CHAPTER 7

Human Systems Integration and Acquisition: Contractor's Perspective

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7.1 INTRODUCTION

Most of the information useful to the human systems integration (HSI) practitioner on the acquisition process has been developed by government organizations from the point of view of government activities and tasks. This chapter provides a different focus—that from the contractor's point of view. Because the contractor is constrained by the contractual language of specifications and standards, much of the emphasis will be on the contractual process that goes on between the buyer and seller. For example, typical HSI tasks required throughout a typical contract are identified not only generally but more specifically in terms of their relationship to contract milestones and required products.

The federal government acquisition process defines, requests, funds, and provides authority for effective (HSI) during product development. This process has changed considerably over the past 20 years in regard to the visibility and effectiveness of human factors in the design process. The change has generally progressed from a few domains of HSI being considered as something to be added to the basic design program to a completely integrated set of HSI domains being considered an inherent part of systems engineering and management throughout the acquisition process.

Several factors have contributed to this change. First, government buyers of systems began to realize that human capabilities were limiting the performance and effectiveness of major high-technology systems. Second, the personnel costs of maintaining and supporting military and space program systems were found to be prohibitive (accounting for more than 50 percent of the total life-cycle costs). Third, the complexity of new systems required multidisciplinary approaches to system design starting with the buyer's requirements process (the manner in which the buyer documents requirements and needs to its vendors), continuing through the contractor's design and development phases, and culminating in the system performance demonstrations prior to buyer acceptance. The HSI approach to

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systems integration not only provides skills and technology that provide positive effects to each of these factors but also its encouragement to focus on the human throughout the process has (for highly successful systems) become the "design driver."

The process by which products begin their life and ultimately are produced is called the system life cycle. A number of very good overviews of the current processes and phases of system life cycle have been described (Kirk, 1973; Clark et al., 1986; Blanchard and Fabrycky, 1990; Cushman and Rosenberg, 1991; and Kirwan and Ainsworth, 1992). Each overview has slightly different terminology, but their descriptions have more similarities than differences. The systems acquisition framework chosen for this chapter will closely follow the military systems life-cycle process shown in Blanchard and Fabrycky (1990) and as laid out in the military handbook *Human Engineering Program Process and Procedures* [U.S. Department of Defense (DoD) (1999)]. This is because military weapon systems procurements have driven the maturation of human factors from sideline commentator to design driver throughout the system life cycle. As more companies become certified to external, international quality assurance management system standards, such as ISO 9000, the process by which products are developed and manufactured will become more standardized such that the distinction between military and commercial processes will be reduced.

The following discussion will cover three major topics:

1. The stages of a procurement activity, from contract award through the system life cycle up to testing and certification. The critical contractor products and HSI tasks will be described for each contract major stage.
2. The principal documentation events of the contractor solicitation and selection process, which include the buyer solicitation announcement, the buyer request for proposal (RFP), the seller proposal, and the buyer source selection.
3. Guidelines for the contractor HSI practitioner attempting to plan and manage an integrated HSI program for the first time.

7.2 STAGES OF PROCUREMENT ACTIVITY

Up until October 2000, it was mandated that a new military system be acquired in four major phases, generally identified as phase I, concept exploration; phase II, program definition and risk reduction; phase III, engineering and manufacturing development; and phase IV, production and deployment. This framework is described in the DoD (1998) regulation 5000.2-R. This mandatory framework of procedures has recently been replaced by DoD Directive 5000.1, which provides guidance through a set of management policies and principles. The cancellation of the mandatory procedures does not diminish the utility of the acquisition that is still commonly used as a model for civil government, military and civilian acquisition. For example, the National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC) Program Life Cycle and the System Engineering Process (JSC 49037; NASA, 1993) is the controlling document for the life cycle of a system, either acquired or built within the agency. This document mirrors that of DoD 5000.2-R and mandates the four-phase framework for the JSC facility. In time a new framework or paradigm for acquisition may emerge, but for the moment the old procedures remain the guiding framework. (See Chapter 4 for detailed discussion of DoD Directive 5000.1).

Consequently, the systems acquisition framework most useful for our discussion in this chapter derives from the four phases laid out in DoD 5000.2-R. The purpose of the concept exploration phase is to conduct the research necessary to support the programmatic decision that the technologies involved have firm scientific basis and have demonstrated application to the system being considered. The purpose of the program definition and risk reduction phase is to transition new critical technologies from the laboratory to practical demonstration. This leads to the programmatic decision that the necessary technologies and resources are mature enough for start of system development. The purpose of an engineering and manufacturing development phase is to design and implement the system to the point where technology risks between components and subsystems that could only be evaluated as part of a completed system have been tested and the maturity of the designs demonstrated. This leads to the programmatic decision that the system can begin phase IV, the production and deployment of a mature, tested system having the necessary characteristics as originally envisioned in phase I and as systematically modified in phases II and III.

Two approaches are important to helping the reader to better understand the role of HSI required throughout the system life cycle. One is to outline the differences in types of tasks and goals for each of the acquisition phases. For example, Table VI, human engineering (HE) analysis methods selection characteristics of (DoD, 1998), shows that during the concept exploration phase, HSI practitioners may be conducting mission analyses, while in the production and deployment phase, they may be conducting workload analyses. The other approach is to help the reader comprehend what it takes for successful accomplishment of the specific contract within each acquisition phase. The different HSI tasks and goals among the four phases are well addressed in the above reviews. Consequently, the emphasis in this chapter is upon the latter, stressing what is required for successful accomplishment of a contract within a system life-cycle phase.

Broadly, there are four key milestone reviews of contractor-developed products for a typical systems acquisition contract. The policies and principles presented in DoD Directive 5000.1 provide flexibility that may modify or even eliminate the framework phases, but it is anticipated that most specific contracts will have these primary milestones:

I. Program requirements review
II. Preliminary design review
III. Critical design review
IV. Testing and certification

Once a contract for work has been awarded, the contract has its own stages and milestones. Accomplishment of each of these contract milestones allows the program to proceed from its current life-cycle phase to the next life-cycle phase. These milestones tend to be constant across the broad gamut of products and possible acquisition strategies. While contracts can be modified, the basic pattern of contract stages tends to be that outlined in Figure 7.1.

The contract award starts a process in which the high-level requirements of the contract are decomposed into low-level specifics. The low-level specifics are then assigned to various disciplines and a preliminary design emerges. After approval of the integrated design, detailed production drawings are created and test articles produced. After certification and testing, production can begin.

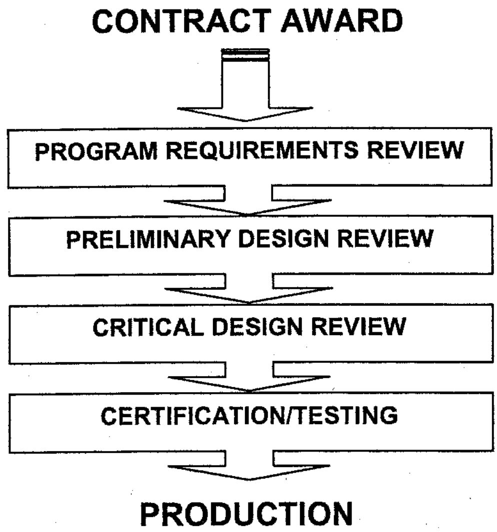

Figure 7.1 Stages in development of a product: overview.

Control of this process is maintained by a hierarchy of documents and a specification tree. The specification tree starts with a single specification that documents what the product must do and what tests must be performed. These are the "parent" requirements to which successive levels of the tree must provide derived "children." The goal is to decompose general requirements into unique, testable design tasks that stand alone. In this manner, every high-level requirement can trace to a specific design task and each low-level can trace to a high-level parent. The sibling relationships can be understood and documented as interfaces.

The HSI tasks will occur in all stages of this process. The tasks will range widely dependent upon phase and task.

The first contract stage begins with contract award and ends with the program requirements review (PRR). At this review, the contractor demonstrates how he or she, as the seller, has accounted for the requirements of a contract and how the proposed product will ultimately demonstrate compliance. Thus at the PRR the contractor demonstrates that he or she understands the requirements of the contract for a product as it is to be designed and developed.

After successfully passing the PRR, the contractor begins to put together the design that will be used to satisfy the requirements of the contract. This second contract stage ends with a preliminary design review (PDR), which links design features to contract requirements. Subsequently, the contractor begins to make detailed designs and fabrication drawings.

The third contract stage begins after PDR and ends when approximately 90 to 95 percent of the drawings are done. This is when the critical design review (CDR) is held, at which the contractor is cleared to proceed to production of equipment and prototypes. The final contract stage is that of testing and certification. In this stage, the designs are tested to demonstrate that the specifications outlined during the PRR have been met. Additionally, some components may require certification when it is not adequate to merely demonstrate the component can accomplish its intended function. For instance, a component may be a critical safety component that is to last 100 hours in use. The contractor may be required to certify that this component will perform as designed for the intended life span. The following sections expand upon these activities and identify the tasks for the HSI program as a function of the milestone reviews of the contract.

7.2.1 Contract Award to Program Requirements Review

The initial contract stage starts upon contract award and ends with the PRR (see Fig. 7.2).

After the contract award, technology research and/or applied research may be needed in order to select material, processes, techniques, and/or technologies with the appropriate characteristics for use in satisfying the goals of the development. During this stage, basic decisions are made about how to approach the design and development of the product.

Type A specification, or system/system segment specification, supplemented by other referenced specifications, as necessary, are developed to specify (1) all essential functional characteristics, (2) necessary interface characteristics, (3) specific designation of the performance characteristics of key functional elements, and (4) all of the tests required to demonstrate achievement of each specified characteristic.

Typical HSI tasks include functional allocation, determination of control/display characteristics, preliminary human interface selection, establishment of personnel limitations, initial task and workload studies, development of target populations, lessons learned, and initial manpower estimates.

A PRR is conducted after functional analyses and preliminary requirements allocation studies are completed. These studies determine the initial direction and progress of the contractor's system engineering management effort for convergence upon an optimum and complete configuration (DoD, 1976). The total system engineering management activity

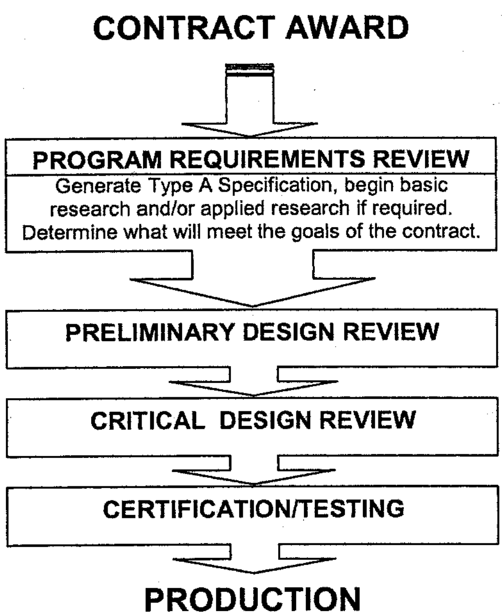

Figure 7.2 Stages in development of a product: program requirements review.

TABLE 7.1 Items for Review in a Program Requirements Review

Analyses • Mission and requirements analysis • Functional flow analysis • System/cost effectiveness analysis • Logistics support analysis • Program risk analysis • Human factors analysis • Life-cycle cost analysis • Manpower requirements/ personnel analysis	Plans • Integrated test planning • Data management plans • Productibility analysis plans • Preliminary manufacturing plans • Configuration management plans • Milestone schedules
	Specifications • Preliminary requirements allocation • Generation of specifications
Studies • Trade studies • Specialty discipline studies • System interface studies • Value engineering studies	Miscellaneous • Technical performance measurement • Engineering integration • System safety

and its output are reviewed for responsiveness to the statement of work (SOW) and system requirements. The products to be reviewed may include any of the items in Table 7.1. Depending upon the major acquisition phase, the contract SOW (and deliverable items list) will require some subset of these products and describe the overall scope of the effort.

Type A Specification The most significant product emerging from the initial-stage contract activities is the type A (or system/system segment) specification. The type A specification (DoD, 1995, p. 6) will

- state the technical and mission requirements for a system/segment as an entity,
- allocate requirements to functional areas,
- document design constraints, and
- define the interfaces between or among the functional areas.

When the requirements review is over, the system/system segment specification will outline the design to be produced, the interfaces, requirements, and test conditions. This document should both support the need for HSI and allow HSI requirements to apply to subsystems for implementation. If the type A specification does not recognize HSI requirements and does not require implementation in its subsystems, implementation of an HSI program will be difficult. Human systems integration must get its requirements integrated into the type A specification or face having its requirements viewed as optional.

HSI Tasks for First Contract Stage There are three major HSI tasks in the initial contract stage. The first major task is compiling and classifying the HSI domain inputs to the system specifications. It is critical that HSI requirements be reflected in the type A specifications. If the requirements are in this document, the program is obligated to pass these requirements to the various subsystems, track that the requirement is implemented, and test for compliance. Chapanis (1996, p. 71) identifies seven classes of HSI input to the systems specification in the requirements stage (see Table 7.2).

The second major HSI task in the initial contract stage is to understand how to make the greatest HSI impact. Chapanis suggests this depends greatly upon recognizing the differences in two kinds of specifications known as "design to" and "build to." The design-to specification focuses on functional requirements whereas a build-to specification attempts to prescribe a proposed solution. Chapanis (1996, p. 71) states that the "distinction between the two kinds of specifications is important for the human-factors professional because the amount of human-factors detail to be supplied depends on the kind of specification for which that information is supplied." For example, a design-to specification might specify a 10-button keyboard be included for operator use while a build-to specification might specify the exact size, shape, and layout of keys on the board. The type A specification should be a design-to specification. The HSI practitioner preparing for a PRR should describe what is functionally required rather than a proposed solution.

The third major HSI task in the initial contract stage is to carefully read the contract and do the following:

1. Find every paragraph in the SOW that has HSI implications or explicit requirements and make a copy of them.
2. Find every deliverable item that HSI is either directly responsible for or provides inputs to and the dates the items are due.
3. Determine the HSI budget for accomplishing both of the above.

There is a significant amount of work for HSI during the period of time between contract award and PRR. To the degree both the buyer and seller have provided quality HSI inputs, it is in this stage that the greatest impact for the lowest cost can be made by HSI by virtue of early involvement. The buyer should identify specific HSI tasks in the SOW and deliverable items list. The seller should recognize an appropriate degree of HSI "front-loaded" activity and estimate man-hours, materials, and budgets accordingly.

Example of HSI/System Activity for PRR At a PRR of a major U.S. Army helicopter program, a full day was devoted to demonstrating that the contractors under-

TABLE 7.2 Suggested Human Factors Inputs to System Specification

Human-performance requirements • Staffing, operating, maintaining, and support requirements • Human–machine interfaces requirements • Identification of areas in which human errors would be particularly serious	Dimensional and volume requirements • Crew spaces • Operator station layouts • Ingresses • Egresses • Accesses for maintenance
Methods of operating the system	Maintainability requirements
Personnel requirements Health and safety requirements	Training requirements

stood how their proposed system was integrated into typical operations of the U.S. Army. The contractors started with a demonstration of how planning for the use of the system within a mission would be conducted and then walked the reviewers through the various operational activities, including

- mission planning,
- support processes to ensure aircraft and support material would be available,
- individual planning,
- mission conduct,
- after-mission briefing,
- aircraft maintenance, and
- the point where another mission cycle could begin.

This activity highlighted the effects of HSI, showing, for example, how crews would be able to meet timelines and performance criteria within the stated manpower goals and the likely available personnel skill capabilities.

7.2.2 Program Requirements Review to Preliminary Design Review

The next major milestone after the PRR is the PDR (see Fig. 7.3).

In the early stages of system design or development, functions are allocated to hardware, software, or people. Early decisions made with little regard to operator capabilities and limitations are likely to result in expensive training, staffing, or redesign of products.

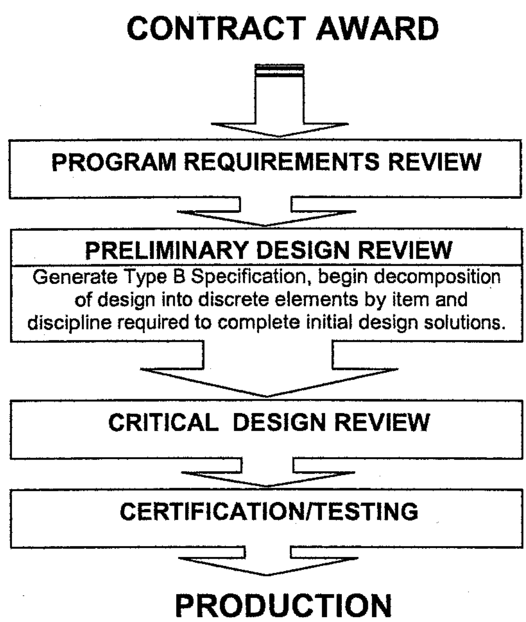

Figure 7.3 Stages in development of a product: preliminary design review.

The type B specifications, or development specifications, state the requirements for the design or engineering development of a configuration item during the development period. Since the breakdown of a system into its elements involves identification, management, and control of configuration items of various degrees of complexity, it is desirable to classify by subtypes. Generally these are prime, critical, hardware, software, interface, noncomplex.

The HSI emphasis during this stage should be upon influencing the system engineering process. Considerations are how human performance affects system performance, identification of skill levels the target population will have, training impacts, performance measurement issues, human–machine allocation, and providing a common view of the human interface across elements and components.

The PDR ends the second contract stage. Each configuration item or aggregate of configuration items will have its own PDR. There are four primary purposes of the PDR. First, the PDR evaluates the progress, technical adequacy, and risk resolution (on a technical, cost, and schedule basis) of the selected design approach. Second, the PDR determines the compatibility of the proposed design with performance and any engineering specialty requirements of the hardware configuration item (HWCI) development specification. Third, the PDR evaluates the maturity of the design definition and assesses the technical risk associated with the selected manufacturing methods and processes. Finally, the PDR establishes the existence and compatibility of the physical and functional interfaces between the configuration item and other items of equipment, facilities, computer software, and personnel. The term *configuration item* is a contracting term used to denote hardware or software products whose design is being monitored and formally controlled by the contract. For computer software configuration items (CSCIs), the PDR focuses on the evaluation of the progress, consistency, and technical adequacy of the selected top-level design and test approach; the compatibility between software requirements and preliminary design; and the preliminary version of the operation and support documents.

The PDR is a formal technical review of the basic design approach for a configuration item or a functionally related group of configuration items. It should be held after hardware specifics are completed and preliminary drafts of supporting computer documentation are available. The list in Table 7.3 is an example of typical products reviewed in a PDR.

Type B Specification The activities between the PRR and PDR mainly involve the generation of requirements documents and preliminary drawings. After the PRR and leading up to the PDR, the agreed-upon type A specifications (from the program requirements stage) are “decomposed” into lower level, more detailed specifications—the type B specifications. Type B (development) specifications state the requirements for the design or engineering development of a product during the development period. Each development specification should be in sufficient detail to describe effectively the performance characteristics that each configuration item is to achieve when an item has matured into a detail design. As shown in Table 7.4, there are five forms of type B specifications.

The systematic statement of a requirement and the generation of additional, detailed requirements necessary to implement the requirement are referred to as the *decomposition* process. Decomposition of higher, more general requirements into lower, more detailed requirements is at the heart of the specification effort. In a perfect program, each sentence of the type A specification, the high-level document, contains a single, unique, testable

TABLE 7.3 Products for Review During Preliminary Design Reviews

Design • Preliminary design synthesis of hardware development specification for item(s) being reviewed • Equipment layout drawings and preliminary drawings • Environment control and thermal design • Power distribution and grounding design aspects • Preliminary mechanical and packaging design of consoles, racks, drawers, etc. • Interface requirements • Mock ups, models, breadboards, or prototype hardware • Transportability, packaging, and handling • Standardization • Human engineering and biomedical • Safety engineering considerations • Electromagnetic compatibility survivability/vulnerability	Data • Pertinent reliability/maintainability/availability data • Preliminary weight data • Development test data • Preliminary lists of materials, parts, and processes Analyses • Trade studies and design studies • Functional flow, requirements allocation data, and schematic diagrams Software • Functional flows • Storage allocation • Control function description • Software structure Miscellaneous • Development schedules • Security • Operation and support documents

requirement for the performance of the item. Each requirement should spawn additional, more detailed requirements that transition from *what* needs to be done to *how* it is to be done. Ideally, each type A requirement has a direct trace to a type B requirement (the type B being the children of the high-level type A). Also no type B requirement should exist without a trace to a higher level parent. (A requirement without a higher level parent requirement is known as an "orphan" requirement.) Prior to the PDR, the HSI program provides requirements for the type A specification that, in the activities after the PDR and leading up to the CDR, are turned into design requirements. Thus the HSI program should be able to monitor the flow of requirements from high-level design-to specifications to the build-to requirements needed for production.

HSI Tasks for Second Contract Stage During the time between the PRR and the PDR (the second contract stage), the HSI program should be active using rapid prototyping, simulators, mockups, and other techniques to understand mission, technology, and emerging designs.

In a recent DoD helicopter program, military flight crews flew simulated missions containing critical tasks in order to evaluate the proposed technological solutions during the development of the type B specifications. Round-table forums, with representatives from all technical disciplines, were then held in which HSI-generated requirements were evaluated for technological risk, availability of alternatives, and operational benefits. The time and money spent in this activity proved cost effective because developing the simulation matured the HSI requirements; flying the simulated missions put esoteric

TABLE 7.4 Type B Specifications

Type	Title	Comments
B1	Prime item specification	Any item that is so complex that it requires (1) formal acceptance by the contracting agency, (2) provisioning action required, (3) technical manuals or other instructional material required, and (4) quality conformance inspection of each item, as opposed to sampling
B2	Critical item specification	Applicable when an item is deemed to be less complex but still has a critical nature
B3	Noncomplex item specification	Applicable when an item is of relatively simple design that can be shown suitable for its intended use by inspection or demonstration, does not require acceptance testing but can use conformance to drawings instead, and is not software
B4	Facility or ship specification	Applicable when the focus is upon a facility (building) or ship development that is an integral part of the system
B5	Software specification	Applicable when software development specifications are required; can further be subdivided between software requirements specification and interface requirements

technology into perspective for the users, and the technologists were able to identify potential risks that could be easily avoided.

The value of prototypes, simulators, and mockups cannot be overstated. It is very difficult for end users to assimilate design features on paper and apply their experience to the ultimate usability of the product. In an effort to design and build crew accommodations for the International Space Station (ISS), the typical design activities were augmented with early, full-size mockups, and crews were given the opportunity to use the mockups in a normal, earth gravity environment. The study was documented with pictures, video, and questionnaires, providing clear evidence that the basic requirements were incorrect and would require additional systems engineering analysis. As a result, it became clear that the contract was flawed. What was required would not meet the buyer's expectations. Ultimately, the contract was canceled and additional effort was made by the ISS program to define the requirements.

The outcome of such efforts is used to provide input to the type B specification development process. Shown in Table 7.5, Chapanis (1996, p. 74) provides a succinct list of the types of inputs made by HSI to type B specifications during the time between the PRR and PDR.

In summary, during the second contract stage, the HSI program should be engaged in monitoring the flow down of high-level requirements from design-to (type A) to build-to (type B) requirements; conducting simulations, evaluations, and testing to verify that allocations of function between machine, individual operators, and possible operator teams are correct and desirable; providing detailed interface definitions and requirements; providing inputs to documentation; and preparing for operational tests and validations.

TABLE 7.5 HSI inputs to Type B Specification

Detailed interface requirements

- Operating modes and functions performed at each station
- Displays and controls used at each station
- Exact formats and contents of each display, e.g., data locations, spaces, abbreviations, message lengths, special symbols
- Formats of all operator inputs
- Control and data entry devices, e.g., cranks, levers, pedals, keyboards, special function keys, cursor controls
- Status, error, and data printouts

Detailed requirements for tests and evaluations interface requirements

Verification of allocation of functions to operators to ensure that their capabilities are utilized and their limitations are not exceeded

Technical manuals and documentation coverage

7.2.3 Preliminary Design Review to Critical Design Review

The third contract stage covers the period from the PDR to the CDR. A CDR is conducted for each configuration item when detail design is essentially complete (see Fig. 7.4).

After the preliminary design is reviewed and approved, the process moves to detailed design of components and ultimately to CDR. In this phase, how tasks will be performed and what human interfaces will look like become determined.

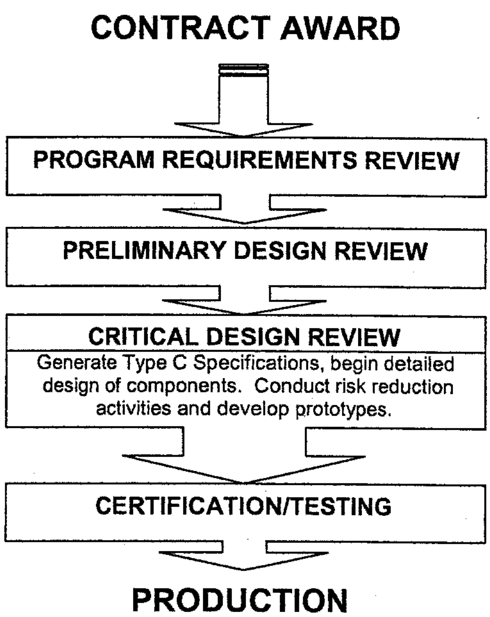

Figure 7.4 Stages in development of a product: critical design review.

Type C specifications, or product specifications, establish the performance, design, test, manufacture, and acceptance requirements for a prime item. A type C may be a function specification when the contractor does not develop the item or a fabrication specification. Fabrication specifications state detailed part specification and assemblies, performance requirements and tests, and corresponding inspections.

The HSI emphasis during this stage continues to be on the system engineering process, but significant attention must be paid to the emerging design specifics. Task inventories and workload predictions become especially important during this stage. Iteration of design and communication between disciplines are key activities.

The purposes of the CDR are to (a) determine that the detailed design of the configuration item under review satisfies the performance and engineering specialty requirements of the HWCI development specifications; (b) establish the detailed design compatibility between the configuration item and other items of equipment, facilities, computer software, and personnel; (c) assess configuration item risk areas (on a technical, cost, and schedule basis); (d) assess the results of the productibility analyses conducted on system hardware; and (e) review the preliminary hardware product specifications.

For CSCIs, the CDR will focus on the determination of the acceptability of the detailed design, performance, and test characteristics of the design solution and on the adequacy of the operation and support documents (MIL-STD-1521). The items to be reviewed during the CDR per MIL-STD-1521 (DoD, 1976, pp. 54–56) include those listed in Table 7.6.

TABLE 7.6 Items Typically Reviewed During CDR

Hardware
- Adequacy of the detail design reflected in the draft hardware product specifications (type C specifications)
- Detail engineering drawings for the hardware, including schematic diagrams
- Adequacy of the detailed design in all areas, including:
  a. Manpower
  b. Personnel
  c. Training
  d. Human factors engineering
  e. System safety
  f. Health hazards
  g. Interface control drawings
  h. Mockups, breadboards, and/or prototype hardware
  i. Design analysis and test data
  j. System allocation document for hardware

Software
- Software detailed design, database design, and interface design documents
- Documentation describing results of analyses, testing, etc., by agreement
- Manuals and operation/support documents

Support equipment
- Requirements review
- Special equipment (problems, provisioning, reliability, logistics support)
- Calibration requirements

Type C Specifications During the third contract stage, the PDR to CDR period of the contract, the emphasis is on the development of the engineering drawings and the type C production specifications. Type C production specifications are oriented toward either procurement of a product through specification of primarily functional (performance) requirements or primarily fabrication (detailed design) requirements (as per MIL-STD-490; DoD, 1995). Type C specifications take many forms due to the wide range of products or product design requirements. The variety of forms of type C specifications are shown in Table 7.7.

HSI Tasks for Third Contract Stage The HSI program will continue monitoring the decomposition of requirements as the contract prepares to go to production. During this period of activity, the difficulties in transitioning technology, packaging and interfacing, meeting weight/space/power goals, and production costs become major drivers. The need for structure, support, bend radius, bolt sizes, and other manufacturing requirements intrudes upon the clean design described in the types A and B specifications. For example, even though size is supposed to be fixed by requirement, components may just not be capable of being packaged with as little structure as desired. Therefore, the size of individual objects may grow within a packaging footprint. Trade-offs and compromises abound during this stage as engineering struggles to make everything fit within weight, space, power, cooling, and other requirements. Often performance of the item is reduced to match what is capable of being produced given cost and schedule. This type of problem exemplifies why the HSI program in the earliest stages needed to spend so much time and effort documenting requirements. When these engineering struggles begin, the HSI requirements must be clean, and crisp and have a well-documented relationship to system function and, ultimately, to usability in order to battle against pressing weight, cost, and schedule demands.

Chapanis (1996, p. 75) states, "no other new human-factors inputs should be required at this time because they should all have been made prior to this point. At this stage, changes required to make equipment meet human-factors requirements would be extremely, perhaps prohibitively, costly." Chapanis does, however, indicate that the HSI program should review the detailed designs or drawings, schematics, mockups, or actual hardware and evaluate by checklists or other formal means the adequacy of designs with regard to items listed in Table 7.8. In addition, time/cost/effectiveness considerations and forced trade-offs of HSI design features should be thoroughly reviewed.

During this stage, engineering deals with trade-offs that affect the operator functions and capabilities, and the maintainer and supporter functions begin to be defined. The HSI program must pay careful attention to the details becoming available about how to maintain and support individual components of the product in order to assemble a clear picture of the manpower, skill sets, and timelines required. This information typically becomes available just before the prototypes of products are built and, owing to the maturity of the design, is very resistant to change. The opportunity for influencing these designs is very limited and will require significant HSI manpower to effect change, depending upon the size and complexity of the product.

Early in the contract, task inventories and workload predictions were "invented." That is, the best thoughts about how the design would eventually turn out and how the product would be used were captured in task inventories and workload predictions. As the program nears CDR, this information should be revisited given the data about the design that is now known. Tasks and workload obtained with simulations and prototypes should be compared

TABLE 7.7 Type C Specifications

Type	Title	Comments
C	Product specifications	Applicable to any configuration item below the system level and may be oriented toward procurement of a product through specification of performance requirements or fabrication requirements
C1a	Prime item function	Applicable to prime items when a "form, fit, and function" description is acceptable
C1b	Prime item fabrication	Applicable to prime items when inclusion of a detailed design disclosure package is required
C2a	Critical item function	Applicable to a critical prime item when performance is of greater concern than interchangeability or control over design and a "form, fit, and function" description is adequate
C2b	Critical item fabrication	Applicable to a critical prime item when a detailed design is made available or where adequate performance can be achieved from the provided design
C3	Noncomplex item fabrication	Applicable when procuring a noncomplex item to a provided detailed design
C4	Inventory item	Applicable when procuring an item from an established inventory such as the DoD inventory
C5	Software product	Applicable to a delivered computer software configuration item and is the "as built" software specification. It consists of the following:
	Software top-level design document	Describes how the top-level components implement requirements allocated from the software requirements specification
	Software detailed design document	Describes the detailed decomposition of upper level components into lower level components
	Database design document	Describes one or more databases(s) used by the configuration item
	Interface design document	Describes the detailed design of one or more configuration item interfaces

TABLE 7.8 Review Items for CDR

Operator displays
Operator controls
Maintenance features
Anthropometry
Safety features and emergency equipment
Workspace layout
Internal environmental conditions
Training equipment
Personnel accommodations

to early predictions, and deviations from predictions should be brought to the attention of management. Although late in the design process, there is still time to make corrections for critical issues.

While conducting reviews and comparisons of obtained tasks and workload to predictions, HSI can facilitate the process of communication and iteration of design details by maintaining a "big picture" focus. Specifically, HSI should focus on overall workload and mission/task workload rather than focusing on any one or two tasks. HSI can identify the "rough seams" between configuration items by identifying the confusion, increase in workload, or errors being made by users when they switch between components or disciplines within the design. For instance, the convention for representing something as ubiquitous as ON/OFF may differ in different functional areas. In some areas, status (*on* or *off*) may be indicated and in other areas the next state (*going to on* or *going to off*) may be indicated. This switch in convention could cause errors in performance. Smoothing these rough seams between design areas will require identification of the problem and an open mind on the part of all concerned to decide how best to resolve cost, schedule, and risk.

The ability of HSI to remain focused on the big picture can also help disparate disciplines resolve trade study issues by providing insight into the relative utility of design features. For example, in a recent military helicopter development program it became clear that the sensor manufacturer, controls and displays group, and software processing group were at odds as far as what they wanted to do. A series of meetings were held with all parties attending along with customer users. At these meetings, the various groups laid out their concerns and impacts with the HSI group, putting the trade-offs into the context of procedures and workload for the customer users. A consensus was reached as to which requirements had to be retained and those that could be modified or eliminated. This sort of meeting was also widely used in the development of the Boeing 777, albeit not as focused on specific technical capabilities as overall customer usability.

7.2.4 Critical Design Review to Testing and Certification

Once the design has been reviewed and all issues resolved, the fourth contract stage is initiated and configuration items start to be built. As configuration items are built, the product begins to be assembled. Whether the product being built is an aircraft, a cellular telephone, or a toaster, at some point in the process the product is tested to make sure that it performs as required or certified as meeting its specifications. The number of evaluations, tests, or certifications required depends upon the product and the contact requirements. In aviation, the requirements call for strict testing and certification due to obvious safety requirements. A hair dryer, on the other hand, may require casual functional testing but rigorous certification testing for achieving Underwriter Laboratories certification.

Five generic types of formal reviews occur after the CDR (DoD, 1976, p. 5). They are listed, along with a brief description in Table 7.9. Typically, one or more of these reviews are used to formally present the results of individual tests called for by the SOW or conducted as part of the development and verification process.

During product certification/testing, the HSI program assumes a major role of design monitor in providing design critique of the product (see Fig. 7.5).

After the CDR determines how tasks will be performed and what the human interfaces will look like, most efforts turn to fabrication and testing. As parts are finished, they are tested or certified for use. As subsystems are assembled, they too are tested. Eventually, the system is available for testing.

The number of tests and certifications required are set by the contract and by the requirements of the type A specification. The format typically is determined by the

TABLE 7.9 Table of Post-CDR Reviews

Review Name	Description
Test readiness review (TRR)	Review conducted for each computer software configuration item to determine whether the software test procedures are complete and to assure that the contractor is prepared for formal testing; more generally, a meeting to assure that the contractor is prepared for any formal testing
Functional configuration audit (FCA)	A formal audit to validate that the development of a configuration item has been completed satisfactorily and that the configuration item has achieved the performance and functional characteristics specified in the functional or allocated configuration identification
Physical configuration audit (PCA)	A technical examination of a designated configuration item to verify that the configuration item "as built" conforms to the technical documentation that defines the configuration item
Formal qualification review (FQR)	The test, inspection, or analytical process by which a group of configuration items comprising the system is verified to have met specific contracting agency contractual performance requirements (specifications or equivalent)
Production readiness review (PRR)	Review intended to determine the status of completion of the specific actions that must be satisfactorily accomplished prior to executing a production go-ahead decision

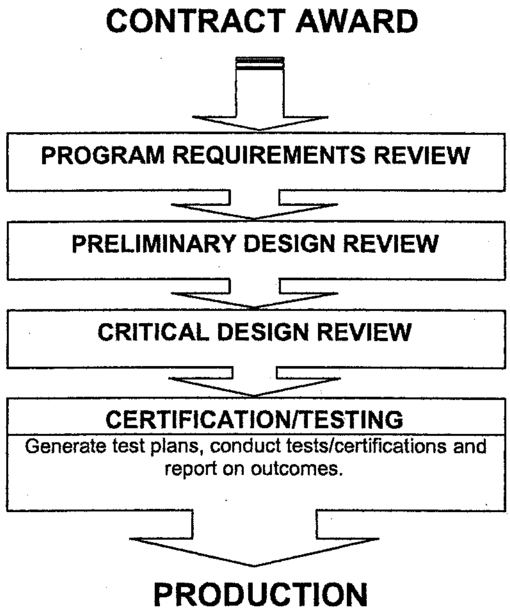

Figure 7.5 Stages in development of a product: certification/testing.

contractor. A verification matrix is used to track specific points for testing and assign testing to disciplines and specific tests. Test plans and test reports are generally created and signed by the contractor and the monitoring technical community of the contract agency.

The HSI emphasis during this stage is to bring closure to the previously identified issues, prepare to test performance requirements compliance, and verify that the design meets identified criteria and standards. This is done through design analysis, generation of test plans, and participation in the certification planning process.

If an HSI program, as espoused in this chapter, has been followed, the HSI program should be using the results of its studies and analyses to aid in speeding product certification and testing rather than trying to force changes into the design. The workload, performance, form/fit/function studies conducted should now all support and verify previous studies, thus indicating that the design is suitable and ready for production.

By virtue of its continuing product studies during development, the HSI community is in a position to significantly enhance the certification and testing procedures. Final certification and testing will naturally focus on the product user. The HSI community can bring its knowledge and experience to the test communities envisioned scenarios along with predicted workload and timelines. This information can shortcut both the planning and execution time required for certification and testing. The HSI community's knowledge of predecessor systems and the target population can help focus testing on critical usability issues and provide a confident benchmark for performance with the new product. The HSI community can assist in generating training materials, user procedures, and lists of general design advantages. The HSI's database, gained over the course of the product development and focused on critical issues, can significantly help reduce the costs and timelines of testing.

The certification and testing of a design for the Warning, Caution, and Advisory System in a new military helicopter program provides a good illustration of the differences between the old ways of testing for system and component compliance versus the HSI method. Past aircraft would typically have simple sensors with dedicated lines to illuminate dedicated alert lamps in the cockpit for warnings, cautions, and advisory signs. For example, a magnetic oil drain plug sensor would have a dedicated line to a warning lamp on engine oil in the cockpit. The certification test was simply: "Use a screwdriver to mimic accumulation of metal shavings on the magnetic plug to see if the light would illuminate and therefore demonstrate the system is working." In the new aircraft, computers that processed sensor information data and controlled the display of information to the crew were dependent upon the content of all the sensors and their status. Everything in the new system (the computers, sensors, displays, and processing algorithms) had to be demonstrated as failure proof. Additionally, the specific sensor and crew display were also evaluated. Ultimately, the certification was awarded based in large part upon prior HSI studies of the Warning, Caution and Advisory System conducted in a full mission simulator as part of the developmental testing. The human factors certification became the validation method, showing that the flight software operated in a manner consistent with the simulator operations.

Installation of a computerized sensor and the Warning, Caution and Advisory System saved the aircraft considerable weight as well as reducing the maintenance burden that would have been imposed had a dedicated alert panel and individual wires been required. Transition to the new technology was feasible because early HSI studies and design involved the crew and the various technologists of the subsystems. High-fidelity simulations verified early testing and workload predictions. The simulations were used to focus certification efforts on the critical elements of the design and establish baselines to which certification testing could be compared. Without HSI, a technologically sound and obvious approach might not have been adopted due to concerns over verification. It is clear that the HSI approach to testing and evaluation helped the design team avoid a requirement for a heavier, redundant system that was conventional in all previous operational "glass" cockpits.[1]

7.3 PRINCIPAL DOCUMENTATION EVENTS OF ACQUISITION

The preceding section followed the execution of a generic contract from contract award through completion of the contract. The tasks of the HSI program were identified and placed within the various stages of the contract. The following section outlines the HSI program and associated documentation that should be developed and implemented in the acquisition process.

7.3.1 Definitions

Acquisition means the acquiring by contract with appropriated funds of supplies or services (including construction) by and for the use of the federal government, or comparable business entity, through purchase or lease, whether the supplies or services are already in existence or must be created, developed, demonstrated, and evaluated. Acquisition begins at the point when agency needs are established and includes the description of requirements to satisfy agency needs, solicitation and selection of sources, award of contracts, contract financing, contract performance, contract administration, and those technical and management functions directly related to the process of fulfilling agency needs by contract.

Contract means a mutually binding legal relationship obligating the seller to furnish the supplies or services (including construction) and the buyer to pay for them. These definitions are uniformly accepted and used by businesses worldwide [Federal Acquisition Regulation (FAR), 1997a].

7.3.2 Solicitation Process Summary

The first step in acquisition is to establish the "needs" of the buyer and solicit sources to fulfill the need; these are the sellers (contractors or vendors). Regardless of the life-cycle phase, the acquisition process of most buyers, including the government, follows a fairly common and consistent process for solicitation and award of contracts. The procedures, in short, are to announce that that the buyer is considering buying a product or services and publish a draft of the specifics of what is needed (work that is being requested and/or the performance requirements of items). This often starts in the form of a request for information (RFI), although the method could be a presentation at business conferences, public hearings, or presolicitation conferences. An RFI is used when there is no immediate intent to award a contract but there is a desire to obtain price, delivery, other market information, or capabilities for planning purposes.

After reviewing seller responses to the RFI, the buyer may make modifications to its requirements and release a RFP. This document communicates requirements and solicits formal proposals or offers to sell. Prospective sellers document how they intend to fulfill the conditions of the RFP, their design, and its features and submit this information, along with cost information, as their proposal. The buyer's technical staff conducts a formal technical evaluation of the competing proposals. As part of the evaluation, face-to-face negotiations may be held about the seller's intent and details of their design. After submission of revisions and/or cost updates, the buyer formally considers each of the proposals received, selects acceptable sources (contactors) and awards the contract.

7.3.3 Request for Proposal

The RFP is used to communicate requirements to prospective sellers and to solicit proposals. For competitive acquisitions, RFPs typically describe the requirements and anticipated terms and conditions that will apply, information required in the seller's proposal and factors, and significant subfactors that will be used to evaluate the proposal and their relative importance. The RFP is, in fact, where the HSI program formally begins for the both the seller and buyer HSI teams.[2] The buyer's HSI staff should be involved in the generation of the RFP. The buyer's HSI staff should be providing program and design requirements to shape the nature and extent of the HSI program that is believed necessary for a successful system development. Proper preparation of the RFP is by far the most significant single factor in ensuring that an adequate HSI program will be applied. When preparing the RFP, inputs must be clear, accurate, and concise, with rationale provided to justify all inputs. There is rarely a way to recover from a poorly constructed RFP; therefore, it is critical to invest the time to ensure a quality RFP. Ambiguity in an RFP forces the HSI practitioner or one's successor to live with that uncertainty. Since the acquisition process typically extends over many years, one may not be around to interpret issues that are ambiguous; therefore, it is better to take the time to be clear from the beginning (McCommons, 1987). HSI inputs to the RFP vary considerably depending on the size and nature of the procurement (DoD, 1999, Section 6.5).

Human Factors Section The RFP typically has a section entitled Human Factors. This section is where the buyer's HSI community can state their requirements under the contract for the seller's HSI programs. The human factors section should make clear what the minimum program requirements are and what is expected of a fully implemented program. The buyer's HSI community needs to consider carefully what it requires from the winning contractor and create contract data requirements list (CDRL) items and data item definitions (DIDs) for products to be delivered. It should be kept in mind that formal data submittals by the seller require considerable labor to prepare and therefore drive the contract cost up. Deliverable items that are "nice to have" can incur significant cost penalties. However, critical items should be on the list regardless of cost. The reason for this list is that the buyer's contract officer monitors the items on the CDRL for compliance because reimbursement of charges may be withheld if the CDRL items are not provided or what is provided is inadequate. That is, the buyer's acquisition office monitors the contract to enforce delivery of the CDRL items. When funding becomes tight (not if, when), items on the CDRL will undergo significant pressure to justify value or face being deleted from the contract. Items not specifically required by the contract are subject to being interpreted as information or suggestions to the seller and can be deleted for cost avoidance. In other words, in order to save documentation money, the requirement might be interpreted as a requirement for doing a workload analysis but not as a requirement for delivering a formal document describing the analysis. Without an explicit requirement for the document, obtaining an adequate budget to document the result may be impossible. In general, complying with a discrete, testable requirement that has a monitored deliverable will provide a certain level of immunity to cost cutting.

In a recent major DoD helicopter competition, the released RFP had little in the way of HSI requirements within the human factors section and only had a total of seven direct crew interface requirements. Despite this paucity of requirements, HSI was a major consideration in determining contract award. The reason that HSI was considered so important was because the RFP required that a contractually binding human factors program plan be included as part of the proposed SOW. By not attempting to define a build-to human factors solution into the requirements, the DoD HSI team was able to help choose the process by which the solution would be engineered. In this manner, the DoD was able to select the contractor whose proposed solution held the best potential for fulfilling the HSI requirements.

RFP Summary In summary, the RFP is one of the most important documents for the HSI community because competitive contractors will budget only for tasks that are explicitly required. In a review of the DoD HSI programs, Wright and Hall (1994, p. B-4) noted that underfunding of the front-end analyses conducted by HSI was a problem even in the relatively strong U.S. Army manpower, personnel, and integration (MANPRINT) program. They attributed this to "a lack of appreciation, among people responsible for funding FEA (front-end analyses), for the critical role FEA plays in the HSI Program during the very earliest phases of the new acquisition." Wright and Hall concluded, "Unfortunately, if the window of opportunity to make meaningful input to major system documentation that drives the design process is missed, there are no inexpensive ways to catch up later in the acquisition."

7.3.4 Seller's Proposal

The government's codification of procedures into a set of regulations has not gone unnoticed within the private sector. Many texts have been written on how the contractors (sellers) can best do business with the government. Alston et al. (1984) has produced a seminal work on obtaining government business. While it is primarily directed at how to conduct business with the U.S. government, the points made are completely appropriate for private-sector contracts.

A proposal is an offer by a seller to supply a product, perform a service, or provide a combination of the two. In some cases, the products or services are simple tasks and have been done before. In other cases, they are unique research-and-development efforts with a number of substantial state-of-the-art problems to be solved. From the seller's perspective, the function of the proposal is to sell the managerial and technical capabilities of the company to carry out the required work at a reasonable cost. The proposal is the point of sale; it should be considered the seller's most important selling tool. The proposal document must convince the buyer that the seller is offering an acceptable solution to the problem for a reasonable cost. It also communicates that the seller has an adequate organization and sufficient personnel and facilities to perform the required effort within the time specified. The seller has considerable latitude in conveying these messages.

The proposal must adequately cover three broad areas. The first area relates to the technical solution to the problem as defined in the solicitation. The second area describes how the seller will manage contract performance, and the third area addresses how much the proposed work will cost. The HSI community of both the seller and buyer should be interested in all three sections. The *technical section* of the proposal should demonstrate the seller's understanding of the problem and the proposed method of solving it. It is in this section that the technical elements of the HSI program belong. This section outlines the specifics of what tools, techniques, and procedures of HSI will be utilized to implement the HSI program. This section should also identify which technical elements will be responsible for delivery of the CDRL items and support other disciplines in fulfilling their CDRL requirements.

The purpose of the *management section* is to explain how the seller intends to manage the effort required under the proposed contract. The seller's HSI staff should provide details of where its management resides within the overall structure of the proposed program. If HSI is truly integrated into the program, then the management of HSI should be visible within the program management structure and in such a position that HSI is able to effect changes deemed necessary by their analyses. In other words, HSI management should be at a high level within the seller's organizational hierarchy.

The third section, *cost*, should also identify the proposed budgets of the seller's HSI effort. A budget within the program is necessary to assign labor and other resources to complete tasks. The scope of the effort described in the technical section should match the proposed costs. Unless the technical and cost are balanced, the management structure proposed will be without the means to accomplish the technical work and deliver the requested products.

Those attempting to respond to a proposal for the first time should consult MIL-HDBK-46855A (DoD, 1999). This handbook is an excellent document on how to decide what tasks and efforts are appropriate under a variety of circumstances. Another excellent source of guidance is DOT/FAA/RD-95/3 (Hewitt, 1995). This document is oriented more toward users and their problems than the more programmatic MIL-HDBK-46855.

The seller should also read and carefully consider both the explicit requirements in the human factors section of an RFP and those requirements that may be buried in other technical sections. For instance, human engineering requirements may be implied by specific information required in a particular test by the test and evaluation sections. Even if HSI is not responsible for a segment of the design or test, HSI involvement may be required that, if not properly documented, will require diverting core HSI program resources into support of other disciplines at unexpected times. For example, a subsystem test may require that sellers test their subsystem in “critical user tasks.” While not explicitly in the human factors section, HSI inputs will ultimately be required to identify the critical tasks and evaluate user workload and acceptance.

As a general rule, the vendor should structure its offering such that the evaluators can easily find all the critical elements requested. If vendors have made up unnecessary and confused breakouts, evaluators may conclude that the proposal does not meet the buyer’s intention. In extreme cases, sellers have been known to follow the RFP sentence by sentence, addressing each sentence in the RFP as a separate topic. In a government RFP, there are specific sections that spell out what the content of the proposal should include and the criteria by which the proposal will be scored.

The seller should look carefully at CDRL requirements outlined in the RFP. Formal deliverables tend to be labor intensive, subject to multiple reviews by management, and take longer to create than anticipated. There should be a logical relationship between work being accomplished in order to get to the desired design and what is deliverable. If a seller finds that new HSI work is being added to the proposal specifically to address CDRL requirements, the seller should revisit its proposed HSI plan, as the plan is probably not complying with the buyer’s intended program. If the seller believes that their proposed HSI plan is fully compliant with the RFP intent and further believes that the CDRL is not required, an argument should be made for modification or deletion of the CDRL as a cost avoidance. Changing the CDRL can be accomplished in a variety of ways, from informal discussion with the buyer’s HSI community to pricing a reduced-cost alternative without the CDRL.

In a recent response to a government, space-related RFP, a seller’s inputs to a team proposal failed to address the technical questions posed. The staff responding to the assigned technical section decided to use the allotted proposal pages to market the company’s background and capabilities. Their strategy was that the technical section submitted would convey the message that they had been successful in the past so they would be successful in the future. However, since technical information about the proposed design did not make it into the proposal, that company did not get the award.

A similar way to ignore the RFP and lose a contract is to adopt the approach that the buyers releasing the RFP do not know what they want or what is good for them. With this approach, the vendor responding to the RFP proposes something related but different than specified. What is proposed is usually a reworked design from either a slightly different but successful project or a previously failed proposal in which the company has already invested heavily. This typically results in yet another failed proposal.

Not all acquisition failures happen to the sellers. In a new space program, crew requirements for habitation were so delayed that a major negative impact was projected for the final product. Due to program delays and reorganizations, the need date for crew habitation accommodations had moved several years behind the rest of the program. This inadvertently caused basic requirements for the crews to be removed from the program since they were outside the contract scope and the seller selected could not legally work on "outside scope" issues. Eventually it became clear that crew requirements would have to be addressed and so the program, to buy time to decide what the "permanent" solution would be, adopted a "temporary" solution. This temporary solution was initiated and a contract awarded, but the winning company soon discovered that fundamental support requirements necessary for contract completion had not been made for the infrastructure (electrical power, computer connections, ventilation, etc.). Ultimately, the contract had to be canceled.

7.3.5 Source Selection

The U.S. Government FAR (1997b) defines proposal evaluation as "an assessment of the proposal and the offeror's ability to perform the prospective contract successfully." The FAR also provides the following guidance: "An agency shall evaluate competitive proposals and then assess their relative qualities solely on the factors and subfactors specified in the solicitation. Evaluations may be conducted using any rating method or combination of methods, including color or adjectival ratings, numerical weights, and ordinal rankings. The relative strengths, deficiencies, significant weaknesses, and risks supporting proposal evaluation shall be documented in the contract file" (p. 15-10).

Once an RFP has been released, sellers may respond with proposals. Typically, representatives of the requesting buyer's HSI community will be asked to serve on an evaluation board with the responsibility to read all proposals and ask the sellers for technical clarifications, omissions, errors, and deletions to their proposals. This may be done in writing or in face-to-face meetings with written commitments for any changes made as a result of meetings. Eventually, the technical work proposed will be scored. According to the instructions of the board, the buyer's HSI representative will be asked to provide ratings for each contractor's technical response to the RFP technical sections. Scoring should consider how well the proposed HSI program will satisfy technical requirements and be integrated into the product development. The buyer's HSI representative should also consider the proposed organizational structure. The proposed organization and management of the program give strong evidence of how well the HSI requirements spread throughout the RFP will be addressed and should reflect the technical expertise of the staff proposed to address the varied technical areas. This is important information to determine the quality of the HSI effort that will result after contract award. It can also help answer such questions as whether the seller's HSI practitioner will have organizational authority to push for HSI-desired features.

Another area of concern to the buyer's HSI community is cost. The HSI programs require significant manpower depending upon the phase of acquisition. An evaluation must be made whether the costs associated with the scope of work match the likely amount of work to be performed. For example, if the seller proposes to do task analysis and workload predictions for a major system in 12 months with two people, the costs might be suspect as being too low to credibly perform. On the other hand, if the contractor already possesses a significant portion of the data, this level of effort might be reasonable. Some sellers may demonstrate company information and prior work with direct application to the contract. This work may significantly reduce costs as well as showing appropriate skills are available to do the proposed work. This work may be the result of prior contracts—either on the current development or on predecessor systems—or may be the result of company-funded independent research and development. If the work is cited as having been independently developed, the buyer's HSI representative should consult with the acquisition authority to determine the status of rights to the data. Independently developed work may or may not become the property of the contract.

In evaluating the program plan and the scope of the planned work, the buyer's HSI representatives will come into contact with the seller's proposed design. The buyer's HSI representatives were presumably selected for their knowledge of predecessor systems and the task/mission being supported. This knowledge can be both a help and a hindrance in evaluating designs. Proposals for design similar to predecessor systems may evoke responses ranging from "its just like" to "its not like" the predecessor system. If the proposed design is a novel approach, the same range of responses may occur. The buyer's HSI representatives need to utilize their knowledge of the systems, tasks, and missions without trying to drive the solution toward one they are comfortable with or away from one they dislike. The evaluation should be on the quality of the proposed plan and the extent to which the design will meet the HSI criteria embedded within the technical sections and requested in the RFP.

7.4 HSI PROGRAM MANAGEMENT GUIDELINES

Acquisition has its own language, timing, and rules. Those who know the language, timing, and rules can promote, limit, or effectively block an HSI program. Section 2 was directed toward helping practitioners involved with the acquisition system understand its basic language, timing, and rules. Section 3 addressed the major events and products necessary to contract for an HSI program. This section provides basic information to help the HSI manager plan and implement an HSI program.

7.4.1 Specifications: From A to E

Throughout the life of an acquisition, the HSI program will remain "information starved." That is, HSI practitioners will constantly be trying to learn how various systems, subsystems, components, and items work and interact, at low and high levels, between components and the users. Since training manuals, descriptions, or overviews will not have been written while hardware/software items are in a design stage, the only place the practitioner can get specific information is from the engineer in charge of the system or subsystem. However, since it takes a significant amount of time to document how to operate a developing system or subsystem, it is likely that the engineer will point to his or her system's or subsystem's primary specification or controlling interface control document (ICD) as the only available information. The engineer would most likely ask the practitioner to review these documents before asking additional questions. This is a helpful suggestion, since much of the needed information should be in the specifications. Reading a specification, however, can be a daunting task, and several need to be read before the system design becomes clear. A few practical tips may help the practitioner get started.

The HSI practitioners should know that specifications run the gamut from top-level system specifications (type A discussed above) to D (process) and E (material) specifications. Type A is usually too general and type C too detailed except where very technical answers to very specific questions are concerned. Therefore, most of the practitioner's time is likely to be spent with type B specifications.

Each specification, regardless of type, follows a standard format. The practitioner generally needs to look in detail only at the section on requirements, specifically at the subsections called:

1. definition,
2. characteristics,
3. design and construction,
4. logistics,
5. personnel and training, and
6. characteristics of subordinate elements.

These sections are required in this standard format specifically to assist other disciplines in understanding how a system works. These documents are reviewed and accepted by the program either at PRR, PDR, or CDR. An HSI practitioner should have previously reviewed the contents of these sections and agreed that the level of detail and information was acceptable for later HSI use. If adequate information about the system is not included during the development phase, funding to revise the document and provide the information later is not likely.

In the past, these sections of the specifications were written by engineers for other engineers of the same discipline and reviewed by those engineers working on the system. The information contained was cursory and often assumed the reader would have significant knowledge of the technology and design. The HSI practitioners did not routinely see these documents until they had become information starved and then steered by engineering personnel to the specification. The cursory information typically found in the specifications made it impossible for the HSI practitioner or researcher to determine how the system or subsystem was intended to work. Tasks and workload predictions would lack definition, and the opportunity to influence design would be lost due to lack of information.

When a specification is in review, the adequacy of sections can be formally challenged and resolved if the information provided is too limited for later use. After review and release, it is difficult and expensive to change documentation, especially just for updating information rather than for a design change. Information will typically be provided only to the level demanded by other disciplines. If the HSI program does not or cannot force adequate documentation in the development of specifications, the HSI program will remain information starved. Later, HSI practitioners, attempting to revise tasks and workload, conduct simulations, or prepare for certifications, will require significant unplanned expenditures of time and money to become familiar with the details of the design. The alternative is to wait until the design is finished, but changes then cannot be economically accommodated.

7.4.2 Planning, Programming, and Budgeting

Planning, programming, and budgeting of the seller's HSI effort are program management requirements that, for HSI practitioners, tend to be learned by mentoring with an experienced manager. A single HSI practitioner can handle some programs such that little management is required. The task required, for instance, may be merely an upgrade to an existing product rather than development of a new function. Many programs, however, require multiple HSI practitioners with a variety of skills, all working across time in a coordinated fashion. Good program management will help make sure that required skills, financial resources, and time are available as required. Planning is used here to refer to the process of explicitly writing down the tasks, activities, and products that will fulfill the contractually required SOW throughout the period of performance. The seller's planning is a written list of all the major and minor tasks that have to be done in order to fulfill contractual requirements and commitments. Programming is used to describe the process of time phasing the planned work and identifying the interrelationships between the various work components. Programming describes what work must be done by what time in order to allow the next, dependent work to be done. It is the cascade or waterfall of work that leads to contract completion. The term *budgeting* is used to place the work to be done (planning) on a time-phased schedule (programming) in order to forecast how much the work to be done will cost over time. The result is a budget request to the program management.

To accomplish the work, staff (either in-house or contracted) must be available to do the work. To get staff to do work (implement the planning), funds (a budget) must be available at the right time. In other words, there must be programming of planned work with a budget to support staff specialists across time. If the management planning, programming, and budget are correct, the HSI program can progress by focusing on technical issues without the diversion of concerns about whether preliminary work was done or if follow-on work will happen. If work is not programmed correctly, the HSI effort will likely miss deliveries and reviews and not get tasks accomplished when needed. This will create a rolling wave of unfinished work moving to the right on the schedule. At some point, some tasks pass their effective window and never get done. At other points, the correct answer comes when it is too costly to implement. Below are some basic rules for planning, programming, and budgeting:

1. *Determine Deliverables and Milestones* Start planning from the end of the program by identifying what is to be delivered when the contract is completed. Work backward from the deliverables toward the start of the program to identify those tasks that must be done in order to complete the deliverables. Account for all deliverables (those items explicitly named in the contract as well as bodies of work that are to be conducted). Identify the date that each deliverable item is to be completed. Develop a timeline that incorporates each of the deliverables and dates under significant, discrete events called "milestones."
2. *Determine Work Tasks* Create a "bullet-sized" statement of work for each of the milestones. Identify all the significant tasks with a brief one- or two-line description of the task. Group the bullets into packages in which there are obvious start and finish activities. This is a task analysis of the HSI work. The HSI practitioners have missions, phases, tasks, and subtasks to complete the HSI program, just like the users of the vendor's products have missions, phases, tasks, etc. The HSI tools apply to HSI activities as well as others in the systems engineering and management process.
3. *Put Work into Monthly Packages* Since the budget comes in yearly packages, break the bullets of work into year groups and grossly identify start/stop points by month.

4. *Determine Labor Required and Costs* Identify how many people with what kind of knowledge and skills will be needed for a bullet and how many days it will take to get the bullet done. Generate a spreadsheet that has *month-by-skill-type* intersections. Fill the cells with the number of days (at 8 hours a day) times the number of people with that skill working (to get personnel hours per day) times the number of days in that month that those people will work on that task (personnel hours per month by skill). The contractor's finance people can help by using a labor rate (cost) for the skill indicated, adding overhead, fee, etc. (burdens), to assemble a budget for that work for that month.
5. *Determine Material Required* Identify any material items that will be needed and when needed. This is the budget for specialized computer software, hardware, mockup material, shop time, etc. For example, if a research assessment is planned using a mockup, the cost of building a mockup should be identified. It might be possible to use someone else's mockup or modify existing mockups to fit the need, but the HSI manager needs to start by identifying to higher management that material items will be required.
6. *Determine Travel Required* Identify any travel projected as needed to conduct the tasks, providing such information as when the travel will likely happen, to where, for how long, and with how many people.
7. *Determine Data Requirements* Identify what data will be needed from what other groups or companies. Summarize what is needed and when, then coordinate, in writing, with the source of the information to get agreement that it will be supplied.

Personal experience, company experience with prior programs, information from vendors, etc., all provide help with this process. Management tools are available to help as well, but there is no substitute for independent thinking about the problem and laying out the planning, programming, and budgeting in language understandable to both HSI and systems management. If the contract is with the government, it is likely that the contractor will be required to manage the work using earned-value accounting techniques. *Earned-value* techniques force the vendor to plan ahead and reduce the number of unpleasant surprises for both the buyer and seller.

7.4.3 Industry's Dilemma

The winner of an acquisition competition is typically the seller that promises significant technical advancement without introducing excessive technical risk, all for the best price. In other words, the winner proposes a design that appears to meet the requirements without reliance on technology that might not be available and at a price the buyer can afford. To win a competition that will result in a system that actually meets these competing criteria presents a dilemma for industry. On the one hand, if the seller promises too much technically—a very strong tendency when moving technology from the laboratory to production—any number of unforeseen problems in critical technologies may cause the following:

a. delays—which means using unplanned time and money (overruns and schedule slips) to resolve problems associated with bringing technology to production;

b. reworks—taking a different approach (new design and development costs for less risky technology) or additional design and development costs to address problems discovered;
c. unforeseen problems with support and logistics—e.g., new technology turns out to require significant maintenance that was unplanned and costly; and/or
d. failure to meet exit criteria for the contract—which always increases time and costs to complete.

On the other hand, promising too little advanced technology runs the risk that the buyer will perceive industry is not offering a solution that will provide significant improvement or benefit. It is generally a rare event when a seller can make this call correctly. Virtually all major acquisitions end with the seller having been either too conservative or too optimistic. An adequate discussion of lessons learned on this topic is outside the scope of this chapter. However, some common pitfalls for HSI can be identified as cautions as the seller struggles with this dilemma. Two fallacies typically applied by the seller are reducing work of "limited value" and assuming that the more work proposed, the better the product.

Reducing Work of Limited Value One frequently used method of addressing the industry's dilemma is to reduce costs by cutting work that is of limited value compared with the "value" of advancing the state of the art. This equates to stripping money from the "support" tasks in order to offset technology risk. The technology is just as risky, but the budget can include costs for rework or risk reduction activities as a management risk reduction program. This reduces the perceived risk to the program of maturing the technology because budget is available to work the problem rather than having to overrun unexpectedly. For example, a contractor might choose to reduce up-front work (such as mission analysis) for design support organizations such as HSI or eliminate documentation in order to free up money for the risk management program.

Within this dynamic interplay, the HSI program can be overlooked and badly damaged. This is where the HSI community must be visible as a member of the design team and not viewed as just an after-the-fact reviewer or "grader" of the work of others. In a successful HSI program, work feeds upon prior work and information. Elimination of parts of the HSI program or reduction in the detail of program components can dramatically lower the ultimate value of specific tasks. Elimination of tasks may make prior lead-in work of no value in that there is no one to use the information (all the work has been done but no one is using it) or make it impossible to conduct follow-on work due to lead-in work not being done. Also, the addition of technology to enhance the chances of winning may place new, unknown burdens on the users that will not be noticed until much later in the program. Management of both the buyer and seller need to understand that *reducing work of limited value* poses a risk just as technology maturation is a risk.

The More Work Proposed, the Better the Product? The simple view is that the more work a seller proposes, the better the proposed product will be, but the cost obviously goes up. If the cost is too high, the contract will be lost. If the amount of work being proposed is too little, the risk that cost overruns and schedule slips will occur while trying to bring the product to production may be viewed as too high and the contract can also be lost. Contracts are continuous, unrelenting trade-offs between cost, schedule, risk, and product quality. The HSI practitioner must understand this and be prepared to modify the

HSI program to maximize the effective contribution to the program. It has been said that many programs have failed because they could not afford to do it right. Balancing technology risks, costs, and schedule challenges seldom allows HSI all it needs, even with programs that attempt to fully apply the HSI principles outlined in Chapter 1. The HSI practitioners should be prepared to do the best they can within risk, schedule, and cost constraints.

7.4.4 Winning through Candor and Cooperation

Typically, a proposal will have a page count imposed that limits the contractor's input, making every word in the response important. Decisions on what to expend words on and how many words on a topic need carefully planning. The following are a basic set of rules to follow when generating a proposal:

- Read the SOW, specifications, and any instructions to the offeror that are provided for HSI content. Reviewers always appreciate the vendor being responsive to the questions and issues they ask about.
- State clearly what the HSI program will be and in what sequence it intends to resolve risk. Refrain from platitudes and marketing.
- Recognize that if all the answers were known, it is likely that the work would not be required. In other words, it is okay to acknowledge that the answers to the problems posed are unknown, but it is critical to show how the HSI program will identify and resolve problems throughout the contract.
- Identify the known items (and unknown factors) that pose risk or that will be difficult to accomplish. Articulate how the HSI program intends to approach and attempt to solve the problem(s) identified. In other words, define how the offeror intends to control risk.
- Coordination, cooperation, and data exchange between the buyer's and seller's technical staffs regarding the proposed HSI program are expected and encouraged by the buyer. Recognize this in the proposal and state how this interchange will be handled.
- Discussion of tools and techniques is helpful provided the seller identifies how the tools and techniques discussed will fit into the overall program. Do not just list tools that might be used. Identify which tools will be used for specific risk reduction, define what knowledge is to be gained, and discuss how that knowledge will solve problems or otherwise contribute to the HSI program.
- Read the proposal in draft form and ask whether it answers questions and/or leaves questions hanging. In reviewing the proposal, typical questions to be asked include "What is going to be done?" "How is it going to be done?" and "How does this contribute to the HSI program?" If the answers are not obvious, rework the text.
- It is especially beneficial for the seller to indicate how the program will assess its own progress and adjust to changing requirements. How will the HSI management team monitor itself to make sure that it is making progress?

7.5 SUMMARY

A new emphasis on HSI has been added to NASA and DoD federal government acquisition processes. Conscientious attention to HSI by contractors who provide services and systems to the government has been demonstrated to save significant money and enhance system performance (Booher, 1990, 1997). To aid the HSI practitioner from the contractor's perspective this chapter discussed three types of information:

1. the specifications and critical HSI tasks for each major stage of a contract,
2. the principal documentation events for the buyer and seller in the acquisition process, and
3. guidelines on planning, programming, and budgeting for an HSI program.

There are four major milestone reviews of contractor-developed products in a typical contract: I—the program requirements review (PRR); II—the preliminary design review (PDR); III—the critical design review (CDR); and IV—testing and certification. Each of these reviews ends a critical stage of work for the contractor that should have incorporated specific planned, programmed, and budgeted HSI tasks.

Successful integration of HSI into product development starts with the RFP. The buyer's RFP must have a clear requirement for the seller's HSI, including an explicit contribution to contract award; otherwise, the message is sent to the vendors that the user's performance with the proposed system is not particularly important.

After contract award, the HSI program begins with early (front-end) analyses in support of generation of the system/system segment specifications. When completed, the requirements and the design outline are reviewed at the PRR.

Once the high-level requirements and design have been agreed upon between the contracting agency and the contractor, work commences on the decomposition of the system/system segment specification requirements into the development specifications that state the requirements for the design or engineering development of a product during the development period. The development specifications indicate how the design-to specifications are to be built-to and ensure that all higher level specifications are addressed. This effort culminates in a PDR that validates the design requirements decomposition process and checks general design progress, technical adequacy, and risk resolution on a technical, cost, and schedule basis.

After the PDR is complete, work focuses on completing the product specifications. All these efforts are reviewed at the CDR during which the decision to proceed to production is made.

The final efforts are for certification and testing of the product. Specifications of a variety of types are the products of these reviews and control development of the product. The HSI practitioner should be involved in the generation, review, and implementation of the specifications.

A winning HSI program will have been well thought out before contract award. This will be reflected in the proposal with a clear description of what will be done and how it will occur. A well-thought-out program will also be reflected in a clear, defensible statement of costs to conduct the program, identify risks, and provide a means to assess risk, progress, and overall quality. The HSI program should be active from contract award through production and should be integrated into the mainstream development effort.

NOTES

1. The term *glass cockpit* refers to an aircraft cockpit in which computer display(s) have been incorporated. These displays are typically cathode ray tube (CRT) or liquid crystal display (LCD)

and are made of glass—hence the use of the term *glass*. Generically, the term is used to describe a cockpit whose crew interface includes computer-synthesized displays and computer-mediated inputs.

2. There are, of course, months to years of analytical activity leading up to the issuance of an RFP.

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