CHAPTER 6

Human Systems Integration Requirements in Systems Acquisition

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6.1 INTRODUCTION

Military effectiveness relies on having the capability to achieve military objectives in the face of equally determined opposition. The issue for "requirements" for systems engineering management and the human systems integration (HSI) specialist is how to express a capability need in a way that will ensure it is achieved or at least minimize the risk of its not being achieved.

Over the last century, the "edge" needed to achieve military capability has become reliant on ever more complex technology that in many cases has failed to deliver the desired result when in the hands of its intended users. This stimulated the birth of human factors (HF) and ergonomics as new scientific disciplines in the mid-twentieth century, but these activities were primarily applied as constraints on designs of equipment rather than addressing the full role of people integrated into system capability: The procurement process was still equipment centered rather than people centered.

Initiatives of the last decade have institutionalized consideration of human users within the procurement process. More recently, thinking about procurement as a whole has broadened to make explicit the acquisition of capability, of which procuring equipment is only a part. All of these moves affect requirements for the "system" being acquired.

A system is "an integrated composite of people, products and processes that provide a capability to satisfy a stated need or objective" [U.S. Department of Defense (DoD), 1992]. This system definition is central to HSI and must be central to system requirements thinking. Hitchins (1998, p. 195) describes a system as "an open set of complementary, interacting parts, with Properties, Capabilities and Behaviours (PCBs) emerging both from the parts and their interactions." This definition focuses on the interaction between parts. Hitchins also emphasizes that system engineering must concern itself with not just the "product system" (that will exist within the user organization) but the "process system"

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that creates it (and is often in a different organization). Both require integration, involving multiple interacting parts and people. Those with responsibility for HSI must therefore think not only about how end users interact with their equipment but also about how the results of HSI analysis will be integrated with the work of system engineers and others whose concerns, training, and mind set may be very different from their own. Traditionally, HSI has been more concerned with the product system, whereas the 10 principles of HSI listed in Chapter 1 strongly concern the process system.

The requirements and other key documents produced early in a project significantly determine what will eventually be fielded. For HSI to be truly effective, human-related issues and their consequences must be *woven into the fabric of the project* rather than appearing as stand-alone items. Developing systems is difficult work, with many trade-offs at all levels. It is important to remember that no "HSI product" is ever fielded or sees action. The equipment that is fielded, the people who operate, support, and maintain it, and the procedures that bind them all together are produced by other stake holders. Human systems integration must inform and add value to the output of these other players, whether it is hardware, software, trained people, or military handbooks. The ultimate test of that added value is how well human and non-human components work together, maximizing their own and each other's performance.

Requirements for a system are motivated by several different factors: what it must be capable of achieving and the constraints imposed on it by the environment in which it will operate, the systems with which it must interact, or the components it must include. At the *total system* level, humans are a vital system component, and they bring many constraints with them. At the slightly lower level of an equipment system (strictly a subsystem) to be procured, the humans represent another subsystem with which it must interact closely.

Requirements (in general) can be expressed in three different ways, often called the *three P's*:

- Product—attributes the product must have (e.g., height, load space).
- Performance—how well the product must do something (e.g., speed, accuracy, failure rate).
- Process—aspects of how the product must be developed or produced (e.g., quality procedures, design disclosure, road testing).

Human-related requirements are of all three types and are discussed further in Section 6.2.2.

Traditionally HSI requirements have been *requirements to conduct human factors tasks* (e.g., "the contractor shall do a task analysis") and requirements for desirable human-related attributes (e.g., "displays shall be easy to read"), but this undervalues the full role of HSI as a contributor to system requirements. Human systems integration can be applied to the full range and depth of system requirements. All aspects of a requirement affect the outcome and, hence, potentially the effectiveness of human to nonhuman integration. All parts of the requirement are legitimate candidates for HSI intervention.

Example 6.1 Security and Operability The feasibility study for a command system was facing many challenging issues, each being explored by respective specialists. The dominant HSI issue was the size of the command team as part of an overall drive for lean manning. One of the pressing technology issues was the need to handle a small amount of information at high security level and the consequent need not only to prove that the software was reliable but to do so in a way that would not greatly increase software development cost. After wrestling with this problem for some time, the system engineers presented a system architecture they believed would solve the problem. Their solution was to minimize the high-security software by dividing the system in two. However, the HSI manning analysis revealed the engineers' solution would add two people to the ship's complement, because the new architecture would split a critical operator role down the middle. This stark revelation, plus the relationship built up with the HSI leader helping the engineers to resolve smaller issues during the project, was enough to cause a rethink in the interpretation of the requirement and eventually come up with a solution to the software problem without increasing manpower.

6.2 HUMAN SYSTEMS INTEGRATION IN REQUIREMENTS

The requirement captures the reason the project exists. It is at the heart of the project. Downs et al. (1992, p. 93) state, "Projects start because people who are in some way significant in an organization feel that things are wrong, or at least that there is a reasonable chance that they could be made better."

This earliest phase of an acquisition program is most critical. The whole direction of the future project (or indeed whether the project goes ahead) will depend on decisions made during the preconcept and concept phase. The decisions will frame the overall requirement, define what risks are to drive the plan, and allocate resources. Human factors have traditionally been perceived as contributing little to this phase, yet failure to capture human-related issues as part of the initial requirement makes it harder to give the human dimension due weight in later phases.

6.2.1 HSI and the Requirements Process

Requirements engineering is a distinct discipline within the systems engineering community. It is the subject of active research with many unsolved problems, but there are established frameworks to which successful HSI must relate.

Requirements engineering has achieved prominence partly because of the widespread experience that it is difficult to do well, and partly because system problems are attributed to failures in requirements more than any other cause. Most phases of systems engineering transform one reasonably well defined entity into another. For example, designing turns a specification of what is required into a description of something that can be built; testing turns a hypothesis about performance into evidence. Each stage of the process expects to receive something well defined from the previous phase. This would mean a precise, unambiguous specification in the design stage and a well-defined set of test schedules and conditions and performance criteria in the testing stage.

The requirements process (as a whole) is more difficult than the design and development processes, since the inputs to requirements engineering are less well defined than those for the engineering processes that follow. The requirements process starts with loosely defined needs and progressively elaborates those needs into a much larger number of precise statements for something that can be contracted, built, and tested.

As a discipline, HSI has much to contribute to requirements. Much of the imprecision and uncertainty in the requirement sources stems from the need to involve people, such as operators and maintainers as components of the total system. But people are complex, hard-to-specify components. Moreover, people "own" the problems that the system is trying to solve. For these reasons, there is scope for productive cooperation between HSI and requirements engineering practitioners and considerable overlap between their research interests.

Figure 6.1 shows a simplified view of how a requirement for system capability is formulated and then split into requirements for the equipment and human parts of the system. Through a series of acquisition steps, the requirements are progressively transformed into a system composed of both people and equipment.

Much of the elaboration of requirements for the technical aspects of an equipment draws on a large pool of knowledge about the equipment domain, whereas many HSI requirements must draw on a very different and smaller pool—one that describes people

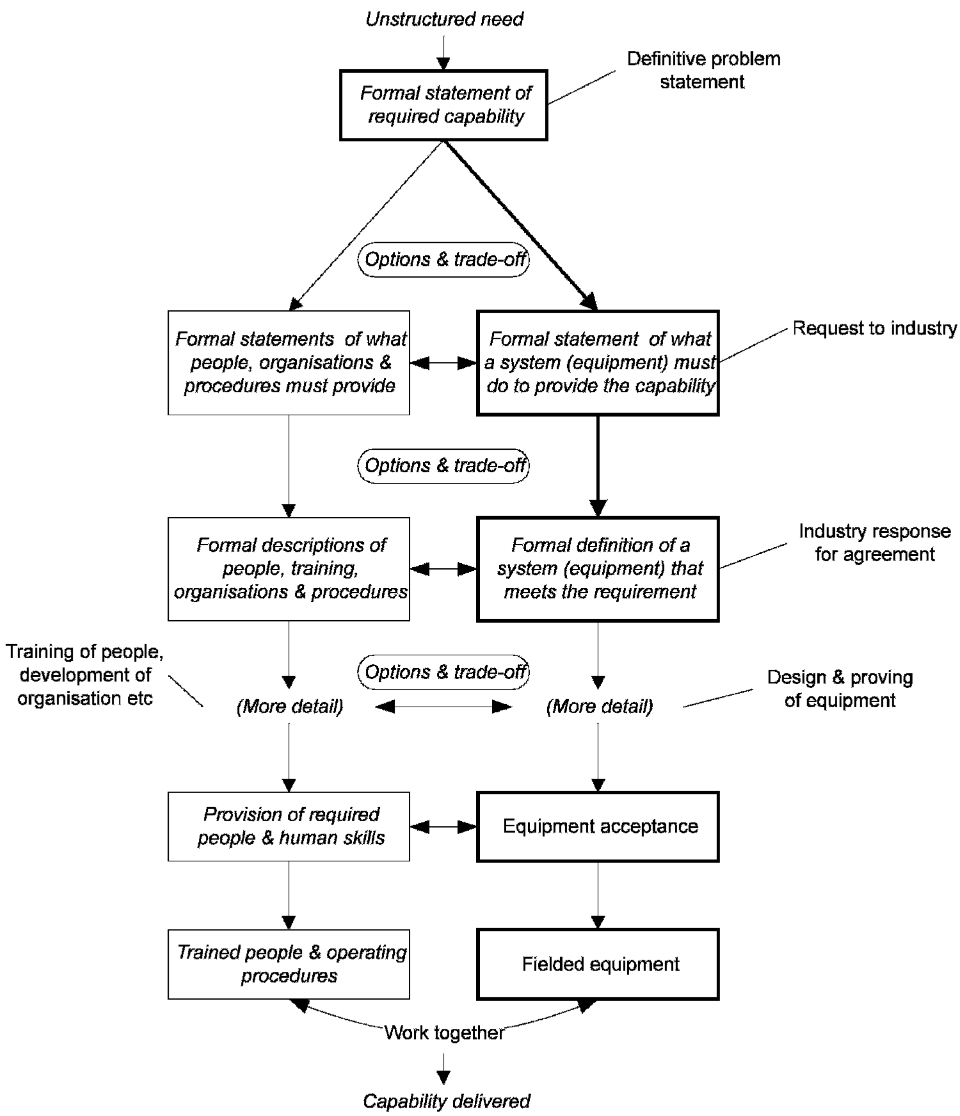


Figure 6.1 Balanced view of systems acquisition process.

and how they behave. Specifiers and procurers can draw on the heavy investment in the underlying engineering science by equipment contractors, whereas for the corresponding human science the most recent HSI advances will generally come from smaller investments by government, academic, and HF consulting firms.

Another function of HSI is to act as the bridge between the human and equipment components of the system. Figure 6.1 shows a balance between the equipment and people paths of the system acquisition process. Without HSI involvement, the process tends to run along the equipment path, as illustrated by the thick-edged boxes along the right of Figure 6.1. From a procurement perspective, this is the "mainstream," but as a means of evolving from the statement of required capability to the fielded capability, it must interact with the people stream on the left, as illustrated in the balanced view. As the examples provided in this chapter illustrate, the HSI practitioner must often take the initiative to bridge human and equipment requirements in such a way that the system requirements can be met in a cost-effective manner.

In this more balanced view of things, the results of human-related disciplines in the left-hand stream complement the traditional activities in the right. This is not just "supplementary information" but ranks on a par with the evolving description of what the equipment must do. The unique role of HSI is to restore this balance and ensure that the two halves are properly coordinated at all stages.

Example 6.2 Radar Display Clutter The engineers designing a naval command system knew that clutter on radar displays made it hard for operators to see targets. They had the technology to suppress clutter. Land clutter was more difficult, especially at the edges, but with advanced digital technology they could suppress all land clutter. Everyone including the user representatives agreed this was a good idea, since it would make target identification easier. The system went to sea, and operators found they could not see the coastline on their radar screens, so they turned off the sophisticated suppression, thus making the advanced technology useless. Had a proper task description (routine with HSI practitioners) been developed in parallel with the ideas on equipment function, it would have become clear that operators need to see the land in some situations (e.g., where the coastline is) as well as enemy aircraft. The technology could have met all their needs at negligible cost and enhanced their performance, but instead a technology was bought that was not used, and performance capability was reduced.

Placing the emphasis of the initial formal statement on operational capability, rather than just on equipment performance (i.e., placing the first box in the center, rather than at the right of the diagram) is having a fundamental impact on procurement thinking, certainly in the United Kingdom (UK). An initial thinking stage has always existed, but traditionally it has been prior to the creation of the first formal requirement (which was for equipment). Tracing requirements to statements of capability, rather than to equipment needs, represents a major opportunity for HSI, since it makes the case for introducing human performance into the system performance equation.

6.2.2 Human-Related Contribution to Requirements

A *capability requirement* is the first to be formalized. Its production is likely to be *user led* rather than *system engineer led*. It will be a well-structured document that defines the required capability in fairly high level terms. Subsequent, more detailed requirements will be traced to it. Although such a high-level statement of military need might seem far from the detailed concerns of much HSI work, it is essential to ensure that human-related concerns are properly reflected in it, to provide the "hooks" that can subsequently be elaborated into greater detail.

The key point to remember is that it is people working with the equipment procured as a result of the requirement that will deliver the capability. The statement must cover, at an appropriate level, all aspects that will affect the ability to work effectively with the equipment. Performance targets must cover human as well as equipment performance. Overarching requirements stemming from legal and moral obligations to people at large as well as people within the system must also be covered.

The *system requirement* as supplied to contractors is mainly focused on what the proposed equipment will do. It is detailed and can be quite large. It will normally be managed with some sort of system engineering tool. Standard requirements practice recognizes the functional (F), nonfunctional (NF), and constraints (C) types of requirement statement. The NF requirements cover performance, quality of service, etc. This nonintuitive usage is well established in the system engineering community but can cause misunderstanding (e.g., the requirement for the speed of a car is NF). In an extreme case, everything that is not *functional* might be bundled together as *nonfunctional*.

The HSI requirements should fit within this framework, and indeed they do, but Table 6.1 shows two additional types—human performance (HP) and process (P)—that are necessary when specifying manned systems and especially the interface between the human and the equipment. Although technically HP and P are subdivisions of the NF type, it is helpful to differentiate them for HSI purposes.

The HP requirements are critical, since without them there would be no contractual check on whether the equipment really was operable and able to integrate the human component properly into the whole system. Making HP requirements explicit allows them to be tested reliably and allows contractors to focus on how to meet them, knowing that it will affect *that part of* acceptance.

The P requirements help to fill an important gap where the functional or performance needs cannot be clearly specified. The buyer specifies something for the contractor to do (e.g., demonstrate design options, explore the effect of certain trade-offs, or conduct pilot trials) without placing unwarranted constraints on the design solution. Process requirements normally appear in the statement of work (SOW) accompanying a contract, but they are mainly at high level and of broad scope, applicable to the system development as a whole (e.g., requirements to maintain records and traceability). Process requirement statements within a system requirement will normally be more specific, relating to a

TABLE 6.1 Types of Requirements

	Requirement Type	Content
F	Functional	What the equipment must do
NF	Nonfunctional	How, or how well, it must do it (quality and performance)
C	Constraints	Limits on the solution
HP	Human performance	How well the user must perform tasks using the equipment
P	Process	Things the contractor must do

TABLE 6.2 HSI Contributions by Requirement Type

Requirement Type	Suggested HFI Contribution
Functional	Functions needed to support human operator or maintainer, enhance or compensate for human performance limitations, and provide for human safety and well-being
Nonfunctional	Requirements to support specified human tasks and required equipment responsiveness to human component
Human performance	Required human performance while using equipment (error and/or time) and requirements for legibility, comprehensibility, ability to manipulate controls, etc.
Constraints	Features to accommodate human characteristics or mode of working and ensure human health and safety and limitations of human mental and physical capability
Process	Required involvement of users to ensure design elaboration takes account of detailed user needs; requirements for operability prototypes, demonstrations, etc., for evaluation; and requirements for coordination (e.g., to ensure common operating principles between different equipments) and process visibility in any areas of uncertainty

particular issue or need that cannot be properly covered at that stage as a functional or performance specification. Such requirements will subsequently be replaced by other requirement types as the detailed requirement becomes clearer and can be unambiguously specified.

Human systems integration should contribute requirements to address the implications for the human component of the system at a comparable level of detail to those from other areas. Several examples of HSI contributions applicable to the various requirement types are provided in Table 6.2.

Example 6.3 Equipment Versus Task-Focused Requirements The requirements for a command system were derived by reference to the predecessor system on an incremental basis. New functions needed were added, functions that did not work well were specified more closely, and redundant functions were dropped. Human issues were of concern during the system definition study, in particular the workload that would be imposed on members of the command team. A contractor studying user tasks noticed that a major fraction of the workload of one member of the team came from encoding and decoding messages using a slow pencil-and-paper method. This significant chore could have been removed by a very simple piece of software as part of the facilities provided by the new system. It was not, because there were no requirements to provide that function. Unfortunately, the requirement was based on replacing the predecessor system, not on enhancing human and equipment performance collectively.

6.2.3 User Interface Requirements

Requirements for the user interface can be the largest set of HSI-inspired system requirements. The user interface mediates much of the equipment's impact on its users and their behavior. The results of much HSI analysis (target audience description, task analysis, workload analysis, error analysis, etc.) eventually make their impact on the equipment design via requirements for how it will interact with users.

TABLE 6.3 User Interface Requirement Structure

Section	Typical sub sections
Context of use	Scenarios, users, environment, assumptions, tasks to be supported
Generic requirements—that apply systemwide	Overall concepts, consistency, views, interaction, alerts, etc.
Function area specific requirements—that relate to individual functions (e.g., for command systems they might be tactical picture, weapon management, navigation, etc.)	Task supported, views used, information required, actions supported, feedback, constraints, alerts
Nonfunctional requirements—quality and performance	Responsiveness, human performance, health, safety, compliance with HFI policy and standards
Acceptance	Methods and criteria

For information-rich systems, a good case can be made for producing the user interface requirement even earlier than the main functional requirement. Typically, the user interface requirement can be derived from the results of an interactive requirements prototyping exercise with users. A user interface requirement is often structured much as a system requirement, with contextual information, and F and NF requirements. Because of the extreme importance of overall coherence in a user interface, it is sensible to separate generic requirements from those for specific functional areas. Table 6.3 shows a typical user interface requirement structure.

6.2.4 Acceptance of HSI Requirements

Acceptance is the formal process to certify that contractual commitments have been met and that the deliverables meet their requirements. Equipment acceptance is based on evidence that the equipment has the required attributes and performs as specified in the system requirements document (SRD). This evidence is normally based on a combination of inspection (of the equipment and supporting documentation) and tests or trials (of the equipment). Evidence should be gathered incrementally during development and manufacture.

Where HSI requirements are expressed in terms of conventionally testable equipment attributes (size, weight, brightness, etc.) based on well-proven standards or the result of prior trials, their acceptance is no different from that of any other equipment attribute. Simple (yes–no) requirements are checked off, while quantitative ones are measured (with ruler, stop watch, photometer, etc.). (See the first two types of tests in Table 6.4.) Other HSI requirements cannot be expressed and tested in this simple way but require direct evidence about how the equipment and users interact with each other, as shown by the third and fourth types of tests in Table 6.4. These requirements (for operability, maintainability, trainability, and supportability) must be tested using people as "test instruments." Doing this reliably needs special procedures and techniques.

The first four tests shown in Table 6.4 are roughly in order of increasing cost. It is therefore good practice to ensure that items that can be simply tested are specified so as to

TABLE 6.4 Types of Systems Tests

Type	Description	Comment
Design inspection (DI)	Formal inspection of design documentation, against principles and requirements in the specification	Offers a cheap and convenient supplement to other approaches for larger amounts of information, normally backed up by selective use of other tests
Functional demonstration (FD)	Formal controlled presentation of equipment and its working to assess the presence or absence of functionality	Suitable for HSI requirements that (through evaluation, experiment, or reference to standards) can reliably be expressed in terms of simple, testable equipment characteristics, and functions
Task walk-through (TW)	Formal controlled presentation of task support facilities; test criteria based upon ability to complete tasks and qualitative measures of user acceptability	Brings human interaction into the loop; semisubjective but controlled; more cost effective than full operability trials, especially with large amounts of detail where complexity and cognitive performance are more relevant than physical and skill-based performance
Operability trial (OT)	Formal controlled and structured data collection of human performance or subjective user reaction against agreed, predefined criteria	Ultimate test of human integration; comes closest to a real-life test and can also be applied to higher levels of requirements hierarchy but costly to implement
Process review (PR)	Review of evidence of development process (records, minutes, plans, etc.). Criteria for acceptance are based upon the existence of required evidence	Does not test system characteristics directly but provides confidence in the way they were derived, is auditable, and enables further scrutiny of supporting evidence if necessary

permit this. The available trials budget and time should not be used up performing operability trials to check well-proven details. Operability trials (OTs) and task walk-throughs (TWs) should be used for areas of uncertain task interaction, task complexity, and overall integrated task performance. The OT and TW should also be used to test things such as performance degradation over extended periods and skill retention during periods of nonuse, as appropriate.

The matrix in Table 6.5 shows which types of test are most suitable for which types of requirement. The primary test for functional requirements is functional demonstration (FD), but in some cases design inspection (DI) or TW might be appropriate. For example, TWs can provide a useful check that the functions have been correctly interpreted from a task perspective. The NF requirements vary considerably, with corresponding diversity in the appropriate way to test them. The primary test for HP requirements is OT, with TW a

TABLE 6.5 Tests Suitable for Type Requirements

	F	NF	HP	P	C
OT	–	?	xx	–	?
TW	x	x	x	–	?
FD	xx	x	–	–	x
DI	x	x	–	x	x
PR	–	x	–	xx	?

Note: xx = primary, x = alternative, ? = Possible, – = unsuitable.

cost-effective alternative in many cases. Process requirements are primarily tested by process review (PR) i.e., reviewing the process evidence, but in some cases it will be more appropriate to inspect the design resulting from the process. Constraints normally relate to functions and design detail.

Combinations indicated with a question mark represent unlikely situations and in most cases could be handled in a different way. For example, meeting a constraint to accommodate users who are physically small could be tested by OTs to see whether small users could perform tasks or by PR to see that small users took part in the trials. Usually, it would be related to dimensions of the design that could be tested (possibly with anthropometric modeling tools). Likewise, a NF requirement for machine response time could be tested in an OT by seeing whether it undermined user performance, but it would be simpler and cheaper to measure it.

Acceptance is a contractual process based on evidence that the system meets its requirements. Traditionally "acceptance" has been equated with comprehensive functional testing of the completed system. Current acceptance practice recognizes that this is not a cost-effective approach and that evidence should be gathered incrementally over the period of development and manufacture within a quality-controlled process. Deficiencies can be corrected earlier, and everything is not tested twice—by both manufacturer and customer.

Evidence of operability should be gathered as early as possible using the most cost-effective type of test. The customer may retain the right (selectively) to repeat some of the tests, but in many cases, it is possible to use evidence from early trials to substitute less costly tests for confirmation later, for example, in production.

Example 6.4 Display Legibility Requirement Consider a requirement for legibility of information on a display. Standards such as MIL-STD-1472 (DoD, 1998) specify minimum angular subtense of characters, luminance contrast, and so on, but legibility can be degraded by vibration, content, and other task-related factors. Use of larger characters and symbols can offset the degradation, but at a cost; it reduces the screen capacity and might increase task complexity if information has to be spread over more screens. At the requirement stage, it might not be clear where the best trade-off lies, so specifying the character size is not appropriate. On the other hand, a performance requirement can be specified, with criteria for permissible error rates based on the nature of the task. Testing the requirement for acceptance is feasible but is costly in time and resources. The performance requirement does not immediately translate into designer action, leaving a risk that equipment might be presented for acceptance that did not meet it. When this happens, there is a high risk that marginal failures (or worse) will be traded away to avoid undermining the whole program, since changes late in development cause delay and can be extremely costly. Conducting appropriate trials as soon as representative displays are available and the information to be displayed is well enough understood can reduce this risk. The tests would build confidence that the performance requirement will be met. The trials could also provide a basis for additional requirements for character size, contrast ratio, etc., that would be less costly to test. The original performance requirement would still stand but should not need to be tested unless there was evidence to suggest that the substituted criteria had been invalidated, for example, by some change in the mode of use.

6.2.5 Human Systems Integration Process Requirements

Requirements for the conduct of HSI have an important role to play in defense contracting. It could be argued that competent contractors do not need to be told how to proceed but that overlooks two benefits that such requirements bring.

First, mandating processes to generate evidence about human aspects of the system can reduce risk by enabling better coupling of contractor results with the procuring authority's own internal HSI processes and program, especially during extended development periods. Such requirements should focus on the evidence to be produced, rather than the detailed technical processes to produce it. The requirements should make clear what is needed, in what form, and when. Such evidence can include, for example, documentary results of analysis, modeling, evaluation, and tests as well as demonstrations and user interaction sessions with prototypes.

Second, since the cost of HSI-related work can be a significant part of a contractor's project budget, mandating key evidence-producing activities puts all competitors on an even footing. Thus the procuring authority is less likely to be faced with an *apples-and-oranges* comparison between a more expensive development bid supported by comprehensive HSI and a cheaper one with no guarantee of such support.

As well as requirements to undertake HSI activities, it is also sensible to require contractors to be able to demonstrate how the design solutions offered have been influenced by the HSI results. For example, the Dunchurch report (MoD-Industry Human Factors Integration Group, 1995, p. 6) concluded. "where designs are produced, task based justification should be expected and should form part of the judgement of contractor competence."

An alternative approach to ensuring that appropriate processes will be deployed is to assess the *capability maturity* of the organization. The concept of a capability maturity model (CMM), developed for U.S. government procurement of large software systems, has spread to other disciplines. One of the earliest relevant to HSI was the usability management maturity grid (Flanagan, 1996). The UK Ministry of Defence (MoD) has recently co-sponsored work under the International Organization for Standardization (ISO) on quality-in-use processes and their integration (ISO, 2001). This is a CMM rooted in the concepts of ISO efforts on human-centered design processes for interactive systems (ISO, 1999).

6.3 HUMAN SYSTEMS INTEGRATION REQUIREMENTS ISSUES

The process of taking full account of the human dimension of systems within engineering and procurement has changed markedly during the last decade. Although the basic framework now seems clear, the process is still evolving, and issues are still being worked out.

Three issues are discussed here:

- the need to integrate with a requirements engineering process that is itself maturing and becoming more tool dependent;
- evolving ideas about how to formulate HSI requirements, especially the role of user interface requirements; and
- how the disciplines of HSI can adapt to an acquisition regime increasingly dependent on "off-the-shelf" equipment.

6.3.1 Working with System Requirements

In order to ensure full integration of HSI concerns into system requirements, it is necessary to understand the broad structures of a system requirement and some of the factors that influence it. System requirements invariably become large and are usually structured hierarchically, though other forms of structure can be imposed by the various software tools used to manage them, for example, to show traceability or dependencies. The use of such tools by system engineers imposes a constraint on those responsible for HSI who (to be fully integrated in the team) need to express requirements using the same tool and thus work within its constraints.

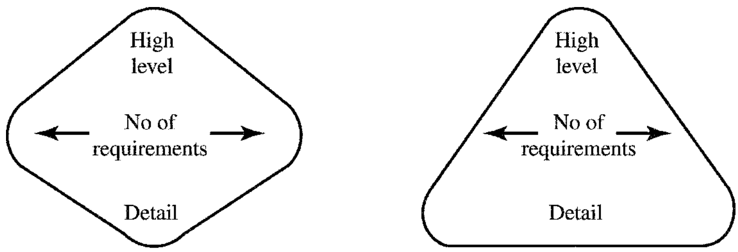
Hierarchical Structures Traditional system requirements were either hierarchically structured textual documents or "flat" databases. The former are difficult to track and the latter are difficult to understand. More recently, requirements management tools have improved the situation with hierarchically structured databases that can automatically generate the structured documents. Even so, it is not uncommon for these to be used in such a way that only the headings are hierarchical, with all the "actual" requirements at the bottom level.

Good requirements engineering practice (Hunt, 1997) encourages the generation of a hierarchy of requirements statements, with a small number of "parent" requirements linked to "children" that describe contributory requirements, specify interfaces, or allocate performance budgets. For example, a high-level requirement might specify the rate at which aircraft will be able to take off. Lower level ones might specify the rate at which fuel can be delivered, the interaction between aircraft movement and ship safety, or the time to be allowed for moving aircraft between decks.

The hierarchical structure permits a much better understanding of how the whole requirement "hangs together" than a large collection of low-level statements. It also provides a better view of how requirements, especially *emergent properties*, of the system as a whole can be tested.

As illustrated in Figure 6.2, a "good" requirement will have a diamond-shaped profile, with a small number of requirement statements at the highest level increasing to a maximum at midlevel and reducing again at very low levels of detail. This differs from a *design* which typically has a more triangular shape with a lot of detail at the base. Traditional requirements databases often "captured" the content of well-thought-out documents only to produce very many (thousands) of low-level statements of detail.

Ideally, HSI requirements should be incorporated in the hierarchical structure of system requirements, not all isolated in a separate section. In many cases, HSI requirements will appear at most levels of the hierarchy, not just at the bottom but higher up as well. Indeed,



Good Requirement Profile

Bad Requirements Profile
(Good Design Profile)

Figure 6.2 Requirements profiles.

many of the more challenging and important human performance requirements will relate to the performance of whole tasks or jobs, i.e., significant areas of functional support. Section 6.3.3 describes how a hierarchical structure could be used to provide coherence to a user interface requirement.

Subject Matter The detailed structure and content depend on the type of system and mainly contains specific, itemized statements about what is needed. The HSI requirements should be subject to the same quality criteria as other requirements. There are many criteria to differentiate between *good* and *poor* requirements; some relate to individual statements and overall structure, whereas others are not always easy to apply. Criteria of particular relevance to HSI are as follows:

- *Justification* The wording should clearly show how HSI-inspired requirements affect system cost and/or effectiveness, so they do not appear either abstract or “merely common sense.”
- *Verification* Requirements that cannot be verified are not taken seriously. Requirements such as ease of use are of less value than specified percentages of representative users being able to achieve designated tasks to a performance criterion. The statement of required capability is not the place for great detail, but it should provide the “hooks” from which more detail can be elaborated in the system requirement produced for industry.
- *Solution Avoidance* Avoiding solutions without being too vague to be effective can be difficult for user interface requirements. Specifying the need to support identified tasks, with appropriate performance requirements, is most effective at the high level. Specifying information and controls to be provided, with format relevant to the task, is appropriate at the low level.
- *Clearly Understood Need* The problem might be understood, but if what is needed to solve it is not, then it would be better managed as a risk, with corresponding activities in the plan to quantify it. Task or broad performance-based requirements can often act as “place holders” for such issues in the requirement, possibly with “to be determined” (TBD).
- *Comments* Some requirement structures allow the addition of comments. Although not part of the definitive requirement statement, an explanatory comment can often

help users of the requirement document to understand it more effectively. Understanding plays a key role in the way requirements are interpreted as well as the "legal" meaning of the words. Many of the people who use the requirement document will not be approaching it from a human-centered perspective.

- *Links to Other Requirements* Human systems integration should tie in with everything else. Note that there should be linkages to as well as from HSI requirements.
- *Overall Balance* The requirements should adequately reflect the importance of the human-related issues faced by the project, but it should not be dominated by too much detail. The level of expression is important.

Perhaps the most difficult aspect for HSI is testability. Section 6.2.4 described different ways to test human-related requirements, but in practice such things can be quite hard to specify. Well-meaning phrases such as "Displays must be clear" might be adequate as reminders or checklist items but will not pass the rigor of requirements engineering, and even if they do slip through, they will be of little help in acceptance. For marginal cases, the contractor will be unsure whether it has met the requirement, and if not, proving it will be difficult.

Focusing on testability has an unfortunate side effect. It can distort what is specified. Easy things to measure get included, while important but harder to measure things can be quietly forgotten.

Example 6.5 Trivial Detail Can Dominate Requirements An information system for a military headquarters involved many complex display screens. The details of all the screen layouts had been derived by analysis and signed off by the customer. Acceptance of the screens was determined by whether they conformed to the agreed screen definitions. To add precision, and because it was easy to test, the analysts had included dimensions on the drawings, i.e., the number of millimeters between the edge of the screen and data fields. During implementation, some of these dimensions were a few millimeters out. This was detected during inspection and the system had to be reworked, often to extremely tight deadlines, to correct the "deficiencies." However, this effort was of little use in determining whether the screens would be useful to the headquarters personnel who would be using them. There were no requirements related to whether the screens were legible or could be used to perform real tasks.

It is often difficult to specify and test what matters most, as in the example above. Traditionally, attempts to specify important higher order properties have resulted in well meaning but vague requirements such as ease of use that in the hard contractual world carry little weight. In most cases, human performance underlies the required quality and should be identified clearly in the early requirements. The expression should be as explicit as possible, specifying what it is that the target audience are required to be able to do and what criteria (time, error, accuracy, etc.) should be used to judge success. The actual thresholds for the criteria might not be known at this stage, but the contractors have a clear view of how they will be judged, and the procurer has a clear agenda of TBDs to be resolved by trial or other means as part of the HSI program.

Subsequent work must refine or elaborate these requirements. Some will lead to full acceptance criteria requiring operability trials with representative users and the associated procedures to ensure reliability of the results. This is costly and not practical for every detail. Recourse to standards, risk-based evaluation, and prototyping will allow some requirements to be replaced by equipment attributes that are easier to test (see Section 6.2.4 on acceptance).

Different System Types Procurement organizations often classify systems in terms of the customer area or the technology, for example, aircraft system, electronics system, missile system, ordnance system, ship system, space system, and surface vehicle system. These are still broad classes and cut across many HSI issues. For example, a ship system could be a whole aircraft carrier, a propulsion system, or a navigation system. An electronic system could be a radar set or a command information system.

Some different types of systems will have a more significant impact on how HSI is handled:

- information-rich systems (also called software intensive systems),
- complex multiprocurement systems, (e.g., platforms), and
- manual intensive equipment.

Information-Rich Systems (Software Intensive Systems) Requirements may be structured in two separate parts, representing *infrastructure* and *applications* (Computing Services Association, 1992). Infrastructure covers physical aspects (equipment on which the software runs) and the underlying *software architecture* for communications and information storage. In software parlance, applications run on this "platform." Applications requirements are often the most numerous—mostly functional requirements split up by area (e.g., weapons, sensors, navigation).

The most direct HSI contribution to a requirement of this type is to specify requirements for the user interface. Many will relate to the applications and should be integrated with each functional area in the requirement structure. Other more generic user interface requirements should be identified separately, possibly integrated with the software infrastructure requirements. Physical aspects of the user interface (size of controls, force required, brightness of displays, etc.) fit logically as a subsection within the *physical characteristics* of the equipment.

Other HSI requirements will be located in the various nonfunctional sections, though there is a case for closer integration of some of these with the functional requirements that they qualify (see Section 6.2.2).

Complex Multiprocurement Systems Major procurements such as military platforms are managed as clusters of systems and subsystems under an overall umbrella procurement. There are separate but related requirement sets at each level, i.e., the whole platform, its major components (hull, propulsion, combat system, etc.), and various subsystems such as navigation.

The platform-level requirements should not duplicate lower level detail, but they must contain the definitive HSI requirements from which lower level requirements can be derived and to which they can be traced. Otherwise, there would not be adequate contractual incentives for them to be fully addressed at the subordinate system levels. Some HSI issues can seem abstract at the platform (or major system) level and may be difficult to address, but particular areas (i.e., whole system performance, work system boundaries, complementing requirements, and coherence) should be covered (see Table 6.6).

TABLE 6.6 Platform-Level Requirements

	Description	Comment
Whole-system performance	Overall capability, subsequently translated into more concrete requirements that can be apportioned between the different component systems (in theory irrespective of whether the systems contain machines, people, or the usual mixture of both)	In practice, this can miss important aspects of performance that depend on people and in some extreme cases can lead to critical equipment that supports human functions such as communication, being almost "invisible" in formal measures of effectiveness
Work system boundaries	Contextual information to ensure that it flows down to each of the affected lower level requirements in a consistent way, especially where human roles, and hence the need for human integration, cross procurement boundaries	Work system boundaries, i.e., the job boundaries of individuals or teams, commonly differ from equipment boundaries
Complementing	Overall requirements for and constraints on the number and type of people who will operate, maintain, and support a system or a group of systems	Partly because of work system boundaries (as above), partly for platformwide issues such as damage control, accommodation, and watch keeping
Coherence	Requirements for consistency of operating practices, user interface conventions, labeling, etc.	Should be made explicit, whether standards, preestablished conventions, project specific "style guides," or merely aspirations

Example 6.6 Seating Is Part of the System A warship procurement included a complex new command system. Human issues featured strongly in the command system procurement, with great efforts to take account of them. Console designers used anthropometric models and a full-scale mock-up to ensure operators would be able to see and reach all of the controls comfortably without risk to health and safety. At the platform and compartment level there was no overarching plan for HSI. The contract to supply the seating was let separately from the contract to develop the consoles, both independent of the ship builder, and with no exchange of information between the various contractors. As a result, the positioning of the seats relative to the consoles resulted in some operators having to twist their spines to use the consoles. This potentially costly risk to the health of the crew could have been avoided by HSI requirements at the platform level.

Manual Intensive Equipment This inelegant title covers the numerically large number of procurements of "hands on" equipment that are often less glamorous than the big complex projects. Two points are worth noting:

- Small items are often procured in large numbers. The number of people using basic items for personal use multiplies the impact of deficiencies in their human compatibility. Individual effects might not be "showstoppers," but the collective effect on force effectiveness can be significant.

- In some cases, incompatibility of simple items can become a showstopper because basic human interactions were not properly anticipated.

Example 6.7 Integration on the Soldier A helmet, body armor, and gun sight were separately procured and performed their specified functions. When integrated on the body of a soldier lying prone, the body armor pushed the helmet forward, making it impossible to see through the sight.

The requirements for such procurements are less complex than for larger systems, and the subject matter is likely to be differently structured. Nevertheless, the same principles apply, and the same type of HSI input is needed. The questions to be answered are the same:

- What must human and equipment be capable of doing (together and separately)?
- In what context must they do it?
- What tasks will the human need to perform?
- Under what conditions will the tasks be performed?
- How well must the human perform them?
- What equipment properties, capabilities, and behaviors will make this possible?

6.3.2 Risk-Based Approach to HSI Requirements

There is a conundrum underlying HSI. Human issues must be recognized very early to avoid major failures of human integration, and yet many of the overtly human-related interventions in equipment development appear to be of a detailed nature best suited for later stages. Traditionally this has led engineers and managers to delay consideration of human-related issues until detailed design, by which time it can be too late or too costly to remedy major shortfalls.

The UK MoD has developed early human factors analysis (EHFA), a simple, intuitive process to help project managers identify and assess human-related risks early in a project. Contractors working on systems with a human dimension can also apply EHFA, but the scope of the risks "owned" will depend on the contractual relationship. Ideally, client and contractor should jointly manage shared risks.

Taking a risk-based approach to HSI makes it easier to know what must be done early and what can be safely left until later. This approach should provide three links with the main system engineering effort:

- Human-related risks can be fed directly to the project risk register. They may need some aggregation to match the level at which other project risks are managed but should be better formulated and more comprehensive having emerged from a formal process.
- After assessment, most human-related risks will point directly to the need for actions to mitigate them or at least to quantify them (e.g., analysis or evaluation). Thus the risks will drive requirements for the HSI program (within the project plan), and the

formal assessment underpinning them should help to justify their priority in the queue for limited project resources.

- Some human-related risks, once identified, can be nominally removed by the creation of new system requirements.

Example 6.8 Skill Practice Requirement The risk that operational performance of an occasional task might be inadequate because of skill fade could be mitigated by a requirement for a built-in training facility to permit regular practice of the skill.

6.3.3 Traceability of User Interface Requirements

Table 6.3 outlines a basic requirements structure for user interface requirements, but having a separate user interface requirement (or section) does not solve all problems. To be valid, a user interface requirement must map onto the task needs of the users, and to be viable, it must map onto the functional requirements for the equipment.

The need to map between user interface requirements and other functional requirements can in principle be handled by using the same requirements tool for both and using it to link the two parts of the database. For example, a requirement for the user to view a particular parameter would be matched with requirements to measure or receive the parameter at a suitable rate and resolution and process it into a form suitable for viewing (e.g., by smoothing it).

In practice, the different levels to which different areas of requirement are broken down during early phases of acquisition can make this form of linking difficult. It also raises issues about tool compatibility between procurement authority, consultants, other agencies, and contractors. Such issues do not arise with simple documents or even flat databases, (see Section 6.3.1).

Mapping between user interface requirements and user task needs is a more complex problem. Traditionally the link has been via the analyst's understanding, but this is not readily amenable to automated checking or tracing to determine the impact of changed requirements. User task needs are traditionally documented in a task structure (often a hierarchy) separate from the user interface requirements. Recent work (Harrison, 1999) has suggested the possibility of linking the two and using the task structure as the organizing framework for the user interface requirement. This would only really be possible using a suitable requirements management tool. The concept is illustrated in Figure 6.3.

The goal level at the top of the task tree represents the small set of high-level responsibilities that define an operational role. Typically they represent the granularity at which tasks can be readily delegated.

Requirements attached higher up the tree would apply to the whole tree below (e.g., broad information needs, types of view required, and alerts relevant to responsibility). Those attached at the bottom would relate specifically to individual actions. Information needed for tasks, constraints, or feedback might appear at different levels depending on whether they cover a single action or a cluster of related actions.

Requirements for alerts would normally link directly to a goal, since it is the goal level responsibility that determines the "need to know" and justifies delivery of the alert to the individual role. Below the alert, both information and an action represent the needed response.

Of course, in some areas the task tree might be quite shallow, possibly with only a single level between goal and action.

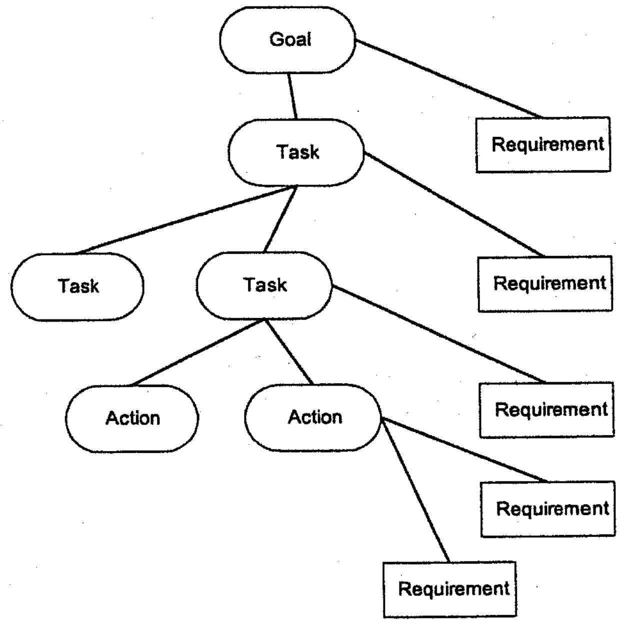


Figure 6.3 Task structure as a framework for user interface requirements.

6.3.4 Implications of Commercial Off-the-Shelf (COTS) Equipment

The major influence of HSI is normally through design interventions, initially at the requirement stage and subsequently through development. Where for political, commercial, or other reasons it is intended to procure *off the shelf*, it is harder to see how the discipline of HSI can exert an influence, but it can, if properly focused. Presented below are a few points of clarification:

- *True COTS means that knowledge of performance can be used in selection.* Buying an item that exists offers the supreme advantage of "try before buy." Real performance information can be used to inform the selection, and to a considerable extent this should reduce the risk of not being able to make design interventions (to forestall unanticipated performance problems).
- *COTS is not nondevelopmental item (NDI).* The term COTS is sometimes wrongly used to describe a NDI. An NDI is not bought off the shelf but off someone else's drawing board. Despite the reduced cost of initial purchase, this offers the worst of both worlds—the risks of new development without the ability to make design interventions.
- *The whole system is not off the shelf.* Rarely is an equipment system bought entirely off the shelf. Normally one or more major components is, with others added or modified. In the extreme case where components are bought off "different shelves" and brought together, the system thus formed is new and requires design at the system level if it is to work. The fact that the system designer's hands are tied by the use of predesigned components is a major constraint that makes the design of the system difficult, but that is not the same as having no design to do.

- *The human component changes.* Even if the equipment system were bought entirely unaltered off the shelf, the system that will be expected to deliver the capability will still be new, because the human component will be different from that with which the equipment previously worked. People from a different force will be integrated with the equipment in a different tactical and possibly physical environment. They will be organized and trained differently, probably come from a different culture, and probably be required to deliver a slightly different operational capability.

From this it is clear that there is no such thing as an off-the-shelf system. The issue is how to design effective systems of people and equipment using major predefined components off the shelf. The principles of system engineering (and HSI) apply to systems in a COTS environment as they do to others, but the constraints are different, notably in the areas of trade-off and in how to manage the issues of human integration.

A particularly important difference between COTS (and other NDI) acquisitions from more conventional acquisitions is the restraint placed on conducting the most critical HSI design analysis. The following two points elaborate on this difference:

- In a COTS or other NDI acquisition, the most critical HSI design analysis is done in the somewhat iterative cycle of requirements statement (including, of course, the human performance requirements) and in the market survey.
- The requirement–market survey cycle occurs before any contract with the vendor is made.

At the level of capability requirement, there is no difference between the two approaches, but the dynamics of the subsequent process are different. A COTS (or part COTS) option will be considered because it offers potential advantages in one or more trade-off. Usually these include cost, time to deliver, and (equipment) development risk. A COTS option must be evaluated in a similar way to any other option to ensure that all the implied costs (initial and through life) are understood and that the risk of it failing to deliver the desired capability is acceptably low.

The difference between COTS-based options and those involving new development lies in the mechanisms available to intervene if some aspect proves unacceptable on initial evaluation. With new development, many limitations can be overcome by design intervention. There is normally a cost, but the cost can be modest if the intervention is made early. Detailed intervention at lower levels can often be left until later, provided such a contingency is planned. The scope for design intervention with a COTS component is severely limited, since changes to a developed item (even if possible) are usually very costly.

In practice, this means that any identified shortfall in total system performance or incompatibility between human and equipment components can only be mitigated by changes in the human component or by changes to any non-COTS elements that bind the major items together. By analogy, we might call the latter “glue.” Such changes might indeed be able to make good the deficiencies, but neither should be assumed to be capable of easy change.

The human users come at the end of the line. If the COTS component is unchangeable and the glue used to join them together cannot be adapted to make good any incompatibilities, then the users will be left to try to make the whole system work. If they cannot (or if they can only do so with a penalty such as high risk of errors or risk of long-term health hazard), then the military customer might be faced with capability failure, high unplanned remedial costs, or both. The COTS-based systems represent a significant problem for HSI, because far more problems must be foreseen and forestalled (before commitment) rather than being detected and cured (during development).

The severe limitations on downstream intervention with a COTS-based system option make it essential to establish whether the system will be capable of the required performance and to identify any intervention needed to make it do so, either with non-COTS items or with the human component (training, selection, support, etc). Only when the true cost of the total system is known can a valid comparison with other options (COTS or not) be made. If the performance cannot be achieved, even with feasible interventions, then either the option must be rejected or the capability targets reduced, in which case other options might need consideration.

The HSI requirements play a key role in ensuring that COTS-based *systems* are selected on a sound basis, thus avoiding the risk of cheap COTS *equipment* leading to high downstream human-related costs and/or poor overall system performance.

Table 6.7 compares HSI activity relevant to COTS-based acquisition, with typical HSI activity for a new development, based on the system engineering activities of which they are a part.

Once a COTS selection has been made, the emphasis of HSI switches from foreseeing the human implications in order to influence the selection to system optimization within the remaining degrees of freedom (or damage limitation if the selection did not adequately account for human-related concerns). The scope for this remaining action is limited to

- any options within the COTS component (e.g., built-in customization facility or changes negotiated as a condition of the selection);
- influencing the design of system components other than the COTS items;
- identifying the need for task aids (e.g., cognitive props such as crib sheets, pocket calculators, overlays, or physical props such as lifting aids, supplementary tool boxes, vision aids);
- optimizing operating procedures;
- optimizing the training; and
- (exceptionally) making a more restrictive selection to increase the skill levels.

The last three options involve changes to the human element of the system. Some of these changes might prove untenable (e.g., tighter selection when manpower supply is already inadequate). All are likely to have a cost (which should have been foreseen and accounted for during the selection process). Changes to procedures and training might introduce less predictable side effects, such as increased errors caused by negative transfer from other equipment, the need to change selection criteria, or the need to reallocate work to different parts of an organization.

Given the difficulty of making major changes to the human component, the most effective way to obtain satisfactory human integration in a COTS-based system is to influence the initial option selection intelligently, by highlighting the true cost and performance of the different options, not just patching up the system afterward.

TABLE 6.7 Comparison of Systems Engineering and HSI Activities for COTS-Based Systems

Systems Engineering Activity	HSI Activity	HSI Activity Relevant to COTS
Define required capability	Identify human issues implied by the capability.	As left (should be solution independent)
Identify and assess system options to provide it	1. Identify human issues associated with predecessor systems. 2. Identify differences in context of use and predict impact on system options. 3. Assess human-related risks and requirements for each option.	1. Identify human issues associated with COTS elements in current use, including user performance. 2. As left, informed by current use of COTS components. 2a. Seek evidence of compatibility of COTS equipment with intended target audience and operational tasks, drawing on existing service performance, comparability analysis, and evaluation of performance in relevant trials. 3. As left.
Define system options for comparison and selection	Ensure human parts of overall system (manpower, training, support, etc.) are adequately defined and costed.	1. As left. 2. Identify and cost all additional equipment needed to make overall system work. 3. Identify and cost human interventions (selection, training, support, etc.) needed to make overall system work. 4. Identify and cost any performance shortfalls of overall system due to mismatch between equipment and people.
Select option	Take part in option trade-off across all system domains.	Inject above into option trade-off process. Focus on the total system, not just the COTS equipment.
Specify system requirements	1. Identify human-related system requirements. 2. Identify human-related risks still to be addressed. 3. Plan activity to mitigate human-related risks.	1. As left, but focusing on any freedom within COTS components, on glue components, and on performance requirements for overall system. 2. As left 3. As left.

Example 6.9 Aircrew Performance Requirements When a replacement aircraft was ordered, the aircraft performance was specified, but inadequate attention was given to the performance of the crew. The aircraft was a derivative of a successful in-service product, but the operational tasks and the manning of the in-service item differed significantly from that intended for the new version. It rapidly became apparent to the HSI team that there would be major performance limitations in some operational conditions, but with contracts already let,

firm evidence would be needed to make any changes. That evidence could only be gained from flight trials. The contracted requirements for flight trials were based on demonstrating acceptable performance of the slightly varied aircraft, with no allowance for evaluating crew performance in the new role. Trials were on a tight schedule that could not be changed. As a result, the project continued heading toward expensive problems that no one could prevent, because requirements had not captured the human implications of operating the aircraft in a changed context of use, and there were no contractual requirements for trials to demonstrate crew performance as part of the total system.

6.4 UNITED KINGDOM HFI PROCESS

After running a UK version of manpower and personnel integration (MANPRINT) for land systems in 1990 and then a slightly modified HFI program for sea systems from 1991, the UK MoD adopted a triservice HFI policy that eventually became mandatory for all acquisition projects (UK MoD, 1998). Human factors integration inherited the six MANPRINT domains: manpower, personnel, training, human factors engineering, system safety, and health hazards.

6.4.1 HFI within Smart Procurement

Following the strategic defence review (SDR) in the late 1990s, the UK adopted an approach to capability acquisition commonly known as smart procurement (UK MoD, 2000). Smart procurement was motivated by far wider issues than HFI, but it is notable that many of the principles it embodies accord well with the changes that the HFI initiative seeks to achieve. Table 6.8 summarizes the key features of the Acquisition Management System (AMS) that implements smart procurement, and their relevance to HFI.

Focusing on capability directs attention toward effectiveness in use (output) rather than equipment performance (input). This provides a more secure basis for reasoning about the human contribution as a part of the solution, rather than something to be added separately when the equipment is in service. The option for a *nonequipment* solution also recognizes the potential to increase effectiveness by upgrading the human component (procedures, organization, training, etc.) in a more positive way than the *do-nothing* option under which such action would previously have been assessed.

Smart procurement picks up some of the HFI changes that were already occurring. For example, the role of HFI focus had already been mandated (UK MoD, 1998) but the greater autonomy of the integrated project team (IPT) and the more formalized inclusion of a wider range of stakeholders in the process should make it a more effective role. Perhaps the greatest challenge to HFI in smart procurement, as under any regime, is the demand it creates for broad-based, talented personnel to manage HFI effectively. The MoD has put in place guidance aimed at nonspecialists responsible for managing HFI (Defence Evaluation and Research Agency, 2001).

The manner in which HFI management should work within a smart procurement project is illustrated in Figure 6.4. The figure shows a high-level view of the HFI process during early development up to main-gate approval. The left-hand side of the diagram shows the HFI management roles of identifying and understanding the human-related issues, supported by analyses of various kinds, and the right-hand side shows how HFI information is used to enrich the key project outputs: requirements, plans, and solutions.

TABLE 6.8 Smart Procurement Features and HFI

Feature	Comment	HFI relevance
Explicit focus on acquiring capability	MoD has always planned for capability, but previous equipment procurement regimes were focused on equipment rather earlier.	Capability delivered by a combination of people and equipment is the underpinning rationale for HFI.
Standing body within MoD is responsible for capability management	Capability working groups (CWGs) spawn new projects and act as the initial central customer.	The broader perspective should enable a better view of cross-project HFI issues.
Integrated project team (IPT) manages a project	Its members (core and associate) span a wide range of specialities.	The IPT manages requirements, ILS, (Integrated Logistic Support) and HFI. One of its members assumes the role of the HFI focus.
CWG works ahead of and then alongside new IPTs to create user requirement document (URD)	URD is the first formal statement of required capability.	The CWG should raise initial human-related issues. URD should include key human-related requirements (see Section 6.4.3).
IPT supported by CWG explores options for providing capability	Options lead to system requirements document (SRD), a formal requirement sent to industry to offer solutions.	SRD defines boundaries between human and equipment components with performance specified at the boundaries as well as for the overall system.
Streamlined acquisition life cycle with approvals at initial gate and main gate	Acceptable business case needed to pass gates. Otherwise IPT leader is free to act within agreed-upon limits of performance, cost, and time.	Opportunity for well-managed cost-effective HFI that can demonstrate added value.
IPT manages project through its whole life cycle	Concept, assessment, demonstration, manufacture, in-service (including incremental capability upgrades), and disposal.	IPT is responsible for development costs (which fund much HFI work) and downstream costs (where HFI can save cost of training, support, etc.).
Industrial collaboration encouraged from the start	Normally an initial period when contractors must collaborate with MoD while competing with each other.	Collaboration should ease HFI management, but the period of partial collaboration and partial competition represents a challenge.

TABLE 6.8 ***Continued***

Feature	Comment	HFI relevance
After down selection chosen contractor becomes full member of IPT		Coordination of HFI with industry should be easier, with better management of trade-off and less duplication, e.g., evaluations leading to acceptance.
Government-funded development not assumed	Off-the-shelf procurement, public–private partnerships, etc., should be considered .	The full implications of this shift have yet to be worked out but promise to take HFI into new areas.

The whole HFI process depends on effective integration with other stakeholders, shown at the top of the diagram, while the bottom of the diagram shows explicit links to requirements and risk management.

Following main gate approval, the focus shifts more to implementation and evaluation, but the requirements process is revisited whenever there are changes, especially when upgrades are initiated.

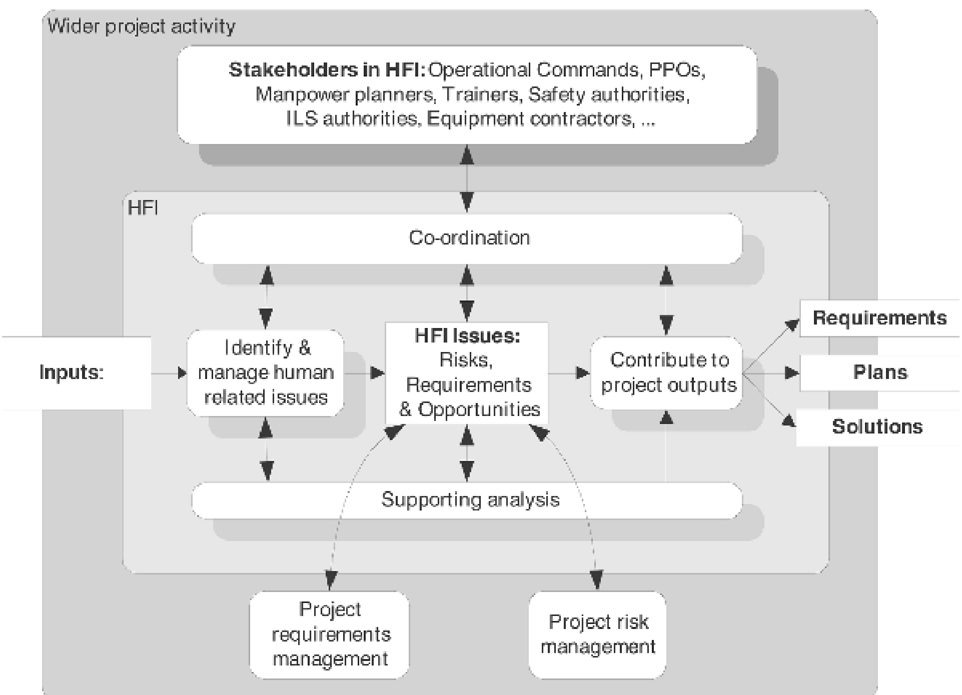


Figure 6.4 Overview of the HFI management process.

6.4.2 Early Human Factors Analysis

Acquisition projects conduct an EHFA as soon as possible in the concept phase, with review at the start of subsequent phases and when initiating major capability upgrades during the in-service phase. A simple, intuitive process that need not require extensive resources, depending on the project scale, EHFA helps project managers to identify and assess human-related risks, for example: capability failure due to human performance limitations, difficulty using or maintaining equipment, the number and type of people required, health and safety problems, or training and maintenance costs. The outputs of EHFA can feed directly into project risk management, requirements engineering, and project planning.

Initially, EHFA was developed to "kick start" the process of HFI early in a project (Defence Evaluation and Research Agency, 1996). Being simple makes it easier to mandate, and by helping to focus on where most value can be added, it appeals to project managers. The need for EHFA grew out of the desire to help identify the key human-related issues early enough for them to be addressed effectively and to feed forward lessons learned from in-service equipment.

Early human factors analysis comprises seven steps:

1. *Document the project baseline* for the analysis (documents, concept options, requirements, constraints, etc).
2. *Document assumptions*, including those arising from baseline material as well as others that become apparent during the analysis.
3. *Identify concerns* that might represent risks to the project. Encourage stakeholders to make concerns explicit rather than taking them for granted or assuming they are not important.
4. *Review the concerns* that need further analysis and treat them as key issues or requirements.
5. *Analyze the key issues* to ensure that they are expressed unambiguously and are properly understood and that associated assumptions have been identified and checked.
6. *Estimate risks* associated with each key issue in terms of the likelihood and dimensions of impact. The result will feed into the project risk register.
7. *Identify strategies to reduce serious risks* in order to provide the basis for planning a work program to reduce human-related risks.

As shown in Figure 6.5 the underlying information model for EHFA is simple; EHFA groups substantive concerns into four general types, broadly reflecting the different motives of stakeholders who contribute them. The terminology reflects the terms in which stakeholder worry statements are often expressed. These are:

It Must... What the system must do is a natural way for stakeholders to express concerns, to retain good features of the predecessor they think might get lost, correct shortcomings in the predecessor they think might get overlooked, or meet more demanding operational needs. These may or may not be formally articulated in the requirements. When focusing on human issues, these statements are likely to be about things that look small overall but have a big impact on operability. Some of these might

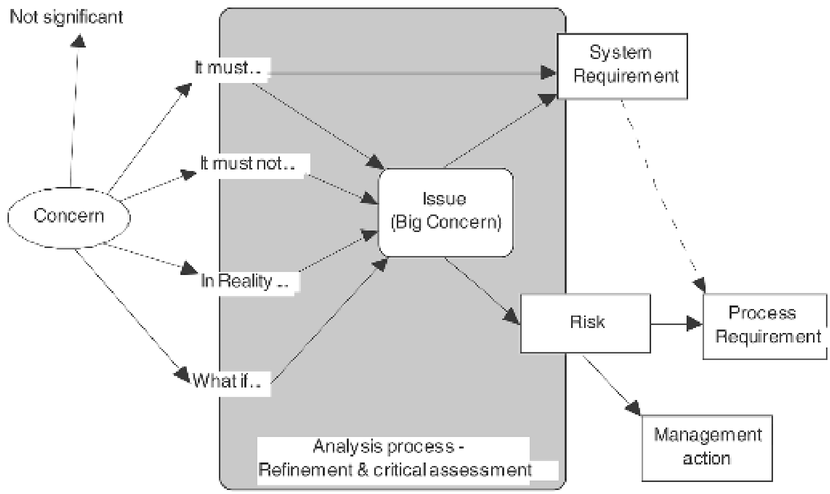


Figure 6.5 EHFA underlying information model.

feed straight into requirements, but others will not, since the concern is not in the articulation of the need but reflects a belief that it might be subverted by other factors.

It Must Not... These statements are likely to relate to bitter experience of what has gone wrong in the past. They will not normally find their way into requirements (but they might subsequently with inverted wording, e.g., "the power shall be at least *x*" for "it must not be underpowered"). As such things have happened in the past, there is a natural concern that they will do so again.

In Reality... This covers a multitude of insights and information about the real-world context in which the system will be used. It is mainly motivated by a concern that the procurers and developers do not adequately understand operational realities. The insight could relate to the environment, the way things are used, the difficulty people have doing things, or the user's experience with the predecessor. These statements are likely to require more interpretation to generate either requirements or risk statements. Some might be better used to inform the use study, task analysis, or target audience description.

What If... This reflects the creative attempts of stakeholders to look beyond what they currently have and visualize future possibilities of equipment, scenarios, or situations, including emergencies and extreme conditions, or equipment being used in ways for which it is not designed.

Figure 6.5 shows two outputs from the central issues box. Except for the dotted line between system requirements and process requirements, there would be a clean divide between system requirements on the one hand and risks plus the processes and actions to manage them on the other. (The dotted line is included because requirements such as operability are often more effectively expressed, at least partly, in process terms; see Section 6.2.2.)

6.4.3 HFI in the URD

The user requirement document (URD) describes the capability needed. It is a relatively *high-level* document (typically several dozen pages) central to the business case for proceeding with the project. Subsequent system requirements will trace back to it, so it must include HFI "hooks" in appropriate places. HFI must inform requirements where people either are or might be involved, even if the human contribution to the capability itself is subsumed within more general statements. This will help avoid later difficulties when deriving the more specific SRD from the URD. The HFI content will depend on the human dimension of the capability requirement. One of the following will apply:

1. A human-free solution is not acceptable for some reason (ethical, moral, or legal).
2. Support to humans is the objective (transporting, housing, and providing them with information, etc.).
3. The most cost-effective (or only technically feasible) solution involves humans.
4. Constraints apply to humans used in the solution.

In cases 1 and 2, humans are inherent to the requirement and must be fully covered by requirements within the URD.

In case 3, human inclusion is a matter for the solution domain (i.e., the SRD). Therefore, the URD should not specify humans in the solution. It might however be sensible to word requirements in the URD in such a way that they can be readily interpreted in terms of human components if this is likely, in order to simplify later trace from SRD to URD.

In case 4, the human aspects are constraints on the solution, rather than requirements for what it must be able to do. These constraints (at a suitable level) must be covered by the URD unless (anticipating the SRD) humans can be categorically ruled out of the solution.

General Description (Part 1) Table 6.9 suggests the HFI contribution, assuming a typical URD structure (UK MoD, 1999).

Key User Requirements (KURs) (Part 2) The KURs form a small, high-level subset of requirements that epitomize the whole need. If they fall short, then the whole capability is undermined. Most military capabilities are critically dependent on human-related requirements. Whether they appear here as separate top-level items or are aggregated with other concerns will depend on the specific situation.

User Requirements and Constraints (Part 3) Most HFI input will appear in the full set of atomized requirements and constraints. The structure will vary with the capability. The HFI contributions might include

- human functions—inherent human tasks that must form part of the capability;
- human support functions—specific equipment capabilities needed to enable effective performance and safety of the human component;
- user and organizational constraints, e.g., the expected availability, characteristics, and performance of the human component; and

- measures of effectiveness (MOEs)—ensure that the MOEs cover all the capabilities of the required system where capability is quantified, in particular those that depend on the performance of the human component.

Context Documents (Part 4) These supplement and provide extra depth to help understand the user need, particularly for those less familiar with the background to the requirement (e.g., industry). They are vital for formulating validation and acceptance tests and trials. Context documents express the conditions under which effectiveness must be achieved. Key reports of HFI studies, particularly EHFA, should feature among the context documents. In some cases, there should be HFI contributions to other context documents, where the people issues feature strongly.

Priorities The HFI requirements must fit within the overall priority structure, as shown in Table 6.10.

Performance requirements may be specified at different priority levels, e.g., maximum number of actions to perform a critical function might be (KUR) 4, (E) 3, (H) 2, and (D) 1.

6.4.4 HFI in the SRD

The SRD specifies a solution to the requirement in terms of what it will do. In most cases, the SRD also makes some high-level decisions about which components (equipment or human) will provide different functions. The boundary around those functions allotted to equipment will represent the contractual boundary for its procurement. The SRD must therefore be explicit about the interfaces between functions and the performance requirements (of human and equipment) at the interfaces.

TABLE 6.9 Suggested HSI Content for Part 1 of Typical URD

Section	Suggested HFI Contribution
Background	State inherent human-related need (case 1 or 2)
Single statement of need	Human issues probably not explicit unless: • Human performance a key driver (e.g., needs enhancing from what could be achieved with current equipment in future scenarios) • Manpower cost a key driver (e.g., must be reduced while maintaining operational effectiveness)
Assumptions	Future manning, personnel, and training, projects that could share resolution of human-related issues, equipment with which human component must interoperate
Dependencies	Human component in related capabilities, outcome of trials
General constraints	Limits on manning, personnel deployment, and factors needed to avoid degrading performance and sustainability of human component
Users (of the capability)	Where capability users will interact with it directly, e.g., hands on or receiving information from it as part of their operational tasks, describe key characteristics (enough to help focus on concepts and options that match intended users)

TABLE 6.10 Requirement Priorities

Priority	Code	Definition	Example HFI Requirements
Mandatory	M	Must be met; requirements and constraints represent legal obligations	Health and safety at work, conditions of employment
Key user requirement	KUR	Mission critical to users of capability; functions not tradable; performance trade-off below a given level might require reendorsement	Factors affecting human performance of critical functions, factors affecting ability to man the solution
Essential	E	Subject to affordable technical capability; functions not traded without reference to user	Factors affecting manpower costs
Highly desirable	H	Tradable, but more important than desirable	Factors affecting working efficiency and noncritical error rates
Desirable	D		Other human-related enhancements

The SRD forms a key part of the business case for proceeding past main gate. Industry's response, and the ensuing contracts, will be traced back to the SRD, so it is essential to ensure that HFI requirements are included in all appropriate places. The SRD is more detailed and therefore larger than the URD but mirrors its structure, with the detailed internal structure depending on the nature of the system being specified. Tables 6.11 and 6.12 indicate the typical HFI content of an SRD.

Note that although a separate section on performance is usual, there is a case for including some performance requirements in the main functional sections, alongside the functions to which they relate. The contributions shown under human performance are in this category.

Operability is listed as another nonfunctional requirement in the SRD template, but it is fundamental to the effectiveness of systems involving people. Operability is about the equipment's effect on human performance. Human performance requirements predominate and should be testable by operator performance trials supplemented where appropriate by task walk-throughs. In areas where there are well-proven design rules to enhance operability, these should be specified and will generally be tested by inspection or demonstration of the corresponding equipment function.

All requirements should be accompanied by agreed-upon acceptance criteria. These might not be fully defined at initial issue but should be completed before main gate. Pass thresholds (values of criteria to be exceeded) should be agreed-upon before contract. See Section 6.2.4 on HFI in acceptance.

Human Components in SRD The main documents for specifying the human components are the target audience description (TAD) and a high-level task description.

TABLE 6.11 Typical HFI Content within an SRD (Equipment Component)

Equipment	Typical HFI-related content
Context	Human-related assumptions, reference to high-level task structure, reference to target audience description (TAD) (see below)
Functional	Functions needed to support human operator or maintainer, enhance or compensate for human performance limitations, and provide for human safety and well-being
Performance	Required equipment responsiveness to human users
Nonfunctional	
Reliability	Requirements to minimize risk and impact of human errors that could cause failure, e.g., inadvertent operational error (violation of safety rules, loss of information, etc.) or maintenance error (incorrect settings, things fitted wrongly, etc.)
Maintainability	Requirements to reduce demands on time and/or skill of maintainers (e.g., to reduce manpower or training costs) and reduce stress and/or hazard to maintainer (e.g., ease of access, visibility, ease of fitting)
Operability	Required human performance using equipment (error, time, accuracy); human interaction requirements (legibility, comprehensibility, ability to manipulate controls, performance over extended periods, etc.)
Safety	Requirements to mitigate adverse effects of system on people who come into contact with it (e.g., "standards", legislation, duty of care); requirements to avoid hazards caused by human action (e.g., erroneous use of confusing controls); requirements relating to operator safety, stress, fatigue, and boredom (might change dramatically with changed technology)
Security	Requirements to make human aspects of security effective (e.g. memorable passwords), requirements for support to human security enforcement (e.g., usable security audit tools), any emergency overrides and safeguards (if appropriate)
Engineering standards	Requirements to accommodate human size, strength, etc. (including future populations); requirements for consistency of use with other systems (e.g., style guides, conventions)
Environmental	Aspects that would affect performance or well-being of human component (e.g., vibration, air quality, heat efflux)
Support	Key human aspects of support requirements; constraints on size, weight, portability, etc.; requirements to simplify loading, assembly, setup, etc.
External interface	Interfaces to operators, maintainers, support personnel, or other people (detail will vary with the type of system)

6.4.5 HFI Content of Requests for Industry Participation

The MoD will invite industrial participation in projects at different phases and in different ways, depending on the nature of the project. Such invitations specify the scope of what the contractor(s) will be required to do as well as system requirements for any equipment to be delivered as a result of the ensuing contract. This should include appropriate HFI requirements. The main types of invitation are as follows:

- *Expression of Interest* A preliminary invitation, published in the *MoD Contracts Bulletin* and the *Official Journal of the European Communities*, this provides a brief description of the project need.
- *Prequalification Questionnaire (PQQ)* This is issued to obtain evidence of contractor capability in order to select a short list. Where management of human-related issues and requirements will be needed, the PQQ should include questions covering relevant experience, resources, etc.
- *Invitation to Tender (ITT)* This formal statement of requirements prior to contract is normally supported by at least a (draft) SRD (or URD for a concept phase study) and a statement of work (SOW). The SOW should include requirements to provide HFI evidence in support of study results, designs, etc., and specify what HFI contribution will be available from the MoD and how the contractor is expected to collaborate with MoD HFI activity (joint working groups, demonstrations, provision of prototypes, etc.).
- *Invitation to Submit Outline Proposal (ISOP)* This is a formal statement of requirement whereby the MoD anticipates contractors will (partly) align commercial development work with an emerging MoD requirement. The HFI requirements are similar to above, but probably with less formal interaction.
- *Invitation to Negotiate (ITN)* Following from above, this occurs when the intention is to adopt a solution heavily based on a commercial development. The HFI requirements will focus mainly on providing evidence of operability, maintainability, safety, etc., to enable coordination with the MoD program.

TABLE 6.12 Typical HFI Content within SRD (Human Component)

Human	Typical Content
Context	Human related assumptions, Task & role context
Human tasks	Tasks to be performed: inherent human functions, human functions that must be supported, human functions to support equipment, human tasks (outside system) that form part of role holder's job
Human performance	Required performance of key tasks
Target audience description (TAD)	Physical, sensory, and psychological, social, and cultural characteristics; organization, training, and career structure
Manning	Availability
Constraints	Policy, legal, and other constraints covering health, safety, well-being, etc.

6.5 SUMMARY AND CONCLUSIONS

The increasing dependence of the armed forces on technology means that military capability must be delivered by a carefully integrated combination of people and equipment. The extreme demands often placed on both can undermine that integration unless specific measures are taken to ensure it is explicitly managed. Procurement based on equipment requirements alone cannot guarantee delivery of intended capability.

Requirements for equipment must therefore be seen as part of the requirement for a wider system, including the people, and this means that equipment requirements must be strongly influenced by human-related requirements. During the last decade, the knowledge needed to ensure effective integration of people and equipment has been institutionalized into the processes of acquisition and procurement, initially in the United States followed rapidly by the United Kingdom and others.

Different initiatives have emphasized different aspects of HSI. The initial approach of mandating HSI processes, with many formal HSI deliverables, achieved some notable successes by avoiding major project costs, but in more routine projects it often proved costly for the benefit gained or else the cost deterred its effective application on the ground. The UK introduced EHFA as an explicitly risk based process to address the cost-effectiveness issue, but cost-effective follow-through still relies on the skills and influence of individuals involved.

Recent thinking has recognized that system requirements are a powerful means to influence the eventual system through the mainstream system engineering activity. Injecting well-supported, human-related information into system requirements provides high leverage. In particular, making human performance requirements explicit provides a firm basis for later acceptance of operability and overall system effectiveness.

Contributing material into system requirements and integration with system engineering are not substitutes for the important analysis and trade-off in manpower, training, task analysis, etc. These need to be done, and using their output to help shape the system requirements directly can be a more effective means of system intervention than merely delivering HSI reports and hoping that someone else will take appropriate actions.

Human systems integration is a relatively young discipline, as is requirements engineering. Both are still evolving and there are many issues to work through. The HSI practitioners need to become more comfortable with system engineering methods and the routine use of system engineering tools, especially requirements engineering tools. One worthwhile goal will be to achieve integrated specifications of the equipment and people (task) aspects of a system in a single tool support environment, without making the result too complex for user stakeholders to understand.

The practice of HSI has been pushed forward on some types of systems more than on others. It is unreasonable to expect the HSI contribution to the requirements for all sorts of systems to look alike, and the HSI approach must adapt to suit different types of system requirements.

The risk-based approach to HSI in general and HSI requirements in particular is appealing to project managers but can appear to HF professionals as an excuse for cutting corners. The approach needs to mature before its full impact can be assessed.

One of the biggest challenges to HSI is the increasing pressure to base systems on COTS, with the dominant component often being predeveloped for a different context of use. In such cases, the role of HSI must engage early and influence the high-level choices of option rather than focusing on the development phase (which will not exist for the COTS components themselves). Equally, where political, economic, or other pressures force a compromise with human-related penalties, considerable creativity will be needed by HSI professionals to manipulate the few remaining variables to achieve a working system—before the “get well program.”

Traditionally HSI requirements have been either too vague to be enforced or at too low a level of detail. Often what was easy to specify or measure took precedence over what really mattered to ensure that people could perform effectively and hence to achieving the desired overall capability. A proactive approach to the early identification of human-related risks and the systematic inclusion of human-inspired detail within the whole fabric of engineering requirements can help overcome these problems. On that foundation can be built systems of equipment that integrates properly with the human component to deliver the sought-for military capability.

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