# NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

# THESIS

**TOWARD AN IMPROVED METHOD OF HSI EVALUATION IN DEFENSE ACQUISITION**

by

Matthew Simpson

December 2006

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| REPORT DOCUMENTATION PAGE | *Form Approved OMB No. 0704-0188* |
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| 1. AGENCY USE ONLY *(Leave blank)* | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | December 2006 | Master's Thesis |

| | |
|---|---|
| **4. TITLE AND SUBTITLE** Toward an improved Method of HSI Evaluation in Defense Acquisition | **5. FUNDING NUMBERS** |
| **6. AUTHOR(S)** Matthew Simpson | |
| **7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)** Naval Postgraduate School Monterey, CA 93943-5000 | **8. PERFORMING ORGANIZATION REPORT NUMBER** |
| **9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)** N/A | **10. SPONSORING/MONITORING AGENCY REPORT NUMBER** |

**11. SUPPLEMENTARY NOTES** The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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| **12a. DISTRIBUTION / AVAILABILITY STATEMENT** Approved for public release; distribution is unlimited | **12b. DISTRIBUTION CODE** |

**13. ABSTRACT (maximum 200 words)**

Each of the domains of HSI is of itself a discipline with vast amounts of research, analytic techniques, educational programs, and methods for evaluating the effectiveness of the system with respect to the specific domain. Relatively recently, domains with a logical similarity have been the focus of interest for researchers studying the plausibility of creating evaluative tools which take into account the constraints of multiple domains. This interest has led to the creation of various tools with which acquisition professionals can more accurately determine the impact of design decisions on the system as a whole. However, no single tool has yet been created which takes into consideration the constraints of all the domains which HSI encompasses. The development of such a tool would give decision-makers the ability to quickly and accurately determine the system-wide trade-offs associated with changes in a single domain. In order for this to occur, an in-depth study of the current tools associated with each of the HSI domains must be conducted. The most accurate tools from each domain must be integrated with a single interface. However, this step will only be realized after a common language has been identified which can speak to the effectiveness of the system in each of the domains. Finally, the interface must be intuitive, and designed with the end-user in mind. This study identified the various resources currently available for evaluating each of the HSI domains. These resources were compiled in a searchable database for use by the HSI professional in the planning of HSI evaluations. Following a description of how HSI relates to the Department of Defense acquisition process, the design effort to produce an overarching interface was presented. This interface would allow the acquisition professional to evaluate the trade-offs between all relevant domains and make well-informed decisions with respect to the overall effectiveness of the human in the system. Next, a plan for insertion of the process and software into the acquisition community, making the tool available to all acquisition professionals, was discussed. Finally, as with all research, the limitations of the present study were discussed, as well as recommendations for future research.

| | |
|---|---|
| **14. SUBJECT TERMS** Human Systems Integration, Defense Acquisition, HSI Analyst, Program Management | **15. NUMBER OF PAGES** 75 |
| | **16. PRICE CODE** |

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL |

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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# TOWARD AN IMPROVED METHOD OF HSI EVALUATION IN DEFENSE ACQUISITION

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Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN HUMAN SYSTEMS INTEGRATION**

from the

**NAVAL POSTGRADUATE SCHOOL**
**December 2006**

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# ABSTRACT

Each of the domains of HSI is, of itself, a discipline with vast amounts of research, analytic techniques, educational programs, and methods for evaluating the effectiveness of the system with respect to the specific domain. Relatively recently, domains with a logical similarity have been the focus of interest for researchers studying the plausibility of creating evaluative tools which take into account the constraints of multiple domains. This interest has led to the creation of various tools with which acquisition professionals can more accurately determine the impact of design decisions on the system as a whole. However, no single tool has yet been created which takes into consideration the constraints of all the domains which HSI encompasses. The development of such a tool would give decision-makers the ability to quickly and accurately determine the system-wide trade-offs associated with changes in a single domain.

In order for this to occur, an in-depth study of the current tools associated with each of the HSI domains must be conducted. The most accurate tools from each domain must be integrated with a single interface. However, this step will only be realized after a common language has been identified which can speak to the effectiveness of the system in each of the domains. Finally, the human interface with the tool must be intuitive, and designed with the end-user in mind.

This study identified the various resources currently available for evaluating each of the HSI domains. These resources were compiled in a searchable database for use by the HSI professional in the planning of HSI evaluations. Following a description of how HSI relates to the Department of Defense acquisition process, the design effort to produce an overarching interface was presented. This interface would allow the acquisition professional to evaluate the trade-offs between all relevant domains and make well-informed decisions with respect to the overall effectiveness of the human in the system. Next, a plan for insertion of the process and software into the acquisition community, making the tool available to all acquisition professionals, was discussed. Finally, as with all research, the limitations of the present study were discussed, as well as recommendations for future research.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| CAD | Computer Aided Design |
| CAE | Computer Aided Engineering |
| CDD | Capability Development Document |
| DAG | Defense Acquisition Guidebook |
| DAU | Defense Acquisition University |
| DDSM | Directory of Design Support Methods |
| DND | Department of National Defence (Canada) |
| DoD | Department of Defense (US) |
| DRD Canada | Defence Research and Development Canada |
| DTIC-ASD | Defense Technical Information Center-A San Diego |
| EATM | European Air Traffic Management |
| EVM | Earned Value Management |
| FAA | Federal Aviation Administration |
| HFE | Human Factors Engineering |
| HFE TAG | Human Factors Engineering Technical Advisory Group |
| HIFA | Human factors Integration in Future Air traffic management |
| HSI | Human Systems Integration |
| HSI TST | Human Systems Integration Trade Space Tool |
| HSIIAC | Human Systems Integration Information Advisory Center |
| ICD | Initial Capabilities Document |
| IPT | Integrated Product Team |
| MANPRINT | Manpower Personnel Integration |
| NASA | National Aeronautics and Space Administration |
| NASA TLX | NASA Task Load Index |
| NPS | Naval Postgraduate School |
| ROI | Return On Investment |
| USAFA | United States Air Force Academy |
| USCGA | United States Coast Guard Academy |
| USMA | United States Military Academy |
| USNA | United States Naval Academy |

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# ACKNOWLEDGMENTS

This work is the culmination of many hours of sacrifice by those not necessarily listed as the authors. Without their foresight, knowledge, support, and determination to see me through the process, it would not have been accomplished.

To Dr. Miller I owe the initial nudge toward this topic and the constant guidance to keep me on task. I give my appreciation to Dr. Rendon for his extensive knowledge of the many nuances of Defense Acquisition policy. Finally, my attending NPS in the first place was only due to the tireless efforts of Mr. Bob Lindberg and those struggling to ensure HSI in the US Air Force.

Most importantly, I thank my wife, without whom my life would be a dark and lonely desert.

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# I. INTRODUCTION

## A. HUMAN SYSTEMS INTEGRATION

In its broadest sense, Human Systems Integration (HSI) is the effort to make human considerations the top priority in systems design. This broad definition, however, does not escape the grasp of the more global study of systems engineering. A system is defined as “a group of interacting, interrelated, or interdependent elements or parts that function together as a whole to accomplish a goal” (Massachusetts DOE, 2001). The basis of systems engineering—systems thinking—requires that any product or service be viewed as a piece of a larger system in order to better understand its requirements and characteristics. Sage and Armstrong (2000) describe systems engineering as having three key components: organizational, technology-based, and humans. As some areas of responsibility—and the interactions between the three components—tend to involve more than a single component, visualizing systems engineering as a Venn diagram may prove useful (see Fig 1).

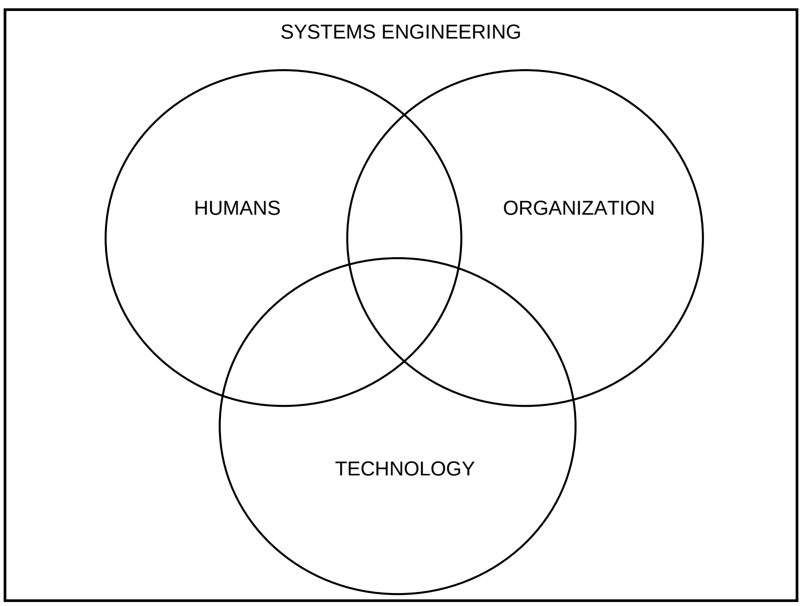


Figure 1. Three key areas of Systems Engineering

Each of the key components of systems engineering falls under the purview of existing disciplines. While systems engineering efforts incorporate all three components, the products differ from that of other engineering disciplines. Systems engineering produces abstract systems, and relies on the other engineering disciplines to design, build and test the tangible products. These well-defined disciplines have explicit knowledge of their specific domains and thereby design products to exacting details.

The organizational component of systems engineering may be viewed through the discipline of macroergonomics. Macroergonomics grounds itself in sociotechnical systems theory, with the chief concern being human-organization interface technology—specifically, the analysis, design, and evaluation of the work system. Dr. Hal W. Hendrick (2002)—considered the “father” of macroergonomics—describes the discipline’s goal as “[optimizing] the work system’s design in terms of its sociotechnical system characteristics” and ensuring that these characteristics are carried down throughout the design of the sub-system efforts.

The traditional engineering disciplines are encompassed by the technology-based component of systems engineering. Practitioners in disciplines such as electrical, mechanical, and aerospace engineering apply their expertise in designing systems to meet detailed specifications. While these specifications ensure the proper functioning of the system with respect to each individual discipline, they do not necessarily ensure the system will function properly with the additional systems with which it may need to operate. This level of integration is left to systems engineers.

The final component in systems engineering—humans—falls under the purview of HSI. Where systems engineering focuses on the defining, developing and deploying of large scale systems, HSI champions the human element within systems design. It has been argued that focusing on the human element of a system is the most likely method for increasing system performance and reducing system life-cycle costs (Booher, 2002). The exact boundaries and areas of responsibility of HSI are not yet completely defined. However, the defense acquisition structure rests comfortably upon the foundation of HSI.

## B. BRIEF HISTORY OF HUMAN SYSTEMS INTEGRATION

Just as the trade space for systems engineering incorporates multiple fields of study, the present trade space for Human Systems Integration coordinates the efforts of several distinct disciplines or domains. These domains from which HSI has emerged have existed for many years. Though known by different names, and having evolved over time, the fields incorporated in HSI have always tried to answer the same question—how can the human be more effective in the system ultimately resulting in enhanced overall system performance. In fact, the predecessors of HSI in the U.S. military date back to the early years of the Army Air Corps, and the efforts to improve the performance of systems (aircraft) specifically at the points where humans interfaced with the machine (Chapanis, 1959). This initial effort resulted in the birth of human factors. More detailed histories of human factors can be found by Meister (1999) and Boff (2006).

Within the past seventy years, the field of human safety has also gained prominence, as the modern consumer-driven society required more standardized practices and better products (Stephens & Rowan, 2006). In 1946, Amos L. Wood presented the first formal presentation on what is now considered system safety (Miller, 1966).

Both of these well established areas of study began as grass-roots efforts to improve the effectiveness of the human interacting with the rest of the system. From the early days of human factors and system safety, additional efforts have arisen for better integrating human and machine, especially with respect to military systems acquisition. More recent efforts include the MANPRINT effort in the U.S. Army (U.S. Army, 1990), and what is now being termed Human Systems Integration—a Department of Defense (DoD) level multi-service effort to champion the human in systems with which they interact. Among other achievements, this latter effort has resulted in the establishment of a Master of Science in HSI available through the U.S. Naval Postgraduate School (NPS) at Monterey, CA.

## C. HSI DOMAINS

While an in-depth history of HSI can be found in Booher's (2002) *Handbook on Human Systems Integration,* the present study requires only an understanding of the fields—or domains—encompassed by HSI and the inherent interactions between these domains. The MANPRINT program identified seven key domains within its purview: manpower, personnel, training, human factors, system safety, health hazards, and soldier survivability (U.S. Army, 2000). The MANPRINT handbook makes note of the existence of the interactions between domains; however, the extent of the information provided consists of the following statement and some brief examples:

> Although each of the MANPRINT domains has been introduced separately, in practice they are often interrelated and tend to impact on one another. Changes in system design to correct a deficiency in one MANPRINT domain nearly always impact another domain (MANPRINT Directorate, 2005).

Building upon the MANPRINT effort, the Human Systems Integration program identified an additional area of specific importance to the U.S. Navy, but with reasonable application to all services—habitability (U.S. Naval Postgraduate School, 2006). Additionally, the NPS Master's program focuses on the interactions between domains, recognizing these interactions and trade offs as a distinct requirement for the HSI professional.

As the discipline of HSI is continually refined, it is possible that the number and definitions of HSI domains may increase, decrease, or evolve. However, since the aforementioned eight domains presently constitute the study of HSI, a brief description of each is given below. The definitions provided are taken directly from the MANPRINT and NPS HSI programs, and from the DAU Defense Acquisition Guidebook.

### 1. Manpower

> Manpower addresses the number of military and civilian personnel required and potentially available to operate, maintain, sustain, and provide training for systems in accordance with Section 2434 of Title 10, U. S. Code. It is the number of personnel spaces (required

or authorized positions) and available people (operating strength). It considers these requirements for peacetime, conflict, and low intensity operations (MANPRINT Directorate, 2005).

Manpower [comprises] the actual number of men and women, in the military as well as civilian and contractor personnel, required to operate and maintain military systems, including those personnel who support and provide training for the users of military systems. Considers the impacts of automation on both manpower utilization rates and on military operator-to-seat ratios in both system operation and maintenance (NPS, 2006).

Manpower factors are those job tasks, operation/maintenance rates, associated workload, and operational conditions (e.g., risk of hostile fire) that are used to determine the number and mix of military and DoD civilian manpower and contract support necessary to operate, maintain, support, and provide training for the system. Manpower officials contribute to the Defense acquisition process by ensuring that the program manager pursues engineering designs that optimize manpower and keep human resource costs at affordable levels (i.e., consistent with strategic manpower plans). Technology approaches and solutions used to reduce manpower requirements and control Lifecycle costs should be identified in the capabilities documents early in the process. For example, material-handling equipment can be used to reduce labor-intensive material-handling operations and embedded training can be used to reduce the number of instructors (USD/(AT&L), 2006).

### 2. Personnel

Personnel addresses the cognitive and physical characteristics and capabilities required to be able to train for, operate, maintain, and sustain materiel and information systems (MANPRINT Directorate, 2005).

[The] personnel [domain consists of] the cognitive and physical capabilities necessary for the training, operation, maintenance, and support of military systems. Includes the attitudes, experiences, and other human characteristics necessary to achieve optimal system performance by matching the “right person” with the “right job” (NPS, 2006).

Personnel factors are those human aptitudes (i.e., cognitive, physical, and sensory capabilities), knowledge, skills, abilities, and experience levels that are needed to properly perform job tasks. Personnel factors are used to develop the military occupational specialties (or equivalent DoD Component personnel system classifications) and civilian job series of system operators, maintainers, trainers, and support personnel. Personnel officials contribute to the Defense acquisition process by ensuring that the program manager pursues engineering designs that minimize personnel requirements, and keep the human aptitudes necessary for operation and maintenance of the equipment at levels consistent with what will be available in the user population at the time the system is fielded (USD/(AT&L), 2006).

### 3. Training

Training is defined as the instruction, education, on-the-job, or self development training required providing all personnel and units with essential job skills, and knowledge (MANPRINT Directorate, 2005).

Training [includes] the instruction, education, and "on-the-job training" necessary to provide personnel with the requisite knowledge, skills, and abilities needed for the correct and safe operation and maintenance of military systems across a wide range of operational conditions (NPS, 2006).

Training is the learning process by which personnel individually or collectively acquire or enhance predetermined job-relevant knowledge, skills, and abilities by developing their cognitive, physical, sensory, and team dynamic abilities. The "training/instructional system" integrates training concepts and strategies and elements of logistic support to satisfy personnel performance levels required to operate, maintain, and support the systems. It includes the "tools" used to provide learning experiences such as computer-based interactive courseware, simulators, and actual equipment (including embedded training capabilities on actual equipment), job performance aids, and Interactive Electronic Technical Manuals (USD/(AT&L), 2006).

### 4. Human Factors

The goal of HFE [Human Factors Engineering] is to maximize the ability of an individual or crew to operate and maintain a system at required levels by eliminating design-induced difficulty and error. Human Factors engineers work with systems engineers to design and evaluate human-system interfaces to ensure they are compatible with the capabilities and limitations of the potential user population (MANPRINT Directorate, 2005).

Human Factors Engineering [is] the comprehensive integration of human characteristics (both physical and psychological) into the definition, design, development, and evaluation of military systems in order to optimize performance in human-machine interactions. This includes human interaction with products, equipment, systems, and environments, and addresses the capabilities and limitations or personnel during this interaction (NPS, 2006).

Human factors are the end-user cognitive, physical, sensory, and team dynamic abilities required to perform system operational, maintenance, and support job tasks. Human factors engineers contribute to the Defense acquisition process by ensuring that the program manager provides for the effective utilization of personnel by designing systems that capitalize on and do not exceed the abilities (cognitive, physical, sensory, and team dynamic) of the user population. The human factors engineering community integrates the human characteristics of the user population into the system definition, design, development, and evaluation processes to optimize human-machine performance for both operation and maintenance of the system (USD/(AT&L), 2006).

Human factors engineering is primarily concerned with designing human-machine interfaces consistent with the physical, cognitive, and sensory abilities of the user population (USD/(AT&L), 2006).

### 5. System Safety

System Safety is the design features and operating characteristics of a system that serve to minimize the potential for human or machine errors/failures that cause injurious accidents (MANPRINT Directorate, 2005).

System Safety [is] the design of machine and system features that minimize the potential for human or machine errors, and of human and machine failures that can cause injuries. Also included is the ability of the system to be operated and maintained without injury to personnel or to other equipment (NPS, 2006).

Safety factors consist of those system design characteristics that serve to minimize the potential for mishaps causing death or injury to operators and maintainers or threaten the survival and/or operation of the system. Prevalent issues include factors that threaten the safe operation and/or survival of the platform; walking and working surfaces including work at heights; pressure extremes; and control of hazardous energy releases such as mechanical, electrical, fluids under pressure, ionizing or non-ionizing radiation (often referred to as "lock-out/tag-out"), fire, and explosions (USD/(AT&L), 2006).

### 6. Human Survivability

Soldier survivability addresses the characteristics of a system that can reduce fratricide, detectability, and probability of being attacked, as well as minimize system damage, soldier injury, and cognitive and physical fatigue (MANPRINT Directorate, 2005).

Human Survivability [is] the ability of personnel to exist and function during and following exposure to hostile environments or situations. [Survivability] includes issues involving enemy and friendly combat weapons-induced injuries and the inherent hazards to personnel during threat/combat conditions, and the inherent hazards of military equipment (NPS, 2006).

Personnel survivability factors consist of those system design features that reduce the risk of fratricide, detection, and the probability of being attacked; and that enable the crew to withstand man-made hostile environments without aborting the mission or suffering acute chronic illness, disability, or death (USD/(AT&L), 2006).

### 7. Health Hazards

Health Hazards addresses the design features and operating characteristics of a system that create significant risks of bodily injury or death. Along with safety hazards, an assessment of health hazards is necessary to determine risk reduction or mitigation (MANPRINT Directorate, 2005).

Health Hazards [includes] the identification of risk factors in military systems and the physical environment that can increase opportunities for system-caused bodily injury or death. This includes many inherent conditions present in the operation, use, and maintenance of a system (e.g., heat, cold, shock, recoil, motion, vibration, toxic fumes, chemical & biological agents, noise, radiation, etc.) that can reduce job performance and contribute to injury, illness, or death (NPS, 2006).

Occupational health factors are those system design features that serve to minimize the risk of injury, acute or chronic illness, or disability; and/or reduce job performance of personnel who operate, maintain, or support the system. Prevalent issues include noise, chemical safety, atmospheric hazards (including those associated with confined space entry and oxygen deficiency), vibration, ionizing and non-ionizing radiation, and human factors issues that can create chronic disease and discomfort such as repetitive motion diseases. Many occupational health problems, particularly noise and chemical management, overlap with environmental impacts. Human factors stresses that create risk of chronic disease and discomfort overlap with occupational health considerations (USD/(AT&L), 2006).

#### 8. Habitability

Habitability [addresses] the physical living environment in which personnel are required to live, work, and sleep while performing their military duties during peace and war. This includes the physical and psychological needs of the individual and group, and takes into account morale and the social environment during both sustained and continuous military operations (NPS, 2006).

Habitability consists of those characteristics of systems, facilities (temporary and permanent), and services necessary to satisfy personnel needs. Habitability factors are those living and working conditions that result in levels of personnel morale, safety, health, and comfort adequate to sustain maximum personnel effectiveness, support mission performance, and avoid personnel retention problems (USD/(AT&L), 2006).

Habitability factors are those living and working conditions that are necessary to sustain the morale, safety, health, and comfort of the user population. They directly contribute to personnel effectiveness and mission accomplishment, and often preclude recruitment and retention problems. Examples include: lighting, space, ventilation, and sanitation; noise and temperature control (i.e., heating and air conditioning); religious, medical, and food services availability; and berthing, bathing, and personal hygiene (USD/(AT&L), 2006).

## D. DESCRIPTIVE ANALOGY OF HSI

An analogy may help illustrate the interactions among the HSI domains and the benefit of a tool which would allow acquisition professionals to visualize the effects of tradeoffs between domains. Take, for example, the light bulb. There are a number of necessary elements which constitute an ordinary incandescent bulb: the glass bulb, the contents of the glass bulb, the filament, and an electric current. While Thomas Edison and many additional scientists and inventors of the 1800’s knew the individual properties of each of these elements, it took over 100 years to advance from Humphrey Davy’s 1809 charcoal strip arc lamp to the incandescent bulb in use today. The significant advancements occurred only when the interactions between the elements were taken into consideration. While Davy's charcoal strips produced intense light, they burned out quickly. The enclosure of a filament in an evacuated tube increased its longevity. Altering the composition of the filament produced a wide range of bulb life. Add to this the injection of different gasses into the previously vacuous bulb, and the filament lasted even longer (Arizona State University, 2006).

As with most design considerations, there were tradeoffs to consider in the development of the light bulb. Such tradeoffs are best understood by a more detailed description of the latest advancements in incandescent bulbs. Filaments burn out as a result of evaporation, or sublimation, during use. Also, in order to produce the proper level of light, filaments have to be heated to a certain temperature. In order to increase filament life by reducing evaporation, the bulb was filled with inert gasses such as nitrogen and argon. However, this addition altered the heating characteristics of the filament. The inert gasses dissipated heat so efficiently that the filament could not produce a satisfactory level of light. An additional change had to be made in order to restore the effectiveness and efficiency of the light bulb. Researchers accomplished this by making a small alteration to the physical characteristic of the filament—winding it into a coil. This procedure allowed enough heat to build up around the coil to produce the necessary light level before the inert gasses could cool the filament.

In a similar fashion, acquisition professionals observe the necessary elements of an acquisition program—one of which is inevitably the human—and seek the most efficient and effective combination of these elements which will meet the stated—and often unstated—requirements.

It is interesting to note that modern incandescent light bulbs are not energy efficient. Today's available technology is advancing the concept of using highly efficient light emitting diodes (LEDs) to produce equivalent levels of light with a fraction of the energy involved in traditional incandescent bulbs. While the concept is essentially the same—passing electric current through a substance to produce light—modern technology is using the available resources in the most effective and efficient manner to date.

## E. SCOPE OF PRESENT STUDY

Each of the domains of HSI is, of itself, a discipline with vast amounts of research, analytic techniques, educational programs, and methods for evaluating the effectiveness of the system with respect to the specific domain. Relatively recently, domains with a logical similarity have been the focus of interest for researchers studying the plausibility of creating evaluative tools which take into account the constraints of multiple domains. This interest has led to the creation of various tools with which acquisition professionals can more accurately determine the impact of design decisions on the system as a whole. However, no single tool has yet been created which takes into consideration the constraints and interactions of all the domains which HSI encompasses. Crisp, Hoang, Karangelen and Britton (2000) emphasize the importance of technologies which support such a total system design, especially with respect to the human operator. With respect to HSI evaluation, this concept may prove to be difficult, if not impossible, to realize. The inherent differences of each system may call for a different set of tools to produce an accurate evaluation. In fact, some systems may require the development of system-unique tools to properly evaluate the human-system effectiveness. However, an overarching interface which allows for the inclusion of any number and variety of resources utilized in the evaluation process would be an invaluable tool to the HSI professional. The development of such a tool would give decision-makers the ability to quickly and accurately determine the system-wide trade-offs associated with changes in a single area. In order for this to occur, a comprehensive study of the current tools associated with each of the HSI domains must be conducted. Following this study, it will be necessary to identify how outputs from the tools, which come in a variety of metrics, can be normalized in a useful manner. This step will only be realized after a common interface has been defined which can be configured to effectively convey the dynamic relationships between decision parameters. Finally, the overarching interface must be properly disseminated to those conducting HSI evaluations. Of course, as is the goal of all efforts involving HSI, the interface must be intuitive, and designed with the end-user in mind.

The purpose of the present study was to describe a process for conducting HSI evaluations and design the necessary resources and software to conduct such evaluations. The study identified the various resources currently available for evaluating each of the HSI domains. These resources were compiled in a searchable database for use by the HSI professional in the planning of HSI evaluations. Following a description of how HSI relates to the Department of Defense acquisition process, the design effort to produce an overarching interface was presented. This interface would allow the acquisition professional to evaluate the trade-offs between all relevant domains and make well-informed decisions with respect to the overall effectiveness of the human in the system. Next, a plan for insertion of the process and software into the acquisition community, making the tool available to all acquisition professionals, was discussed. Finally, as with all research, the limitations of the present study were discussed, as well as recommendations for future research.

This chapter has introduced the concept of HSI, defining the common domains associated with HSI, and discussed the purpose of the present study. The following chapter discusses the effort conducted to collect information on HSI evaluation resources, and the result of this effort—a database for HSI analysts to use in planning HSI evaluations.

# II. HSI RESOURCES

## A. DATA COMPILATION

Compiling the information on resources available to HSI professionals is somewhat complicated. There are many characteristics by which the resources can be identified. While these characteristics may include such items as cost, manufacturer, and other less pertinent details, the characteristics most relevant to a better understanding of their usefulness to the HSI professional were selected as data points. The standardized format for data collection is provided as Figure 2. For the most part, the data collection headings are self explanatory and require no further description. Three headings, however, benefit from additional discussion. These headings are Cross-Domain Utility, Readiness, and Classification.

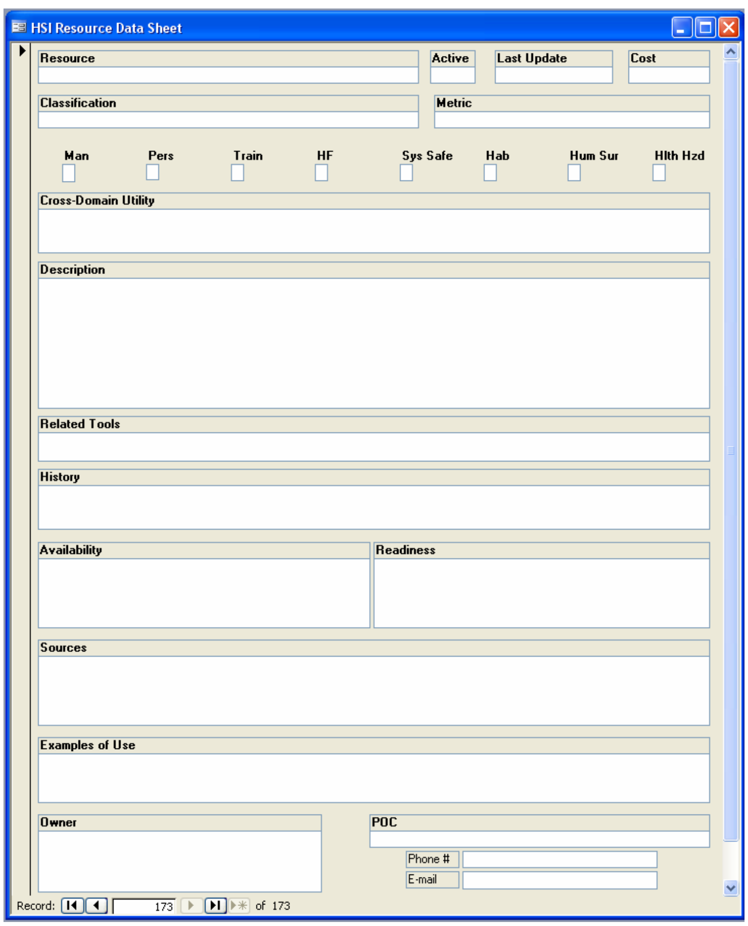


Figure 2. HSI resource data collection format

### 1. Classification of HSI Resources

There are myriad ways to classify the resources available to HSI analysts. The classification method selected needed to provide the user with the most relevant information based on the purpose for which the resources were classified. In the review of resources conducted for this study, a number of common terms were initially identified. These terms captured a majority of the available resources, and are listed below with a brief description on how each is differentiated from the others.

> Tool: something (as an instrument or apparatus) used in performing an operation or necessary in the practice of a vocation or profession.
>
> Method: a systematic procedure, technique, or mode of inquiry employed by or proper to a particular discipline or art.
>
> Model: a description or analogy used to help visualize something (as an atom) that cannot be directly observed.
>
> Database: a usually large collection of data organized especially for rapid search and retrieval (as by a computer).
>
> Questionnaire: a set of questions for obtaining statistically useful or personal information from individuals. (Merriam-Webster, 2006)

The definitions above describe types of resources in a general sense. As one of the products of the present study would be a useful, searchable database of resources for HSI professionals, a more detailed classification of these resources would allow the HSI professional to conduct a more refined search for the appropriate resource. Lockett and Powers (2003) describe a classification process for tools pertaining specifically to the field of Human Factors Engineering. Tools were classified as follows:

- guidelines and standards
- checklists
- subjective assessment tools
- simulations—unmanned (with multiple subcategories)
- simulations—human in the loop
- miscellaneous analytical tools

This classification process was slightly modified and implemented in the compilation of the Human Factors Engineering Technical Advisory Group (HFE TAG) Directory of Design Support Methods (DDSM), which is reviewed in greater detail below (personal communication with Teresa Alley, 2006). The final classification structure used in the DDSM was as follows:

- Guidelines and Standards
- Checklists
- Subjective Assessment Tools/Surveys
- Perceptual Models
- Simulation – Unmanned
- Task Network/Workload Tools
- Cognitive Process models
- Graphic Human Models
- Human Behavioral Representations (HBR) in Simulation Federations
- HFE Tools Embedded in CAD/CAE Suites
- Simulation – Human-in-the-Loop
- Integrated Tools
- Government Courses and Handbooks
- Design Shells
- Information Service Center
- Databases
- Other

Since a majority of the resources reviewed in this study were present in the DDSM, it was determined that the same classification structure would be utilized in the present effort as well.

### 2. Cross-Domain Utility

One of the key tenets of HSI is an understanding of the interactions that exist between the identified domains. Individual resources were categorized by how they assist in the evaluation of the specific domain for which they have been designed. However, there exists the potential that a resource may provide additional information relevant to other domains for which the resource was not initially designed. Also, the domains of HSI are not firmly set and resources may very well have been in existence longer than the present field of HSI. It therefore becomes necessary to view these resources not only with respect to their domain specific relevance, but more importantly, in how each resource assists the HSI analyst in evaluating the overall effectiveness of the system. The resulting information strengthens the HSI analyst's ability to most accurately define the relationships between the relevant domains.

### 3. Readiness

A necessary consideration in selecting a resource to use is how quickly the resource can be ready for use. For example, a commercially available resource may be purchased, installed and 'ready-for-use' in a matter of hours. However, utilizing the resource in an effective manner may require the user to attend an extensive training program or to purchase additional required resources. With a clearer understanding of the ancillary requirements associated with a particular resource, the selection process would be more effective. Left out, the decision could result in costly overruns of both budget and schedule, as well as a reduction of the overall effectiveness of the HSI analysis.

## B. CURRENT REPOSITORIES

It has already been noted that each domain of HSI is a fully developed discipline. As such, lists of resources for specific domains are prevalent. A majority of these refer to the Human Factors, Safety, Manpower, Personnel and Training domains, while the relatively newer areas of Habitability, Survivability, and Health Hazards provide few lists. Locating and including every list of HSI domain resources may be virtually impossible. However, many of the most prominent lists from around the world have been included in this study. The following are descriptions of each of these well-established repositories.

### 1. DDSM

The Directory of Design Support Methods (DDSM) began as an effort of the Designing for the User Subgroup of the Department of Defense's Human Factors Engineering Technical Advisory Group (HFE TAG). The DDSM is a living document, updated continuously to provide the most accurate information on design support tools and techniques developed by agencies such as DoD, NASA and the FAA, as well as those developed by NATO countries, academia and the private sector (DTIC-ASD, 2006). The online document is updated by the office of the Defense Technical Information Center-A in San Diego, CA (DTIC-ASD). A site map of the DTIC DDSM website is included as Figure 3. In addition to the current resources listed in the DDSM, those resources which are no longer supported, have transitioned into newer tools, or are proprietary and accessible only through contractual support—while not included in the report—are available through an online archive (Teresa Alley, personal communication, Sep 29, 2006).

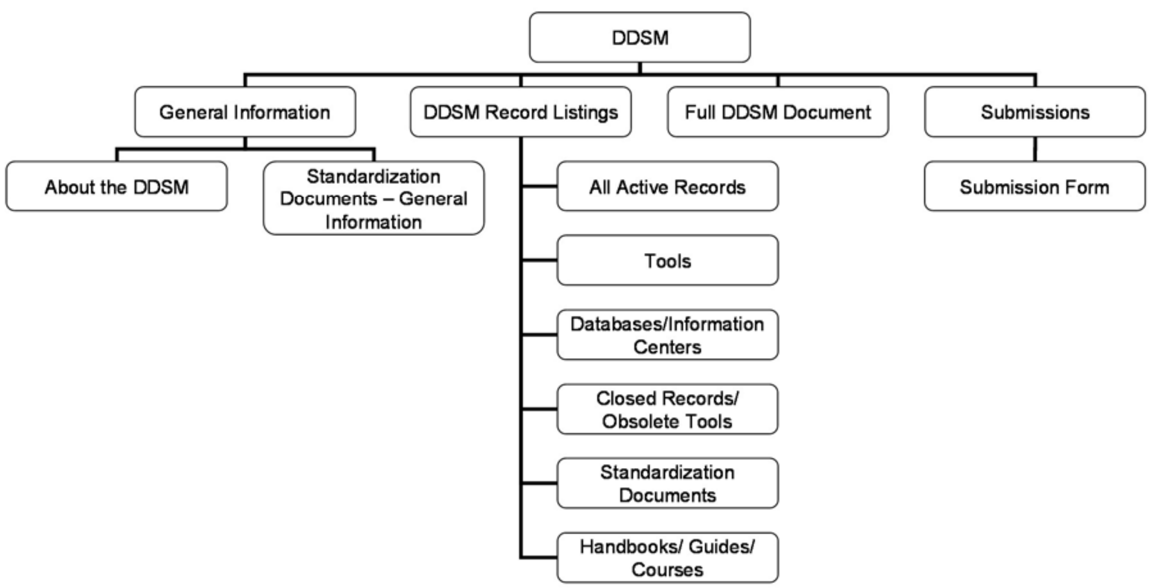


Figure 3. DDSM site map

The DDSM is a great resource for the experienced HSI user, and it provides a wealth of readily accessible and current information on methods used in HSI efforts. The DDSM uses the aforementioned classification structure described by Lockett and Powers (2003). The standard information collected on each method of the DDSM includes the method title, contact information, a general overview, required equipment, input/output/processing information, documentation including references in academic and professional journal articles, alternative approaches, the method's stage of development, date of current version release, and validation studies. With such accurate and detailed information, the HSI user can more efficiently select the appropriate methods (DTIC-ASD, 2006).

There are, however, limitations to the DDSM. The list is not in a database format and there are no search options. While originally compiled using a database, the database files were lost, leaving only the text format used currently. The user must scan the entire alphabetized list of methods or, in the case of a novice, search each record for the appropriate method. Fortunately, the current version of the DDSM is scheduled to be updated before the end of FY2007, with the intention of rebuilding the database (Teresa Alley, personal communication, Sep 29, 2006).

### 2. FAA Human Factors Workbench

The Federal Aviation Administration operates a Human Factors Workbench from their official website which boasts over three hundred human factors research tools and techniques. The resources are grouped into the following categories: Physical Ergonomics, Human Factors Knowledge, Knowledge Elicitation, Human-Computer Interaction, Data Analysis, Modeling and Simulation, Human-System Performance, Program Planning, and Safety. Each of these categories is further broken down in a structure unique to each category. The FAA Human Factors Workbench tools and techniques categorization is provided as Figure 4.

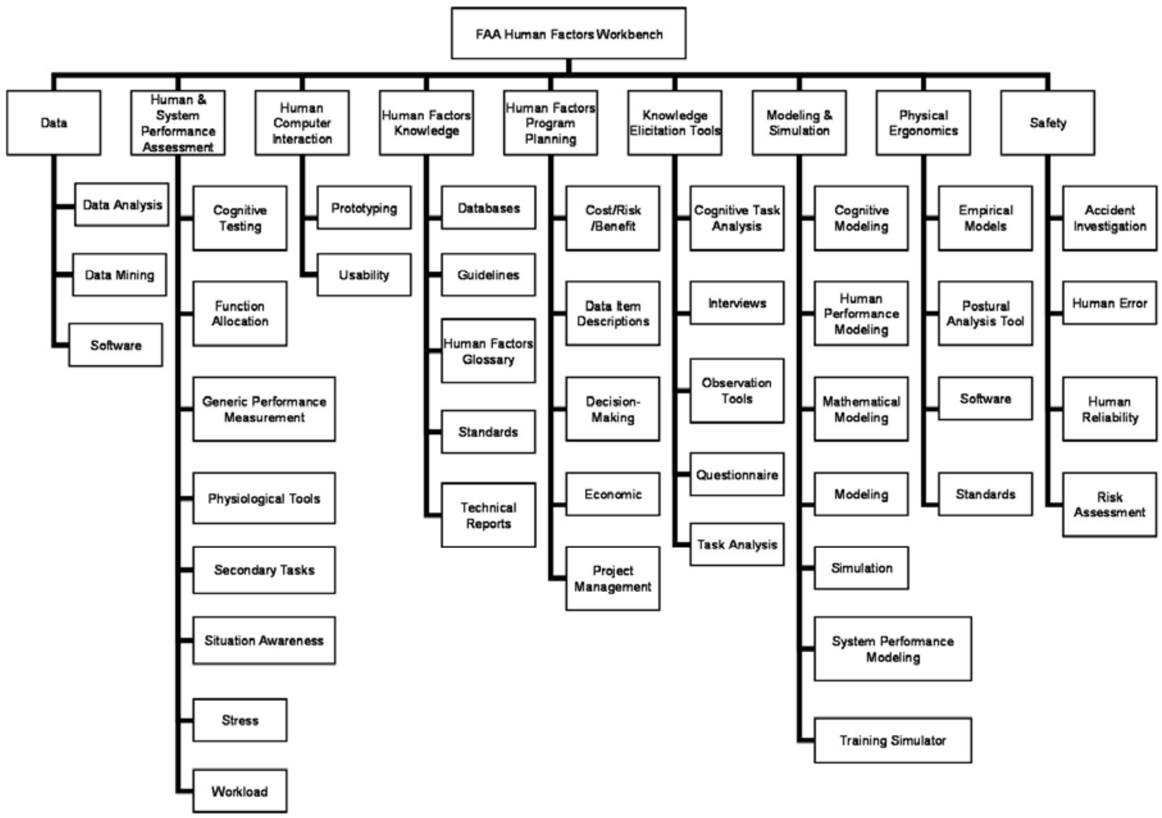


Figure 4. FAA Human Factors Workbench site map

### 3. EuroControl

As part of the Programme for Performance Enhancement in European Air Traffic Management (EATM), EUROCONTROL manages a database of tools and methods of human factors which are used to resolve tasks related to HSI. This list is available online through the EATM Quick access link on Human factors Integration in Future Air traffic management systems (HIFA). HIFAdata, and EUROCONTROL in general, specifically target HSI activities related to air traffic management systems. However, as indicated on their website, the tools and methods can be applied to the development of "any other human-machine system". The structure of the HIFAdata website is broken out similar to that of the FAA. General headings of Lifecycle, Tasks, Checks, Methods, Tools, Domains, Roles, References, and Glossary provide the HSI user with a convenient classification structure. Additionally, information on specific resources in the HIFAdata database is linked to all relevant categories. This database design allows the user to identify the most appropriate resource through multiple avenues. A breakdown of the HIFAdata classification structure is provided in Figure 5.

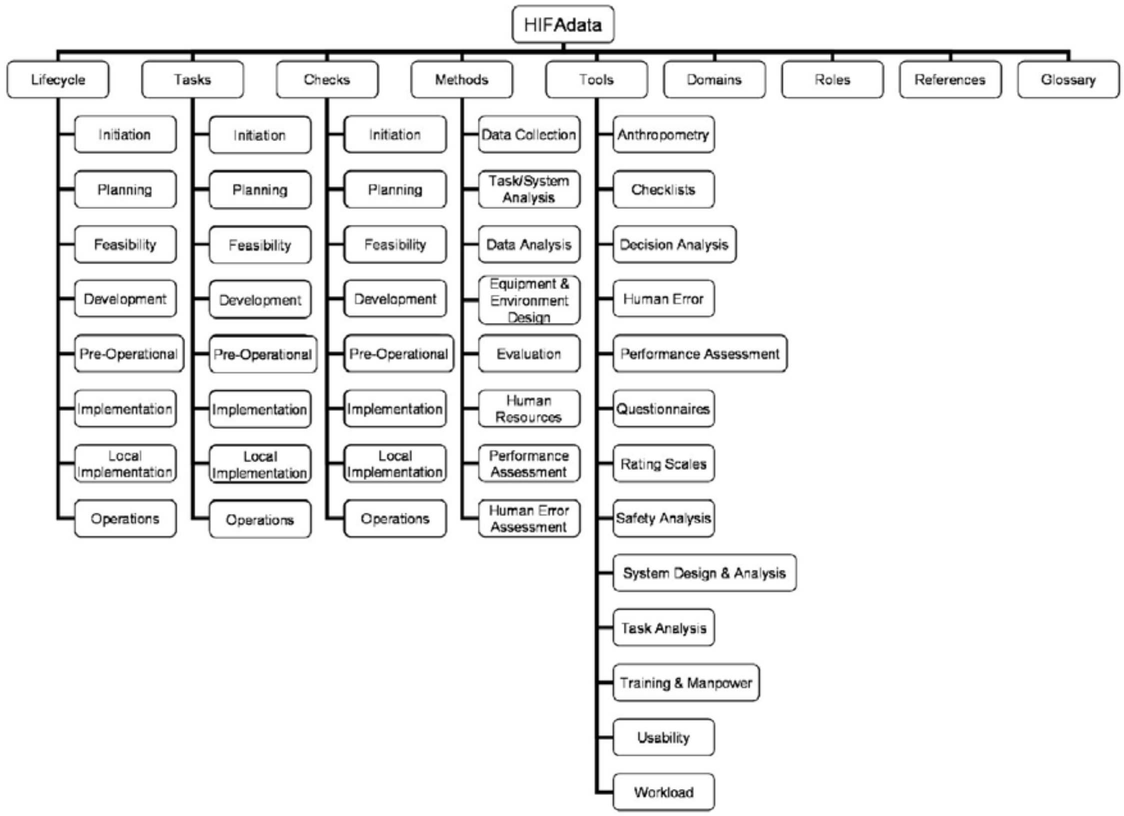


Figure 5. EUROCONTROL HIFAdata site map

#### 4. HSIIAC

The Human Systems Integration Information Analysis Center (HSIIAC) supports research and development efforts in HSI. This resource began in 1988 as an effort by the Defense Logistics Agency, and has evolved over time to its current configuration. As of 2005, the HSIIAC is managed by the Air Force Research Laboratory's Human Effectiveness Directorate, operated under contract to Northrop Grumman. HSIIAC's mission is to provide analysis services in support of research, design and development of defense crew systems. Among the information on the HSIIAC is a list of available products and services. The majority of these are informative books or reports detailing methods for conducting human systems analysis. However, there are some models and tools listed directly, such as the NASA TLX and a variety of anthropometric data sets. The website is designed to provide HSI resources by taxonomy, though at the present time few resources are included. The overall structure of the HSIIAC website is provided as Figure 6.

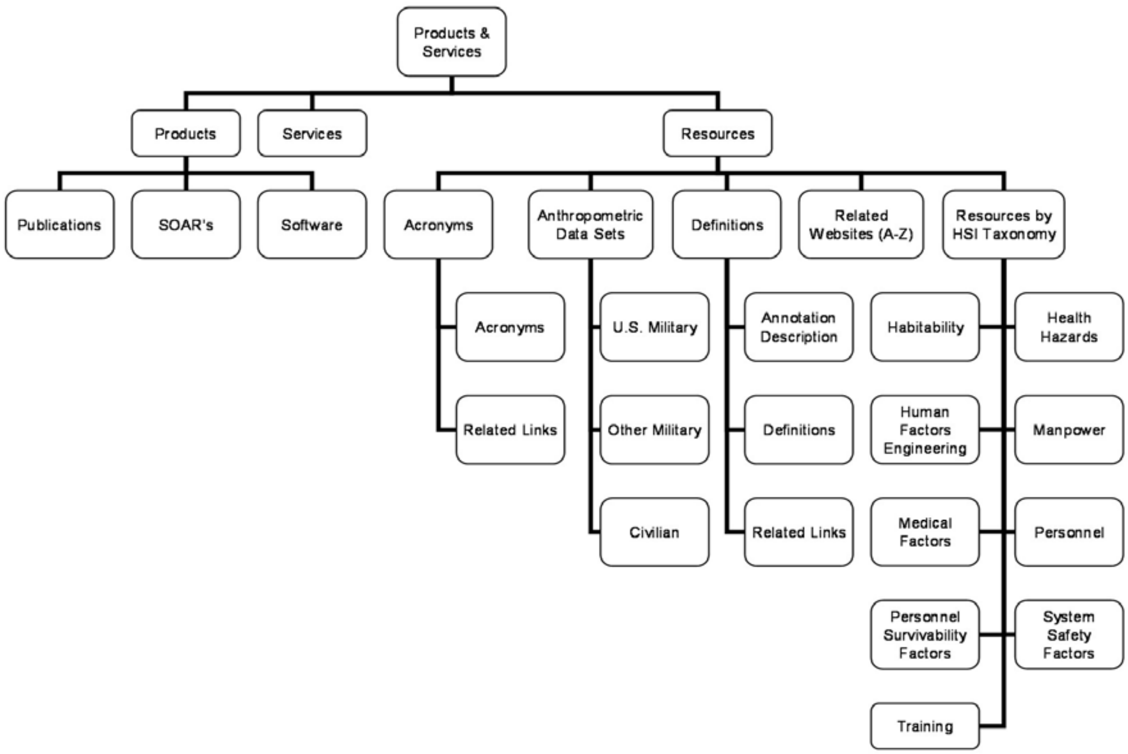


Figure 6. HSIIAC HSI products and services site map

## 5. Defence Research and Development Canada

The Canadian Department of National Defence (DND) began serious research efforts in HSI in 1998. DND initiated an effort to identify, define, and coordinate the HSI process as part of the HSI-Process Models project under the Defence Research and Development Canada (DRD Canada). In answer to the original objective to “document, demonstrate, and continually enhance a set of HSI analysis tools and techniques as well as models, simulations and related databases” (Greenley, 2000), DRD Canada developed an online repository of HSI information.

Focusing mainly on the HSI process, the project limits its list of tools to describing those used specifically by the DND for HSI analysis, while providing links to additional lists and resources outside the DND. Unfortunately, the descriptions are somewhat limited, and only a DRD Canada contact is provided if further information is desired. However, beyond the limited tools listed, the site also contains abundant information on the HSI process as conducted by Canadian Forces. As much of this information is valuable to the development of HSI, it is included as part of the website description provided in Figure 7. The site is in the process of being moved, and will soon be the responsibility of the acquisition framework of the DND (Shaw, personal communication, Nov 9, 2006).

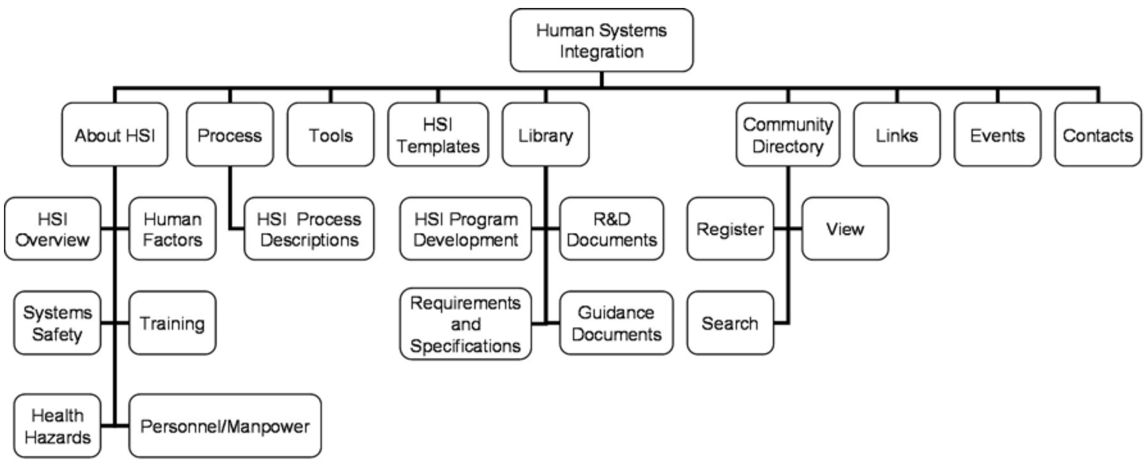


Figure 7. DRD Canada HSI site map

### 6. ONR Science and Technology Manning Affordability Initiative

The Office of Naval Research began a partnership with the acquisition community in 1998 to conduct research with the end goal of optimizing systems for the warfighter while at the same time reducing system costs and improving system performance. In a similar fashion to what is being done in the present study, one of the products of the Manning Affordability Initiative was a process which would "be used as a roadmap for identifying and (where required) developing tools and capabilities for the S&T project's Human-Centered Design Environment" (DD 21/ONR, 1998). The process resulted in a collection of tools linked to the six-step systems engineering process as it relates to human engineering. The steps include Mission Analysis, Requirements Analysis, Function Analysis, Function Allocation, Design, and Verification. A webpage is devoted to each tool and provides a general description, the related step, and contact information for the tool proprietor. Additionally, many of the tools include a link to a more detailed description. The detailed description answers a host of questions pertaining to the use and functionality of the tool:

- What analyses does it conduct? What does the tool do?
- What questions does the tool answer?
- How complex is the tool?
- What fidelity does the tool have to have?
- What experience does the user have to have?
- What are the tool inputs, and who provides them?
- What are the tool outputs and who/what uses them?
- What platform does the tool currently run on? What language is it written in? How is the data stored?
- What other support, infrastructure, or tools are required?

While the website is a great resource for HSI-related tools, it also contains excellent information on the human engineering process as it relates to systems engineering. Specifically, the site breaks down each of the systems engineering processes and details how to conduct each process with respect to the human element. The overall site map is provided as Figure 8.

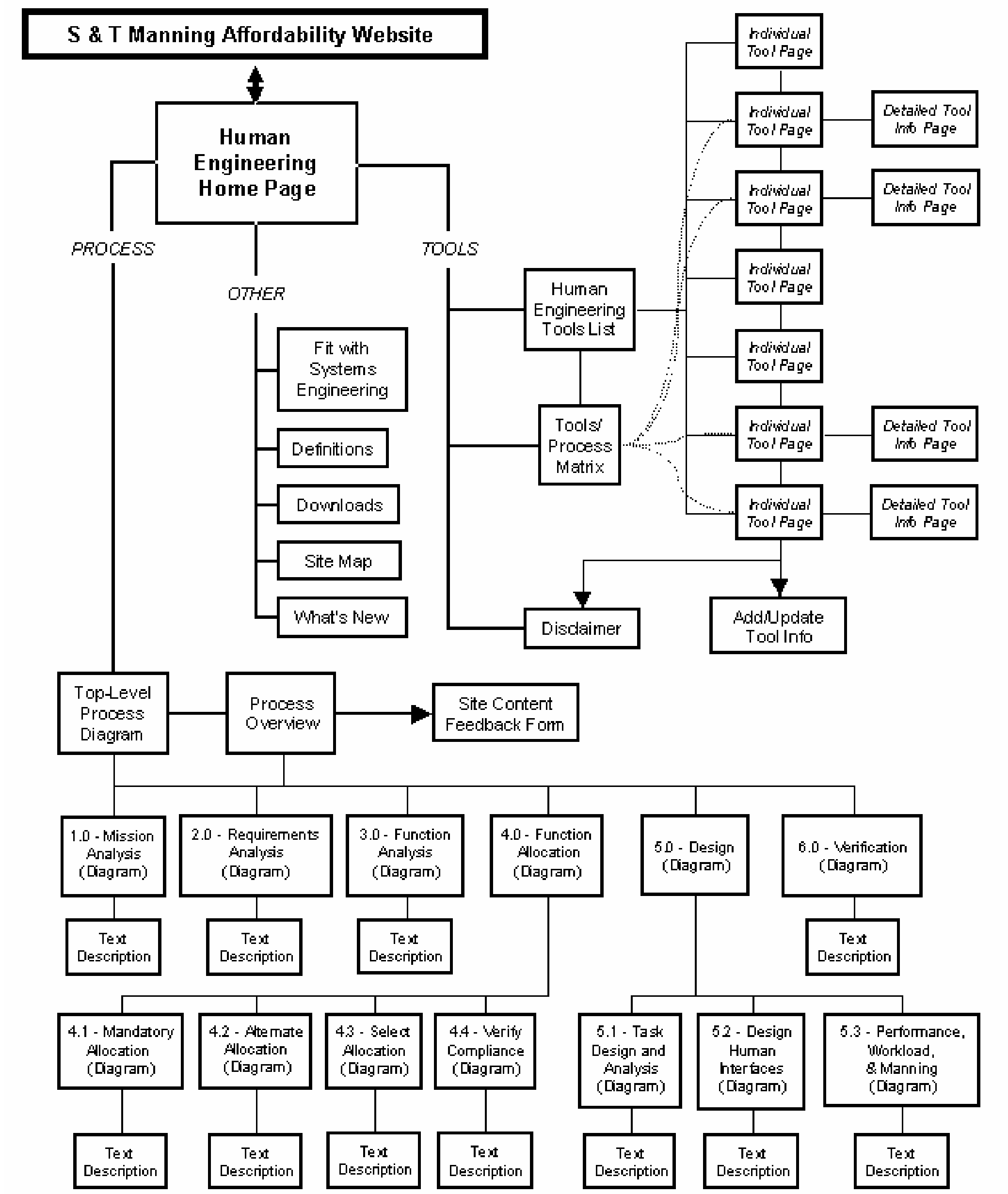


Figure 8. ONR S&T Manning Affordability site map (from http://www.manningaffordability.com/s&tweb/index.htm)

### 7. Ongoing Research

Research is underway by the National Academy of Sciences to develop a study on HSI resources (John Lockett, personal communication, Sep 29, 2006). The Human-Systems Design Support for Changing Technology study panel was chartered to "develop a vision for incorporating human factors engineering considerations into the design process for complex systems, especially in view of technologies that are changing rapidly and increasing in complexity" (The National Academies, 2006). One of the panel's goals is to issue a report which considers "the techniques for an integrated, interdisciplinary, adaptable human-system design methodology and tools that can be applied in both civilian and military arenas" (The National Academies, 2006). The study initiated in 2005, and while much effort has been devoted to this endeavor, the group's findings, to include databases and reports, are not expected to be available until spring of 2007.

### 8. An Explanatory Note

It is apparent that, as with most complex systems, there is no global solution to the question of what resource, or set of resources, will be most effective. Any attempt to identify the 'essential' resources for the evaluation of HSI will inevitably limit the ability to properly evaluate a system. Each system's intricate design requires careful study by properly educated and experienced personnel to most accurately assess the level of integration a system has achieved across the HSI domains. Defense Acquisition University identifies these individuals as HSI Analysts (USD/(AT&L), 2006). More will be discussed with respect to these individuals in Chapter V. Carr and Scholl (2006) describe the HSI process as a refining process whereby the relevant domains are placed under scrutiny to ensure that every possible advantage is identified and weighed. The products of this process are referred to as the 'silver bullets' of HSI. It is important to note that the term is used in the plural form. Each system's unique design, characteristics and requirements will require an equally unique 'silver bullet'.

The database described in this chapter presents the HSI analyst with a starting point when planning HSI evaluations. The purpose for these evaluations, as well as how HSI fits into Defense Acquisition are the subject of the next chapter.

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# III. THE LANGUAGE OF HSI AND ACQUISITION

## A. DEFENSE ACQUISITION

As previously noted, a key area of influence for Human Systems Integration is in the design, development, manufacturing and support of processes and products. The Department of Defense (DoD) utilizes the Defense Acquisition Management Framework as the means for procuring these new items, as well as for improving existing processes and products (Figure 9). Using the framework, the DoD identifies each product or process as a program, and assigns a program manager to oversee the procurement of the item. Program managers, with the support of Integrated Product Team (IPT) members, make the decisions affecting a program based on information about the program's budget, time constraints, and key performance parameters. Since this information is vital in decision-making, the chief concerns of program management center on the cost, schedule and performance of a program mitigated by the associated risks. In fact, DoD acquisition professionals are trained on the evaluation of these three areas as they relate to a given program (USD/(AT&L), 2001). Often, the success of a program manager is measured by how well he/she manages the cost, schedule, and performance of the program.

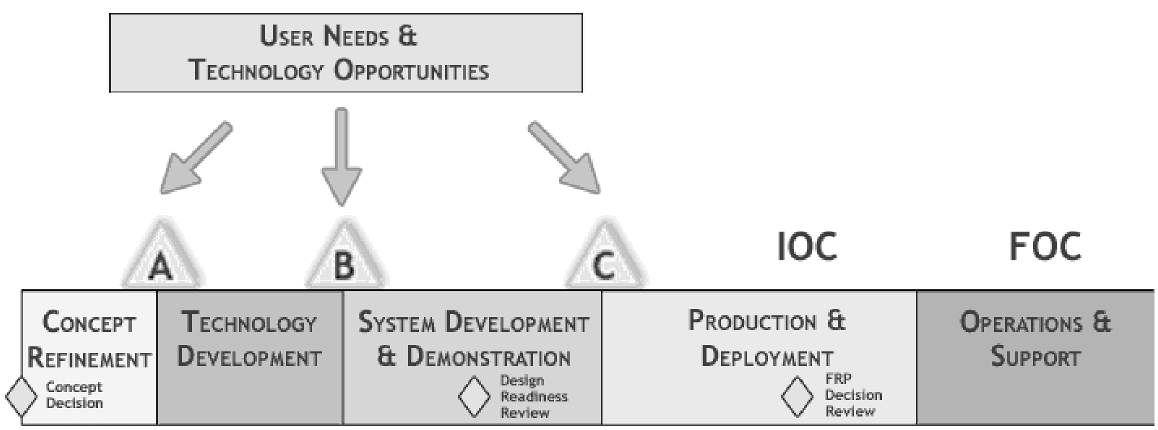


Figure 9. Defense Acquisition Framework (From http://akss.dau.mil/dag/DoD5002/Figure1.asp)

The costs associated with any system are not restricted to the amount of money spent to buy the item. In order to better understand how much resources will be required by a system over its entire life, a metric is needed which takes into account the cost of designing, developing and manufacturing the system, as well as the necessary operational and sustainment costs, and the eventual cost of disposal. Life Cycle Cost (LCC) is the term used to describe the summation of all costs associated with the system. There is sufficient anecdotal evidence that Program Managers have, on occasion, made program decisions based on the short-term acquisition cost of a system without paying attention to the associated future costs that would be required. In these situations, cost overruns are inevitable. By determining the LCC of a system, Program Managers and the DoD can conduct fiscal management with more accurate detail, avoiding the 'hidden costs' that may otherwise surface. For clarification, the costs described in the remainder of this study relate to the system's LCC.

To assist program managers with keeping programs on schedule, within budgetary constraints, and meeting performance parameters, the DoD provides a host of courses, guidelines, best practices and additional information available through the Defense Acquisition University (DAU). Managing the trade-offs between the triple constraints of cost, schedule and performance is similar to the management of the trade-offs between domains of HSI.

The DAU has implemented specific guidance with respect to the relationships between the three key areas of interest to the program manager. The DAU instruction describes the interrelatedness of cost and schedule through the concept of Earned Value Management (EVM) and the associated EVM system (Berta & Mandley, 2005). The EVM system allows program managers to measure the amount of work going into a project and the productivity of that work in dollars and hours. While the EVM system provides excellent information on cost and schedule, system performance, measured by the effectiveness of the system in meeting the key performance parameters, is tracked only in the early stages, or as changes to the system require. Since the human element of a program offers the greatest potential for improving system performance (Booher, 2002), incorporating HSI into the acquisition process gives program managers up-to-date information on the system's performance. Acknowledging this opportunity, the DoD includes HSI in the latest versions of its acquisition-related documents.

## B. HSI IN DEFENSE ACQUISITION

The main sources of information on acquisition in the Department of Defense are the DoD 5000 series documents and the Defense Acquisition Guidebook (DAG). Within the 5000.1 directive, HSI is implied or mentioned by name in the enclosure under the subsections of Safety and Total Systems Approach. Specifically, the document directs that program managers "shall apply Human Systems Integration to optimize total system performance, operational effectiveness, and suitability, survivability, safety, and affordability" (USD/(AT&L), 2002a). After mentioning HSI as one of the purposes of the System Development and Demonstration phase in the acquisition framework, DoD Instruction 5000.2 includes an entire enclosure on the implementation of HSI. The enclosure opens with a statement that the program manager "shall have a comprehensive plan for HSI in place early in the acquisition process to optimize total system performance, minimize total ownership costs, and ensure that the system is built to accommodate the characteristics of the user population that will …[use]… the system" (USD/(AT&L), 2002b). Unfortunately, no additional instruction pertaining to the HSI plan is given, and the remainder of the enclosure describes typical activities that should be conducted in each of the individual domains. In effect, the instruction reduces HSI to a grouping together and managing of activities related to the human. The latest draft version of the Acquisition Strategy Guide states that "the Program Manager should pursue HSI initiatives within the strategy to optimize total system performance and minimize [total ownership cost]" (Defense Acquisition University Press, 2003). However, nowhere does the DoD require mandatory briefings of HSI to senior leadership at the major decision points of a program known as the Milestone briefings.

However, HSI is enjoying increased visibility in the acquisition community. The latest version of the Defense Acquisition Guidebook (DAG) devotes an entire chapter to HSI (USD/(AT&L), 2006). Building upon the information given in the Directive and Instruction, chapter 6 of the DAG provides a more detailed description of the activities associated with each domain of HSI, as well as detailing the need for integration of the efforts occurring in each of the domains. Specifically, the DAG recognizes integration as the “key to a successful HSI strategy”. The US Navy’s NAVAIR Acquisition Guide describes the importance of HSI in acquisition, with the goal “to influence system design and associated support requirements so that …systems can be operated and maintained in the most cost-effective and safe manner consistent with manpower structure, personnel aptitude and skill, and training resource constraints” (NAVAIR, 2004).

Any attempt to cohesively incorporate the efforts of HSI evaluations and the acquisition management strategy currently supported by the DoD must speak in the language of defense acquisition—that is, cost, schedule, and performance. Expressing HSI in these terms requires identifying the parameters to be measured and defining the relationship that each parameter has with program costs, schedule, and performance. For each program, this process is unique. The model described in Chapter IV provides a workspace for HSI evaluation—converted to the language of defense acquisition—without restricting the evaluator. With myriad parameters for evaluation, an example of the conversion of a simple parameter with respect to each domain may prove useful. The next section describes how each domain may be expressed in terms of one of the most notable dialects of defense acquisition: life-cycle costs.

## C. AN EXAMPLE: EXPRESSING THE DOMAINS OF HSI IN TERMS OF LIFE-CYCLE COSTS

Cost estimating is a vital part of defense acquisition. In order to produce a preliminary budget, the costs involved must be estimated. Thereafter, any potential change to the system must be evaluated with respect to its effect on the program’s budget. The resulting estimates are only as accurate as the amount of variability accounted for by the cost estimator. Essentially, cost estimators attempt to define as much of the trade-space surrounding a decision as possible.

For this reason, a more accurate estimation of life cycle cost is achieved through understanding how changes affect the human element of the system. Since HSI in the US Navy's SEAPRINT is currently envisioned by eight domains, the possible conversion of each of these domains into life-cycle costs is provided below as an example.

**1. Manpower**

By definition, manpower relates solely to the number of individuals required to operate and maintain a system (U.S. Navy, 2006). To put this in terms of cost we must consider all expenses associated with manpower. Expenses related to military manpower include wages, services such as health care, housing, sustenance, transportation, etc. Once these expenses are identified, a per-individual amount can be derived which will provide a unit cost for unit of manpower. In essence, knowing that a system will require twenty individuals to operate it, a rough estimate of the cost to supply those twenty individuals can be determined.

**2. Personnel**

Returning to the definitions of HSI domains, the personnel domain is associated with the cognitive and physical capabilities, as well as additional human characteristics and individual experiences necessary for a system to function at a given level (U.S. Navy, 2006). Costs associated with personnel center chiefly on the selection process and assignment of compensation. Determination of the level of individual attributes, or perhaps the scarcity of the personnel attributes required, will allow for identification of the requisite wage for such individuals. The cost of personnel can therefore be described in compensation (easily converted to dollars) per individual required.

**3. Training**

Current standard business practices call for an accounting of costs incurred by a company and benefits derived from those costs. The ratio of these two amounts, known as Return on Investment (ROI), is commonly used to evaluate training programs (Bartel, 2000). Total costs of training include development costs, lost time from performing work, overhead of education department, physical materials, etc. While instructor based training may incur higher costs such as travel to and from training, instructor salary, and even refreshments, computer-based training also incurs costs stemming from media programming, production and distribution (Connor, 2002).

#### 4. Human Factors

The field of human factors has used cost as an evaluative measure of usability for many years. The idea of a curvilinear relationship between dollars spent on usability and benefit received from such efforts is the basis for cost-justifying usability (Bias and Mayhew, 1994). There is a point where increased spending or effort results in diminishing returns.

As with most engineering efforts, the human factors engineering industry estimates a certain amount of production for each hour worked. With respect to cost, human factors can be described as the level of effort—defined as hours billed—given to the human factors design of a system throughout the development process. The cost per hour can be calculated and, when multiplied by the number of hours required, will result in a cost for the human factors effort. In theory, the more hours dedicated to human factors design, the more usable the system will be.

#### 5. Safety

Describing system safety as a cost measure requires an evaluation of the potential number of hours lost due to mishaps and converting those lost hours to a dollar amount by multiplying the number of hours by the per hour wage for the affected individual(s). This would result in the ability to ascertain the associated costs given the level of safety designed into a system. Increasing the level of safety would reduce the associated costs just as lowering the level of safety would increase associated costs.

#### 6. Health Hazards

Within a system, each system-caused stressor adds to the level of hazard inherent in the operation of the system. Mitigation of these hazards reduces the risk of bodily injury or death. Stress fractures caused by repeated jumps with +200 pound packs, inadequate design of steam pipes in a naval vessel, and high levels of vibration from sustained operations in a tank can all lead to injuries ranging from mild to severe and resulting in the temporary or permanent loss of personnel. Somewhat similar to the costs of safety described as hours lost, the costs of health hazards can be calculated by assessing the estimated associated treatment costs for level of exposure allowed in the design of a system. Added to this are the hours lost by such injuries, and—in the case of permanent disability—the costs of compensating the injured personnel and costs of acquiring another equally qualified individual. Exposure to nuclear, biological, and chemical weapons will have increased costs as the level of protection diminishes. As more attention is paid to addressing the health hazards of the system, the associated costs to the system can be reduced.

The interrelatedness of the HSI domains is readily apparent from this example. Improved efforts in the area of health hazards and human factors can reduce costs associated with training, manpower, and safety.

### 7. Human Survivability

Survivability describes the ability of the human in the system to remain unharmed by non-system-related causes throughout operation of the system (U.S. NPS, 2006). The level of survivability afforded by the system will determine the number and frequency of personnel being gained by the system (through loss of personnel), as well as injury rate and severity from outside causes. Costs associated with survivability should therefore include a combination of the predicted probability of kill, a measurement of possible injury rate, and costs for acquiring additional adequate personnel and costs associated with injury recovery.

### 8. Habitability

Arguably the most difficult of the domains to define, habitability refers to accounting for the physical and psychological needs associated with sustained operation of the system (Naval Postgraduate School, 2006). State-of-the-art berthing, with soundproof sleep chambers and a schedule designed to minimize fatigue during the planned year-long mission, may rank low in habitability if there exist no means for personnel to communicate with loved ones or enjoy down-time. The cost of habitability can be expressed as the costs associated with maintaining adequate services and facilities to induce personnel to remain as part of the system.

## D. THE NEXT STEP

While the exact dimensions of the HSI foundation are still being deliberated, it is readily apparent that the world of defense acquisition rests solidly within its borders. When discussing metrics for acquisition, cost, schedule, performance, and risk are the essential dependent variables. Determining how acquisition program decisions will affect the cost, schedule or performance of the system allows the analyst to communicate most effectively with program management.

Each defense acquisition system will require a tailored approach to HSI. The temptation to produce a single equation which could be applied to any acquisition program will not be satisfactory. However, since the concept of HSI is based on the evaluation of trade-offs and interactions between parameters, a general process and workspace within which an individual evaluation can be developed is critical, and will provide much needed guidance for those individuals conducting HSI evaluations. The next chapter presents an approach to the design of such a workspace.

# IV. AN INTERACTIVE HSI VISUALIZATION TOOL FOR THE ACQUSITION PROFESSIONAL

## A. VISUALIZING HSI

A logical process for the Human Systems Integration evaluation of an acquisition program can be summarized in four steps: planning and conducting the evaluation, compiling the results, presenting the findings, and receiving feedback from program decision-makers. Using this process as a guide, a series of interfaces were designed to aid both the individuals conducting the HSI evaluations and those who would use the results in making changes to the program. The interfaces were designed with the intent to be quickly and easily interpreted. To this end, they are highly visual in nature. The three interfaces include an HSI Resource Search interface, a parameter interaction editor, and the culminating HSI Trade Space Tool (HSI TST). Each of the three interfaces is described in detail below.

## B. PLANNING AND CONDUCTING THE EVALUATION

In order for any acquisition program to be initiated, the need for which it is being developed must be defined. As part of this process, the Initial Capabilities Document (ICD) details “the need for a materiel approach…to satisfy specific capability gap(s)” (DAU, 2006a). When necessary, the ICD leads to production of the Capability Development Document (CDD). The CDD further defines the necessary operational mission performance parameters. Based on the human performance requirements identified in the program’s CDD, the HSI analyst must develop a plan for conducting the necessary assessments to ensure the program meets performance parameters.

Similar to the HSI Resource Data Collection Sheet described in Chapter II, the user interface designed for planning an HSI evaluation (Figure 10) provides key information with respect to the myriad products available for use in evaluating specific human performance parameters. Whereas the data collection sheet allows for the input of data, the interface allows the user to search the database of resources by a variety of fields: name, classification, metric, and HSI domain. After filling in the relevant data and executing the search function, the analyst is presented with a list of resources matching the query. Selecting any of the listed resources opens the database information on that resource, allowing the analyst to determine the best resource for the requirement. Once methods for assessing the human performance requirements have been identified, the HSI analyst can proceed with conducting the evaluation knowing all requirements are accounted for.

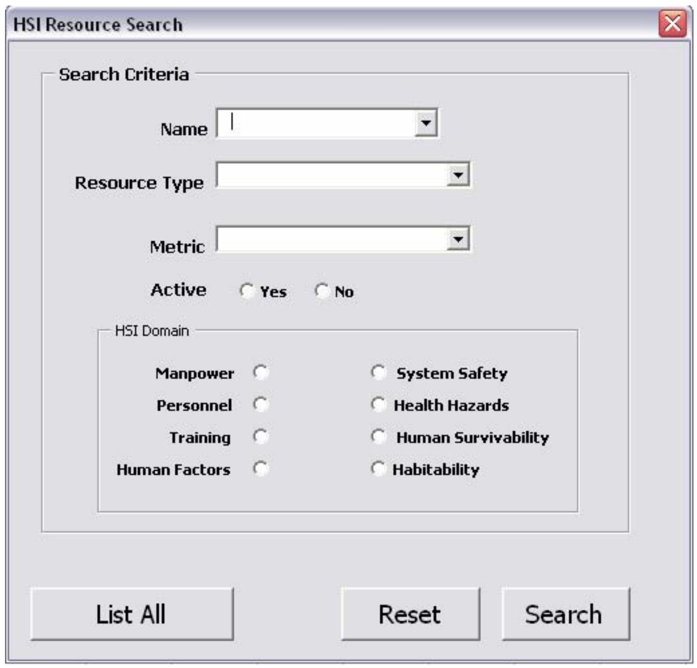


Figure 10. HSI Resource Search Interface

## C. COMPILING THE RESULTS

Once an analysis of the design decisions has been conducted on all relevant parameters, the HSI analyst must create a logical relationship between the parameters. It is at this point that true Human Systems Integration takes place. By identifying the relationships between parameters, the impact of design changes can be made much clearer.

Considering the possible parameters for evaluation, an HSI analyst may be required to define a vast number of relationships in order to account for enough of the trade space to provide a usable solution. Looking solely at the two-way interactions between parameters could severely limit the effectiveness of the evaluation. Taking the historical conceptualization of HSI as seven to nine individual domains, the complete list of two-way interactions only accounts for as much as 17.5% or as little as 7% of the possible interactions. It would be irresponsible to base decisions affecting large-scale programs on such limited assumptions. Expanding the model to include all possible interactions (between 128 and 502), however, would result in an excessive load for the analyst in both time and complexity. In order to limit the scope of the model, a fresh approach to the traditional domains of HSI was considered.

Cameron and Rench (2005) propose that HSI consists of experts in the four domains of Manpower, Personnel, Training, and Human Factors, working toward goals related to the remaining domains. These four key domains exist in each of the services' HSI paradigms, with the services differing in the observance of the final three to five domains (Figure 11). Expanding on the idea posited by Cameron and Rench, the four key domains can be viewed as inputs to the system of HSI evaluation, with the remaining domains viewed as functions of the interactions between key domains, and the output being total system performance. Focusing on these four domains as the driving force behind HSI effectiveness and representing the remaining traditional domains as functions—along with the acquisition imperatives of cost, schedule, performance and risk—reduces the workload to a more manageable level: defining 27 interactions and four functions.

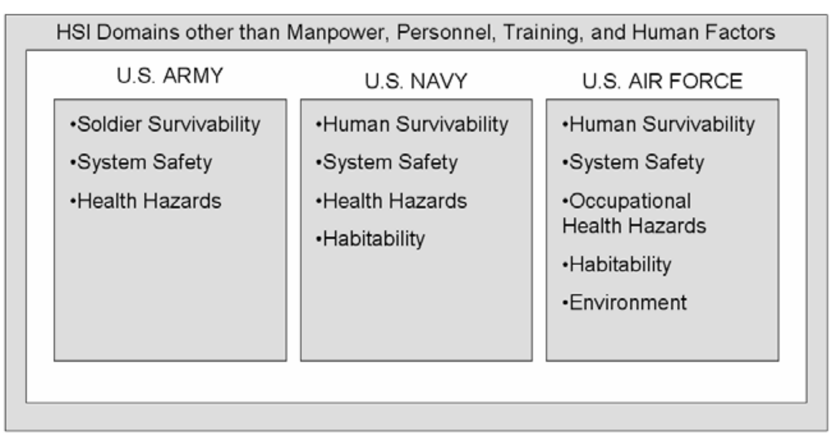


Figure 11. Service specific HSI domains

By scoping the model to the four key HSI domains and their interactions with acquisition parameters, the design of the interface becomes more tailored to the Defense Acquisition HSI analyst. The field of HSI is still evolving, and may not be fully defined. Ensuring customizability of the interface would allow HSI professionals to experiment with optional parameters. Also, it would allow the interface to evolve with the current understanding of HSI. To this end, the interface was designed with preset parameters for each of the services as well as a customizable feature where the user could create and define each parameter.

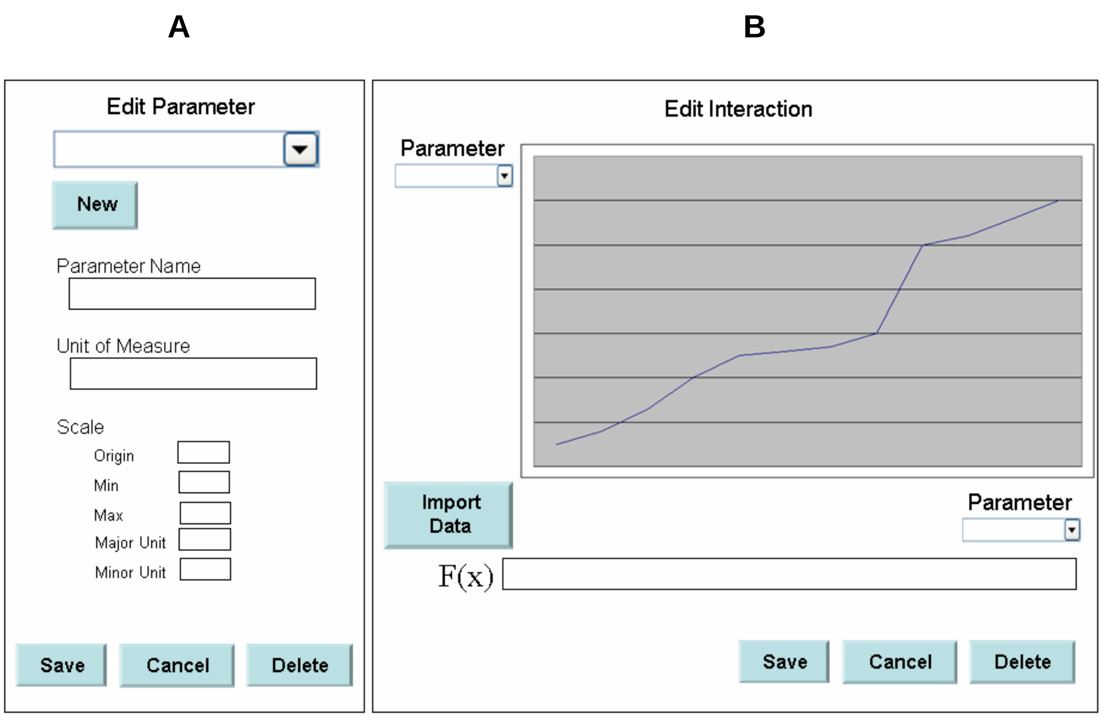


Figure 12. HSI analyst interface: 'Edit Parameter' (A) and 'Edit Interaction' (B).

After selecting a parameter to edit from a dropdown menu in the 'Edit Parameter' box (see A in Figure 12)—or selecting to enter a new parameter—the HSI analyst enters information defining the parameter. This information includes editing the parameter name, the unit of measure, and a series of inputs describing the scale to be displayed. The interface was designed to allow the analyst to enter ranges of acceptable, questionable, and unacceptable levels associated with the acquisition parameters of cost, schedule, performance and risk. These ranges were designed to be used in the decision-maker's interface described later. The information for each parameter is saved by selecting the 'Save' button at the bottom of the 'Edit Parameter' box. Additionally, options for clearing the contents or deleting a parameter are offered.

Once this process has been completed for each parameter, the HSI analyst defines the interactions between parameters through the 'Edit Interaction' box (see B in Figure 12). Here, the HSI analyst can manipulate the two-way interactions through selecting the appropriate parameters and using one of three methods to describe the relationship: text input, imported data, and line manipulation. The text input option allows the HSI analyst to enter a mathematical equation which the interface then displays graphically. If the analyst has previously correlated the two parameters—for example, identifying the costs associated with certain manpower levels—the data can be imported directly into the interface by selecting the 'Import Data' button. The user is then prompted to identify the appropriate file which contains the XY coordinates. The coordinates are then displayed graphically according to the parameter settings. The final option for inputting relational data is to select the general type of line from a dropdown menu resulting in a line displayed in the graphing area. This line can then be manipulated by clicking and dragging points on the line. The interface is designed with the capability of converting the manipulated line into an equation which is displayed in the equation text box. Once the user is satisfied with the result, the interaction is saved, and the process continues for each interaction.

To this point, the analyst has defined all two-way interactions between the main parameters and the acquisition parameters of cost, schedule, performance and risk. Here it becomes difficult to graphically represent the final multi-parameter interactions. The interface was designed to input these multi-parameter interactions solely through the text input option. When known, these multi-parameter interactions can greatly enhance the detail of the evaluation. Unfortunately, these interactions are difficult to define. Nevertheless, the option has been designed into the interface. Potentially improved methods for accounting for multi-parameter interactions are discussed in the final chapter.

## D. PRESENTING EVALUATION RESULTS AND RECEIVING FEEDBACK

The main objectives of the HSI analyst are to convey the level to which consideration of the human element has been designed into the system, and demonstrate the potential effects of system changes on the human element. These objectives can be accomplished through a simple graphical representation of the current assessment of the system, as well as the capability to manipulate the current levels in order to view probable outcomes. The HSI Trade Space Tool was designed with such an interface in mind.

### 1. 'Slider' concept

In 2002, under a work project for the Air Force's 311th Human Systems Wing, Veridian Engineering, with guidance from Air Force Major Robert Lindberg, developed a conceptual tool that expressed the idea of displaying, in a simple interface, the trade-offs among HSI domains associated with program decisions (Fig 13). The intent of the project was to emphasize the importance of understanding the bivariate relationships that exist between the domains of HSI. This project was a simple demonstration, and the interactions between elements were defined using curves derived from general observations.

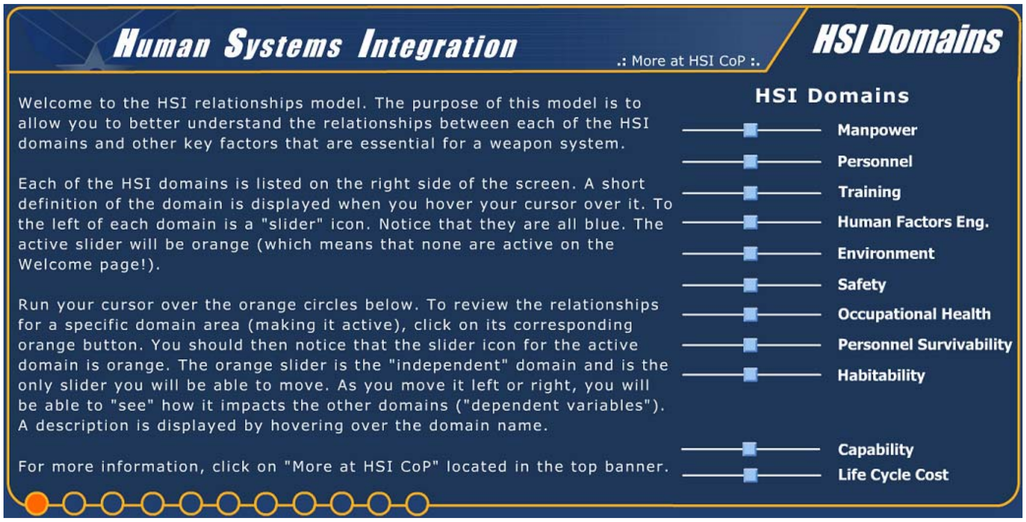


Figure 13. HSI slider tool concept (From http://Kn.gd-ais.com/ASPs/eLearning/HSI_Sliders/concepts/application.swf)

Initially, the concept of the model was based on describing the two-way relationships between a single domain and each of the others, as well as the relationships of that single domain to the life cycle cost and capability of the system. As discussed previously, a more accurate model was needed which would include multivariate interactions. While the concept could remain relatively intact, the processes behind it, as described in the previous section, became more involved.

### 2. HSI Trade Space Tool (HSI TST)

The HSI TST interface is designed using a concept similar to that of the slider tool developed for the Air Force. Each parameter is placed on the left, with descriptive labels identifying the parameter, unit of measure and present value. The acquisition parameters (cost, schedule, performance and risk) are placed on the right, with similar labels. Additionally, the text box associated with the present value for each of the acquisition parameters is color-coordinated with the present value, based on the ranges defined in the parameter editor (green=acceptable, yellow=questionable, red=unacceptable). The capability to select an individual parameter to alter is accomplished by placing a selection button above each parameter. Once selected, movement of the associated slider bar presents the predicted changes in the remaining parameters. The movement of the remaining parameters is designed to utilize the interactions defined by the HSI analyst, with the acquisition parameters defined as functions of the main parameters. A conceptual design of the HSI TST interface is provided in Figure 14.

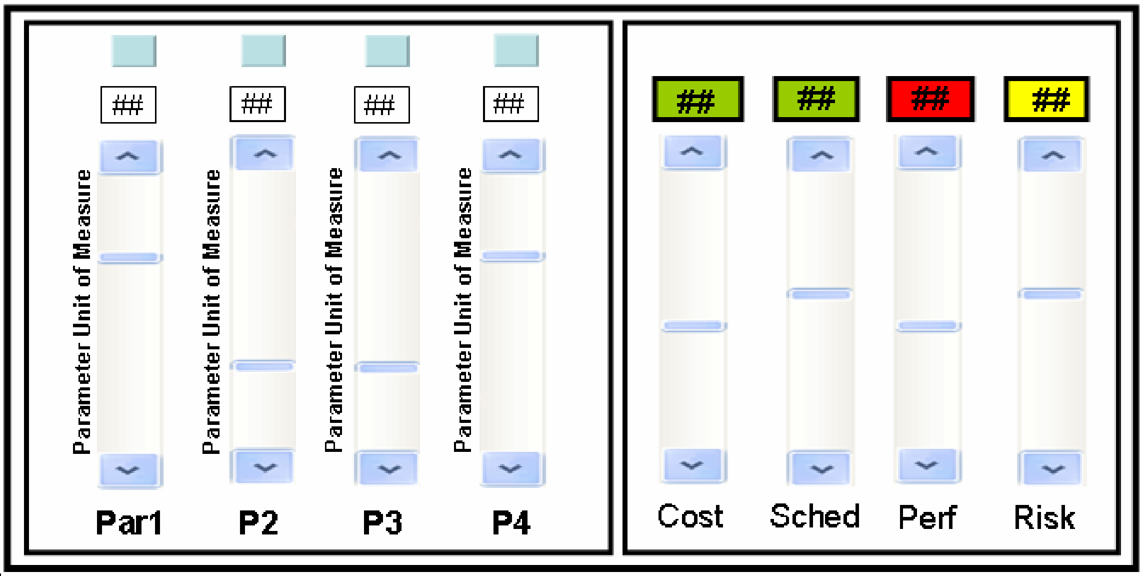


Figure 14. Modified 'Slider'—HSI Trade Space Tool (TST)

## E. JOINT DEVELOPMENT OF INTERFACE SOFTWARE

At the same time as the interfaces and process described above were being developed, an effort to produce a stand-alone introductory course in HSI was underway at the Naval Postgraduate School by Professors Larry Shattuck and Nita Lewis Miller. They offered the assistance of the Office of Continual Learning (OCL) at NPS in developing the software for the interfaces, with the intent of using the process and interfaces as part of the introductory course. With the basic designs and detailed descriptions of the functionality of each interface well defined, the OCL at NPS initiated software development of the interfaces in late November, 2006.

The design of the various interfaces and coursework outlined in this chapter would be of no use if it did not reach the audience that can most effectively use them. Identifying these individuals, as well as venues for introducing the interfaces and coursework discussed above, is the purpose of the next chapter.

# V. DISTRIBUTING THE MODEL

## A. VENUES OF DISTRIBUTION

Recent guidance to acquisition professionals identifies HSI analysts as those who implement HSI in systems acquisition and "assist program managers by focusing attention on the human part of the system and by integrating and inserting [domain] considerations" (USD/(AT&L), 2006). However, the current guidance does not elaborate on the qualifications of these individuals, how to find such individuals, or the process for becoming such an individual. These HSI analysts, as well as the acquisition community at large, are the target group for distribution of the HSI evaluation process and interfaces.

Including HSI in acquisition guidance opens the door for regulation of the qualifications and certification of those labeled HSI analysts. Through the Defense Acquisition Workforce Improvement Act (DAWIA), the Under Secretary of Defense/Acquisition Technology and Logistics (USD/AT&L) outlines the education, training and experience level required for certification in many of the fields related to defense acquisition (i.e. Program Management, Systems Engineering, Contracting, Test and Evaluation). In general, certification consists of meeting the requirements at one of three levels. As outlined in the Defense Acquisition University (DAU) Catalog Appendix B (DAU, 2006), requirements for certification follow the general guidelines listed below:

| | |
|---|---|
| **LEVEL I:** | **Education**— Baccalaureates Degree |
| | **Experience**—1 year experience in related field |
| | **Training**— Basic acquisition courses in related field |
| **LEVEL II**: | **Education**— Baccalaureates Degree or Graduate studies |
| | **Experience**—2 years experience in the related field |
| | **Training**—Intermediate acquisition courses in related field |
| **LEVEL III**: | **Education**—Masters Degree (Desired) |
| | **Experience**— 4 years experience in related field |
| | **Training**— Advanced acquisition courses in related field |

A similar certification process must be included for the HSI analyst in order to ensure a more consistent level of expertise at the HSI analyst position. This process must be initiated by the establishment of a functional career field in HSI as has been done for all other acquisition related career fields.

It is imperative that resources such as the ones designed in the present study be available to as many HSI analysts and acquisition professionals as possible. Widespread availability will facilitate standardization of HSI practices, allowing program managers to know what to expect in the way of HSI analyses. To this end, the key organizations and communities of such individuals were identified as points of entry for the software. The remainder of this chapter describes how the model can be introduced in the following organizations and communities: Defense Acquisition University, service-specific acquisition communities, major defense contractors, and NPS/AFIT/Service Academies.

### 1. Defense Acquisition University

The major provider of instructional material and resources related to acquisition is the Defense Acquisition University (DAU). The DAU provides coursework and instruction in accordance with DAWIA. Under DAWIA, acquisition professionals gain certification, and continual learning, on the best practices of defense acquisition.

Incorporating the HSI evaluation process model and software into DAU's coursework and website is a key step in standardization. As the hub of information for the DoD Acquisition, Technology, and Logistics (AT&L) workforce, the DAU provides a clear path to each of the services, to industry professionals, and to other federal agencies. Simply placing the information on the DAU website will not produce the desired results. Incorporating the process and software into required coursework will ensure that all acquisition-trained personnel understand—or at least have been exposed to—the HSI evaluation process. As mentioned in Chapter IV, coursework is currently under development at the Naval Postgraduate School (NPS) where the interfaces and process can be inserted. The products of these efforts will be a stand-alone introductory course on HSI as well as a four-course certificate program in HSI offered by NPS. Adding these courses to the DAU catalog and including them as part of the basic acquisition education will disseminate the understanding of HSI throughout the fields of management, logistics, engineering, and analysis which receive training through DAU. While the coursework is presently designed solely as a certificate program, it may be the answer to the DAU Level I, II, and III training requirements for certification as an HSI analyst described previously.

#### 2. Service Specific Acquisition Communities

Though all of the services rely on the DAU as a source for continuing education in acquisition, each service in the DoD handles the acquisition process differently. Regardless of the composition of the individual service's acquisition force, each service educates its acquisition personnel on the service specific processes involved with the acquisition process. This service specific education includes a basic understanding of systems thinking as it relates to program management. As has been argued throughout this study, recognizing the human as a key component in the system—and the component where, through proper utilization, the most benefit can be gained—is vital to systems acquisition. The products of this study can provide the means whereby this understanding can be incorporated into the service specific acquisition management processes.

#### 3. Major Defense Contractors

Most of the work involved with the acquisition of a system is conducted by defense contractors. Knowing that the more comprehensive understanding they have of the acquisition process makes them more appealing in the selection process, defense contractors attempt to stay abreast of the changing regulations and requirements set forth in defense acquisition guidance. In 2002, both Boeing and Lockheed-Martin entered into strategic partnerships with DAU in order to ensure best practices in acquisition management (Glass, 2002a; Glass, 2002b). This strategic partnership provides contractor personnel the same opportunity for instruction as any other defense personnel. Those defense contractors who have created these ties to DAU will benefit from the coursework outlined above. However, not all defense contractors have made these ties. Where necessary, providing these defense contractors with the process, software and instruction on

HSI will afford them the opportunity to remain competitive in the selection process and ensure a higher caliber of proposals where HSI is a concern.

#### 4. Service Academies, NPS, and AFIT

While the greatest visibility of HSI may lie within the acquisition community, the concept of Human Systems Integration relates to many other academic degrees sought after by DoD personnel, beginning with the service academies. Coursework in HSI fits easily into academic departments of the U.S. Air Force, Naval, Coast Guard and Military Academies. Both the U.S. Military Academy and the U.S. Air Force Academy have Behavioral Sciences and Leadership departments. Additionally, each of the four service academies has a department or degree program related to systems engineering: Systems Engineering Department (USMA), Systems Engineering & Systems Engineering Management degree program (USAFA), Department of Weapons and Systems Engineering (USNA), Engineering and Management Departments (USCGA). Providing an understanding of HSI through introduction of the software and process described in Chapter IV at the undergraduate level will instill the importance of systems thinking—especially related to the human—that will drive the future of HSI. While not all academy graduates will seek higher degrees in HSI or Systems Engineering, they will certainly be involved in human-systems and/or with HSI at some point in their careers. Their previous exposure to HSI could tip the scales toward a human-centered decision.

Academy graduates who desire to further explore the field of HSI should find the opportunity to do so within the military academic community. As mentioned in Chapter I, the Naval Postgraduate School offers a Masters degree in Human Systems Integration. However, similar to the undergraduate level programs, HSI can be easily integrated into other programs at NPS, such as the Systems Engineering department, as well as through the Air Force Institute of Technology's Department of Systems and Engineering Management and Center for Systems Engineering.

### 5. Result of Proper Distribution

Incorporating the process and software as outlined above creates an unbroken link of HSI understanding through the entire acquisition community and the acquisition process. The potential exists to educate all essential personnel in the significance of Human Systems Integration and the potential improvement that focusing on the human can produce. From senior leadership who determine new capabilities are required, to the users identified to participate in initial capabilities studies, to the acquisition professionals who plan for and execute the management of the acquisition, to the contractors who are selected to deliver the end produce, a clearer understanding of HSI will result in better systems.

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# VI. FUTURE RESEARCH AND SUMMARY

## A. FUTURE RESEARCH

While the present study has described interfaces to aid HSI analysts and acquisition program decision-makers in communicating human effectiveness in the system, continued research should be conducted to ensure that this approach provides the most accurate description of the parameter interactions. Additional approaches for considering multivariate HSI trade offs have been suggested. These approaches include nearly orthogonal Latin hypercubes, and optimal computing budget allocation.

One approach to modeling HSI involves the use of nearly orthogonal Latin hypercubes (Lucas & Sanchez, 2003). Through models based on this concept, the HSI analyst would conduct evaluations on parameters similar to the process presented in this study. With the results of these evaluations, and after defining the parameters for the model, the HSI analyst would be presented with a limited series of scenarios—selected through application of nearly orthogonal Latin hypercubes. In this manner, the HSI analyst would not need to solve every possible scenario. The limited series would provide sufficient statistical data from which any scenario could be evaluated.

Another approach, which similarly attempts to effectively reduce the enormity of scenarios involved in multivariate analyses, is optimal computing budget allocation (OCBA) for simulation (Chen, H. C., Lin, J., Yucesan, E. & Chick, S. E., 2000). Through this approach, a highly efficient number of scenarios are determined with the intent to significantly reduce total costs associated with simulation.

The present models of HSI must be refined and validated. Researchers must conduct detailed investigations into the interactions which exist among the domains of HSI—whatever those domains may end up being. Having a better concept of how the domains interact will reduce the uncertainty with which HSI analysts are forced to deal with at present.

In the same manner as basic use case data were collected for fields such as cost estimation and usability, HSI professionals must begin collecting and consolidating use case information on the outcomes of program decisions as they affect the human element. Building a database of HSI domain-assessed systems will provide future analysts with vital information as they attempt to influence program decisions in the earliest stages of system design. Similarly, building a database of the observed interactions between HSI system parameters will result in a knowledge base from which HSI analysts can draw when identifying human performance parameters in future system capabilities.

## B. SUMMARY

The concept of Human Systems Integration is being included increasingly in the world of Department of Defense acquisition. As that role continues to be defined, it is imperative that processes for conducting HSI evaluations be standardized across the DoD. Such standardization removes the ambiguity surrounding HSI and allows decision-makers to know what to expect in the way of HSI evaluations and inputs to the acquisition process.

The present study has defined a process whereby HSI evaluations can be planned, conducted, analyzed, and presented to decision-makers. Products currently available for conducting analyses were reviewed and included in a searchable database, scheduled for release via the internet on the NPS HSI homepage. Software for defining the interactions between relevant parameters of HSI, as well as an interface to display potential effects of program changes to decision-makers was designed and is now in development. This software will also be available via the NPS website when completed. Additionally, a plan for distribution of such tools to the acquisition community was discussed. While improvements to the design of specific software will always be made, the basic process for conducting HSI evaluations, as well as the individuals who should be apprised of the process and resources available, is relatively constant.

In an era of manpower drawdowns and continual reductions in program budgets, recognizing the potential for system improvement through better integration of the human element represents a veritable goldmine of savings. Omission of the burgeoning concept of HSI will result in wasted time, taxpayer dollars, and potentially, the very lives of service members themselves.

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