Human systems integration in the military

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Human systems integration (HSI) acknowledges that the human is a critical component in any complex system (Booher, 2003). It is an interdisciplinary approach that makes explicit the underlying trade-offs among a set of technical domains, facilitating optimization of total system performance in both materiel and nonmateriel solutions to address the capability needs of organizations. HSI is deeply rooted in the military–industrial complex. Whether looking at HSI in the United States and Canada or at its British counterpart, human factors integration, one can trace the inception of this interdisciplinary field to governmental efforts to manage defense acquisitions more effectively. Many of the chapters in this handbook address HSI in the private sector, and it is evident that steady progress is being made to apply HSI in civilian and commercial contexts. However, the focus of this chapter is on how HSI is practiced in the U.S. military, particularly in the U.S. Army, and primarily in the context of the U.S. Department of Defense (DoD) acquisition life cycle. Here, we review the domains of HSI and HSI trade-offs, illustrating how trade-offs are made using actual examples of HSI in action. We also describe how HSI is typically implemented at various stages of the DoD acquisition life cycle.

Like all interdisciplinary fields, HSI overlaps with other closely related specialties. HSI has much in common with human factors engineering (HFE) and systems engineering (SE). This chapter explores both the commonalities and differences among these disciplines, looking at examples of why other disciplines do not address HSI in the most effective manner.

WHY HSI?
The traditional defense acquisition process has failed to produce military systems that perform as advertised. One consequence is that in 2003 Congress mandated that the DoD include HSI in its acquisition process, and this is reflected in DoD Instruction 5000.02 (DoD, 2008) and DoD Directive 5000.01 (DoD, 2003). The Defense Acquisition Guidebook (Chairman of the Joint Chiefs of Staff, 2012b) also addresses the requirement that HSI be considered in defense acquisition. This congressional mandate has led to widespread debate about the definition of HSI and the number and composition of the technical domains encompassed by this interdisciplinary field. Also, the exact process by which HSI should be practiced has been unclear, adding some confusion about HSI’s primary principles and their application. Nonetheless, there is agreement that to achieve the best possible outcome, HSI should be implemented at the earliest stages of an acquisition life cycle—or, as in the adage about voting in Chicago, it should be done “early and often.”
DISTINGUISHING CHARACTERISTICS AND GOALS OF HSI

The original goals for HSI, according to the congressional language, were to manage life-cycle cost and to optimize system performance in military acquisitions. Two major characteristics distinguish HSI from other related fields in accomplishing these goals. The first characteristic is a primary focus on making trade-offs among the technical HSI domains and the SE domains of cost, schedule, risk, and performance. Trade-offs are made in every system and in every part of the acquisition life cycle. All too often, however, the effects of trade-offs that have been made are not evident until later in the system’s life—sometimes too late. For example, the decision to limit the size of a crew on a Navy warship, though seemingly a great cost-cutting move before a new ship is commissioned, may need to be reexamined if results from the test and evaluation phase indicate that the workload is too high for the reduced crew to sustain the required level of performance. If the ship has already been designed and built before a decision is made to increase the crew size, there may not be adequate berthing space, and crew members may be required to share berthing bunks or beds (called hot-racking because the bed, or “rack,” always remains warm). Habitability is negatively affected because the ship was not designed for the larger crew complement. Also, the food stores on this smaller ship may not support larger crews, so resupply may have to occur more frequently, increasing the cost of normal operations. The second distinguishing characteristic of HSI is a persistent and continued consideration of nonmateriel as well as materiel solutions in any analysis of new capability alternatives. Although the final recommendation for an acquisition may be to procure a new system—that is, a materiel solution—HSI stresses the potential benefits that can be realized by leveraging nonmateriel concerns, such as manpower, personnel, and training. For example, the U.S. Air Force (USAF) required more missions be flown by remotely piloted aircraft to support the war efforts in Iraq and Afghanistan in 2007 and 2008, an HSI recommendation that was nonmateriel in nature. Several alternative materiel solutions were explored, such as redesigning remotely piloted aircrafts so that a single operator could fly multiple aircraft simultaneously. However, the final decision was to quickly ramp up to meet the required capability by retraining qualified personnel, mostly pilots, who were already part of the USAF. Using personnel on hand until recruitment and training processes could begin to deliver personnel with the new skill sets was the original nonmateriel HSI recommendation.

These two characteristics of HSI differentiate it as a discipline from HFE and SE. Although HSI, HFE, and SE use many of the same tools, techniques, approaches, and methods, there are fundamental differences in their goals and rewards. A major goal of HFE is to improve human performance by making tasks easier and less prone to error. Unlike HSI, in most HFE efforts, life-cycle cost or overall system performance may not be big drivers in defining the solution space of a problem. HFE professionals may not be well-versed in areas such as manpower, personnel, training, or life-cycle costs. In general, there are no built-in incentives for human factors engineers to save money or to calculate life-cycle costs. In contrast to HSI and HFE, a major goal for SE is the delivery of a system—on time and within budget while managing risk. Systems engineers focus on materiel solutions that could include designing a new system or redesigning an existing one. Nonmateriel considerations—such as manpower, personnel, training, and HFE—may fall outside the realm of expertise of many systems engineers but are essential to the successful practice of HSI.

HSI faces some challenges in accomplishing its congressionally mandated goals. Contract requirements may specify system performance levels, but currently there may be few incentives for acquiring a system with reduced life-cycle costs. Life-cycle cost could be made a priority if it was a KPP in contracts, but that has not been done. A big question that remains is how to provide effective incentives for conducting HSI.

HSI IN PRACTICE: HSI DOMAINS

In military HSI, the focus is not only on the individual domains but also on what ties those domains
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Trade-Offs Among HSI Domains: The Interstitial Spaces

At the Naval Postgraduate School (NPS), students are taught that HSI is a challenge because it dwells in the “interstitial spaces” among the HSI domains. HSI is the glue that holds the individual HSI domains together. The domains overlap, creating seams that require attention to maintain the integrity of the entire system. An assessment of the HSI domains must also include an assessment of the impact of the integration of the domains.

What exactly are these HSI domains, and what do they encompass? Table 3.1 lists the HSI domains that have been adopted by various governmental agencies. The left three columns of Table 3.1 list the domains that are specified in the Handbook of Human Systems Integration (Booher, 2003), those that are taught at the Naval Postgraduate School in the HSI graduate education program (Miller & Shattuck, 2008). There are minor differences in the three lists, most notably the addition of Habitability to the Naval Postgraduate School list of domains. The four right-hand columns show how various branches of the U.S. and Canadian military forces address the domains of HSI. There is considerable agreement on the domains across the service branches, although there are minor wording differences, and Canada combines Personnel and Manpower into a single domain.

In assessing Table 3.1, there is clearly a great deal of agreement about the composition of major HSI domains. For example, each of the sources listed includes the six domains of Manpower, Personnel, Training, Human Factors, Safety, and Health Hazards. Additionally, the various branches of the military services have specific emphases in their domain lists. All three branches of the U.S. military add a seventh domain, Human (or Soldier) Survivability. The U.S. Navy and USAF add Habitability as an

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**TABLE 3.1**

Human Systems Integration (HSI) Domains for Various Groups

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**Note.** The left three columns of Table 3.1 list the domains that are specified in Booher (2003), those that are identified in U.S. Department of Defense (DoD) language, and those that are taught at the Naval Postgraduate School (NPS) in the HSI graduate education program (Miller & Shattuck, 2008). There are minor differences in the three lists, most notably the addition of habitability to the NPS list of domains. The four right-hand columns show how various branches of the U.S. and Canadian military forces address the domains of HSI. There is considerable agreement on the domains across the service branches, although there are minor wording differences, and Canada combines Personnel and Manpower into a single domain. HFE = human factors engineering; ESOH = environment, safety, and occupational health.
eighth domain, whereas the USAF adds Environment as its ninth domain.

**Brief Definitions of HSI Domains**

The following are brief descriptions of the domains of HSI as practiced by the service branches of the DoD. These definitions are shorter versions of those found in Enclosure 8 of the *DoD Instruction 5000.02* (DoD, 2008).

- **Manpower:** The number of people needed to operate, maintain, train, and support a system; includes military, civilians, and contractors.
- **Personnel:** The performance-related characteristics of people needed to operate, maintain, and support the system. This includes the cognitive and physical capabilities required to train for, operate, maintain, and sustain materiel and information systems.
- **Training:** The process of designing and delivering a managed set of experiences so that people have the knowledge, skills, and attitudes that will enhance user capabilities, maintain skill proficiencies, and decrease individual and collective training costs.
- **Human Factors Engineering:** The integration of human characteristics into system definition, design, development, and evaluation to provide for effective human–machine performance under operational conditions.
- **Survivability:** Ability of personnel to exist and function during and following exposure to hostile situations or environments, includes combat weapons-induced injuries, enemy or friendly casualties, hazards inherent to personnel during threat or combat conditions, and inherent hazards of military equipment to include egress when system is damaged or destroyed.
- **Habitability:** Those living and working conditions that are necessary to sustain the morale, safety, health, and comfort of the user population. These conditions directly contribute to personnel effectiveness and mission accomplishment, and they often are related to recruitment and retention problems.
- **Safety:** The design features and operating characteristics of a system that serve to minimize the risk of illness, disability, or death to users, operators, and maintainers.
- **Health Hazards:** Design features and operating characteristics of a system that create significant risks of bodily injury or death. Prominent sources of health hazards include acoustics energy, chemical substances, biological substances, temperature extremes, radiation energy, oxygen deficiency, shock (not electrical), trauma, and vibration.
- **Environment (USAF only):** Those system design characteristics that serve to minimize the impact of the system on the water, air, and land and the interrelationship that exists among water, air, land, and all living things. Prevalent issues include the prevention of pollution of the environment by reducing the use of hazardous materials and the release of pollutants into the environment.

**Making HSI Trade-Offs Explicit**

The HSI domains cover a tremendous breadth of information. The HSI professional, however, is not required to be expert in all of these individual domains. The effective practice of HSI requires leveraging the unique contributions of each of the HSI domains to arrive at viable recommendations from which decision makers can choose. Combinations of these HSI domains and the additional factors of SE (cost, schedule, risk, and performance) form the solution space for an HSI problem. It is understood that trade-offs are made in every DoD acquisition program. However, trade-offs often are not recognized or explicit until after the system is fielded—or until a problem arises that limits system effectiveness. By applying HSI principles, multiple alternatives are explicitly considered at each decision point in the acquisition life cycle. The trade-offs that are made are systematically identified, documented, and analyzed for potential impact so that they are considered before final recommendations are made.

Certain levels of system performance are achieved by trading among the various HSI and SE domains. For example, the cost of training operators of an aircraft has become prohibitively expensive.
Cost analysis of USAF pilots or U.S. Navy pilots shows that if more highly skilled personnel, such as civilians who already have a pilot’s license and flight experience, are recruited, less training will be required, and operators will reach training goals much faster. Before making this recommendation, however, HSI professionals must consider the cost of recruiting and retaining these more highly skilled individuals. Although less training results in an initial cost savings to the program, the recruiting and retention costs must also be factored into the equation before a final decision is reached. This example illustrates how the use of trade-offs between the HSI domains of personnel and training directly and importantly feed into decisions about cost, schedule, risk, and performance.

Throughout history, warfare has been associated with innovations and creative solutions—especially during periods of active military engagement—and this is still the case today. Emerging military threats require changes in conventional thinking, tactics, and equipment—and military acquisition and doctrine races to meet these challenges. An example of this process is the jet fighter aircraft. The earliest versions of the modern jet fighter first surfaced during World War II with the German Messerschmitt ME 262. However, other countries quickly followed suit by developing and acquiring their own versions of jet fighters. The Korean War propelled these jet fighter aircraft to the forefront of the war effort as each nation sought air superiority. Since then, multiple generations of fighter aircraft have been developed and have moved through the DoD acquisition pipeline, with some efforts proceeding more smoothly than others.

In the current DoD environment, the Joint Capabilities Integration and Development System process provides the formal mechanism to facilitate warfare innovations that are required to address emergent security threats. A recent example of this sort of warfare innovation can be seen in the mine-resistant ambush protected (MRAP) vehicle. During the early years of the second Gulf War, Iraqi and Afghan insurgents began targeting conventional U.S. military vehicles with improvised explosive devices, causing hundreds of battlefield casualties. Military commanders requested up-armored vehicles that would help its passengers and crew withstand the detonations and explosive blasts of the devices. This request led to the rapid development and acquisition of the MRAP, designed specifically to address soldier survivability, one of the major HSI domains. As a result of the HSI lessons learned from the MRAP in the field, future generations of land combat vehicles should include design requirements for crew and passenger survivability.

**HSI WITHIN THE ARMY**

**History**

The MANPRINT (Manpower and Personnel Integration) program was established to implement HSI in the Army. That program was recently renamed Army HSI. When MANPRINT was established in 1986, it was the first large-scale implementation of HSI. The foundation of the program was provided by General Maxwell Thurman, who commissioned the U.S. Army Research Institute for the Behavioral and Social Sciences to perform a study (Promisel, Hartel, Kaplan, Marcus, & Whittenburg, 1985). The researchers found that several major weapons systems would have been more effective if, during their development, their operators’ capabilities and limitations had been considered.

Harold R. Booher, the first director of the HSI program, visited the various Army program executive offices and many of the key program managers to familiarize them with HSI. The visits were complemented by a series of courses that taught HSI principles and analysis techniques. The effort to build acceptance of HSI was aided by establishing the *HSI Army Regulation 602-2* (U.S. Department of the Army, 2001). This regulation gave the HSI director the responsibility to formally assess Army systems by considering the domains of HFE, manpower, personnel capability, training, health hazards, and system safety. Soldier survivability was added later as a seventh domain. Each HSI assessment (HSIA) describes the adequacy of the developing system in meeting basic requirements in the domain areas and in evaluating the risk assumed by domain trade-offs. There are no other assessments of these areas that are
considered holistically in the Army systems acquisition process.  

Army Regulation 602-2 provided a solid basis for the implementation and management of the HSI technical mission. The HSI director was given a senior rank equivalent to that of a general. This level of seniority provided critical leverage to propagate HSI objectives across the Army.

hsi today

Crucial to the HSI process was the development of an organizational structure for the application of HSI expertise that, as its core, incorporated technical professionals of the Human Research and Engineering Directorate of the U.S. Army Research Laboratory. The Human Research and Engineering Directorate is responsible for the analysis of manpower, personnel capability, HFE, and training. Other agencies were identified to be responsible for safety, health hazards, and soldier survivability. It is the responsibility of the HSI director to compile the individual domain area reports into a single HSIA document that is used to make a recommendation to the Army acquisition decision makers.

The recommendations represent an assessment of risks to individuals and system performance, and they consist of GREEN, meaning “all is fine”; YELLOW, meaning the program is suitable as is but would benefit greatly from recommended HSI changes; and RED, meaning that this program should not be permitted to progress until these HSI problems are mitigated. RED ratings are discussed with program managers before they are assigned so that the program managers often will have time before the acquisition decision to formulate an effective response. The purpose of the HSIA is to motivate an effective mitigation of HSI problems, not to interfere with the planned progression of the system through the acquisition process. If there is no planned mitigation of the problem, the importance of the deficiency is discussed by the members of the Army acquisition decision board, which includes the HSI director.

The HSI director is a member of several senior-level requirements and system acquisition approval boards. Through both the representation of HSI on high-level review boards and the formal HSIA, HSI considerations are always a part of the Army’s acquisition decision. The Army, at any one time, has several hundred major acquisition programs under way and several hundred additional minor programs. Though almost always performed on major systems, HSI analysis is somewhat less likely to appear in minor programs.

The Army’s HSI program is also supported by regulatory language in DoD Instruction 5000.02 (DoD, 2008) and requirements from the Joint Chiefs of Staff Instruction 3170.01H (Chairman of the Joint Chiefs of Staff, 2012a). These documents require the military services to establish and maintain an HSI program relevant to making acquisition decisions, but they do not describe the type of program or how its findings will be used in acquisition decisions.

the application of hsi

The acquisition of major systems by the Army, and the DoD overall, is aptly described as complex. Major systems are developed over a span of many years because, as technology improves, requirements are refined, and lessons are learned from real-world applications that change the system, often dramatically. The Patriot Air and Missile Defense System is an example of such a project. It started in the 1980s and is still undergoing substantial modification. It was first conceived as a defense against piloted aircraft, but now it is also effective against missiles. Billions of dollars have been invested in the Patriot system, with even more investment planned for the future.

The complexity of military acquisition perhaps is most easily recognized in the requirements process. The requirements process begins with a capabilities-based assessment (CBA; Joint Chiefs of Staff & Force Structure, Resources, and Assessments Directorate, 2009) that is performed, in the Army, by the Training and Doctrine Command, which usually gets involved in response to an urgent operational need, issuance of new military strategy and Joint mission concepts, or periodic senior warfighter forum reviews (Chairman of the Joint Chiefs of Staff, 2012a). The CBA compares the new requirement with existing warfighting capabilities and requests that an analysis of the current threat environment be performed by the intelligence community.
These analyses determine whether existing capabilities are sufficient for new requirements or whether capability gaps exist. The Army seeks to address capability gaps through a systematic evaluation of a solution space that considers various combinations of changes to doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy (DOTMLPF-P; Chairman of the Joint Chiefs of Staff, 2012a).

The DOTMLPF-P categories can also be combined with the HSI domains to explore novel approaches for bridging gaps. The relationship between the DOTMLPF-P focus areas and HSI domains is illustrated in Figure 3.1. Although there is not a one-to-one correspondence among all categories, there is a strong relationship between the two approaches. There is also a strong relationship within the DOTMLPF-P and HSI categories, whereby decisions made affecting one focus area or domain will have repercussions on all other categories.

The CBA team is directed to first pursue nonmateriel solutions before recommending a materiel solution. Materiel development implies either an engineering change to an existing system or the development and acquisition of a new system. If the decision is made to pursue a nonmateriel solution, traditional engineering approaches are, for the most part, avoided entirely, leaving the solution space to the HSI domains and the DOTMLPF-P categories. The acquisition process is driven by a set of requirements that are a result of both the identified capability gaps and a more general consideration of required and desired capabilities.

The process of specifying requirements can be thought of as a delicate balance between many legitimate but competing interests. For example, in the design of new armored vehicles, there may be a stated need for lethality, survivability, mobility, cost, size, crew capacity, maintainability, and, of course, usability. Note that many of these interests, but not all, are HSI related. Some participants in the requirements process will argue for a bigger gun on the vehicle, whereas others will want a smaller gun to reduce weight so as to permit more armor to protect the crew. Other arguments will be made by those seeking to reduce vehicle size, so that the vehicle can fit inside a cargo plane, or to minimize vehicle signature, so as to reduce its probability of detection by the enemy. The HSI community will analyze the requirements and their implications for system design from the perspective of each HSI domain. They will ask questions such as what size crew is needed to perform the required tasks?; what will the workload of the crew be?; will they safely fit into the vehicle?; and will they be able to exit the vehicle quickly, even if the vehicle has overturned? Given the constraints of design and funding, the Army must accept risk in some areas, so it is not surprising that certain HSI domains may be considered less important than lethality or other requirements. Throughout all of the discussions of system requirements, there is always the underlying thread that the true cost of a poor compromise may be other capabilities lost, lives needlessly sacrificed, and battles lost.

**FIGURE 3.1.** Relationship between doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy (DOTMLPF-P) categories and human systems integration (HSI) domains. HFE = human factors engineering.

**HSI THROUGH THE ACQUISITION LIFE CYCLE**

HSI is important through all phases of acquisition but is most effective when it is applied at the earliest
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stages of the acquisition life cycle (Booher, 2003; Hendrick, 2003). Design changes that occur later in the acquisition process become increasingly expensive to implement (Graine, 1988). Most major DoD development programs follow the flow of major events described in Figure 3.2. In general, products are at different stages of maturity at the different milestones. For example, at Milestone A, the product exists only in terms of the required capabilities and some initial ideas of what that product will look like. Moving to the right, at Milestone B, there is a plan that describes the product, but there may not be an actual prototype of the product. At Milestone C, a product already exists, and an acquisition decision board will decide whether the product is ready for initial low-rate production.

Pre-Milestone A

The value of HSI early in an acquisition can be immense. The decisions made as acquisition options are first explored will have a tremendous impact on the solutions that are chosen to supply a given capability. If the decision is made to proceed with a materiel (vs. nonmateriel) solution, HSI can ultimately influence the design, cost, schedule, and performance effectiveness of a system. According to Graine (1988), decisions made early in an acquisition life cycle have far more influence on total life-cycle cost than decisions made later in development. The major contributor to system life-cycle cost is usually the cost of manpower required for both operations and maintenance. When system development is just starting, acquisition decision makers should be aware of any significant differences in expected life-cycle costs associated with alternative concepts. The HSI community makes a powerful contribution to an acquisition by making this information compelling and clear.

An important pre-Milestone A activity for HSI is participation in analysis of alternatives (AoA) studies to ensure that the human perspective is included in simulations and trade studies that the Army conducts to compare alternative capability concepts. For example, the Army may need an improved method for preventing attack from short-range indirect munitions, such as artillery, mortars, and rockets. In this example, there are three major conceptual approaches to performing this operation. Incoming munitions can be shot down using a high-firing-rate gun, attacked with a defensive missile, or attacked with a high-energy laser. The first two approaches currently are being used. The Army uses a variation of the Navy’s Phalanx gun, whereas the Israelis use the Iron Dome missile system for defense. Neither of these systems performs perfectly, so improvements to their performance (e.g., hit rate under differing conditions) or lower costs might be useful after trade-offs are considered. The purpose of the AoA is to compare alternative system concepts on several dimensions. An HSIA, as part of the AoA,
would analyze the expected effects of the system concepts on HSI-associated issues, such as man-power availability, soldier capabilities needed, potential safety concerns, and training implications. The laser-based solution might be the most challenging materiel solution, because there are currently only prototype high-power laser systems in the Army inventory. The Army has limited experience in operating and training such systems, so they may have to create a new enlisted career field if the required skills and training are significantly different than for existing systems. Moreover, there may be unique safety and health hazard concerns associated with such systems. Although none of these possibilities necessarily make a laser system unacceptable, the HSI community should responsibly convey these concerns and potential consequences to the acquisition decision makers.

There are other examples of how the application of HSI early in system development contributes to the AoA. In one aviation system, there was a need to determine how many soldiers could fit into different sized transport helicopters. Using a human physically based modeling program, HSI practitioners were able to determine the space required to accommodate soldiers with their standard combat loads in the troop compartment. Competing helicopter design alternatives were then compared with credible estimates of their troop-carrying capacity. Another analysis of a planned armored fighting vehicle found that a three-soldier crew was required to perform the needed tasks. This determination has important consequences for manpower, personnel, and human factors considerations. In a similar application, the workloads associated with different vendors’ enterprise resource planning logistics software systems were compared; results showed that a less expensive commercial product could effectively provide a higher level of performance and greater usability. During the AoA, initial requirements and a preliminary understanding of expected system performance and functions are developed. At this stage, however, the requirements should not be overly constrained to ensure that there is room for differing competitive ideas for system design. Historically, the Army HSI community has had a limited role in recommending HSI-related requirements. A key reason is that funding for this activity has been absent. Recently, funding has changed, and some funds have been identified for HSI activities in support of Milestone A. This funding has allowed for insertion of such requirements as mandating user interface standards to ensure commonality across different platforms. Also, at this stage of acquisition the roles of humans and machines are considered, and some alternatives for allocation of functions have been generated in a number of recent acquisition programs.

The AoA and other HSI activities contribute to the development of the initial capabilities document, which represents the operational or “working” architecture for the system’s functional components (North Atlantic Treaty Organization & Research and Technology Organization Task Group, 2010).

**Milestone A**

Although not all system development has HSI involvement prior to Milestone A, all systems can still profit from significant HSI input after Milestone A. After Milestone A and during the phase leading up to Milestone B, the formal requirements of the system are validated, and preliminary design decisions are made. HSI engagement in the finalization of requirements is a key part of this phase because the requirements determined here lock in the operational and functional characteristics of the system. For example, a requirement for a gun might include that it have a range of x meters and a certain measurable effect on a target. Other requirements might specify accuracy and weight limits. These types of requirements are considered so important that they are called key performance parameters (KPPs). Contracts are judged on the merits of the approach to meet KPPs; awards are made to contractors based, in part, on their ability to meet all KPPs for a given system.

Potential KPPs are nominated by different Army communities. For a weapons system, the warfighting community will define requirements, such as those described above for the gun. Other stakeholders will require sufficient reliability and maintainability. There may be demands for mobility of the system that relate to size, weight, and power. HSI issues are not usually KPPs, although there is often a training KPP. For example, a KPP might require that trained soldiers be
able to complete 90% of critical tasks on the first attempt. Training KPPs are not as measurable as firing range or vehicle speed, so measuring training effectiveness remains an HSI challenge. There has been recent interest in defining a usability KPP. Usability may be easier to measure than training success, but meeting thresholds for usability is a function of several factors: the effectiveness of the system design in simplifying the operation, the effectiveness of the training, and the aptitude of the soldier. It is difficult to attribute usability to a single factor for compliance.

Recently, a combination usability–training KPP has been proposed by HSI analysts. The idea is to demonstrate the feasibility of measuring the relationship between training and usability as an inverse function—that is, as usability design improves, training should become less intensive, lengthy, or subject to extensive practice. Although the function is likely not a straight line, the Army requirements and testing communities have agreed to work with HSI to investigate this concept using portable radios and handheld devices being developed for dismounted troops (P. Savage-Knepshield, personal communication, May 13, 2013).

Although a training or usability KPP would be useful in furthering consideration of the HSI domains, the acquisition community usually seeks to minimize the number of KPPs. The more KPPs there are, the greater the cost of meeting those requirements and the less discretion that the system developer has in trading off capabilities. Also, keeping the number of KPPs to a minimum reduces the chance that a KPP will not be met. The assessment of the system’s success in meeting KPPs is critical to an affirmative milestone decision. KPPs are usually considered so fundamental that a failure on any of them leads to significant and difficult questions from the Army leadership, DoD oversight, and even Congress.

**Milestone B**

As the system approaches Milestone B, the form, fit, and function characteristics of the system become much clearer. For example, an armored personnel carrier program will have a reasonable estimate of the ultimate vehicle’s size and weight and the number of soldiers it will transport. There also will be an understanding of the crew’s tasks in operating the vehicle and responding to mission conditions. Even though information about the system is still limited, the pre-Milestone B activities are a critical point during which HSI engages with the program office to develop an HSI management plan and working group to identify human-risk issues, design trade-offs, and mitigation strategies. This is the essential difference between early HSI work (i.e., pre-Milestone A) or support and a formal acquisition program. As shown in Figure 3.3, HSI effort evolves from an analytic, conceptual-process-oriented approach to a deliberate risk-identification and reduction-cycle procedure.

The HSI plan is implemented by addressing straightforward questions about such issues as

- **manpower and personnel capability.** Will there be sufficient crew with sufficient skill to perform the required tasks under expected conditions? For example, is the crew large enough, and does it have sufficient access to an outside view to know whether the enemy is approaching? Will the crew be able to resupply its vehicle with heavy-weight ammunition in a reasonable amount of time without exhausting themselves?
- **human factors engineering.** What information will have to be displayed for the crew? Will a display large enough to show and share that information fit into the vehicle? Will the crew be able to egress quickly in an emergency? Will casualties be able to be removed expeditiously?
- **health hazards.** Will firing the weapons system produce noxious fumes? Will the vehicle be operable by the crew in very hot environments?

This is a partial list of the questions that must be asked, and the HSI working group is chartered to ask and answer them. Specifically, the group’s objective is to ensure that HSI risks are adequately addressed by identifying and tracking HSI issues, determining issue risk severity, conducting studies and analyses as required to inform risk definition, providing recommended positions to the system program manager and engineer, and ensuring that unresolved issues are brought to the program leadership for resolution or acceptance.

Some issues will span more than a single HSI domain. For example, if a display is so large that it significantly hinders crew compartment egress
(a safety issue), there will have to be a human factors analysis of whether multiple displays could be used instead. If there is insufficient manpower to perform some tasks, a system component function may need to be redesigned. Safety issues often have HFE solutions, and many safety issues are also soldier survivability or health hazards issues. Finally, there is often an ability to solve HSI problems with multiple alternative approaches. If what first appears to be a manpower issue is difficult to mitigate, perhaps more skilled soldiers, better design, and improved training will resolve the problem.

HSI practitioners have a suite of tools they are trained to use. In the early stages of development, task analytic techniques are critical tools to HSI practitioners. A sound task analysis may serve multiple purposes. For example, a comprehensive task analysis may inform the human factors design for a system interface as well as helping with the manpower estimate, the personnel descriptions, and the job assessment. Interested readers should consult Kirwan and Ainsworth (1992) for a comprehensive description and explanation of the benefits of task analytic techniques.

For HSI to be effective, it is necessary to determine the influence of system design alternatives on soldier (or other user) performance as early as possible in an acquisition. Modeling and simulation tools often are used by the HSI practitioner. Some of the most frequently used modeling and simulation tools include the following:

- the Improved Performance Research Integration Tool (Mitchell, 2012; U.S. Army Research Laboratory & Alion Science and Technology, 2009a, 2009b), a trade-off analysis tool used to help assess the interaction of operator and system performance. It is used to evaluate individual and crew workload, including maintenance hours. Primary outputs of the Improved Performance Research Integration Tool include task performance time, task performance accuracy, and cognitive workload (visual, auditory, etc.).
Command, Control, and Communications: Techniques for the Reliable Assessment of Concept Execution (Kilduff, Swoboda, & Katz, 2006; Plott, 2013; Swoboda & Plott, 2012), which is used to simulate communication and information-flow patterns to predict the information assimilation and processing load of system inputs on operator team capability and response suitability.

- human figure modeling (Hicks, Durbin, & Kozycki, 2010; Kozycki, 2012; UGS Corporation, 2006), which is used to determine whether a given workspace design accommodates ingress, egress, seating, visibility, and reach.

- the Crew Station Design Tool (Walters, Archer, & Pray, 2003), which supports visualizing and analyzing various workstation layouts. It provides such information as operator-component compatibility, operator resource conflicts, frequency of use of each control or display element, and the optimal coordinates for the various components.

- the Spatial Analysis and Link Tool (Sonalytics, 2013), a computer-aided design software tool developed for the U.S. Navy to allow visualization and analysis of the layout and arrangement of humans, the hardware with which they will interact, and the physical properties of a given workspace. It allows for modeling of spatial layouts as well as analysis of visual and auditory communication patterns.

Using these and other tools, techniques, approaches, and models, the HSI practitioner is responsible for identifying problems that will affect system performance and quantifying the risk to mission success if those problems are not mitigated. This analysis includes framing the issues within a trade space. The trade space is the virtual whiteboard where multiple HSI issues interact and their relationships and consequences are apparent. HSI practitioners also identify solutions to mitigate or reduce risk. At this point, the program manager must decide whether a solution will be adopted or whether the assumed risk of not mitigating the problem is acceptable.

A visualization of the human–system design trade space is very useful in presenting HSI risks and mitigation options to program managers and systems engineers. The Army HSI community often uses diagrams to make the trade space more “hands on” and concrete. For example, Figure 3.4 contains a flowchart analyzer showing soldier performance risks and mitigation options for information displays for a military operations center. The diagram shows how to

![Figure 3.4](image-url)

**FIGURE 3.4.** Human systems integration trade space visualizer for risk identification and mitigation options (see text for details). Ops = operations; Ack = acknowledge.
navigate the trade space in sequential steps: A ground operations center (Point 1) reacts to events and receives raw data for soldier and machine processing (Point 2); at times (Point 3), processing performance may not meet output demands (Point 4) due to information overload, task complexity, decision time constraints, and so forth. When these processing issues persist, available mitigation or “how-to-fix” options (Point 5) include reducing information input, changing situation awareness and analytic tools, offloading tasks to others, or revising reporting and response requirements (Point 6). The solution space (Point 7) is reached by comparing option feasibility and cost to acceptable risk (dollar values for risk reduction options will vary with each system).

MILESTONE C AND BEYOND
An affirmative decision on Milestone C is a commitment for the government to begin initial low-rate production and to deploy the system in operational environments consistent with the number of systems available. Government initiation of some rate of production often represents a major financial commitment, so the Milestone C decision, although not the end of the system development process, is a significant decision.

The activities performed between Milestones B and C during the development of a major system are not likely to resolve all outstanding issues. HSI analyses based on system concept drawings or mock-ups of system components, by themselves, are unlikely to have identified all HSI problems that may arise. Closer to Milestone C, working with prototype equipment gives the HSI analysts an increased capability to identify HSI issues. Here, the HSI analyst will intensify work with the engineering design team on such activities as spending additional hours with equipment, studying realistic work scenario sessions, and observing experienced users, often those who have field experience. This close teamwork builds trust and provides an opportunity to mitigate some design issues on the spot.

Each system is subjected to a test and evaluation process that often reveals unresolved or unanticipated problems, some of which are HSI related. For example, initial analysis of a display may have helped to determine the size needed for various icons. However, test and evaluation may reveal legibility problems when the display is viewed under field conditions, perhaps caused by vibration or lighting conditions. Also, there may be last-minute changes to requirements that require modifications to design that subsequently result in unanticipated performance challenges. HSI analysis will again have to be applied to these design changes.

Because much of the system is already designed as it nears Milestone C, the cost of making changes here is much greater than if a problem had been mitigated earlier. Still, if the system is deployed without the mitigation, the cost to fix it after deployment becomes even greater.

THE VALUE OF HSI IN ACQUISITION
The Army and the DoD acknowledge that the HSI program has a long record of demonstrated successes that have saved both lives and significant life-cycle costs. Most program managers readily accept the requirement to have an HSI program and often are enthusiastic because HSI, through its analysis of soldier capabilities, significantly helps to improve system performance. Program managers are evaluated on their ability to deliver systems that meet the stated requirements without exceeding costs and schedules. HSI analysis and assessment rarely cause significant delays in system development if the program manager has adopted and maintained a dedicated HSI team effort throughout the program life cycle. If HSI issues are addressed as part of the overall system engineering risk management process, the cost–benefit ratio for HSI is favorable. Therefore, the cost of maintaining an HSI program is miniscule compared to the total program cost. A recent Canadian study on the cost and benefit of HSI showed a 40:1 return on investment over the entire life cycle of a program (Greenley et al., 2008).

The return on investment for HSI is evident in the consideration of physical workload and health hazards. A recent HSI activity involved assessing injury claims of Army engineers who build bridges. Some of the tasks to build a bridge span over dry trenches involve two- and three-person lifting of heavy components for assembly. This task requires repetitive bending and lifting that often results in
Drillings, Knapp, and Shattuck

acute and then chronic back injury. Since back injury benefits are a large cost driver in claims to the U.S. Department of Veterans Affairs, the Army has been taking steps to reverse these types of physical injuries. HSI has helped by recommending simple lift tools and push carts and then computing medical costs if these or similar techniques are not used. The medical cost avoidance model (Bratt et al., 2010) has been a signature accomplishment of the Army’s health hazards and HFE components of HSI, since it shows emergent care and long-term disability costs that would be incurred if HSI design mitigations are not taken. The ratio of cost avoidance has been computed as 70:1 (unmitigated cost to mitigated cost); this one simple HSI solution will save millions of dollars in veterans’ claims for retired soldiers-engineers over a 20-year time span.

Given that HSI can provide great value, how influential is it in acquisition decisions? Acquisition decisions are complex and can depend on the perceived need and urgency for system capability, especially during periods of conflict. It is difficult to describe the exact circumstances under which HSI findings will be persuasive. Most of the “red” recommendations in HSIA’s are acted on. Procurements of some systems have been terminated because of their failures to satisfy HSI requirements, whereas other systems have been significantly modified. Still other systems are not modified, but the conditions under which they are deployed are changed to reduce, though not eliminate, the identified risk.

During wartime, decisions on system acceptance and deployment are sometimes directly related to the specific needs of theater commanders. Commanders may be willing to accept HSI risks rather than not have the system, even if it is less than optimal. Commanders and their soldiers often will employ a somewhat deficient system only under special conditions or within environments that reduce the identified risk. For example, a recent HSIA identified a misleading fuel gauge in an aerial drone as a significant problem. Rather than not using the system during the recent conflicts, crews adjusted their procedures to ensure a full fuel tank before take-off, kept careful track of how long the drone was flying, and made sure to land well before predictive models suggested the drone would run out of fuel. The fuel gauge problem remains, and there is a plan to fix it, but by using adaptive tactics, techniques, and procedures, both HSI and military commanders were accommodated.

CASE STUDY

Consider the example of a submarine design program. The HSI professional must immediately determine where the program lies within the military requirements and acquisition system life cycle. This determination will indicate which program activities have occurred, or may be underway, and what opportunities may be ahead. HSI professionals may have been involved with the generation and specification of submarine requirements prior to this point. Because a materiel solution in the form of a new submarine program has been proposed, a program manager would have already been designated to oversee the procurement, and the program is likely to be past Milestone A. Imagine that the program has identified six HSI issues as important: displays and sensors, control of assets, physical environment, shiftwork, staffing, and personnel. The HSI professional would provide support either as a government HSI practitioner or as part of a defense industry contractor team. HSI typically would be located within either the program’s SE center or integrated logistics and supportability cost center. HSI is part of the program’s budget, so it will compete with other program needs for funding.

The HSI team should obtain from both the government and pertinent contractors any program and system engineering documents and data that specify the system vision and plans for realizing the vision. The HSI team also should pull “lessons learned,” task analyses, and models from legacy platforms. Then, the HSI team should create operator workflow concepts that can be represented visually with diagrams and descriptive models to illustrate the tasks that humans will perform, giving particular attention to the submarine’s crew and emerging hardware and software component designs.

This initial workflow representation becomes the reference point for all succeeding tasks and the source from which HSI issues relevant to the submarine program can be generated. For example, will the
system’s command and staff structure be the same or different from current submarines in the inventory? What sensors and data streams will be associated with the system, and can these data be accommodated by displays in predecessor systems? Are new functions and tasks expected? Do personnel have the appropriate skills to perform the expected tasks? Will the submarine be taking on more varied and demanding missions than predecessor systems, and will the operational tempo be more intense? Workflow documents and diagrams will help address these questions.

In-depth discussions with system engineers, operator subject matter experts, and HSI experts would follow. Information from the first two tasks—HSI fact-finding and workflow representation and annotation—leads directly to the third task, which is creating an HSI plan to comprehensively specify how HSI will support the submarine design process by taking the individual HSI technical domains into account and supporting any trade-off decisions by the program manager. This plan is the critical tool for the management and execution of the HSI effort, because it details the sequence of activities and timetable for HSI activities and shows how these activities will be coordinated with the overall system master plan and schedule. It will expand the initial operational workflow into a time-based task flow for all potential submariner roles. Then, role interactions will be assessed in low- to high-fidelity settings, starting with computer modeling and computer validation of workflow and automation concepts by experts. From this, trade studies and operational experiments can follow. Finally, demonstrations of system prototypes will be conducted, followed by formal testing. HSI activities also would include development of appropriate metrics for each level of activity, oversight of data collection, identification and resolution of issues in operator–system component compatibility and performance outcomes, and periodic status reviews and reports to the chain of command.

FUTURE CHALLENGES

Military defense systems are becoming more complex. Tasks required to operate the equipment are more cognitively intense, information is arriving faster, and more systems are being networked into “systems of systems.” Increased autonomy and automation further challenge human operators’ ability to intervene when systems degrade or fail. Moreover, these autonomous systems may degrade in ways that make their failure hard to discern and overcome. As technology improves, more and more functions and capabilities are placed within the same systems. We should not be surprised by the desire of users for more and more system capabilities, and we should not avoid the challenge of providing usability for these complex systems. Operators will always desire more capability from the systems they use. Providing these capabilities in a usable form is a primary goal of HSI.

Each of these negative consequences of complexity can be managed by the application of HSI. Their solutions, however, are likely to demonstrate the trade-offs inherent in virtually all system acquisition projects. For example, increased data flow and input could subject an operator to excessive workload. HSI experts can identify the risk of data overload and evaluate alternative design concepts to include, perhaps, the use of additional automation. Increased system automation, however, moves the operator from direct control to supervisory control of the system. Teaching humans to exercise supervisory control requires a different type of training than that for direct control and may require more aptitude from personnel.

System designers and trainers may not be prepared to respond to these challenges even after they have been clearly identified by HSI practitioners. Within the Army, we are using this challenge to call for a renewed commitment to better system design, particularly regarding decisions required early in the system design process, and for the reconsideration of how we train, where we train, and the very nature of training.

References


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