CHAPTER 4

Human Systems Integration and Systems Acquisition Interfaces

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4.1 INTRODUCTION

In 1974 the U.S. Army Training and Doctrine Command, which is responsible for defining the U.S. Army's need for new systems, signed a letter of agreement with the U.S. Army Materiel Command to develop a remotely piloted vehicle system technology demonstration (U.S. Army, 1988). The intent, following a 1971 recommendation by the Defense Science Board, was to demonstrate how a remotely piloted vehicle could aid a ground commander to perform reconnaissance, acquire targets, designate targets with a laser, and adjust artillery fire. The system, later named Aquila, was to capitalize on emerging technology and give the U.S. Army a state-of-the-art multipurpose remotely piloted airborne system second to none. In 1988, after the expenditure of approximately $1 billion (Ladendorf, 1988), the army cancelled the program. The reasons for the cancellation are many, but surely failure to adequately address HSI-related requirements early in system development and integrate them fully into early testing and evaluation were among the problems that led not only to an inefficient expenditure of large amounts of money but also to a delay in fielding a needed system (Stewart et al., 1989). As the army entered the twenty-first century, it still did not have a widely fielded unmanned air reconnaissance system.

The acquisition of complex systems such as Aquila requires the successful execution of three functions: definition of requirements, design and development of the system, and deployment. This chapter will focus on processes required for the acquisition of complex systems and how to integrate human performance considerations into those processes in order to avoid more costly examples such as Aquila. It will begin with an overview of acquisition life-cycle models and then discuss various ways in which human systems integration (HSI) interfaces with the life-cycle process. The discussion will center around the U.S. Department of Defense (DoD) defense acquisition management framework. Since

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the purpose of the chapter is to show how human factors can be integrated into systems acquisition, attention will be paid to identifying acquisition documents that are normally part of the process and should be attended to and modified with human factors information if HSI is going to be successful.

An assumption underlying the discussion is that human factors personnel who are involved in this process must be well trained and educated in the field of human factors if they are going to have an impact on the systems acquisition process.[1] Just being interested in human factors is not enough. One must be cognizant of the human factors and human performance literature that comprises the field; must be facile with human performance measurement methods, modeling tools, and analysis techniques; and must be familiar with the functional area (e.g., vehicles, communications systems, individual soldier weapons, etc.) in which he or she is working. Without a strong grounding in these fundamentals, the human factors representative will have little to offer during the system development process and will be ignored.

Finally, throughout the chapter it will be noted that the author uses the term *operators and maintainers* when referring to the users of a system. In the past HSI has too often focused on issues associated solely with operating a system and neglected issues concerned with maintaining the system. But modern complex systems require a great deal of maintenance in order to keep them functioning. For example, the Aquila system mentioned above had such high maintenance requirements that it was impossible to keep the system at full operational status for more than several days with the maintenance manpower that had been allocated to it. Designing for the maintenance of complex systems can be just as important as designing for operation. Use of the term operators and maintainers is done to reinforce that point.

4.2 SYSTEMS ACQUISITION PROCESSES

A key element in the systems engineering of complex systems is a life-cycle model to lend structure and organization to the development process. In its simplest form, the process occurs in three phases: system definition, system development, and system deployment (see Fig. 4.1). During system definition, the requirements for the system are specified in accordance with the stated needs of the users of the system. In system development, the system is conceptualized, designed, built, and evaluated. Finally, in system deployment, the completed system is delivered to the end user.

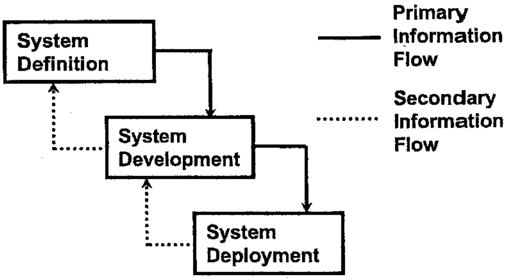

Figure 4.1 Fundamental system engineering life-cycle phases [*Handbook of Systems Engineering and Mangement*, Sage, A. P. and Rouse, W. B. (Eds.), (1999). Reprinted by permission of John Wiley & Sons, Inc.]

4.2.1 DoD System Life-Cycle Model

A variety of life-cycle models have been produced by systems engineering professionals since 1970 [for overviews see Blanchard and Fabrycky (1998) and Sage (1992)]. One of the most well known is that produced by the DoD (2000b). The DoD has spent a great deal of effort modifying and adjusting its life-cycle systems model over the years, partly because the DoD is unique in being both the user and developer of its systems. This is required because many of the systems that it develops are for combat with distribution limited strictly to the armed forces of the United States and its allies. In fact, DoD system acquisition is strictly governed by a number of authorization documents, to include the law (e.g., Title 10 of the *United States Code*), directives of the executive branch of the government and the Federal Acquisition Regulation. Finally, because of the need to constantly improve the capability of the armed forces, the DoD is one of, if not the largest, acquirer of complex, customized systems in the world and thus needs an effective life-cycle systems model to help manage such a large endeavor. Because the DoD model is so ubiquitous, it will serve as the basis for most of the discussion in this chapter. Nevertheless, the principles and guidance espoused have general applicability to the acquisition of any complex system, regardless of what life-cycle model, document names, process identifiers, or other nomenclature are used.

The version of the DoD model presented in acquisition documents in effect until August 2002, as well as its immediate predecesssor, is shown in Figure 4.2.[2] It is useful to review the older version in order to understand the newer version. The older version has four phases with milestones (0 to III) leading into each phase. Following concept exploration is essentially each of the classic life-cycle phases shown in Figure 4.1. In past years system acquisition typically began with concept exploration and proceeded lock

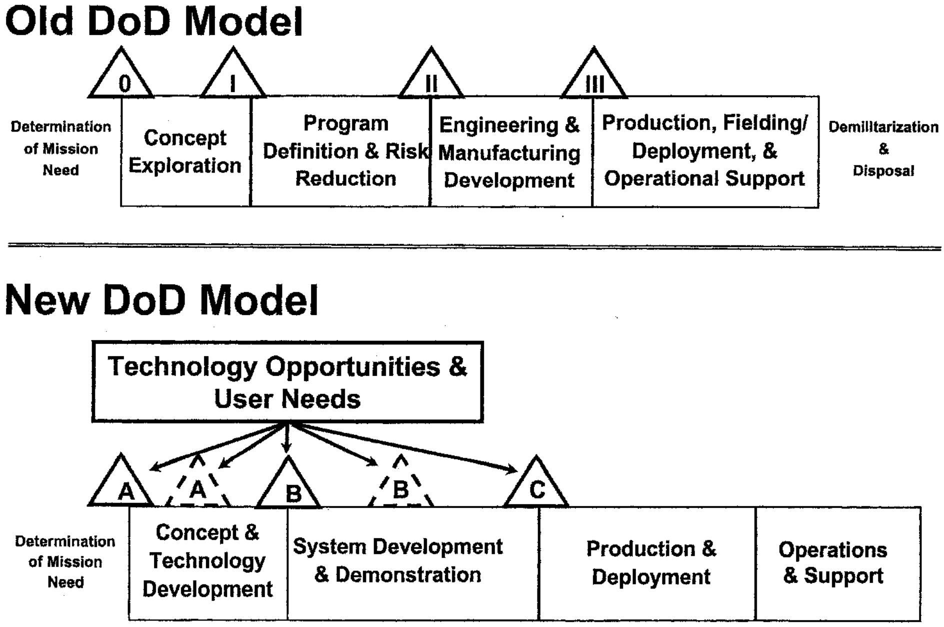

Figure 4.2 Old and new DoD system life-cycle models.

step through the remaining phases. However, this resulted in rather long acquisition times, on the order of 10 to 15 years. It came to be recognized that the life-cycle model needed to be modified in order for the DoD to be able to capitalize on rapidly evolving technology characteristic of today's business environment. Consequently, the DoD revised its acquisition guidance regulations (DoD, 2002a, b, 2001) around a set of principles designed to make systems acquisition more rapid, affordable, and effective. In the process, the life-cycle model was modified to accommodate this new environment. As can be seen in Figure 4.2, it is still a four-phase process, but with the provision for entering the process at any point during the first two phases of *concept and technology development* and *system development and demonstration*, depending on the state of the primary technology or technologies that are forming the core of the new system.

The new life cycle, now called the defense acquisition management framework, is shown in more detail in Figure 4.3. It consists of three overarching *activities* (presystems acquisition, systems acquisition, and sustainment), which in turn are divided into a series of *phases* (concept and technology development, system development and demonstration, production and deployment, and operations and support). The four phases are each broken down into two *work efforts*. The nature of the work occurring in each work effort is obvious from the titles. It is important to note that the system acquisition process can begin at any point during the first two phases as long as an established materiel need can be satisfied by a technology at a state of development appropriate for that point in the cycle. To enter at a milestone B point would require a technology that is already mature and has been demonstrated in some application. To enter at milestone C would only be possible if there were already a system that had been developed for other markets and was fully capable of meeting a particular defense materiel need. This is not to imply that the DoD has never acquired previously developed technologies or systems; it has. But such

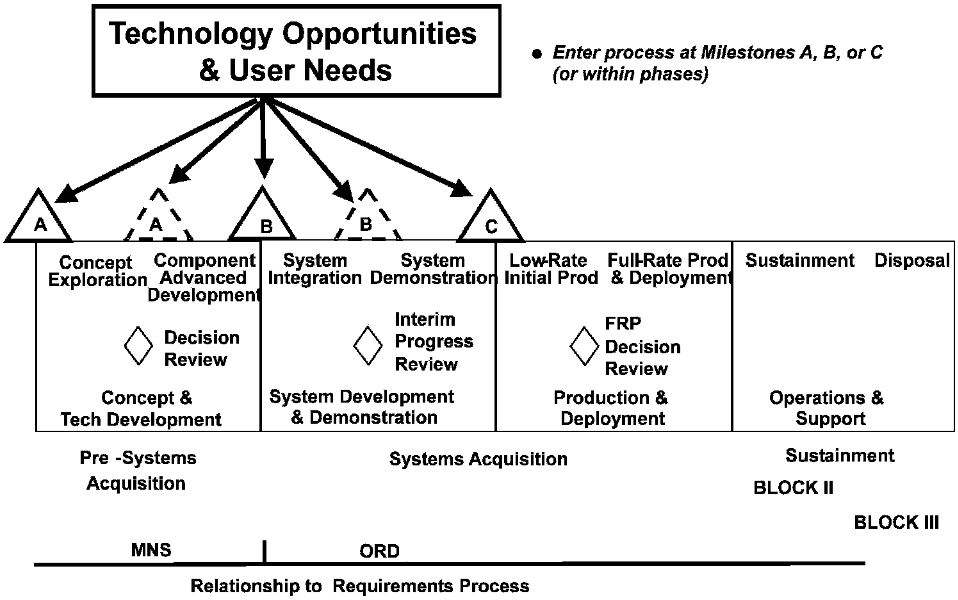

Figure 4.3 Defense acquisition management framework.

acquisitions have been treated as exceptions to the acquisition process. Under the current defense acquisition management framework, they are part of the standard acquisition process.

Another advantage of the new life-cycle model is the accommodation of time-phased requirements in support of evolutionary acquisition. Under the evolutionary acquisition concept, an acquisition strategy is adopted for fielding a core capability with a modular open structure and the provision for future capability upgrades.[3] The new life-cycle model allows time-phased requirements to be introduced at various points in the life cycle, thus facilitating fielding, over time, systems of increasing capability. While this approach is not appropriate for all acquisition programs, it is essential for the timely acquisition of automated information systems in today's environment of rapidly evolving automation technology.

Another important emphasis in the DoD (2000a, b, 2001) 5000 series is a total systems approach to systems acquisition. The DoD Directive 5000.1 (which is the lead regulation in the 5000 series and provides overarching guidance) states: "Acquisition programs shall be managed to optimize total system performance and minimize total ownership costs by addressing both the equipment and the human part of the total system equation, through application of systems engineering" (DoD, 2000a, p. 5). This statement has profound implications for HSI, since it states up front, for the first time, in the highest level DoD regulation that governs system acquisition, that human performance considerations must be looked at in conjunction with equipment considerations when optimizing system performance and minimizing system cost. The directive goes on to state: "Program managers shall give full consideration to all aspects of system support including logistics planning; *manpower, personnel, and training; human, environmental, safety, occupational health, accessibility, survivability*, and security factors; and spectrum management and the operational electromagnetic environment."[4] The directive clearly indicates the importance of and need for HSI in the systems acquisition process.

4.2.2 HSI in the Life-Cycle Process

The question that arises at this point is how to accomplish the integration of human performance considerations into the life-cycle process to optimize system performance and minimize cost. How does one ensure that the human engineering, i.e., the design of the interfaces in the system, does not cause operators to make errors at critical times or does not cognitively overload the operator such that he or she makes repeated errors? How does one ensure that enough maintainers with the right skills are available to support the system when it is fielded without extraordinary amounts of training? An approach to doing this is to iterate an HSI cycle through the various phases and work efforts of the systems acquisition life cycle. Such an approach is shown in Figure 4.4. As can be seen, a total system concept must first be formulated. This is based on the requirements that have been specified for the system, its intended method of employment, notions of what technology will be used as the core of the hardware, and what parameters will characterize the operators and maintainers of the system. From this total system concept is derived requirements for human performance, such as numbers of operators required for operation; special cognitive, physical, or sensory skills required; estimates of the training that will be required; estimates of the workload under various scenarios; and so forth. From this estimate of human performance requirements, a judgment must be made as to whether the

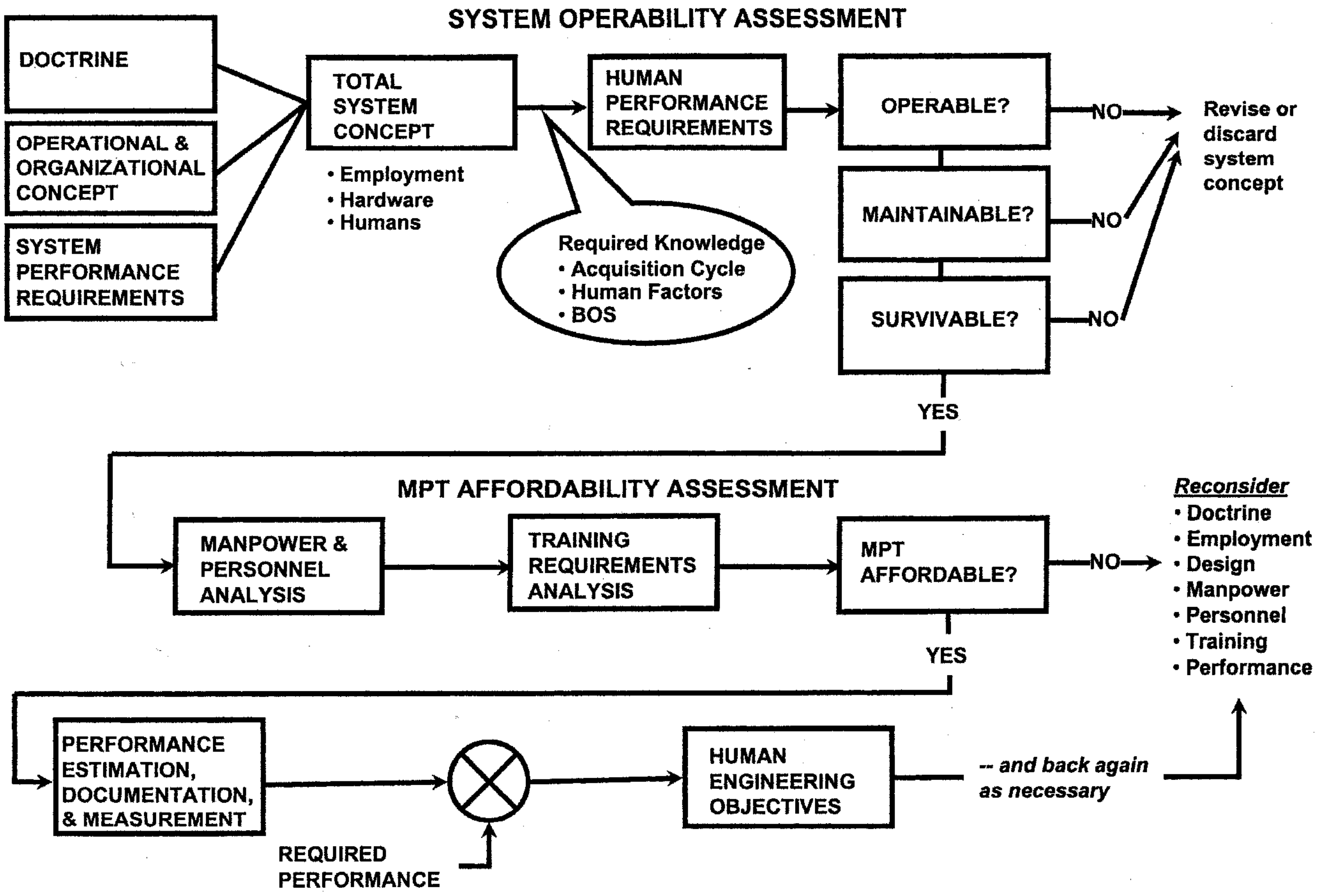

Figure 4.4 HSI in the life-cycle process.

system is operable, maintainable, and survivable by the typical soldier, sailor, airman, or marine that is going to use it. This decision must be made jointly by the system program manager and the human factors professionals who have the knowledge of human performance in similar systems, the familiarity with the relevant human performance literature, and the skills for using the modeling and simulation tools that can help make such an evaluation.[5] If the decision is negative, then the system concept must be revised.

If the decision is positive (e.g., it is decided that the system as envisioned can be effectively operated and maintained by the typical humans who will be using it and the design will not put such a large workload on them that they will become fatigued and overwhelmed by all of the tasks that they are required to do, thus reducing their chances of surviving when coming under attack, etc.), then one proceeds to make a determination as to whether or not the human aspects of the system are affordable. This focuses on manpower, personnel, and training. The annual costs of recruiting, training, and paying personnel are among the largest costs in the DoD, typically exceeding 50 percent of the entire budget (Price, 1990). Costs related to manning and training on a system typically account for nearly 60 percent of total life-cycle costs (Graine, 1988). Therefore, this part of the analysis is critical to determining if the system if affordable. Reliable estimates must be made of the number of operators and maintainers that will be needed, whether any specialized aptitudes will be required (e.g., persons with extremely high cognitive abilities are expensive to recruit and retain), and how much training will be required. The training requirements analysis is particularly critical since training costs can escalate rapidly. Items that contribute to such costs are specialized facilities and training equipment, highly trained instructors, and the sheer length of time that a human sits in a training environment rather than being a productive member of the force. As above, human factors professionals must use their knowledge of manpower, personnel, and training needs of similar systems; their knowledge of the technical literature; and their skills with modeling and simulation tools to help the system program manager make a determination as to whether the manpower, personnel, and training costs will fit within budget constraints. If not, then trade-off analyses between manpower, personnel quality, training requirements, and design must be made in order to meet budget constraints.

It should be noted that the above decisions are not always made in as linear a fashion as Figure 4.4 implies. In the early phases of the system life cycle, decisions about operability and maintainability are made at a more general level so that affordability can then be addressed. The decisions are then refined as more detailed information becomes available during the system design process.

If the affordability decision is yes, then the next step is to make and document reasonable estimates of total system performance and costs and the contribution that human-related variables make to them. From these estimates one can make decisions as to how total system performance can actually be improved without increasing costs and set human engineering-related design objectives for accomplishing this.

This HSI cycle should be applied in the early phases of system acquisition and iterated during each phase. It will be most effective when it is applied early, i.e., during *concept exploration* and *component advanced development*. It is early in system development that human-related system development problems can be most easily and cost effectively addressed by changing the design of the system. By the later phases many aspects of the design have become fixed and are enormously expensive to change. Most life-cycle costs are determined by decisions made early in system development, even though the majority of life-cycle costs are not expended until production of the system is complete (Fig. 4.5).

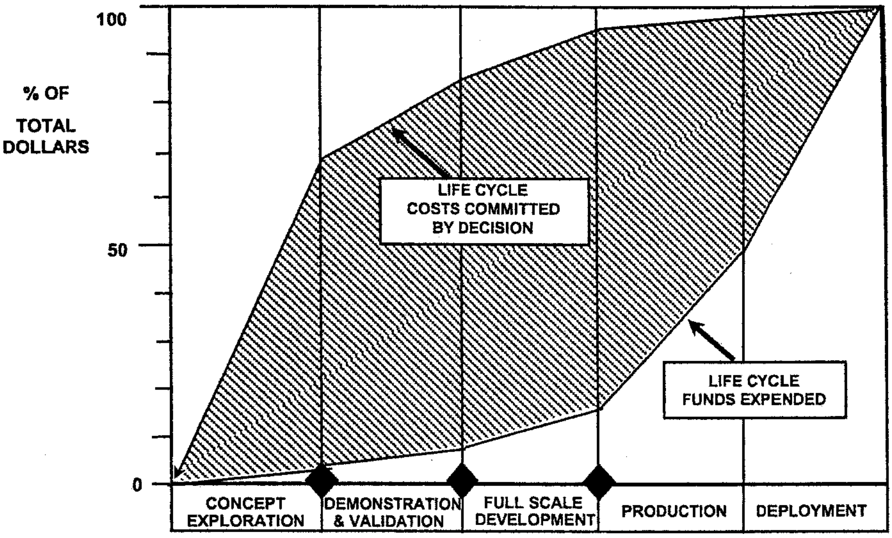

FIGURE 4.5 Schedule of commitment decisions and life-cycle costs [Graine, G. N., "The Engineering Syndrome vs. the Manpower Personnel and Training Dilemma," *Naval Engineers Journal*, March 1988, p. 56. Reprinted by permission of the publisher].

One of the critical activities that is done early in the acquisition cycle is specifying requirements for the system. The DoD has emphasized in recent years that requirements be performance based; e.g., an armored vehicle must be able to traverse off-road terrain at a given speed, destroy an enemy armored vehicle at a given distance with a given probability, travel a given distance before requiring major maintenance, etc. It is critical that requirements related to the human factors of the system be specified at the same time. It is also critical that these requirements be adequately incorporated into the test and evaluation program that determines whether the system that is developed meets the requirements laid out for it. This has not always been done well in the past and has received renewed emphasis recently by the DoD. The 2001 version of Directive 5000.2-R (DoD, 2001, p. 83) states: "The program manager (PM) shall work with the manpower, personnel, training, safety and occupational health, habitability, survivability, and human factors engineering (HFE) communities to translate the HSI thresholds and objectives in the operational requirements document (ORD) into quantifiable and measurable system requirements. The PM shall include these requirements in specifications, the test and evaluation management plan (TEMP), and other program documentation, as appropriate, and use them to address HSI in the statement of work and contract." These two topics, HSI in requirements specification and testing and evaluation, receive particular attention in this chapter.

4.3 PRESYSTEMS ACQUISITION

The system requirements generation process typically begins before the system development process but overlaps its early phases. Adequate and comprehensive requirements generation is critical to the successful development of a system. If it is not clear what specific need a system is filling, it is unlikely that what is developed will fill any need satisfactorily. The DoD's requirements generation process is detailed in an instruction issued by the Chairman of the Joint Chiefs of Staff (DoD, 1999c). It provides for the creation of two basic documents; the mission needs statement (MNS) and the ORD. While these documents are military oriented, the principles underlying their development have generic application to requirements generation in general.

4.3.1 Needs Determination

To determine if there is a need to develop a new system, a series of analyses must be performed to match existing capability with what is needed to cope with the situation at hand. In the case of a private corporation that builds vehicles, for example, this might involve looking at how well its current vehicles satisfy the demands made by the marketplace as well as stack up against the competition. For the military, the process is a bit more complex. It requires an analysis conducted in the context of existing system capabilities, the current and projected future capabilities of the perceived threat, and how the four armed services plan to operate together in a joint fashion. From this analysis are derived needed future operational capabilities, which in turn give direction to future research and technology development and a set of assessments based on experimentation, modeling, and testing and evaluation to help determine how best to meet any deficiencies that have been uncovered [see TRADOC Pamphlet 71-9 (U.S. Army, 1999) for how the U.S. Army approaches this]. It should be noted that materiel solutions are not the first choice for addressing a deficiency. Rather, the following are considered first, in the following order: changes in doctrine, training, leader development, organizational structure, and soldier capabilities. Only after these have been considered and dismissed as not being able to address the deficiency is a materiel solution considered.

If a materiel solution is determined to be the best course of action, then a document is produced that describes the capability required and the rationale for it. Within the DoD this is called an MNS, and it drives the activities in the *concept and technology development phase* of the systems life-cycle process. An MNS does four primary things. First, it defines a need in terms of mission, objectives, and *general* capabilities (it purposely does not describe a need in terms of *specific* performance characteristics). The threat and threat environment to be countered are described, as are the shortfalls of current capability. Second, the reason why nonmateriel solutions are not acceptable is discussed. Third, potential material alternatives that already exist in other armed forces or in the commercial market are explored. Finally, constraints related to infrastructure support are discussed. These include manpower, personnel, and training constraints as well as available facilities, logistics support, and transportation, among other things.

The human factors professional has an important role to play in this process. The understanding that he or she has of the manpower, personnel, and training demands of similar systems in existence, based on experience with such systems, knowledge from reports and databases on those systems, along with access to modeling tools that can be used to conduct trade-off analyses on these variables, can make him or her an important contributor to the establishment of manpower, personnel, and training constraints. In addition, his or her expertise in the area of human performance can be of tremendous benefit in conducting the analyses and assessments needed to support the mission needs analysis and in identifying user–system interface issues associated with new technology.

4.3.2 Operational Requirements Development

Once a need has been documented and accepted by the appropriate decision authority at milestone A, it becomes necessary to state specific operational requirements for the new system. These are performance based and, within the DoD, are derived from efforts in the concept and technology development phase of the *defense acquisition management framework*. The concept exploration effort begins right after an MNS has been approved and validated and involves a series of studies that compare various system approaches to satisfying the needs stated in the MNS. The focus is on analyzing and evaluating the feasibility of alternative concepts and assessing their relative merits. This is followed by defining the most promising concepts in terms of broad objectives for cost, performance, interoperability, infrastructure, etc., after which the most promising concept for which there are available technologies is pursued. With this concept in hand, the component advanced development work effort begins wherein advanced technologies are further developed and demonstrated in relevant environments. The demonstrations are formal exercises that can become quite elaborate and involved and are of two types: advanced technology demonstrations (ATDs) and advanced concept technology demonstrations (ACTDs). The ATDs are designed to demonstrate that a technology is mature and has the potential for enhancing military operational capability in a cost-effective manner. The ACTDs determine the military utility of technology that is already proven and help develop the concept of operations that will optimize operational effectiveness. The information coming out of these technology demonstrations is then used to establish system architecture based on those technologies.

The results of these efforts also serve as the basis for specifying the requirements for a system in realistic operational terms. Within the DoD, these requirements are compiled into a formal document called the ORD (DoD, 1999c). Requirements are stated as operational performance parameters specific to a type of system (e.g., weapon, ground vehicle, communications system, etc.) and include system-level performance capabilities (e.g., probability of kill, maximum maintenance time per unit time of operation, range of transmission, etc.). They are written in output-oriented and measurable terms with both threshold (i.e., minimum) and objective (i.e., desired) criteria. Those parameters that are considered to be absolutely essential to successful satisfaction of the capabilities required by the MNS are called key performance parameters (KPPs). They are limited in number (usually eight or fewer), and failure to meet the threshold of even one of them can serve as the basis for terminating a program. They clearly serve as the drivers of the system development process.

4.3.3 Concept Exploration

In concept exploration efforts it is important to estimate operator and maintainer performance capabilities and limitations with various technologies. Models of total system performance can then be built that incorporate those estimates and be used to make reasonable comparisons of the effectiveness of the various technologies. Furthermore, such models can be used to support trade-off analyses by comparing the effectiveness and cost of various technologies under different levels of manpower, personnel capabilities, and training.

It is during this time that the human factors team should begin putting together an HSI plan for managing the human factors effort. A solid HSI management plan identifies and tracks the HSI issues and concerns that are identified for a new system and gives direction to the HSI effort by mapping a strategy for resolving those issues. To be successful, it must be fully coordinated with the PM or other individual who has oversight of the program at this stage in the life-cycle process.

4.3.4 Component Advanced Development

The role of HSI during component advanced development efforts is somewhat different than that in concept exploration. Since the emphasis is on demonstrations and experimentation, the need is for input into the design of the demonstrations and experiments to ensure that the right human performance data are collected so that the contribution that the human makes to total system performance can be accurately measured. Without reliable and valid data indicating what types of errors operators and maintainers are making or what critical tasks they are failing to complete within required time constraints, it is not possible to accurately evaluate the effectiveness of the operator or maintainer as part of the total system. The right human performance data must be collected and analyzed in the context of their contribution to total system performance in order for the data to be useful.

4.3.5 HSI Management Plan

It is critical that HSI considerations be fully incorporated into the ORD. The Joint Chiefs of Staff (DoD, 1999c) address the role of HSI in operational requirements generation, although it is in that part of the ORD called Program Support (pp. E-A-3 to E-A-6) rather than under the Capabilities Required section that includes the KPPs. Table 4.1 shows those

TABLE 4.1 HSI Functions To Be Accomplished and Addressed in ORD

1. Establish broad manpower constraints for operators, maintainers, and support personnel.
2. Identify requirements for manpower factors that impact system design (e.g., utilization rates, pilot-to-seat ratios, and maintenance ratios).
3. Establish broad cognitive, physical, and sensory requirements for the operators, maintainers, or support personnel that contribute to or constrain total system performance.
4. Establish requirements for human performance that will achieve effective human–system interfaces.
5. Identify requirements for combining, modifying, or establishing new military occupational specialties.
6. Describe the training concept to include requirements for the training support package (e.g., simulators, training devices, embedded training) and training logistics.
7. Include safety or health considerations that reduce job performance or system effectiveness, given the operational environment.
8. Identify critical errors that reduce job performance or system effectiveness, given the operational environment.
9. Determine objectives and thresholds for the above requirements, as appropriate.

Source: Adapted from U.S. Department of Defense, 1999c.

HSI considerations that must be addressed under Program Support. As one can see, the requirement is to cover the basic domains of HSI and to include manpower, personnel, training, and human factors engineering as well as safety and health hazards. However, it is important that the HSI professional closely examine the HSI issues and determine if any of them warrant being included in the capabilities section as a KPP. If the evaluations and analyses during concept exploration and component advanced development have revealed any human performance parameters that are likely to lead to system failure if they are not adequately considered during system development, then they need to be put forth as KPP candidates. This is where the existence of an HSI management plan that documents HSI issues and concerns can be helpful. It can serve as a ready source of issues for inclusion in the ORD.

The HSI management plan can also serve as the vehicle for introducing HSI considerations into plans for testing and evaluating the system. The DoD regulations require that the PM establish an overarching document, called the TEMP, early in the life cycle that lays out the plan for testing and evaluating a system during the course of its development. It is essential that human performance issues be integrated into that document if the human is to be adequately tested and evaluated as a contributor to total system performance. Directive 5000.2-R (DoD, 2001, p. 83) addresses these points. It indicates that “the program manager shall initiate a comprehensive strategy for HSI early in the acquisition process to minimize ownership costs and ensure that the system is built to accommodate the human performance characteristics of the user population that will operate, maintain, and support the system.” It goes on to state: “The PM shall work with the manpower, personnel, training, safety and occupational health, habitability, survivability, and HFE communities to translate the HSI thresholds and objectives in the ORD into quantifiable and measurable system requirements.” Finally, it states: “The PM shall include these requirements in specifications, the TEMP, and other program documentation, as appropriate, and use them to address HSI in the statement of work and contract.” Clearly, an HSI management plan is needed to coordinate and satisfy these requirements.

A completed ORD with detailed performance specifications is required for entering the next phase of the life-cycle process. Once the appropriate decision authority has given a favorable decision at milestone B, then a new system acquisition is formally started and the process enters the next phase.

4.4 SYSTEMS ACQUISITION

At this point in the life cycle a system architecture has been specified based on technologies that are relatively mature and have a reasonable chance of contributing to successful system development, and the operational requirements have been specified in the ORD. The ORD, rather than the MNS, now drives the life-cycle process. The first phase of system development in the DoD life-cycle model is called system development and demonstration. As the name indicates, its purpose is to develop the system fully while reducing program risk, ensuring operational supportability and affordability, designing for producibility, and demonstrating system integration, interoperability with relevant systems, and utility. It consists of two work efforts; namely, system integration and system demonstration. If these are successful, the production and deployment work efforts follow.

4.4.1 System Development and Demonstration

During system integration the various technologies or subsystems are integrated into the overall systems architecture to produce a complete system. An initial prototype is built and demonstrated in an environment that is relevant to the system in which it is expected to operate. The focus of the whole effort is to ensure that the subsystem technologies can be made to work in an integrated fashion and reduce system-level risk. Following the successful demonstration of the initial prototype, the system demonstration work effort is begun wherein the system is fully developed and engineering development models are successfully demonstrated in the intended environment. It is during this work effort that the system is subjected to a variety of testing and evaluation to ensure that it is on track in meeting the specifications and requirements laid out in the ORD.

4.4.2 Request for Proposal

During the system development and demonstration phase it is important to refine and update the issues in the HSI plan by iterating through the HSI framework discussed previously and shown in Figure 4.4. In addition, there are a number of activities that are unique to this phase and that should have HSI input. It is at the very beginning of this phase that the PM issues a request for proposal (RFP), which describes to industry the requirements for a new system. This document contains numerous sections, but there are several in which HSI should be represented.[6] They include the statement of work (SOW), the system specifications, and the basis of award.

The SOW contains a description of the work to be performed by the contractor to include any efforts needed to produce required management and technical data. The HSI tasks that are appropriate for this section include the scope of the contractor's HSI effort, including the various HSI domains that need to be addressed, and specific HSI data collection efforts and analyses to be performed to ensure that human performance is effectively contributing to total system performance.

The system specifications section describes the performance requirements for the system to be developed and are based on the operational requirements found in the ORD. Key HSI issues in the ORD must be reflected in this section. For example, if there is a limit on the manpower available to operate and maintain the system, that should be stated clearly in the specifications.

The basis of award section describes how the technical proposals from the various vendors will be evaluated and how a winning vendor is selected. Proper attention to the inclusion of HSI in this section is critical if HSI is to be given meaningful attention by the vendor who is awarded the contract for system development. Typically, management, technical, and cost considerations have been given the highest weight in system proposal evaluations. However, the U.S. Army HSI community has pushed for and been successful in getting HSI to have equal weight with those factors. In the case of one system, the Comanche, HSI and training were given 17.5 percent of the total weighting; reliability, availability, maintainability, and integrated logistics support, which have clear HSI implications, were given 17.5 percent; and technical, which had numerous areas with HSI implications, was given 35 percent (Booher, 1997). The result was that HSI had as much or more weight in the final evaluation leading to source selection than any of the other evaluation factors. The Comanche development has been quite successful from an HSI point of view.

4.4.3 Design Support

Human systems integration has an additional role to play during system development and demonstration. It is during this phase of the acquisition process that the design becomes relatively fixed. The HSI information is needed to make rational design decisions, and much of this information comes from the knowledge of the HSI professional and the information he or she can derive from small focused human performance experiments and from modeling and simulation.[7] The DoD has in the past few years put increasing emphasis on the use of modeling and simulation as a means to reduce development costs and acquisition time. Human figure modeling tools[8] can give critical information about the adequacy of the physical layout of operator and crew stations, to include reach distances, fields of view, and display and control layouts. Task performance oriented modeling tools can give valuable information about the likelihood of operators and crews being able to effectively interface with the design.[9]

4.4.4 Testing and Evaluation

Another important function occurring during this phase is testing and evaluation (T&E) of the prototype system. While planning and some preliminary test and evaluation activities occur in the concept and technology development phase of the life cycle, most formal testing and evaluation are accomplished during the system development and demonstration phase and the production and deployment phase. There are two basic types of testing that are typically done to support the evaluation of a developing system: developmental testing (DT) and operational testing (OT). Developmental testing is engineering-oriented testing directed toward ensuring that adequate progress is being made technically. It is under the control of the PM and seeks to minimize design risks and, at the appropriate time, certifies that the system is ready for initial operational testing. On the other hand, OT is operations oriented and is done to ensure that the system can be operated and maintained by typical individuals and crews in mission environments. It is controlled by agencies that are independent of the PM. Developmental testing examines not only the system but also subsystems and components, whereas OT typically looks at the whole system. Within both DT and OT are a variety of tests that are executed, depending on the state of the system.

Human systems integration has a role to play in both DT and OT [see Meister (1986) and O'Brien and Charlton (1996) for detailed expositions on the role of HSI in T&E]. Both are opportunities to collect human factors data that can address the issues that have been laid out in requirements documents and the HSI management plan. The DoD military handbook 46855A (DoD, 1999b) lists the following HSI activities that should be accomplished in T&E:

- Verify that personnel can safely perform tasks to time and accuracy standards without excessive workload.
- Verify that system characteristics support effective and efficient operation.
- Verify that the human engineering design of the hardware supports human use.

- Determine the adequacy of human performance as a component of system performance.
- Determine the effects of operational variables on human performance.
- Determine the appropriateness of modifications.

In the past, HSI professionals have not attended to DT as much as to OT. This is partly due, perhaps, to the fact that the DT environment is not as operationally realistic as the OT environment. Nevertheless, DT has an advantage in that there is usually much more control over the total test environment, thus increasing the likelihood of the HSI professional being able to collect substantial amounts of reliable and valid data. In the future it would behoove the HSI community to take more advantage of the opportunities that DT has to offer.

Regardless of whether one is working in a DT or OT environment, there are a number of approaches that are used to collect human factors data relevant to HSI. These include taking physical measurements of equipment, the system environment, and the human; measuring task performance when operators and maintainers are using the system or components thereof; and administering instruments to obtain subjective assessments from operators and maintainers, such as questionnaires and interviews.

Information from physical measurements is the most standardized. Methods and instrumentation for obtaining such information [e.g., see Eastman Kodak Company (1983) and Meister (1986)] and associated standards (e.g., see DoD, 1999a) are well established and can be found in a variety of resources. It is obvious that humans operate best when various aspects of their work environment are within limited bounds, including air temperature, humidity, and quality (i.e., absence of noxious and toxic gases); illumination; sound (to include limits on the intensity of background noise and the relative intensity of communications and auditory signals); vibration; and physical characteristics of equipment (e.g., the weight of an item that has to be raised to shoulder height when setting up a system, the force required to activate a switch, etc.). Measurements on these variables are important not only because they contribute to operator and maintainer efficiency but also because extreme levels can be hazardous to health. Along these lines, measures of operator physiological state are sometimes taken to obtain indications of the extent to which he or she is experiencing stress (O'Brien and Charlton, 1996).

Measurement of operator and maintainer task performance consists of determining the critical tasks that have to be completed for successful accomplishment of a system's mission and then determining the extent to which these critical tasks are actually accomplished during a mission. The performance measures that can be taken include type of error made, time to accomplish a task (which can be a type of error in and of itself), and frequency of errors [see Gawron (2000) for a more detailed discussion of human error measurement and Reason (1990) for a theoretical treatment of human error]. Collection of error information can be done in a variety of ways. Trained observers can watch operators and maintainers perform their tasks and record and describe errors as they occur, either during the test itself or from videotape that was made during the test (the latter is usually more practical since there is often not enough room in crew compartments or operator stations for an extra person). Or information can be tapped from system databases to indicate the status of switches and controls relative to activities that are occurring during the test, thus revealing whether or not the operator took the correct actions at the appropriate time.

Error data are arguably the most important HSI information that can be collected, for without an objective, quantitative measure of human performance it is very difficult, if not impossible, to determine the effect the human is having on total system performance. When a system fails to meet a mission goal, the only meaningful way to determine if the operator or maintainer contributed to that failure is by linking the performance of the system at critical times to pertinent actions of the operator or maintainer. If such linkage shows that task errors partially or fully led to the degradation of system performance and mission failure, then the reasons for the task failure can be investigated and HSI-related changes made, such as redesigning the user–system interface, reallocating tasks among crew members, increasing the training of operators on that task, increasing the size of the crew, and so forth.

The most widely used approach to obtaining HSI information during T&E involves the use of subjective instruments. These include questionnaires, rating scales, and interviews. Such instruments, when properly designed, can provide a wealth of information to the HSI professional. However, they are most useful in providing information for explaining why errors have occurred or are likely to occur and as such are best used in conjunction with actual error measurement methods. The most common approach is the use of the questionnaire, most likely because it can be put together quite easily, rapidly tailored to the characteristics of the system under consideration, and easily administered [although see Babbit and Nystrom (1989) and Charlton (1996) for discussions of good questionnaire construction techniques]. But good questionnaires take a fair amount of thought and effort to ensure that the questions asked are well constructed, clearly understandable by the target audience, and focused on relevant issues. They are best supplemented by one-on-one interviews with respondents to clarify the answers given.

Other subjective techniques include various types of rating scales. Many of these have advantages over tailored questionnaires because they have been validated in a variety of situations, whereas a questionnaire is usually tailored to a given system, with the questions being written so that they have face validity; no independent validation is attempted. Several rating scales for obtaining subjective assessments of workload and situation awareness have become quite popular and have been widely used in recent years (e.g., see Gawron, 2000).

Regardless of the subjective technique that is used, it is important to recognize the point made several paragraphs ago—namely, that these are best used to provide supplemental information to direct performance measurements in order to explain why critical tasks are not being performed correctly or to provide information indicating that certain critical tasks are not likely to be performed correctly under certain situations, as in high workload, for example.

4.4.5 Production and Deployment

Once the relevant DoD decision authority has deemed a system mature enough for production (i.e., it has passed milestone C), it enters the production and deployment phase. In this phase it has to undergo a major initial operational test and evaluation (IOTE), which is a statutory requirement that must be performed on all major military systems by an agency independent of the developer. It is a large field test conducted under relatively realistic operational conditions with production representative systems. It is the final hurdle of system development before proceeding into full-scale production. A low-rate initial production of systems off of the assembly line is authorized for the test. Following a favorable evaluation, full rate production is authorized and the system is fielded.

The IOTE is usually the final opportunity to collect HSI-relevant data on the system during the formal acquisition process (although sometimes a system is required to have additional testing—called follow-on T&E—if some troublesome but not serious problems are uncovered in IOTE). A tremendous amount of time and effort is spent on IOTE, and HSI concerns and issues are typically prominent in the overall data collection plan, especially if they have been prominently identified in the ORD and are included in a KPP. The IOTE data collection effort is structured around critical operational issues and criteria (COICs) found in the TEMP. The COICs in turn are derived from critical issues and requirements in the ORD, most notable of which are the KPPs. But COICs are not the only issues addressed in IOTE; many additional issues are also addressed. What is important about IOTE with respect to HSI is that multiple copies of the system are being exercised as part of a unit with typical operators and maintainers in a relatively realistic operational scenario occurring over several days. This context gives the data that are collected more meaning than previously collected data, and inferences drawn about numbers, skills, and training of operators and maintainers needed for effectively operating and maintaining the system are likely to be more valid, as are conclusions about the user–system interfaces. However, the downside of this situation is that the design of the system is essentially complete, so any recommendations that the HSI professional might make for improving the design are not likely to be accepted unless they result in the correction of a design characteristic that is contributing to the substantial degradation of system performance. Thus, HSI must place substantial effort on the early stages of system design; efforts at that phase are likely to have the most impact.

4.5 SUSTAINMENT

The final activity in the life cycle is that of sustainment. During this period the fully fielded system is supported with maintenance activities and minor modifications that are needed to keep the system fully operational during its useful life. The HSI activities have not focused on this period in the past. However, much useful HSI data could be obtained here without a tremendous amount of effort. Perusal of maintenance records can reveal much about maintenance demands of the system over time, revealing high driver maintenance tasks that should be avoided in future upgrades to the system or in the development of similar systems. Questionnaires and interviews can be used to solicit information from operators and crews about operational problems they have experienced with the system, serving much the same role. It is impossible to thoroughly test a new system in all of the situations in which it is likely to be employed, and some flaws in a system may only be revealed when the system is in one of those types of situations. Such information that might be of use to the HSI community is lost unless specific focused efforts are made to retrieve it.

4.6 CONCLUSION

The life cycle of a system proceeds through a number of activities, to include defining what the system should be; designing, building, and evaluating the system; and sustaining it after fielding. Human systems integration has an important role to play in each of these periods, but its contributions with the most potential are in the early stages of the life cycle, when the system requirements are being established and the initial design is being derived. It is here that fundamental decisions are made about what functions the system is to perform and how it is going to be designed to satisfy them. The HSI professionals must step forth with their knowledge of human factors, their measurement methods, and their analysis and modeling tools and help program managers and system developers design systems that are operationally efficient and cost effective. While HSI activities in the latter phases of system acquisition are useful, their contribution by then is mainly in helping to make corrections to minor system problems and in providing information that may be of use in later upgrades of the system or in the development of future systems. It is only in the early stages of acquisition that substantial impact can be made. It is incumbent upon the HSI community to strive to make an impact during this early period to ensure that the systems that are developed can be used effectively, efficiently, and safely. The men and women of the armed forces who will use many of these systems in life-threatening situations deserve no less than our full and dedicated efforts in this endeavor.

NOTES

1. See Chapter 5 for a discussion of education issues in HSI.
2. On 29 August 2002 DoD announced that it was revising its acquisition policy. Pending formal publication of the revised policy, interim guidance was issued in SecDef Memorandum, “The Defense Acquisition System,” August 29, 2002, and in SecDef Memorandum, “Operation of the Defense Acquisition System,” August 29, 2002. The interim guidance retained the newer DoD model shown in Figure 4.2.
3. See Chapter 10 for a discussion of evolutionary and incremental acquisition.
4. Italics has been added for emphasis.
5. See the chapters in Part III for a description of essential HSI tools and techniques.
6. See Chapter 7 for a contractor’s perspective on this process.
7. See Chapter 9 for a description of simulation-based acquisition.
8. See Chapter 13 for a description of human figure models.
9. See Chapter 11 for a description of human performance models.

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