An Overview of the Air Force Institute of Technology's Human Systems Master's Degree Program

Jeffrey C. Parr(✉), Christina F. Rusnock, and Michael E. Miller

Systems Engineering and Management, Air Force Institute of Technology,
Wright Patterson AFB, OH, USA
{Jeffrey.Parr,Christina.Rusnock,Michael.Miller}@afit.edu

Abstract. The US Air Force employs systems today to perform tasks we could only have dreamed of in the past. The evolution of the Wright Brother's flying machine permits operators to fly farther, faster, and higher than originally imagined. Too often, however, the complexity of these and other DoD systems lead to complex, non-intuitive user controls and interfaces that produce less than optimal performance or excessive system brittleness. The Air Force Institute of Technology's (AFIT) Human Systems specialization, sponsored by the research branch of the US Air Force 711th Human Performance Wing, is designed to provide students with systems engineering and human factors knowledge to permit them to contribute to the research and development of complex systems and systems of systems. This specialization within AFIT's systems engineering programs, introduces the student to the interdisciplinary technical and management processes for integrating human considerations within the design of complex systems.

Keywords: Human factors · Human-Systems Integration · Systems Engineering

1 Introduction and Philosophy

As the term Human Systems Integration (HSI) appears to have originated with the United States Department of Defense (DoD), it is useful to view the guidance provided by this institution regarding the meaning of this term. DoD Instruction 5000.02, which specifies the operation of the defense acquisition process [1], outlines the process the DoD employs to acquire new material solutions to address gaps in current capabilities. Enclosure 7 of this instruction specifies HSI policy. This enclosure requires the program manager within any acquisition program to plan for and implement HSI "beginning early in the acquisition process and throughout the product life cycle", with the goal of optimizing total system performance and ownership costs. This optimization is to consider human factors engineering, personnel, habitability, manpower, training, safety and occupational health, as well as force protection and survivability. Within HSI, each of these considerations are referred to as domains. While DoD Instruction 5000.02 does

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not clearly define HSI, it is clear that this concept includes a number of human considerations–beyond those typically considered in human factors engineering–necessary in the design and procurement of man-made systems.

The Defense Acquisition Guidebook (DAG) provides further definition of the policy stated in DoD Instruction 5000.02 [2]. While the guidance within this document is not specific or complete, it provides a few additional insights. First, although the program manager is responsible for implementing HSI, HSI is to be conducted within a Systems Engineering Process and applied throughout the entire process (Sect. 6.4.3.2). The DAG also makes it clear that systems become less affordable as the number of people associated with the system increases, as the required capability of these people increases, and as training requirements increase (Sect. 6.4.3.2). To optimize performance and lifecycle costs, these influences must be considered early in the system design lifecycle. The DAG also makes it clear that redesign of the system later in its lifecycle to overcome performance or safety issues encountered after the system is produced will incur additional cost (Sect. 6.4.3.2.1). Further, continuous application of human-centered research data, methods, and tools are encouraged to maximize operational and training effectiveness of the system (Sect. 6.4.1). The DAG also specifically discusses the allocation of functions between human and machine components, explicitly discussing machine aids or automation as a potential means for reducing manpower requirements.

Within the human factors discipline, we use many different terms to distinguish among categories of specialists in our field [3]. Often these terms designate differences in academic training among professionals within our society. With the advent of the HSI moniker, we must ask, “What is the requirement for preparing individuals to perform Human Systems Integration?” Alternatively, one could ask, “Is there a need to or do we currently produce some individuals with specialized the unique skills to perform Human Systems Integration?” To answer this question and decide upon an appropriate education framework for HSI professionals, we must decide whether HSI is its own discipline, a subfield within human factors and ergonomics, or simply a specialist within some existing human-centered field.

Philosophically we might argue that HSI is not a discipline, but an avocation. Looking at the role of the HSI practitioner as it is evolving within United States Department of Defense programs, we can see that a future potential organization chart–which includes a human systems integrator–might appear as shown in Fig. 1. Note that the top layers of this chart are generally consistent with the organizational structure present in many large engineering or acquisition programs. As shown, a systems or lead chief engineer often is responsible for the engineering effort, leading a team of lead discipline engineers and designers. These individuals ensure the correct level of resources are applied to various aspects of the design. Further, these lead engineers typically have extensive experience working with their discipline’s sub-disciplines as well as working with individuals in the other disciplines. Therefore, their role is to anticipate and foresee necessary interactions among their teams and individuals within the other disciplines, aiding appropriate decision making and engineering tradeoffs within their areas of responsibilities. Only the issues that cannot be resolved by the lead engineers are elevated for mediation at higher organizational levels.

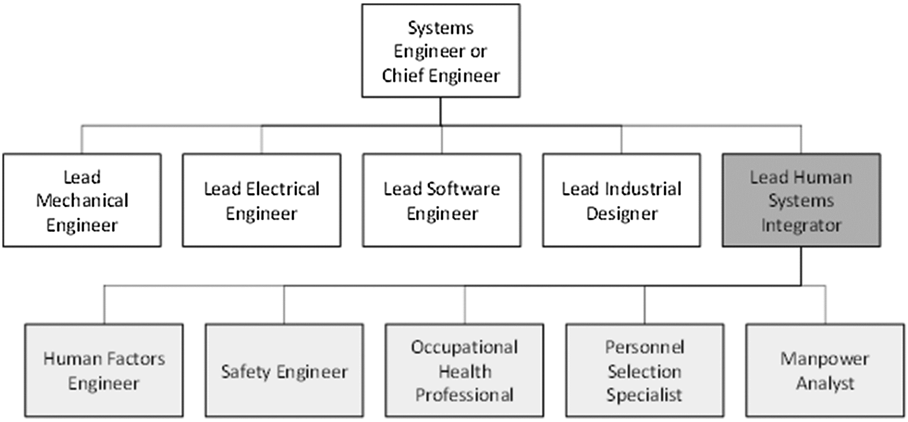

Fig. 1. Potential organization program chart

Figure 1 diverges from traditional team structures through the presence of the Lead Human Systems Integrator. Without the HSI lead, each of the individual human-centered domains must report directly to the systems engineer. As the systems engineer typically originates from a technical engineering field, they often do not have experience with the human-centered disciplines. In fact, these individuals typically do not have significant depth of knowledge outside of one engineering discipline. Therefore, the Systems or Chief Engineer is often challenged to ensure appropriate resourcing and decision-making within and among the human-centered domains and relies on their lead engineers for discipline level decision making. The presence of the HSI lead, therefore, provides the systems engineer with access to an individual who appreciates the human-centered domains and has the ability to make resourcing and trade decisions among these domains. As is the case with the discipline leads, an important characteristic of this individual is the experience and knowledge necessary to perform this role. However, even if we say that HSI is an avocation, the larger human-centered community must find ways of fostering the knowledge and experience to prepare them to assume this role during their career. It is also important to note that this role is decisively a design or engineering role, which requires the training of design-oriented individuals to assume roles as practitioners within each of the domains.

Unfortunately, it is not clear that we have successfully fostered the appropriate education and training of individuals to enable growth of design-minded individuals within each of these domains. Instead, we often discuss or train individuals to fulfill sub-disciplines within Human Factors, such as Human-Computer Interface specialists, Hardware Ergonomists, cognitive systems engineers, etc. Alternately, we may not be creating individuals with the ability and vision to seek roles, such as the HSI lead.

At the Air Force Institute of Technology (AFIT), our initial response to the DoDs need for HSI has been to create what we describe as a Human Systems track within our Systems Engineering program. We seek to produce individuals who understand the types of system trades that must be made throughout the acquisition process, educate our students to understand many human factors concerns and then to provide these students a high level overview of the remaining HSI disciplines and common trades among these disciplines. While educating young military professionals, we are also providing education to experienced acquisition professionals. Our program is new and our long-term impact and the utility of translating our current models to the civilian sector is yet to be demonstrated. However, we are encouraged that the opportunity to create human-centered leadership within future systems will improve the impact of human-centered disciplines on future system performance. In this paper, we seek to describe the program we have created that we believe is consistent with this philosophy. We seek to educate individuals who are able to perform deep analyses within one of the human-centered areas but with knowledge of systems engineering, systems engineering tools, and the ability to step back from the deep area of analysis to examine possible system trades, early and often, throughout a development process.

2 Overview of Human Systems Education Opportunities

Sponsored by the research branch of the Air Force 711th Human Performance Wing, the Air Force Institute of Technology (AFIT) provides a Certificate in Human Systems, as well as, Human Systems specializations within the Systems Engineering and Engineering Management Master of Science programs, and within the Applied Systems Engineering Master of Engineering program. Additionally, a similar specialization is available in the Systems Engineering Doctoral Program. The Human Systems courses are designed to provide students with systems engineering and human factors knowledge to permit them to contribute to research and development of complex systems and systems of systems.

The graduate degree programs are designed to introduce the student to the interdisciplinary technical and management processes beyond human factors engineering for integrating human considerations within the design of complex systems. Several human factors-focused courses then provide students a deeper understanding of this domain, equipping the graduate to participate in and lead, research and development efforts involving a human interface. Finally, thesis and PhD research conducted within these programs expands the state-of-the-art within the intersection of these disciplines with the HSI domains.

2.1 Overview of the Air Force Institute of Technology

The Air Force Institute of Technology (AFIT) is located on Wright-Patterson AFB, OH. AFIT is the Air Force's graduate school for technical research and graduate education. AFIT is co-located with the Air Force Research Lab (AFRL) on Wright-Patterson AFB, providing students the opportunity to work with world-class researchers within AFIT, within the U.S. Air Force Research Laboratories and within the Navy Aeromedical Research Unit – Dayton (NAMRU-D). Students are highly encouraged to select research topics that will make a lasting impact on the future direction of the Department of Defense. For human systems, Wright-Patterson AFB provides an especially rich environment in which to study, as AFIT is located within walking distance of most of the

711th Human Performance Wing and NAMRU-D. Further, it is located just down the street from Wright State University, which has graduate programs in human factors both within its psychology and biomedical, industrial, and human factors engineering departments. Educational sharing programs permit students to enroll in classes within any of these programs with advisor counseling to obtain degree credit.

The Graduate School within AFIT offers a variety of programs leading to the award of master's and doctoral degrees, as well as graduate certificate programs. It maintains a strong applied research component through its research centers, some of which have been formally recognized by the Air Force as centers of excellence. The Graduate School is unique among graduate schools in the country: it is a graduate-only, research-based institution – in the company of only a very small number of other institutions in this category. Being a graduate-only institution provides our students with desirable advantages: a more personalized educational experience with a student to faculty ratio of approximately 6:1 in master's degree programs; academic programs with focus; and research with real-world relevance. Students wishing to enroll at AFIT must be affiliated with the U.S. Department of Defense or a defense contractor.

2.2 Systems Engineering

The majority of students enrolled in the human systems specialization are seeking a degree in Systems Engineering. AFIT has granted degrees in Systems Engineering since 1975. Over the years, programs have been created to fill changing needs for resident and online/distance learning students, including: a traditional resident Masters, an on-line Masters with thesis, an on-line Masters without a thesis, a Graduate Certificate, and a Doctoral Program.

The research-based Systems Engineering programs provide an ABET accredited MS or PhD program that provides students an in-depth study of the unique challenges associated with engineering complex systems or systems of systems within the Department of Defense and the Air Force. Entry into this program requires a prior degree in engineering. The core curriculum for the SE program includes courses in Systems Engineering, Software Engineering, System Architecture, and Systems Engineering Management. Additional math requirements include Probability and Statistics. These courses are combined with specialization courses in Human Systems.

The resident Graduate Systems Engineering (GSE) program is a 6-quarter (18-month) program. When taken online, the program usually takes 24–36 months, and includes four systems engineering core classes (Systems Engineering Design, Software Systems Engineering, Systems Architecture, and Project Management), a course in research methods, an applied probability and statistics course, and at least 12 credit hours of human systems courses. By default, the human systems track includes Human Factors Engineering, Software Interface Design, and Human-Agent Interaction. In-resident students often complete 2 specialization tracks. While students have the ability to select their second specialization track from a large number of potential tracks, the operations research track is recommended, which includes a course in human performance modeling using discrete event simulation, decision analysis, and a linear or nonlinear optimization course.

The online Applied Systems Engineering (ASE) program is a 24–36 month program. Like GSE, ASE includes four systems engineering core classes (Systems Engineering Design, Software Systems Engineering, Systems Architecture, and Project Management), an applied probability and statistics course, and at least 12 credit hours of human systems courses. For ASE, students also complete a 12-credit hour Analytical Toolset Track.

2.3 Engineering Management

The Graduate Engineering Management (GEM) program is an accredited MS program that provides students an in-depth study of the unique challenges associated with the research, development, and use of technology, products, and systems within the Department of Defense and the Air Force. Entry into this program requires a prior degree in a technical field or a prior degree with subsequent technical experience. The core curriculum for the Human Systems emphasis includes courses in Research Methods, Statistics, Management and Behavior in Organizations together with specialization courses in Human Systems.

2.4 Doctoral Systems Engineering

This research-based degree recognizes mastery in the field of Systems Engineering, a demonstrated ability to conduct independent research, and the dissemination of significant and original contributions to the SE body of knowledge. This is a resident-only program, but can be completed by part-time, local WPAFB employees. Coursework is selected to be consistent with the individual's desired area of research. As such, individuals seeking to specialize in human systems will be expected to complete a preponderance of human systems courses.

2.5 Human Systems Certificate

The certificate in Human Systems includes a four-course sequence and a capstone course. The four-course sequence includes Systems Engineering, Human Factors and two Human Systems elective courses.

2.6 Research Focus

Each program requires an appropriate research project; including a capstone project for the certificate and ASE MS program, a thesis for the GSE and GEM MS programs, and a dissertation for the PhD program. This research project is the culmination of a student's graduate education and demonstrates an understanding of the issues involved in conducting academic and scientific research relative to Human Systems. By investigating a specific problem, the student contributes to extending what is currently known, believed, or argued in the field of HSI, human factors, or behavioral sciences. The thesis must embody accepted standards of rigor and relevance as well as the selection and application/execution of one or more appropriate research methodologies within the discipline. It will also reflect a deeper understanding of prior literature related to the selected problem. This component allows the student to evaluate a specific problem area and provide a better understanding of the contribution of ongoing research. Additionally, a component of this research is desired which relates the deeper research topic under investigation to its impact to HSI. Research topics are highly encouraged to align with the needs of the 711th Human Performance Wing, Air Force Program Offices, Air Force Operational Units, or Naval Aeromedicine.

3 Available Courses in Human Systems

The applicable human-systems courses are described in the following paragraphs. While these courses are available, the default 12 h sequence within our program includes HFEN 560, HFEN 663 and HFEN 665. HFEN 620 is recommended as an analysis course within the students secondary track but can be used to complete the 12 h specialization sequence.

3.1 SENG 560—Human Systems Integration

A human-centered design approach (i.e., "system" includes people within an organization that apply technology to accomplish a task) is explore d through readings, discussion and a project. Included are discussions of the Human Systems Integration domains (manpower, personnel, training, human factors, system safety, environmental safety, occupational health and survivability) and a method for considering these domains within the Systems Engineering Lifecycle.

3.2 HFEN 560—Introduction to Human Factors

This course examines the study and application of humans and the system interface, including the knowledge of human cognitive/social/physical behavior, capabilities, and limitations. Topics include anthropometrics, sensation-perception, decision- making, mental workload, situation aware ness, display/control design, warnings/alerts, human error and accident investigation. Numerous case studies are used to highlight course topics.

3.3 HFEN 610—Human Performance Measurement

Theories, concepts, and methods for measuring and evaluating human performance will be discussed with an emphasis on facilitating the design of systems having enhanced human performance and satisfaction. The student will gain practice in measuring human performance and applying the results to suggest and validate system design improvements. Influence of fatigue, environmental/task stressors, and social/team factors will be discussed.

3.4 HFEN-620—Human Systems Modeling

This course introduces students to using discrete event simulation to model complex human-machine systems. Through this course, students will gain an appreciation of defining systems, processes, and workflows using task network analysis. This course is intended to provide students with the requisite knowledge to construct and validate discrete event simulations as well as use simulation outputs to interpret system behavior and evaluate potential solutions with respect to impacts on system performance, human performance, and operator workload.

3.5 HFEN 663—Human-Computer Interaction

This course covers the principles of human-computer interaction in the design and evaluation of useful, usable interfaces as well as the social consequences of technological innovations. Topics include the joint performance of tasks by humans and machines, the structure of communication between human and machines (including machine response to changes in user state), algorithms and programming of the interface itself, engineering concerns that arise in the design and construction of interfaces, the process of specification, design, and implementation of interfaces, and design trade-offs.

3.6 HFEN 670—Human Interaction Technologies

Robust human-system interaction re quires information flow between the system and human brain. This course will introduce technologies available to mediate this flow of information, discussing the important characteristics and considerations for input and output technologies. Emphasis will be provided on visual information processing and visual display design. Human auditory processing and various input device technologies will also be discussed.

4 Research Examples

A significant element of human-systems education is derived from the research element. Research projects, including theses, dissertations, and to a lesser degree capstone projects are typically designed to include research to address a significant issue in one of the HSI domains, but to also encourage the student to examine the impact of the research on system-level trades that include multiple domains. The following three examples illustrate this focus.

4.1 Neck Injury Criterion Relevant to Aircraft Ejection Safety

The development of new ejection seats and helmets, as well as an increase in the anthropometric variability of pilots has the potential to increase the risk associated with neck injury during aircraft ejection. As a result, recent AFIT student projects have been structured to provide stronger criteria for neck injury based upon available human and cadaver data. Through collaboration with the 711th Human Performance Wing, the Federal Aviation Administration and associated civilian universities, significant work has been performed to revise neck injury criteria [4–6]. This work has been incorporated into the Air Force Lifecycle Management Center's developmental testing specifications for ejection systems, for both new systems and modifications to existing systems. While this in-depth work provided revised safety criteria, the student's work included the development of a framework for viewing trades between improved performance provided by advanced helmet systems with increases in fatigue or injury that may occur with the increase of head-borne weight [7]. This work illustrates the development of deep technical knowledge within one HSI domain, while requiring the student to analyze the system in which this technical knowledge lives with the purpose of understanding system trades that influence and frame the value of the technical work. This research stream continues with additional students investigating decision analysis frameworks for helmet selection [8], and integration of the safety criteria within test and evaluation.

4.2 Integrating HSI with Systems Engineering

Even though it is largely accepted that the human user is important to consider during system design, common system design models, such as the System Modeling Language (SysML), typically represent human users and operators as external actors, rather than as internal to the system. An AFIT student explored and presented a method for integrating human considerations into system models through human-centered design (HCD) [9]. They analyzed a case example system to identify the task and information flow. Then both system- and human-centered diagrams were separately created to represent different viewpoints of the system. These diagrams were compared and analyzed, and new diagrams are created which incorporate both system and human considerations together into one concordant representation of the system model. These new views allow both systems engineers and human factors engineers to effectively communicate the role of the user during early system design trades.

This research was further extended into human performance simulation [10]. The same AFIT student presented an approach for systems engineers to integrate system models with human performance modeling for early and more effective system design. Unlike analyses using traditional physics-based models found in most extant MBSE literature, adjusting system parameters for human-based analyses can greatly impact the design of the system itself. Adjusting a human-system parameter can lead to design implications including adjustments to task allocation, process and workflow, and interface design. To demonstrate this, a quantitative case-study approach was used. Starting with a set of Systems Modeling Language (SysML) diagrams, a task analysis was performed to inform an "as is" model of human performance in the Improved Performance Research Integration Tool (IMPRINT). An alternative IMPRINT model was created with varying design parameters and utilized to perform a trade study. Through the analysis, constraints and assumptions placed on the human were verified and the results applied to create a human-system integrated set of SysML models. With current design emphasis in MBSE and Model-based Engineering (MBE), there is great opportunity to emphasize human considerations and integrate human performance analysis.

4.3 Level of Human Control Abstraction Framework

The automation literature includes frameworks for discussing the level of automation. However, these frameworks have been criticized for not focusing on capabilities or the cognitive tasks transferred from the human to the automation. An AFIT student has developed a human-centered framework for classifying system states based upon the level of abstraction of the human control inputs to the system. This framework was designed to describe system states based upon the attentional resources required of the individual and the specificity of the operator's control over the system. It was demonstrated that a simple decision tree effectively permitted the classification of many modern vehicle control systems, including automotive, fixed wing, rotor wing and legged ground vehicles, regardless of whether they were manned or unmanned. Further analysis of the framework indicated that describing available system states based upon this framework had further implications for personnel selection and training. As in the earlier examples, this research selected an area of analysis within one HSI domain for in-depth analysis, but permitted the student to make observations, which were relevant to multiple HSI domains.

5 Summary

This paper provided an overview of the Human Systems program at the Air Force Institute of Technology (AFIT). This program, housed within the graduate school at AFIT, seeks to provide students with systems engineering or engineering management degrees with a specialization in Human Systems. It is the philosophy of the program that HSI is not a discipline on its own, but an avocation. Specifically, the HSI professional serves as the lead engineer in traditional engineering disciplines. It is their responsibility to guide human systems activities, across the domains, and to serve as the interface to the systems engineer or chief engineer within a program, facilitating robust decision-making regarding the human element within the system.

This viewpoint has implications for the structure of our program. Specifically, we seek to educate individuals who have an appreciation for the depth of analysis within one of the human-systems domains, an appreciation of trades among each of the domains, and a background in systems engineering and project management. This last element is critical to permit the individual to communicate effectively with the chief or systems engineer. Our desire is to educate mid-level acquisition professionals (e.g., senior first lieutenants or captains in the United States Air Force) who have acquisition experience within an engineering or related science discipline to serve in this role. Additionally, we seek to educate operators, primarily through our distance-learning program, of the importance of thorough requirements analysis for systems where the systems includes the human element. It is important that these individuals understand the human element within a system and the interface design between the humans and machines with which they interact significantly affects the performance of any weapons system. It is our belief that as HSI continues to evolve within the DoD, this educational experience will prepare individuals to take on leadership roles as HSI professionals.

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