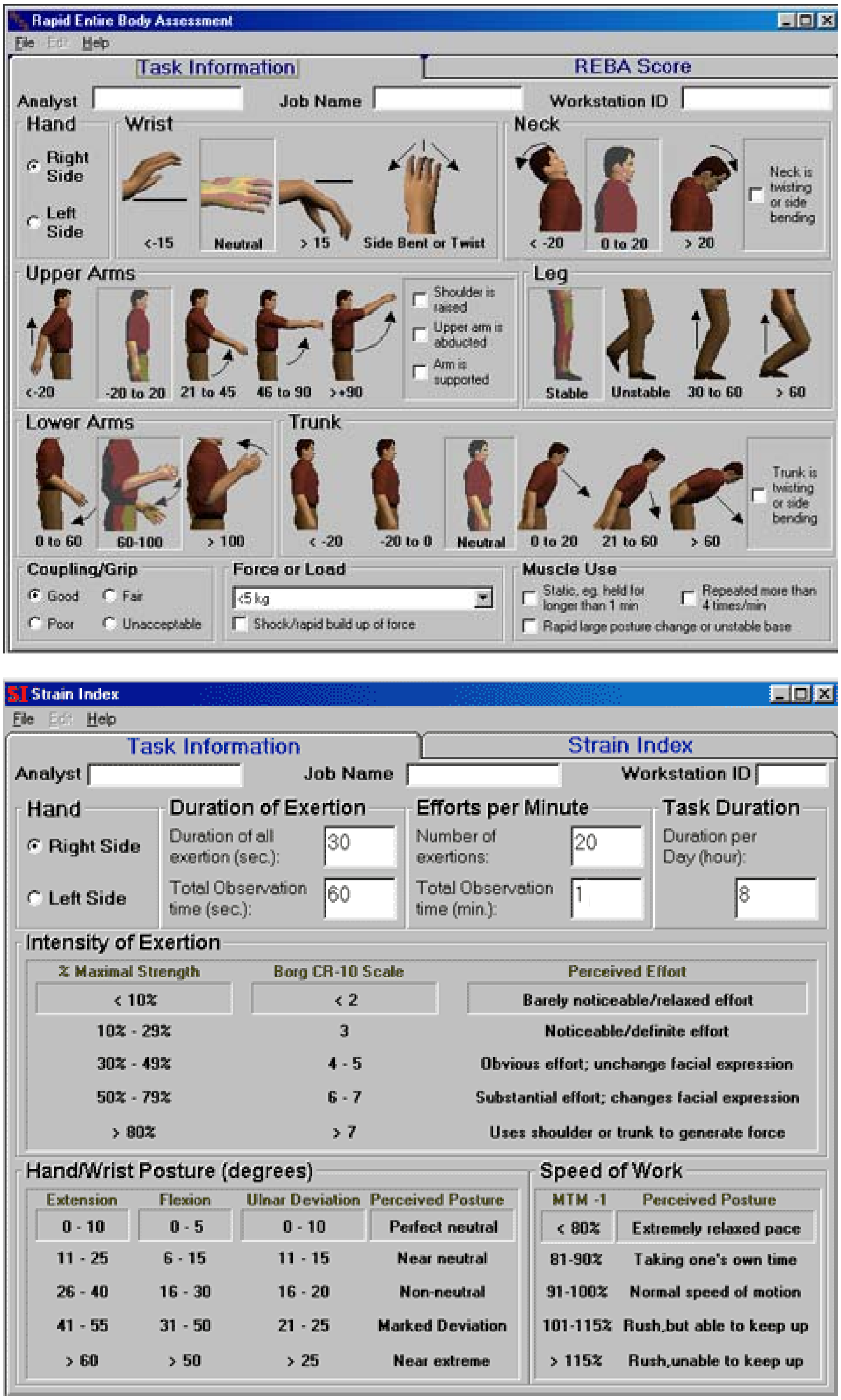


Figure E-9. ErgoIntelligence upper extremity assessment.
Top: rapid entire body assessment (REBA). Bottom: strain index. (from www.nexgenergo.com)

E.14 ErgoIntelligence™ MMH (Manual Material Handling)

Description

The ErgoIntelligence™ MMH (Manual Material Handling) modules focus on material handling applications and provide an in-depth risk analysis for low-back injury using the NIOSH Lifting Equation, Biomechanics, Energy Expenditure, Mital Tables and Snook & Ciriello Tables.

Tool/Method Content

ErgoIntelligence combines accepted manual material handling assessment tools into one integrated software package with a graphical user interface.

- There are two versions for the NIOSH Lifting Equation module (both incorporating Single and Multi-Task), with the PRO version including biomechanics and a manikin stick figure that can be manipulated.
- The Snook & Ciriello tables can be used for the evaluation and design of manual handling (lifting, lowering, pushing, pulling and carrying) tasks. Mital tables utilize the same population and database used in the Snook tables. However the values are adjusted for various biomechanical, physiological, and epidemiological criteria. In addition, the data is also adjusted for factors that are commonly found to be significantly affecting the maximum acceptable weight of industrial workers.
- The Job Severity Index (JSI) is based upon the ratio of the required weight of the lift to worker capacity. A JSI is a measure of the musculoskeletal strain based on weight handled, frequency of lifting, and a worker's physical capacity of lifting.
- The Energy Expenditure module is based on the assumption that a job can be divided into simple tasks and that the average metabolic energy rate of the job can be predicted by knowing the energy expenditure of the simple tasks and the time duration of the job. The Energy Expenditure module can be applied to stoop, squat, and arm lifts.

HSI Domains Addressed:

This tool addresses the safety domain; specifically Workstation Design, Physical Ergonomics, Manual Material Handling, and Task Analysis.

Questions Addressed:

- Is the lift/lower/carry/push/pull task safe?
- Where do the maximum forces occur during the task?
- What percentage of people are capable of performing this task?

Content Modeled:

- Tasks and task sequences

Model Granularity:

The model relies heavily on the quality of the task breakdown and input in to the analysis.

Communication

Form of Output, Terminology, and Taxonomic Conventions:

Graphical outputs suitable for reports are standard in this software package.

Computer Language and Interface Support:

Computer language is not an issue with these proprietary and self-contained tools. The tool set contains a full range of interfaces for data entry, analysis and reporting, as shown below.

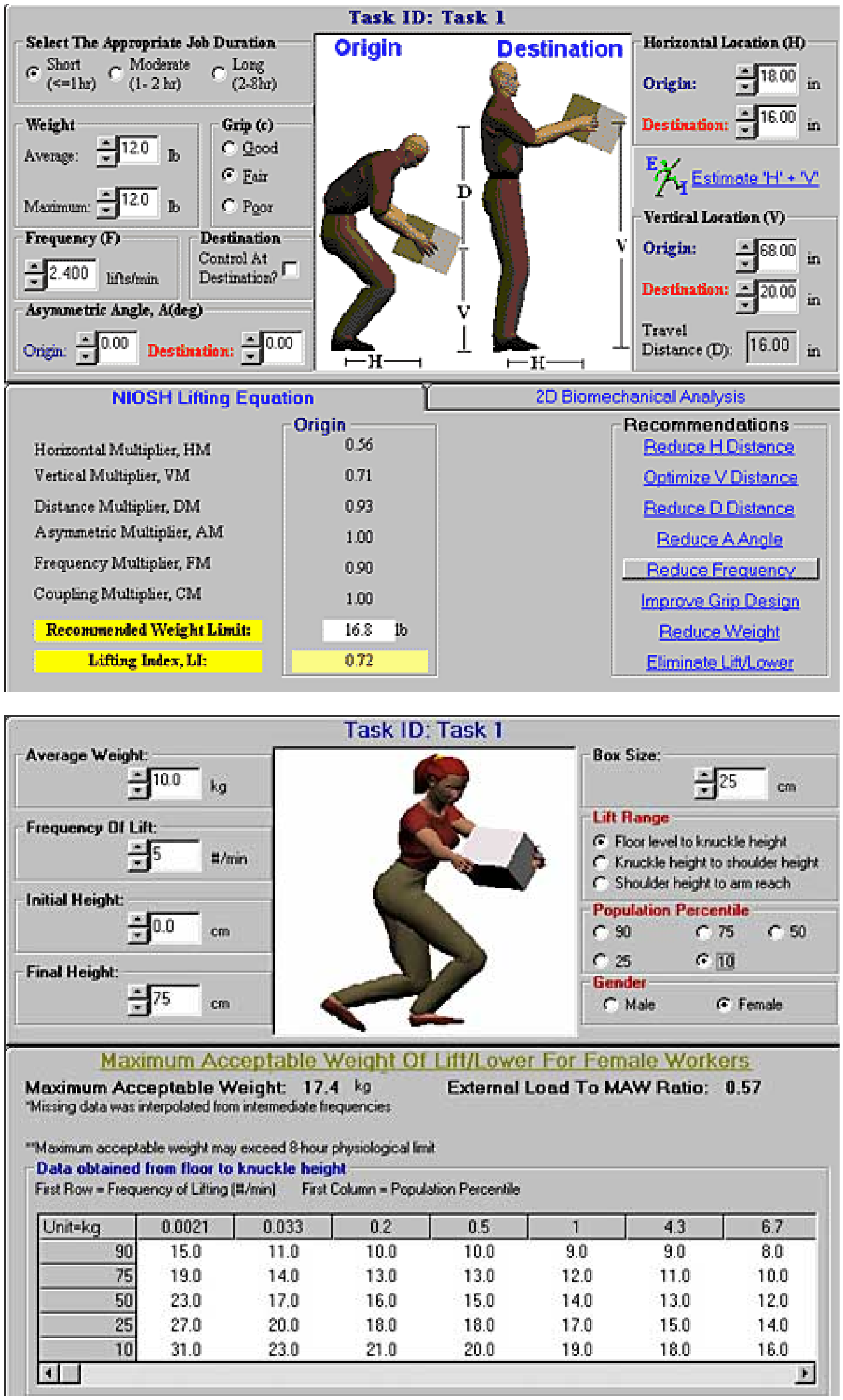


Figure E-10. ErgoIntelligence manual material handling input and analysis screens. (from www.nexgenergo.com)

Risk and Trade-off Management

Assumptions Regarding Risk:

This tool is to be used in conjunction with other analysis methods and should not be use alone to determine risk.

Traceability

Development Steps Supported:

Function analysis
Task design
Performance/workload/training estimation

Other Evaluation Criteria

Learning curve: Moderate

Reliability, Validity, and Platform Requirements:
ErgoIntelligence runs on Windows 2000/NT4 and Windows XP

Availability, Cost, and Contact Information:

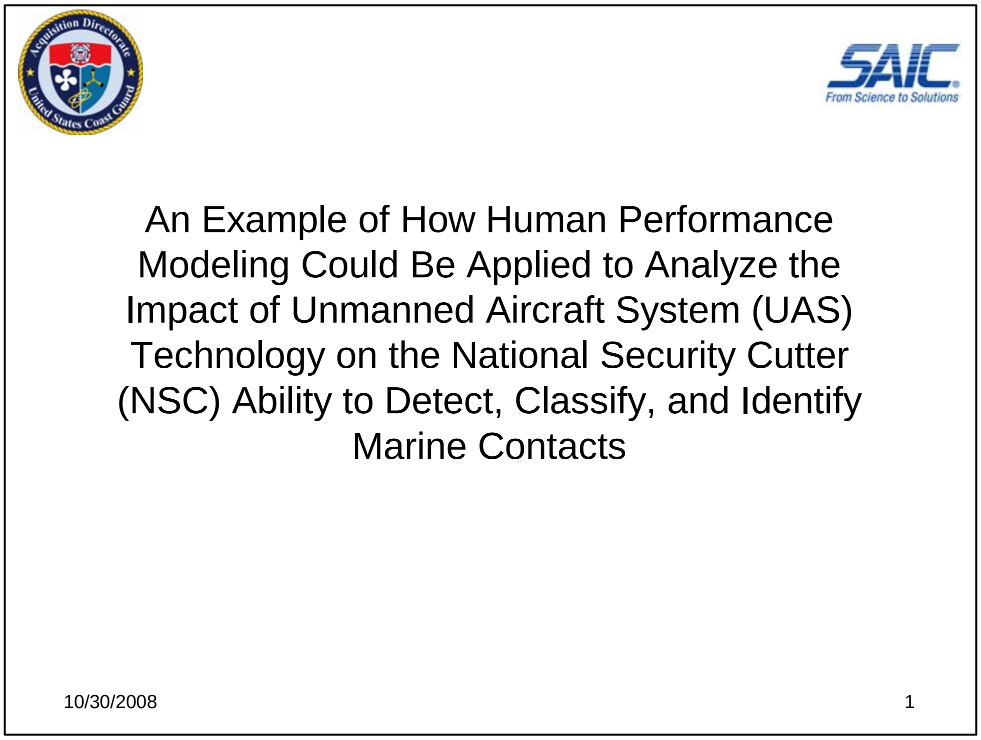
6600 Trans Canada Highway Suite 750
Pointe Claire (Montreal), Quebec
Canada
H9R 4S2
Telephone: (514) 685-8593
Fax: (514) 685-8687

This page intentionally left blank.

APPENDIX F. A NOTIONAL EXAMPLE OF HUMAN PERFORMANCE MODELING APPLICATION

This appendix provides the reader with an example of how human performance modeling is applied in the context of a notional study that evaluated the potential mission performance gains obtained by incorporating an Unmanned Aerial System (UAS) into the National Security Cutter (NSC) system. The example is provided as an annotated PowerPoint presentation. This appendix uses the notes pages from that presentation.

Slide 1



Human performance modeling is a powerful tool available to HSI professionals. Human performance models (HPM) provide a means for representing human performance computationally; enabling representation of the dynamics of human performance in complex systems and situations. This provides much better insight into emergent effects such as workload and situation awareness than can be gained from static task descriptions. When HPM are integrated with system and mission environment models and simulations, a more complete understanding of total system performance (people plus hardware and software components) and the effects of mission environment factors can be obtained. This set of slides provides an example of how human performance modeling could be applied to evaluate potential performance gains achievable by incorporating an Unmanned Aircraft System (UAS) into the National Security Cutter (NSC) system.

Slide 2

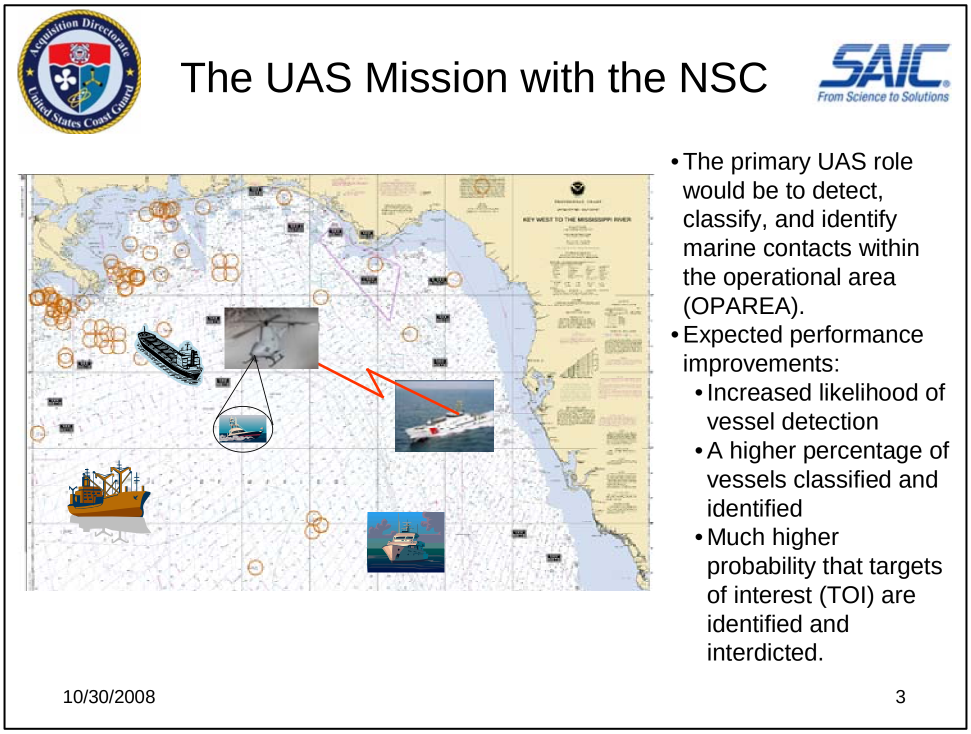
Some Caveats

- The purpose of the example is to illustrate how human performance modeling **could** be applied to support evaluation of a **notional** UAS use concept
- Coast Guard concepts for UAS use are still evolving
  - This example is not based on any particular UAS concept being considered
  - The HSI team did not want to distract attention from the purpose of the example by, perhaps, misstating a current concept
- Operational inaccuracies and inconsistencies might exist in the example
  - Please forgive and disregard these

10/30/2008 2

Before we begin with the discussion of the example, there are a few caveats that need to be made. First, this example is completely notional. It is not based on any existing UAS concept (that we are aware of) being pursued by the Coast Guard. While the Coast Guard is actively pursuing concepts and roles for UAS capabilities, those concepts are still evolving. We did not want to distract the audience from the message of our example by misstating a concept. Second, there might be operational inaccuracies and inconsistencies in the notional example presented. Please try to forgive and overlook these. Limited time and resources were available to develop the example and the team did the best we could.

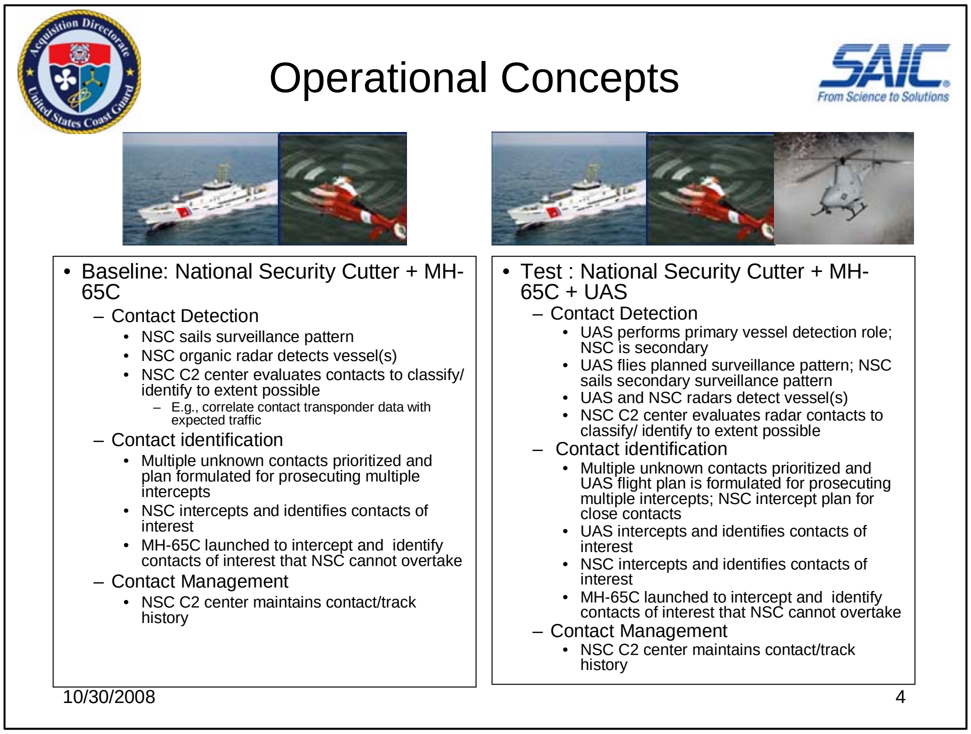
Slide 3



This slide depicts the mission context of our notional UAS-integrated-with-the-NSC example. In our notional example, the NSC's basic mission is to surveil a specified operational area (OPAREA); detect, classify, and identify vessels in that area; identify targets of interest (TOI) from the complete set of vessels in the OPAREA; and prosecute those TOI engaged in illegal or dangerous activity. The NSC can perform this mission using it's organic surveillance radar to detect and classify targets but the radar's range is limited. This fact coupled with the NSC's relatively slow speed combines to constrain the area that can be surveiled effectively.

The UAS has its own surveillance radar and travels at much higher speeds than the NSC. Consequently, the UAS can extend significantly the size of the OPAREA that can be covered. The effect on mission performance should be to increase the likelihood that vessels in the OPAREA are detected, classified, and identified. Equally, the likelihood that TOI are found among the detected and classified vessels should be increased. Hence, the mission effectiveness of the NSC system should be improved significantly.

Slide 4

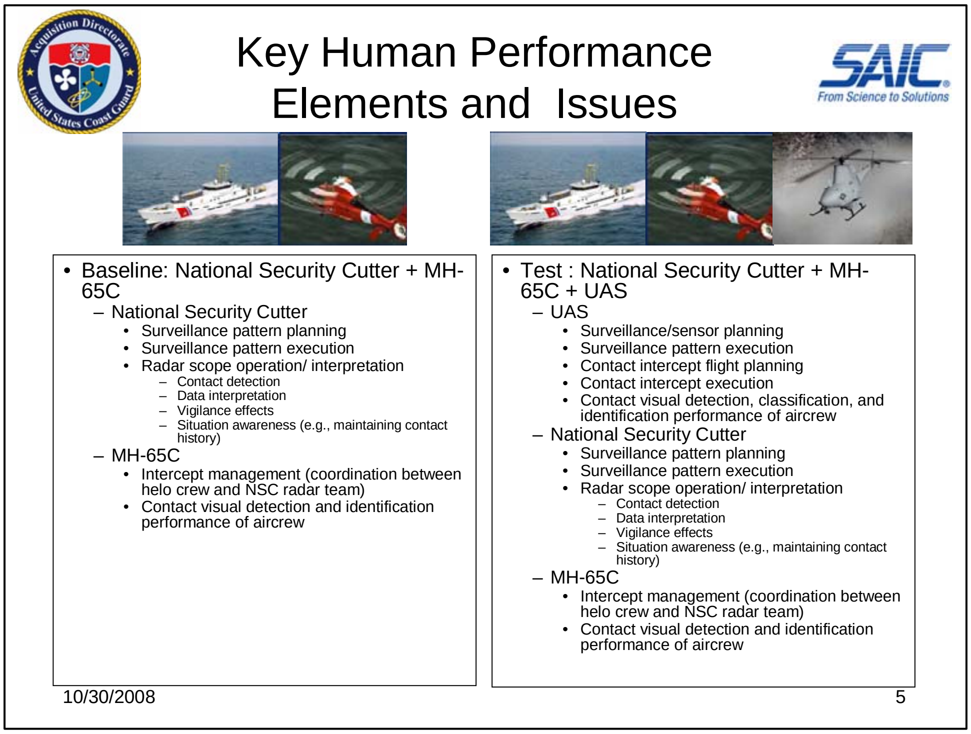


In order to evaluate the magnitude of any effectiveness gains offered by UAS technology, simulations will be developed that represent current (baseline condition) NSC capabilities and the addition of a UAS capability (the test condition) to the NSC and that exercise those capabilities in the context of surveillance missions in an operational environment. The NSC and UAS simulations must incorporate behaviors that reflect the concepts of operations (CONOPS) that drive system employment. This slide outlines the notional CONOPS associated with the NSC and UAS capabilities.

The baseline NSC capability consists of the ship itself and one MH-65C helicopter that operates off the ship. Within the OPAREA the NSC would sail a surveillance pattern and use it’s onboard radar to search for and detect vessels. Radar operators in the NSC Combat Information Center (CIC) would examine the radar data and other available information (e.g., Automated Identification System or AIS data) to classify the vessels. Contacts would be evaluated to determine which are possible targets of interest. In instances in which multiple contacts are found in the same area, personnel in the CIC will prioritize the contacts and formulate a plan for prosecuting them. In some instances the NSC itself will intercept a TOI. In other instances the MH-65C will be launched to intercept and identify the target. Regardless of which capability is used to make the identification, a key function throughout the mission will be to keep track of vessels that have been detected, classified, and identified so that valuable time is not wasted re-identifying vessels that have been previously identified. This function will be performed in the CIC.

The test condition adds a UAS to the NSC plus MH-65C baseline capability. The UAS has its own surveillance and imaging radar and electro-optical (EO) and infrared (IR) sensor capabilities. The UAS would launch from the NSC and use its surveillance radar and speed to surveil a large portion of the OPAREA. The UAS surveillance route would complement the route sailed by the NSC to maximize the area covered. UAS surveillance radar data would be fed to the NSC CIC to provide a common operating picture of contacts. When needed the UAS imaging radar would be used to provide additional target classification data. As in the baseline condition, CIC personnel would determine potential TOI from among the contacts and, in the case of multiple contacts, prioritize the contacts and formulate a plan for intercepting and identifying the TOI. The UAS would be the primary means for accomplishing TOI identification but the MH-65C and even the NSC could be used to make identifications in instances in which greater efficiency is obtained by not diverting the UAS from its current activities. As in the baseline condition, a key CIC function throughout the mission will be to keep track of vessels that have been detected, classified, and identified.

Slide 5



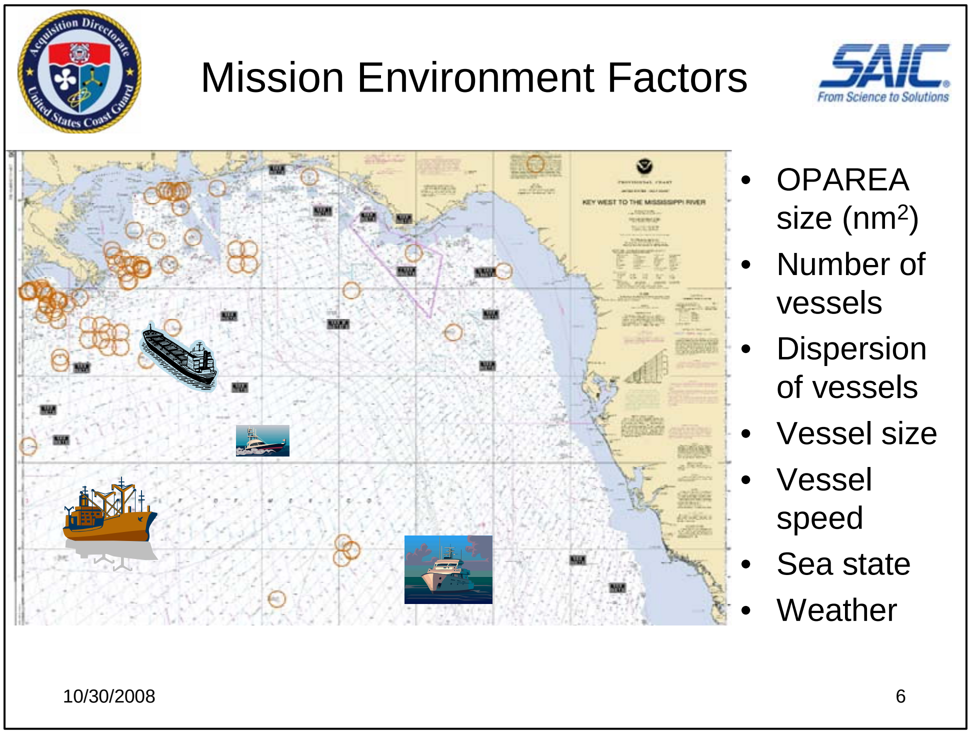
Human performance modeling will be one of the simulation technologies applied in our notional NSC-UAS example. A first step to developing human performance models is to identify the human behaviors to be modeled. This slide specifies key human behaviors to be modeled in the baseline and test conditions. It is important to understand that human performance modeling does not involve detailed modeling of all human activities performed in a system. (Like all hardware and software elements of a system will not be modeled in detail in a system simulation.) The focus of human performance modeling will be on those human-mediated activities that are most directly related to the mission or functions of interest. In our notional example this will be the personnel and activities involved in conducting the surveillance mission and detecting, classifying and identifying targets of interest.

In the baseline condition this includes bridge/navigation personnel and their development and execution of the surveillance patterns the NSC will sail. It also includes the Combat Information Center (CIC) personnel that operate and monitor the NSC's surveillance radar and data systems to detect and classify vessels, identify TOI, and maintain contact histories. Given that the MH-65C will perform most of the target intercepts required for the identification process, it also will be important to model the aircrew's activities. Executing the intercept and performing a visual identification will be included in these.

In the test condition, the NSC and MH-65C personnel and activities described above would be modeled and the activities of the UAS crew would be added. UAS crew activities would include surveillance pattern planning and execution (similar to the surveillance pattern planning required by the NSC), contact intercept execution (similar to that performed by the MH-65C), and visual identification of TOI by the UAS aircrew (similar to the MH-65C).

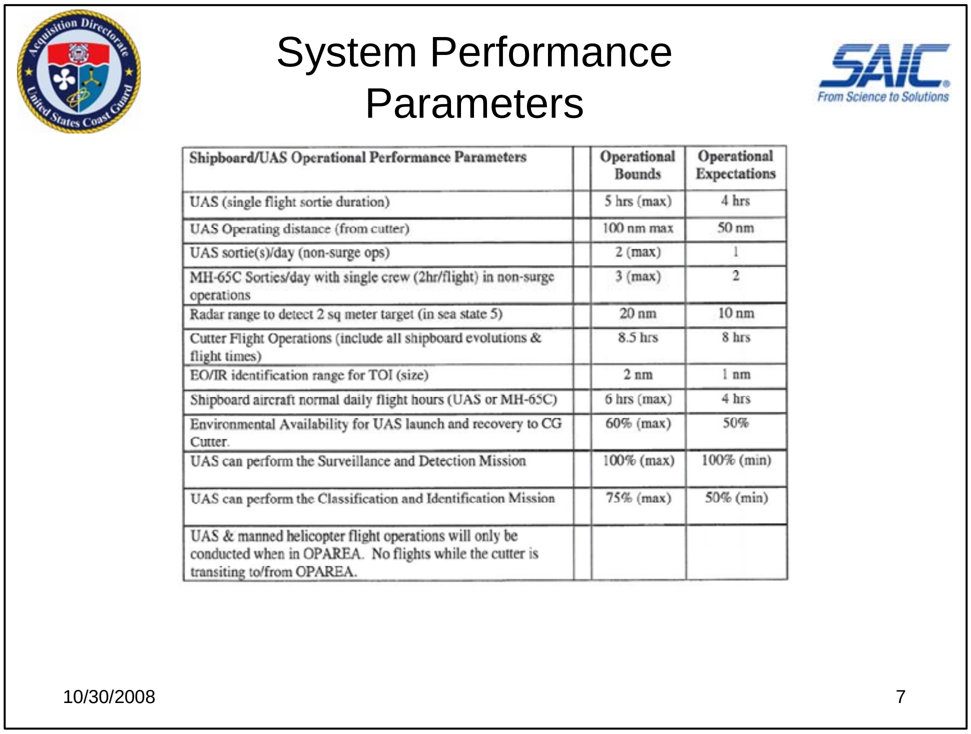
Note that the UAS aircrew shares performances that are similar to both the NSC and the MH-65C. This is important information to the human performance modeler because it suggests opportunities to reuse model elements across test conditions. Implementing a model architecture that supports reuse of model components across test conditions can result in significant savings in the cost, time, and effort required to build the human performance models. Note that while there are similarities in the tasks and activities performed by different teams, detailed elements of task performance might differ. For example, the algorithms that calculate probability of target detection and identification using the naked eye or optical aids by the MH-65C aircrew might use minutes of arc subtended by the target. The algorithms that calculate probability of target detection and identification using the UAS camera by the MH-65C aircrew might use pixels subtended on the video display by the target. Consequently, even when model components are reused it sometimes is necessary to adapt elements to fit a slightly different performance requirement.

Slide 6



A particular area of interest in our study will be how factors related to the mission environment affect overall mission performance. The mission being performed is one of surveillance; detection, classification, and identification of vessels in the OPAREA; and identification of particular TOI. Factors in the environment that can affect the mission will include the size of the OPAREA to be surveiled; the number, types, and sizes of vessels to be detected and identified; the speed of the different vessels; the extent to which vessels are scattered across the OPAREA; sea states; and weather. A test plan would be developed that defines test conditions made up of unique combinations of levels of these factors. When the test plan is executed and data are collected, statistical and other analyses will use the mission environment factors as a basis for organizing the analysis, characterizing results, and extrapolating results into environment states not tested.

Slide 7



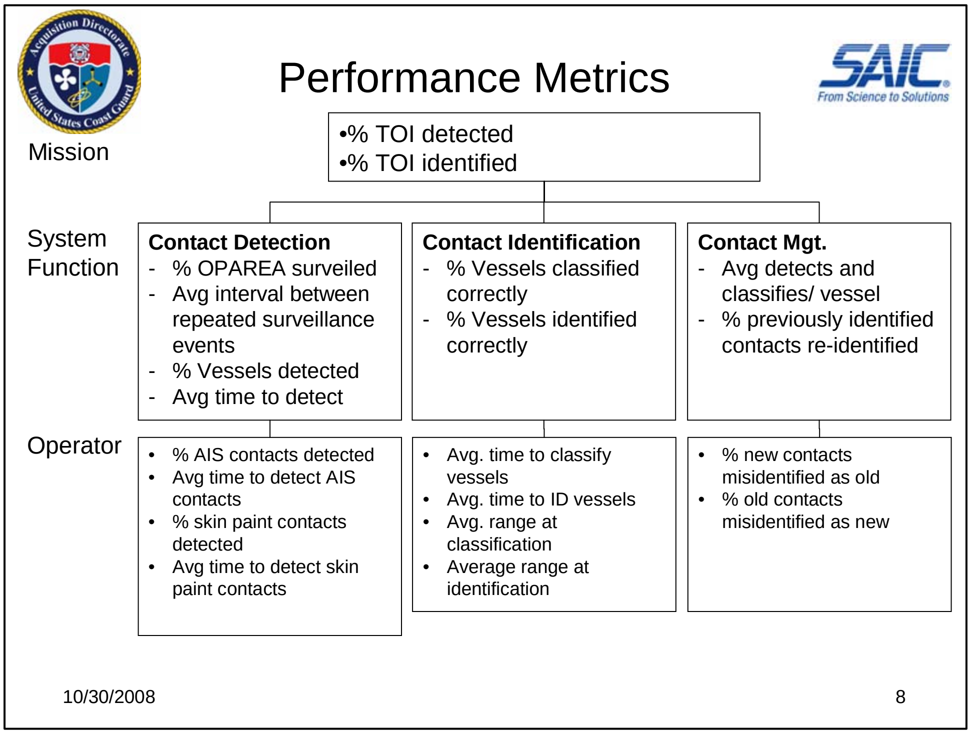
System Performance Parameters

Shipboard/UAS Operational Performance Parameters	Operational Bounds	Operational Expectations
UAS (single flight sortie duration)	5 hrs (max)	4 hrs
UAS Operating distance (from cutter)	100 nm max	50 nm
UAS sortie(s)/day (non-surge ops)	2 (max)	1
MH-65C Sorties/day with single crew (2hr/flight) in non-surge operations	3 (max)	2
Radar range to detect 2 sq meter target (in sea state 5)	20 nm	10 nm
Cutter Flight Operations (include all shipboard evolutions & flight times)	8.5 hrs	8 hrs
EO/IR identification range for TOI (size)	2 nm	1 nm
Shipboard aircraft normal daily flight hours (UAS or MH-65C)	6 hrs (max)	4 hrs
Environmental Availability for UAS launch and recovery to CG Cutter.	60% (max)	50%
UAS can perform the Surveillance and Detection Mission	100% (max)	100% (min)
UAS can perform the Classification and Identification Mission	75% (max)	50% (min)
UAS & manned helicopter flight operations will only be conducted when in OPAREA. No flights while the cutter is transiting to/from OPAREA.		

10/30/2008 7

In our notional study NSC, MH-65C, and UAS platform hardware and software functionality will be modeled in addition to human performance. This is necessary to represent the "total system." Modeling the platforms also is important as a means of establishing bounds for human performance (e.g., range and resolution of the UAS optical sensor). This slide lists some system performance parameters that were specified for a previous USCG UAS study. Note that parameters are not always physical factors. They can be operational factors as well. Factors like sorties per day and sortie duration also are important because they establish operational bounds on UAS performance that ultimately affect mission factors such as the size of the area that can be surveiled in a twenty-four hour period.

Slide 8



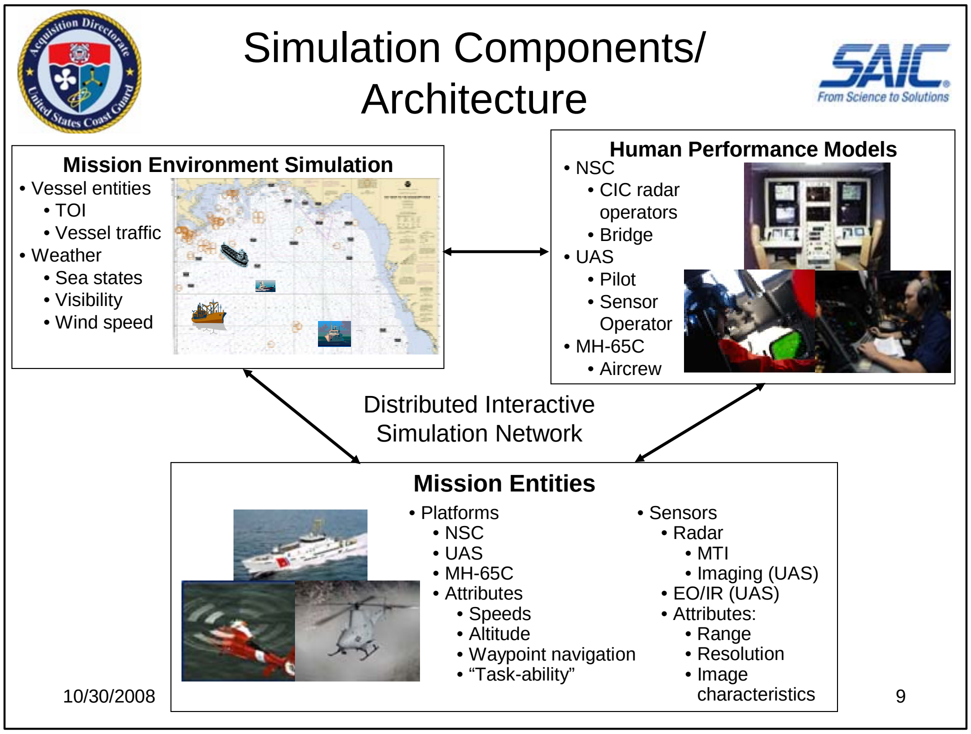
Ultimately, the purpose of modeling and simulation is to produce data that informs acquisition decision-makers about factors related to an acquisition. Typically, these data provide measures of simulation outcomes. Outcomes usually are measured at multiple levels of system decomposition. Mission performance measures are the highest level of assessment. Mission performance measures provide a sort of bottom-line for comparing overall performance among the alternatives. Performance measurement schemes also include other lower level measures that assess operation of key mission functions and system components and elements. These measures provide an in-depth understanding of how lower level system capabilities contribute to (or detract from) overall mission performance.

This slide offers some performance measures that could be used in our notional UAS study. At the mission level measures are focused on assessing the essential outcomes of the surveillance mission. In the context of our notional study the mission of the NSC system is to find and correctly identify targets of interest. Mission performance is perfect when TOI detections and identifications are 100%.

At the system level there are enabling functions that must be accomplished if the mission is to be successful. The first is to simply detect vessels in the OPAREA. The ability to detect vessels is directly related to the ability to surveil the entire OPAREA. Given that the OPAREA probably is larger than the area that can be surveiled by a sensor from one location in the OPAREA, a surveillance pattern must be established that allows the OPAREA to be covered. When OPAREA size is combined with sensor “footprint” (the area a surveillance sensor can cover) and surveillance platform speed, another important factor that emerges is how often segments of the OPAREA are surveiled. This is important because vessels move through the OPAREA over time. Ideally, surveillance intervals for portions of the OPAREA must be sufficiently short to ensure that a vessel crossing through the OPAREA is detected. The % of vessels detected provides an overall evaluation of the detection function. The average time to detect vessels entering the OPAREA is a measure of the efficiency of the detection process. Vessel identification is another key enabling function. There are two steps in the identification process. The first is to classify a vessel (e.g., type, size). The second is to identify it (e.g., registration, name, country of origin). Errors in either step can lead to TOI not being identified correctly. Finally, contact management is the process of keeping track of vessels that have been detected, classified, and identified so that valuable time is not spent performing that process yet again. The average number of detections and classifications of a vessel is a measure that recognizes that a vessel might be detected multiple times by sensors as it crosses the OPAREA and the NSC conducts its surveillance route. The detection event will require some classification activity for the NSC crew to deduce that it is a previously identified vessel. The measure of contact management efficiency is the % of previously identified contacts that are re-identified. The larger the number the more time that is being wasted on re-identifications.

People perform critical roles in the contact detection, identification, and management processes and some possible human performance measures are offered in the slide. Visual observation of radar screens is described as a vigilance task because operator must be “vigilant” to detect the appearance of a target symbol at any time on any portion of the display. In our notional study the probability that a NSC radar operator detects radar contacts of vessels would be determined jointly by factors such as the assumed visual capabilities of the operator, the duration of the contact symbol on the display, the proximity of the contact to other contacts, and the number of times the vessel comes within the NSC's surveillance pattern over the course of a mission. Thus, the human performance outcome is only partially deterministic, based on HPM parameters. The actual performance observed is the confluence of a number of "real world" factors. In our notional example there are two different types of contact that operators would detect. The first is Automatic Detection System (AIS) contacts. AIS uses radio broadcast of digital data about a vessel to provide course, speed, and other data about that vessel to other vessels within radio range. AIS data are displayed with symbols and labels that are expected to be more readily detected than the other category of contacts, which is "skin paints." Skin paints are radar generated symbols that indicate objects the radar has detected. Two measures are used for each contact type. One is the % of contacts detected by the operator. The other is the average time required to detect a contact once it is displayed on the radar. Operator classification and identification performance is captured by measures of time and range. Lower times mean more efficient performance. Conversely, longer ranges also mean more efficient performance because less time is needed to get close enough to make a classification or identification decision. Finally, contact management is measured in terms of errors that operators can make in determining whether a detected vessel is one previously identified or is a new vessel that has not been identified. Instances in which a new contact is misidentified as an old one means that an identification process might not be performed. This makes it possible to overlook a TOI. Instances in which old contacts are misidentified as a new one means that time will be wasted re-identifying a vessel.

Slide 9



In our notional study, a simulation environment is envisioned that consists of three major components. The mission environment simulation would provide entities that represent the TOI and other vessel traffic in the OPAREA. It also would provide the capability to simulate sea states, weather, and other environmental factors that can affect mission performance. Multiple simulations might be used to represent these elements of the mission environment.

The mission entities component of the testbed would provide the simulations of the NSC, MH-65C, and UAS platforms and sensors. Attributes of the platforms that would be modeled include cruising and intercept speeds, operating altitudes, waypoint navigation (following a preplanned surveillance or other route through a series of waypoints), and "task-ability." Task-ability is a particularly important feature. It means the ability to receive and respond to directions to change course and speed to perform maneuvers such as intercepting a vessel so it can be identified. One of the functions of the different NSC platform crews modeled in the HPM will be to make decisions regarding which vessels to intercept and when. The different NSC platform entities must be able to implement these decisions. Because surveillance is such a significant portion of the mission in our notional study, modeling the sensors used by the different NSC platforms is essential. This includes representing both the types of sensors (radar, EO, and IR) and their modes (e.g., moving target indicator mode or MTI and imaging for the radars). We should point out that sensor modeling in the context of this example would not include generating actual images. Rather, it would consist of generating data about an image or other output of the sensor. The model for an EO sensor, for example, might combine data on target size, shape, orientation, and range with information on mode and resolution of the sensor to estimate the number of pixels the target would occupy on the EO display. The HPM would use this data to determine whether and-or when the target is detected or identified.

The human performance model component would represent the NSC platform personnel performing key mission activities. These would include personnel that man the CIC and bridge on the cutter as well as the UAS pilot and sensor operator, and the MH-65 aircrew. Specific performances that would be modeled are presented on the next slide.

Slide 10

Modeled Human Performance

- NSC
  - CIC Personnel
    - Monitor NSC radar display
    - Detect contacts
    - Evaluate/ classify contacts
    - Determine contacts requiring intercept and identification
    - Coordinate intercept with bridge, MH-65C, or UAS
    - Maintain contact history/ situation awareness
  - Bridge
    - Determine intercept course
    - Execute intercept
- UAS
  - Pilot
    - Take-offs and landings from NSC
    - Determine waypoints based on planned routes and intercept routes
- UAS (Continued)
  - Pilot (Continued)
    - Enter waypoints
    - Manage airspeed and position during intercept and orbit
  - Sensor operator
    - Coordinate radar surveillance with CIC
    - Acquire vessel with EO/IR sensor during intercepts
    - Coordinate UAS positioning with pilot to obtain positive ID vessel
- MH-65C
  - Pilots
    - Take-offs and landings from NSC
    - Coordinate intercept with CIC
  - Aircrew
    - Visually acquire, classify, and identify vessel

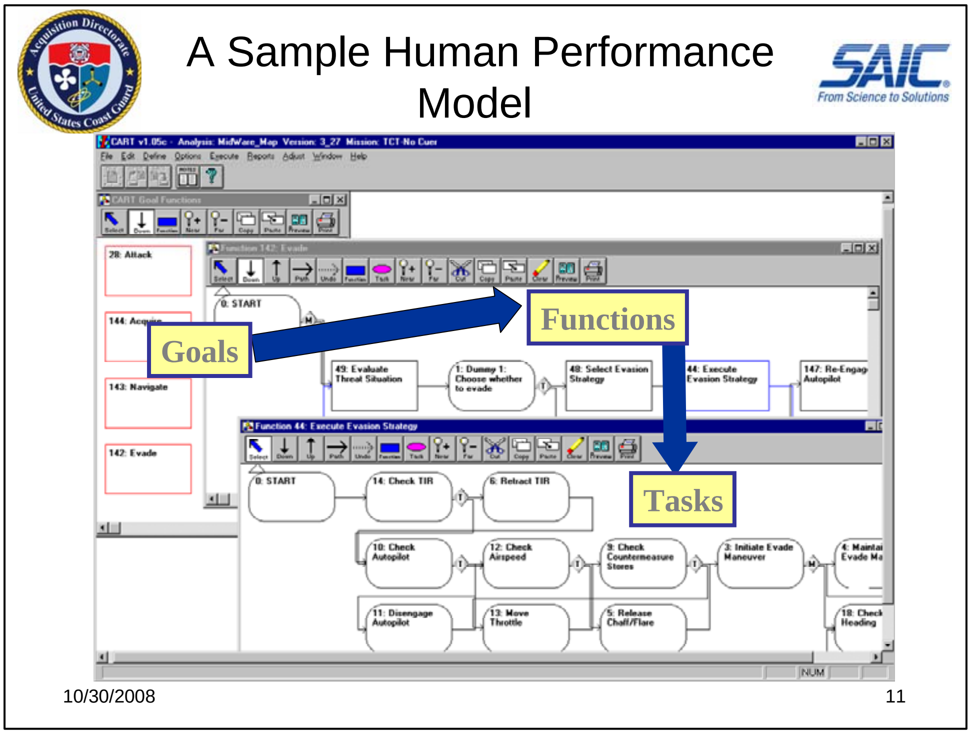
10/30/2008 10

While the NSC is a large vessel with a sizeable crew, only are small number of personnel will be modeled in our notional study. This reflects a fundamental principle of modeling and simulation, which is to focus modeling efforts on those factors that really matter. For the purposes of our study we assume that if everyone else in the NSC system does their jobs correctly then it is the personnel listed on this slide that will affect the outcome of the surveillance mission. Among the standard personnel complement of the cutter it is personnel from the CIC and bridge personnel that are most involved in mission execution. The behaviors that we would model for CIC personnel consists of monitoring the NSC radar display to detect contacts, evaluate and classify those contacts, determine which contacts are possible TOI and require intercept, coordinate target intercept with the platform making the intercept, and maintaining a contact history in an effort to avoid re-identifying previously identified targets. Modeling of the cutter bridge personnel is limited to planning and executing intercepts (when the cutter is making the intercept). Note that surveillance route planning, which was listed as a key mission behavior earlier in the briefing, is not listed as a modeled behavior. This is because the surveillance route or pattern would be determined prior to mission execution and would be part of the platform script. Consequently, the HPM would not be generating these routes.

Both UAS pilot and sensor operator performance would modeled. Key pilot behaviors that would be modeled include take-offs and landing from the NSC; determining and entering waypoints based on planned routes and intercept routes (in many UAS pilots do not actually manipulate stick and throttle controls; they enter waypoint data into a mission computer and automation software flies the UAS to the waypoint); and managing the positioning of the UAS so that a target remains in the sensor view or a target intercept is achieved. The sensor operator model would need to coordinate UAS radar surveillance with the CIC. Remember, the CONOPS requires integrating the cutter and UAS radars to maximize OPAREA coverage. This requires some coordination between CIC radar operators and the UAS, particularly when there is overlapping coverage and common targets must be resolved. The sensor operator also must employ the EO and-or IR sensors to identify targets. Finally and as part of the intercept and the identification processes, the sensor operator must coordinate with the pilot to ensure that the UAS is positioned such that the sensor operator keeps the target in view and obtains good imagery of the target.

The most limited portion of the human performance modeling would be with the MH-65C aircrew. Here we would model take-offs and landings from the NSC; coordinating target intercepts with CIC; and visually acquiring, classifying, and identifying vessels.

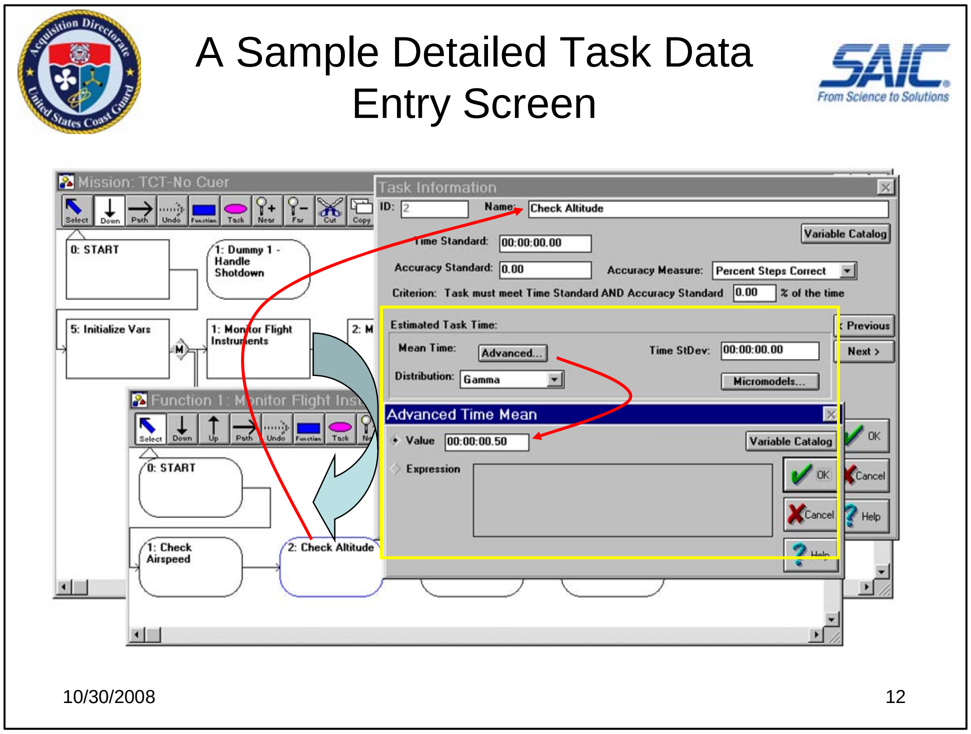
Slide 11



To create an actual human perform model, the behavioral descriptions provided in the previous slide would be transformed into HPM elements within a human performance modeling environment. This slide shows a human performance model constructed using the Army Research laboratory's Improved Performance Research Integration Tool (IMPRINT) environment. IMPRINT uses task network modeling to represent human performance. As the name implies, task networks use a flow chart type format to specify detailed task performance sequences, decision points, and branches. Task networks are organized in terms of higher-level functions. Functions are organized in terms of goal states. Goals states are a concept from cognitive psychology. The idea is that goals provide an executive function that organizes and controls behavior. Goals are triggered by conditions in the mission environment that the performer needs to maintain within certain limits. For example, a navigation goal state would be triggered in a pilot when he/she determines the aircraft is off course. Once the goal state triggers, lower-level functions and tasks would be activated to bring the airplane back on course (restore performance within desired limits).

Modeling environments such as IMPRINT generally have two major components. The first is a model development module. In IMPRINT this is a graphical interface in which the user specifies goals, functions, and tasks and arranges their organization and sequences. The user also enters data that controls how the goals, functions, and tasks execute. These data include trigger criteria, task performance times and variances, task output and effects data, and behavioral process algorithms (e.g., visual detection and identification, information processing, etc.). The second component is a runtime module. This module actually executes the model, manages time, generates and collects data, and manages any interfaces to other models and simulations. Task networks similar to those shown in the slide would be developed for each of the NSC system personnel modeled in our notional example.

Slide 12



Defining model elements is only one part of the model development process. Once tasks have been specified, data must be provided that governs how the task executes. The simplest constituent of task data is task performance time. This slide shows an IMPRINT data screen for entering task performance time data for a task. Other more complex data might be entered for tasks also. These data often are entered in “effects” fields provided by other IMPRINT screens. Effects data are used to describe detailed task performance and capture the output of that performance. Effects data can be entered as expressions, algorithms, and even computer code. Often effects data are used to model behavioral processes involved in a task. In our notional example these would include modeling visual perception of vessels, and remembering vessels that have been identified.

Slide 13

Key Performance Moderators Modeled

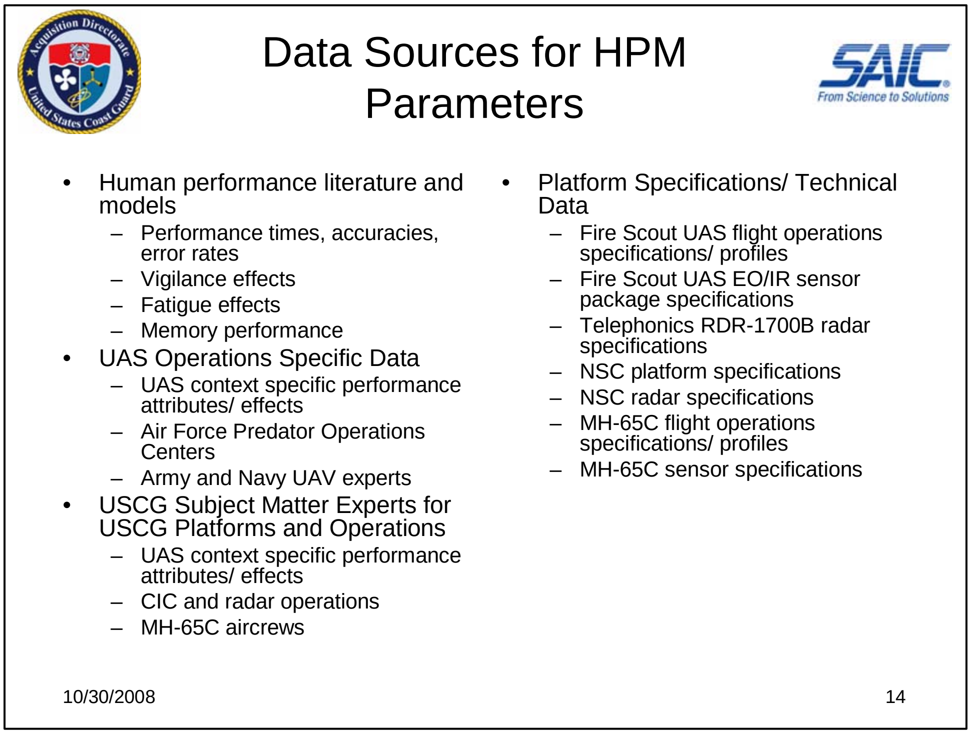
- Vigilance
  - A factor in sustained attention tasks that typically require observers to monitor displays over extended periods. The likelihood of detecting events of interest varies as a function of time, event density, and attributes of the displayed event data.
  - In this study the primary effects would be on detection of radar contacts.
- Fatigue
  - A complex state affected by factors such as how long an individual has been awake, the duration of recent sleep, where an individual is in his or her circadian cycle of alertness; physical, cognitive, and or attentional demands of the job.
  - In this study the primary effects would be on detection of radar contacts (a potential interaction with vigilance) as well as the time and accuracy of acquiring, classifying, and identifying vessels visually and with the UAS EO/IR capability.
- Memory
  - The ability to retain and recall information quickly and accurately.
  - In this study the primary effects would be on determining which contacts have been identified already so that time is not wasted re-identifying them.

10/30/2008 13

In the previous slides we have discussed modeling in terms of representing performance and effects at the level of tasks. But, there are behavioral processes that operate over time and can affect performance across tasks. These often are referred to as performance moderators. Within the context of our notional example there are several that should be considered as part of the human performance modeling effort.

Vigilance is a factor in sustained attention tasks that typically require observers to monitor displays over extended periods. The likelihood of detecting events of interest varies as a function of time, event density, and attributes of the displayed event data. In our notional study the primary effects would be on detection of radar contacts. Fatigue is a complex state affected by factors such as how long an individual has been awake, the duration of recent sleep, where an individual is in his or her circadian cycle of alertness; physical, cognitive, and-or attentional demands of the job. In this study the primary effects would be on detection of radar contacts (a potential interaction with vigilance) as well as the time and accuracy of acquiring, classifying, and identifying vessels visually and with the UAS EO/IR capability. Memory is the ability to retain and recall information quickly and accurately. In this study the primary effects would be on determining which contacts have been identified already so that time is not wasted re-identifying them.

Slide 14

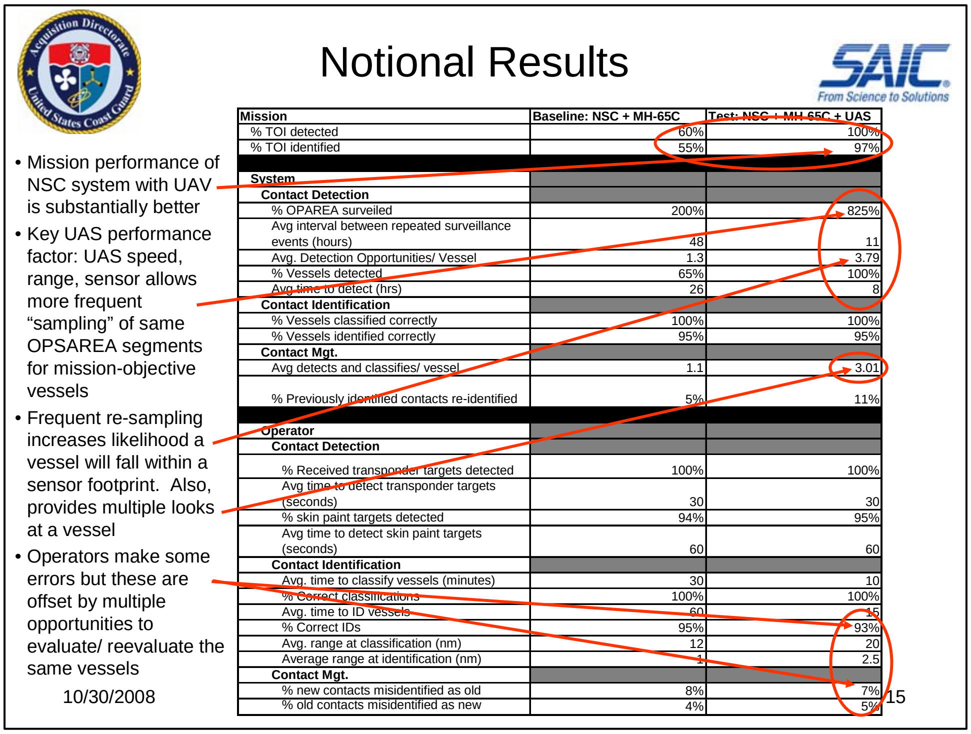


A particularly important part of the human performance modeling process is obtaining the data need to set parameters within the HPM and provide the algorithms for the behavioral processes that need to be modeled. The data used can significantly affect the validity of the HPM that is produced. This slide presents some possible data sources and types that could be used in our notional scenario.

The first source is the behavioral science literature on human performance. This can be a rich source of information, particularly for fairly common behaviors (e.g., visual detection of different objects and data) and behavioral processes (e.g., fatigue, memory effects). Often, however, other sources are needed to gain insight into the platform or operational-specific performances and data required by a model. Operational and platform-specific documents on systems, operations, doctrine and tactics and subject matter experts (SME) are the sources of this information. We would anticipate using two operational data sources for our notional study. One would be defense organizations that currently are using UAS operationally. This includes the Air Force, Navy, and

Army. Because UAS are new to the USCG, there is no experience base from which to obtain operationally-related UAS data. By interacting with experts from the other services we can obtain data on UAS context specific performance attributes and effects that we can incorporate into our models and simulations. This will help us model UAS processes and tactics more realistically. Similarly, it is important to accurately model processes and activities of CIC and MH-65C personnel. USCG SME would be used to obtain this data. Finally, it will be important to have accurate operational data for the NSC platforms and sensors that the HPM employs to conduct the surveillance mission. These system components provide capabilities that both enable and constrain mission performance by NSC personnel. This slide lists some of the platform specific data that would be of interest. The Fire Scout UAS is used here as an example UAS. The Fire Scout is currently in use by the Navy and is one of the UAS being considered by the USCG.

Slide 15



Mission	Baseline: NSC + MH-65C	Test: NSC + MH-65C + UAS
% TOI detected	60%	100%
% TOI identified	55%	97%
System		
Contact Detection		
% OPAREA surveiled	200%	825%
Avg interval between repeated surveillance events (hours)	48	11
Avg. Detection Opportunities/ Vessel	1.3	3.79
% Vessels detected	65%	100%
Avg time to detect (hrs)	26	8
Contact Identification		
% Vessels classified correctly	100%	100%
% Vessels identified correctly	95%	95%
Contact Mgt.		
Avg detects and classifies/ vessel	1.1	3.01
% Previously identified contacts re-identified	5%	11%
Operator		
Contact Detection		
% Received transponder targets detected	100%	100%
Avg time to detect transponder targets (seconds)	30	30
% skin paint targets detected	94%	95%
Avg time to detect skin paint targets (seconds)	60	60
Contact Identification		
Avg. time to classify vessels (minutes)	30	10
% Correct classifications	100%	100%
Avg. time to ID vessels	60	15
% Correct IDs	95%	93%
Avg. range at classification (nm)	12	20
Average range at identification (nm)	1	2.5
Contact Mgt.		
% new contacts misidentified as old	8%	7%
% old contacts misidentified as new	4%	5%

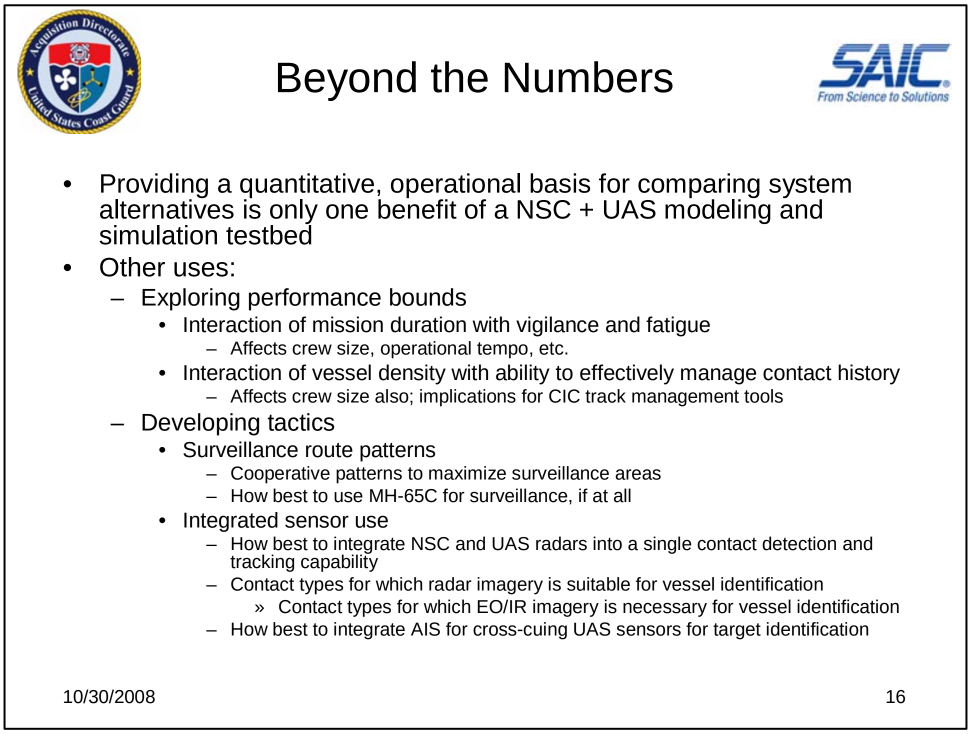
This slide presents some very notional results that might be obtained from our notional study. The intention of this slide is to demonstrate how simulation data can provide insight to the performance of system alternatives and where and why differences occur. Not unexpectedly, the data show that the UAS enabled NSC out performs the baseline NSC significantly. The lower level data explain why.

The main reason is that the UAS does a much better job surveiling the OPAREA. A score of 825% on the "% OPAREA Surveiled" measure means that the UAS covered the entire OPAREA eight times over the duration of the mission. (Remember the OPAREA is larger than the sensor footprint of the UAS so the UAS must fly a surveillance pattern to cover the OPAREA.) This means that portions of the OPAREA are revisited more frequently by the UAS than the cutter, which only covered 200% of the OPAREA. The result is that the UAS has more opportunities to detect vessels passing through the OPAREA. This is demonstrated in the "Average Number of Detection Opportunities per Vessel" metric. The ultimate effect is seen in the "% Vessels

Detected" metric: 100% for the UAS versus 65% for the cutter alone. Interestingly, a side effect of the UAS's more effective coverage of the OPAREA is the greater number of "Average Detects and Classifies per Vessel." This suggests that the contact management job probably is more difficult when using the UAS because targets are revisited more often and there are more opportunities to get confused and re-identify an old target.

Finally and as regards operator performance, there is relatively little difference between contact detection and identification metrics. To some extent this is not surprising given the nature of the tasks are similar across the different systems. The most remarkable result is the interaction of the "% Correct IDs" metric with the operator contact management metrics and the system level contact management metrics. Overall the operator model correctly identified vessels only 93% of the time but at the mission level 97% of the TOIs were identified correctly. This difference is due to the fact that because the UAS revisited targets more often than the cutter, the UAS sensor operator had more opportunities to correct wrong IDs. This ultimately led to more effective overall mission performance.

Slide 16



While most of this presentation has focused on modeling and simulation as a means to generate data for acquisition decision-making there are other benefits that should be highlighted as well. Some of these are listed on this slide. Exploring performance bounds is accomplished by adjusting system or mission environment parameters until mission performance becomes unacceptable. For example, this might include adjusting OPAREA size or number of vessels in the area beyond expected limits until the mission fails. This will provide insight into the robustness of the system and its ultimate capacity. Exploring boundaries also could involve manipulating factors such as mission duration and number of vessels surveiled to obtain a better understand of possible human performance limits. This information can help resolve HSI issues such as crew size, watch length, sorties per day, etc.

Another powerful application of modeling and simulation is the development of tactics for a new systems. Often, system developers don't have a complete understanding of the ways to employ new technologies and capabilities that maximize mission performance. Simulation provides a means of experimenting with different concepts, processes, and tactics and objectively measuring the outcomes to determine what works best. Our notional testbed described in the example could be used to address issues such as the most effective cooperative surveillance patterns for the UAS and cutter that maximize OPAREA coverage and how best to incorporate the MH-65C for surveillance (if at all). Sensor use would be another potential area of study. Issues addressed here might include: how best to integrate NSC and UAS radars into a single contact detection and tracking capability; the contact types for which radar imagery is suitable for vessel identification and the contact types for which EO/IR imagery is necessary for vessel identification; and how best to integrate AIS for cross-cuing UAS sensors for target identification.

While there would be specific test conditions that would be constructed to explore these different issues and performance data would be obtained, the knowledge gained exceeds the numbers that result. The ultimate benefit is stronger, more effective system concepts and a better understanding of how to maximize system performance capabilities and avoid limitations.