CHAPTER 1

Introduction: Human Systems Integration

HAROLD R. BOOHER

1.1 BACKGROUND[1]

On March 28, 1979, the central control room operators were alerted to a loss of feed water to the pressurized water reactor (PWR) of the Three Mile Island Unit 2. The safety injection pumps came on automatically to pump in auxiliary water to the reactor vessel. The indicators for the pressurized vessel, however, showed a dangerous "water-solid" condition for the pressurized vessel. In an attempt to reduce the pressurizer water level, the operators turned off the safety injection pump. Consequently, the reactor core water cover became depleted, leading to a near meltdown. As a result, the nuclear industry radically changed its management and organizational approaches to nuclear safety but has never fully recovered from the effects of the accident or alleviated the public concerns with nuclear energy.[2]

In the Persian Gulf on July 3, 1988, the U.S. Navy crew of the *Vincennes* shot down an Iranian commercial jetliner killing all 290 civilians on board.[3] On February 16, 1996, Maryland Rail Commuter (MARC) train 286 collided with AMTRAC passenger train 29 near Silver Spring, Maryland. The 3 crewmembers and 8 of the passengers on the MARC were killed, and 26 people on the two trains were injured, in the derailment and subsequent fire.[4] October 31, 1999, Egypt Air flight 990 went into a rapid descent 30 minutes after takeoff from New York to Cairo, crashing into the Atlantic Ocean, killing all 217 people on board.[5] Although the cause is still undetermined, pilot suicide cannot be ruled out.

These are only a few of the more dramatic examples of the effects on society from failures in technology at the interface of people and machines. Internationally remote areas such as Bhopal, India, and Chernobyl, USSR, are now part of household vocabularies because of the tragedies there. The *Challenger* showed us even space is not immune from human-designed technological mistakes, and although safety is constantly improving in some technologies, it is still the leading cause of death in others. More people die in automobile accidents every year than the army casualties for the entire Vietnam war.[6]

Handbook of Human Systems Integration, Edited by Harold R. Booher.
ISBN 0-471-02053-2

Although technology is constantly improving, the number of catastrophic incidents can be expected to rise as well, if for no other reason than the opportunities for both human and machine failures increase with complexity, and rapidly developing technologies involve greater and greater operational complexity (Perrow, 1999).

The loss of lives is not the only cost. The waste in productivity every year is astronomical. The Three Mile Island accident, where no lives were lost, cost General Public Utilities Nuclear over $1.3 billion in radioactive waste cleanup and borrowed electrical energy expense. The cost to the American industry from failure, rework, and waste resulting from substandard manufacturing has been estimated at over $600 billion a year—enough to pay off the national debt in less than 6 years![7]

Solutions to this modern societal problem of unnecessary losses in lives, productivity, and quality of life are extremely complex. People are both the cause and the solution. People are the benefactors and the victims. Through human error in design, operation, or repair of machines, people are hurt, killed, made unhappy, or, at the very least, inconvenienced. On the other hand, it is through human intelligence and unique human skills that equipment, organizations, and knowledge-enhancing products are designed and operated effectively, efficiently, and safely. The quality of any product produced by any industrial organization depends ultimately on the interplay of several primary factors, all under the control of people themselves. The manner in which people can assess how well they are controlling these factors depends on how well they can determine and manage cost, performance, schedule, requirements, and risk.

1.1.1 Focus on Human Element

It is a fundamental belief of this writer that through a focus on the human element it is possible to achieve both (a) dramatic reductions in waste and victims on the debit side of society's ledger and (b) dramatic increases in system performance and productivity on the credit side.

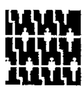
It is further believed that unless the human element is considered to be a critical component of the complex system, few of these benefits can be achieved by an organization that produces, buys, or operates complex systems. On the other hand, these benefits are most likely to be achievable if an organization's focus is first and foremost upon the people who, in some manner, will be directly exposed to the complex system.

The need to consider the human element as a critical component tends to be supported by the vast number of horror stories such as those sampled above. This recognition of the importance of the human element is generally accepted by systems engineering and systems management philosophies. People, technology, and organizations make up the three top-level components of any complex system (Sage and Rouse, 1999, p. 57). The idea that dramatic organizational benefits are *most likely* to be achieved through focus on people, however, is unique to the human systems integration (HSI) philosophy. While we may avoid some of the catastrophic outcomes from poorly human-engineered designs of systems or increase efficiency of poorly performing systems by recognizing that the human component is critical, it is not so obvious even to systems engineers and systems integrators that the *dramatic* reductions in costs, both human and financial, and the *dramatic* increases to performance and productivity are *most likely* to appear when the focus is upon the human element inherent in the system.

1.1.2 The Army HSI Program

The U.S. Army was the first large organization to fully implement and demonstrate the benefits of an HSI approach, by focusing upon the human element. In 1986, the army created a Manpower and Personnel Integration (MANPRINT) management and technical program designed to improve weapons systems and unit performance. The army leaders decided it was necessary to change the focus of equipment developers away from "equipment-only" toward a "total system" view—one that considered soldier performance and equipment reliability together as a system. The program was extremely broad, including all army management, technical processes, products, and related information covering the domains of manpower, personnel, training, human factors engineering, system safety, and health hazards. After the Gulf War, largely because of the fratricide incidents, the army added a new domain, soldier survivability, to MANPRINT (see Fig. 1.1).

The most unique aspect of the program was effective integration of human factors into the mainstream of system definition, development, and deployment. Organizationally, the MANPRINT domain functions were spread throughout the army with major roles being performed by Army Materiel Command, Training and Doctrine Command, Office of the Surgeon General, Army Safety Center, Army Research Institute, and the Human Engineering Laboratory. Responsibility for integrating these varied human factors functions into the materiel acquisition process was with the Deputy Chief of Staff for Personnel (DCSPER) on the Department of Army Staff. The policy that provided the formal definition and various roles and responsibilities was presented in Army Regulation



Manpower
The number of human resources, both men and women, military and civilian, required and available to operate and maintain military systems.

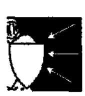
Personnel
The aptitudes, experiences, and other human characteristics necessary to achieve optimal system performance.

Training
The requisite knowledge, skills, and abilities needed by the available personnel to operate and maintain systems under operational conditions.

Human Factors Engineering
The comprehensive integration of human characteristics into system definition, design, development, and evaluation to optimize the performance of human-machine combinations.

System Safety
The inherent ability of the system to be used, operated, and maintained without accidental injury to personnel.

Health Hazards
The inherent conditions in the operation or use of a system (e.g., shock, recoil, vibration, toxic fumes, radiation, noise) that can cause death, injury, illness, disability, or reduce job performance of personnel.



Soldier Survivability
The characteristic of a system that can reduce detectability of the soldier; prevent attack if detected; prevent damage if attacked; minimize medical injury if wounded; and reduce physical and mental fatigue.

Figure 1.1 MANPRINT domains.

602-2, Manpower and Personnel Integration (MANPRINT) in the materiel acquisition process (U.S. Army, 1990).

In the latest revisions to the MANPRINT policy (U.S. Army, 2001), several major roles have changed, most significantly with the Army Research Laboratory performing the technical work of all the domains except systems safety (Army Safety Center) and health hazards [Army Center for Health Promotion and Preventive Medicine (CHPPM)]. However, even though the basic philosophy laid out originally has not changed, implementation effectiveness has varied considerably over time (see Section 1.7).

1.1.3 Other HSI Programs

The desired objectives of the MANPRINT approach to systems integration and the human factors domains of the army program have both been adopted by the U.S. Department of Defense with its HSI program and in the UK Ministry of Defence with its human factors integration (HFI) program. The Federal Aviation Administration (FAA) has also implemented major portions of MANPRINT into its HFI program. The MANPRINT philosophy presented in the original MANPRINT book (Booher, 1990) is presented here as an HSI philosophy, with the understanding that essentially the same concepts and principles apply whether the term used is HSI, HFI, or MANPRINT. As the HSI philosophy evolves, newer HSI programs (U.S. Air Force, U.S. Navy, UK Ministry of Defence, The Netherlands Applied Scientific Research Organisation and FAA) are making significant contributions both in the development of advanced HSI technology and in procuring new systems with HSI in their systems engineering and management processes.

1.2 HSI CONCEPT

The HSI concept is described in several different ways:

1. The formal Department of Defense (DoD) definition
2. In terms of key benefits
3. As a top-level conceptual model

1.2.1 HSI Definition

Human systems integration is primarily a technical and managerial concept, with specific emphasis on methods and technologies that can be utilized to apply the HSI concept to systems integration. As a concept, the top-level societal objectives of HSI are to significantly and positively influence the complex relationships among:

1. People as designers, customers, users, and repairers of technology
2. Government and industrial organizations that regulate, acquire, design, manufacture, and/or operate technology
3. Methods and processes for design, production, and operation of systems and equipment

It is believed that most of the technical and managerial advances suggested by the HSI concept can be accomplished within an overall systems integration philosophy that places a special emphasis on how its roles and technology can be included within systems engineering and systems management processes. As such, the HSI concept is considered to be an important adjunct to the various levels of systems engineering and management described in the *Handbook of Systems Engineering and Management* (Sage and Rouse, 1999). The HSI concept is fully compatible with those systems engineering processes relevant to systems definition, development, and deployment and their life-cycle phases, as well as the systems engineering methods, tools, and technologies.

Organizations that have created programs that adopt certain aspects, wholly or in part, of the HSI concept provide their definitions in programmatic language. The army has defined its MANPRINT program as a comprehensive management and technical program "which focuses on the integration of human considerations into the system acquisition process to enhance human/system design, reduce life cycle ownership costs, and optimize total system performance. MANPRINT accomplishes this by ensuring that the human is fully and continuously considered as part of the total system in the development and/or acquisition of all systems" (U.S. Army, 2001, p. 1).

The DoD lists its requirements for HSI under its systems engineering requirements[8]:

> For all programs . . . the PM [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. The PM shall work with the manpower, personnel, training, safety and occupational health . . . , habitability, survivability, and HFE [human factors engineering] communities to translate the HSI thresholds and objectives in the ORD [operational requirements document] into quantifiable and measurable system requirements. The PM shall include these requirements in specifications, the TEMP [test and evaluation master plan], and other program documentation, as appropriate, and use them to address HSI in the statement of work and contract. The PM shall identify any HSI related schedule or cost issues that could adversely impact program execution [U.S. Department of Defense, 2001, 5000.2-R, paragraph C5.2.3.5.9. HSI].[9]

1.2.2 HSI Benefits

Whether HSI professionals seek out their customers or the customer comes to them for assistance, both may be surprised at the wide range of HSI benefits possible depending on the customer's role in the organization. Table 1.1 lists three types of audiences who could benefit from HSI applications. One group includes those who have high levels of responsibility for systems decision. The second group includes those who are primarily concerned with the operational processes within the organization that form its day-to-day reason for existence. The third group comprises those who are closer to the technology and engineering disciplines with roles in assuring the organization actually produces something tangible and usable.

The cells show sample benefits that can be provided by the HSI professional for different audiences. Depending on the HSI theme, for example, "user focus," "integration," or "performance measurement," benefits can vary considerably. For example, if the leadership of an organization is open to knowing the value added from an HSI approach, the HSI

TABLE 1.1 HSI Activities by Benefit Areas

Benefit Areas	User Focus	Integration	Performance Measures
Management and organization	Show leadership potential benefits of user focus and how to implement cultural change needed for their organization.	Show management how to integrate people, processes, and technology to achieve organization objectives.	Show decision makers how to assess risk from human error in their organization and how to measure costs and benefits of user-centered business decisions.
Operational processes	Develop new or revised operational processes that utilize user-centered techniques (such as functional and task analysis). These are compatible with systems engineering and operational analysis techniques.	Write policies and procedures for developing, changing, and conducting processes that integrate contributions from multiple skilled disciplines in human sciences and technology.	Measure effectiveness of processes with human–machine interfaces. Provide guidelines for changing processes to reflect user-centered performance and safety enhancements.
Product design	Develop and implement user-centered design procedures.	Utilize human factors skills and tools in the design and development of products.	Evaluate human performance, safety, and usability of products.

professional can show top-level management ways to "integrate" people, processes, and technology in terms of the organizational objectives. It is always helpful to show the leadership ways in which HSI performance can be measured, as in assessing the risk from human error in their organization and how to measure costs and benefits from user-centered business decisions.

Benefits of interest for the operational process audience might include the development of revised procedures for the organization, which utilize such user-centered techniques as functional and task analyses. It would be helpful for the HSI specialist to point out how their techniques are compatible with systems engineering and operational analysis techniques.

When working directly with designers of products, the HSI specialist should be sufficiently familiar with the various human-related technologies and disciplines (sampled in the other chapters in this Handbook) to help the designer meet the organization's product goals and the user's needs without compromising cost, schedule, performance, or safety.

1.2.3 HSI Model

The model illustrated in Figure 1.2 describes HSI at its highest conceptual level. The HSI process inputs are systems that utilize all aspects of systems engineering and management, which can be summarized within the three fundamental stages of systems processing—systems definition, development, and deployment. The output of the HSI process is systems integration of people, technology, and organization. The reader might note that even without the HSI process being imposed, the principles and disciplines of engineering and operations would still define, develop, and deploy systems that would integrate people, technology, and organization. This process would be accomplished without full consideration, however, of the human requirements of the user or the expertise and technology offered by the HSI field, resulting in those very conditions of poor systems integration that organizations would like to avoid.

The HSI model, therefore, emphasizes two additional inputs that guide the HSI process as it influences the systems engineering and management processes. These inputs are (1) a user focus on all aspects of the systems definition, development, and deployment stages and (2) the combined application of human-related technologies and HSI disciplines. Any system, product, or equipment that passes through the HSI process modulated with these two inputs will have a high likelihood of having an adequate consideration of the people component.

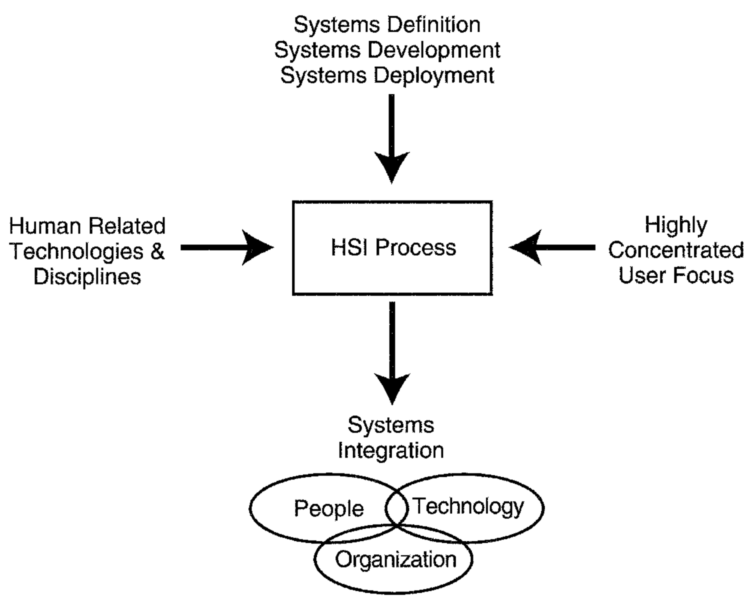


Figure 1.2 Human systems integration model.

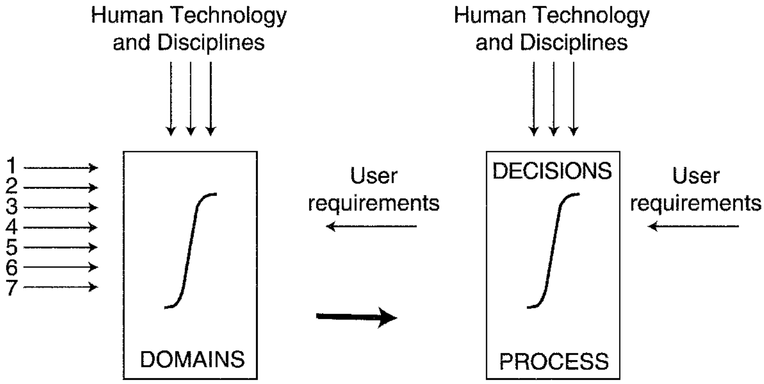


Figure 1.3 HSI double-integration process.

1.2.4 Double-Integration Process

Figure 1.3 shows the HSI process behind the high-level concept. The HSI process is essentially a double-integration process where both integration steps are modulated by human-related technologies and disciplines and driven by user requirements. The first integration step creates a common focus for all seven HSI domains. Before MANPRINT in the army, each of the domains operated directly with the program manager (PM) for trade-off decisions regarding human concerns. Several of the domains, such as manpower, personnel, and training (MPT) were seldom considered at all in design trade-off decisions. The human factors engineer may have had the ear of the PM, but not early enough in the requirements definition process to make a design decision that affected MPT. Further, the HFE specialist had little expertise on these three domains. In other cases, perhaps several of the domains would raise a safety or health issue, but individually they were traded off, so that the issue was not given the visibility that MANPRINT provided. In the final analysis, the enormous increase in cost-effectiveness of a common HSI approach is critical to meet the system objectives. On one major aircraft program, it was demonstrated that the dramatic cost, performance, and safety objectives achieved with HSI were met with the same percentage of program funding as had been provided to past aircraft programs; yet in the earlier programs no such benefits were demonstrated. The difference was attributed to more effective use of funds when managed through HSI than when managed by domains independently.

At the second integration step, HSI contributions are fully integrated with the systems engineering and management processes. All the policies, procedures, guidelines, standards, specifications, and other documentation that relate to systems acquisition in the federal government and its contractors are part of the decisions process indicated in Figure 1.3. Such documentation must address all the HSI information needs and the roles and relationships of HSI with all the other systems engineering and management information needs, roles, and relationships.

For example, the types of user requirements (such as anthropometric measures or number and skills of personnel) might be reflected in a target audience description (TAD). The HSI technologies might include such items as man-in-loop simulation, human performance assessment, cognitive workload measurements, work space anthropometrics, or human systems trade-off methodology. Some of the disciplines closely associated with

HSI include human factors engineering, engineering psychology, manpower/personnel research, operations research analysis, systems safety engineering, and health hazards analysis.

1.3 SOCIOTECHNICAL SYSTEMS COMPLEXITY

The applicability of HSI varies with sociotechnical systems complexity. Table 1.2 shows sociotechnical systems ranging from very highly complex organizations with thousands of interactions between technology, people, and organizations to relatively small devices that make up functional systems (levels A to F). The HSI technology and disciplines are currently capable of aiding most directly in the design, development, and deployment of sociotechnical systems indicated as level D and below.

The greatest impact for life-cycle costs and performance improvements are centered on levels D and E. Examples include systems such as aircraft, tanks, cockpits, and other workstations for command and control operations. It is at these levels where the HSI state of the art is sufficiently developed to make major contributions. There are complex sociotechnical systems currently operating at level C and above, but HSI technology is not itself far enough along to make significant changes that will help make these levels perform more effectively. However, the needs of level C sociotechnical systems do suggest research and development (R&D) activities that should be taken to advance HSI technology. The military is already beginning to recognize that new HSI technology is needed to contribute to "technological system of systems" such as the navy's future aircraft carriers and the army's future family of battlefield vehicles. In a military "system of systems," the goal is to design complex sociotechnical systems made up of several diverse D level systems that will operate during war in a completely cohesive manner, analogous to individual systems.

Possibly the most complex operating environments outside the military that utilize current state-of-the-art HSI technology are human/machine control rooms for Air Traffic Control and National Aeronautics and Space Administration (NASA) Space Flight Centers. Nevertheless, because of the similarity of the items being controlled, and the design complexity of the technology, they are still level D sociotechnical systems. A hospital emergency center is conceptually a level C technological system because of the large number of activities (systems) going on simultaneously. An operating room may be considered a level D technology system because of the extreme diversity of procedures requiring people and technology interface. However, the "emergency and operating room system" is primarily made up of large numbers of level F systems of people and small devices. There are so few HSI sociotechnical applications for medical environments at the E level that it would be a great innovative leap to design a major technological system for an emergency or operating room.

The HSI applications to sociotechnical level A requires working with numerous other disciplines such as economics and political science in the formulations of policies, procedures, education, etc. The significant HSI changes to date have been directed at level B sociotechnical systems such as the DoD and FAA acquisition processes and their contractor organizations. It is believed that similar changes could benefit other mission areas such as health care, energy, and education with dramatic improvements in technological systems procured and/or regulated (see the Afterword). In two instances, level A organizations have provided the support and understanding necessary to introduce

TABLE 1.2 Sociotechnical Systems—Levels of Complexity by Mission Areas

	Mission Areas			
Sociotechnical Systems	Military	Health Care	Energy	Transportation
A. Very highly complex organizations				
Governmental agencies	Army department		Dept. of Energy	Dept. of Trans.
Unpredictable environments	Warfighting units			
B. Highly complex organizations				
Procurement/regulation agencies	DoD acquisition	Food and Drug Admin.	Nuclear Reg. Com.	Federal Aviation Admin., Federal Highway Agency
Product/service organizations	Large contractors	Hospitals	Nuclear power plant	
C. Complex organizations				
System of systems	Aircraft carrier	Emergency room		
D. Major technological system	Aircraft, tank, command & control	Operating room	Power generator control room	Train, car Air Traffic Control (ATC) room
E. Critical technological subsystem	Aircraft cockpit		Controls/displays	ATC console
F. Small systems/devices (system parts)	Radio, radar (engine, wings)	MRI, monitors (tubes, cables)	Feed water pump (steam pipes)	Bicycle (tires)

HSI into their B level organizations for systems acquisition. These organizations are the U.S. Department of the Army and the Ministry of Defence in the United Kingdom.

1.4 HSI UNIQUE ASPECTS

Table 1.3 lists unique aspects of the HSI philosophy characteristic of those organizations that adopt a people-oriented concept in their systems integration approaches to product design and manufacture. To begin, the benefits of a common focus of management is provided through the practice of top-down leadership and goal setting combined with bottom-up planning and execution. By giving high-level visibility to people-oriented concepts at all levels, the desired wide-sweeping changes have a realistic environment in which to grow. Understanding the concepts at the very top of an organization can bring focus on people throughout and sets up a reward system that instills competence and motivation in its employees.

The HSI concept recognizes the strengths and weaknesses of various disciplines. It may be wise to let the human factors engineer take the lead for integrating several other disciplines into any specific system design. But HSI would immediately remind the systems integrator of military systems, for example, that it is the enormous unnecessary MPT costs resulting from poor design that most influence the minds of government decision makers.

In HSI, decision makers and facilitators take advantage of technological developments in systems engineering and systems management. Inherent in several of these advances is the capability to quantify and measure human characteristics. These newer methods also allow better decisions to be made early in the design and development process where changes are relatively inexpensive to make.

The HSI process subscribes to the belief that investment in the front end on human factors will provide paybacks manyfold in the long term. But it goes beyond this to promise more immediate benefits as well. One of the problems of long-term payback is that the long-term rewards for the front-end decision makers often do not accrue for them

TABLE 1.3 HSI Unique Aspects

- High-level visibility of people-oriented concepts
- Focus throughout total organization on competence and motivation
- Top-down approach rather than bottom-up
- Multidisciplinary views of design
- Quantification of people variables
- Systematic early warning of human error considerations
- Provides trade-off techniques early in design
- Pushes technology and aids engineering advances
- Inherent part of system—not just supporting role
- Communicates in decision maker’s language
- Encourages resources redirection rather than net increases
- Educates all people in the process
- Reduces demand for manpower, personnel, and training

personally. The HSI concept looks for more immediate productivity and cost avoidance measures first and then, as a bonus, points out the long-term advantages.

The HSI concept forces product technology to become more innovative. A company that recently adopted HSI into its helicopter engine design found out it had also produced an engine more competitive for commercial purposes. It did so at *no added cost* over its original design plan. Routinely, companies are finding that HSI provides the needed incentive to make the product not only user-friendly but also more reliable and cheaper to produce.

A fundamental concept of HSI is that people are considered part of any system being developed. At the same time, it is recognized that people issues and recommended actions must be described for decision makers in their own language. Frequently, these issues and actions are in terms of mission, resource, product, and/or process information.

Once introduced into an organization, a challenge for HSI is to remain viable during periods of budget constraint. It is easier to introduce new ideas when resources are increasing. But ideas that produce marginal returns during good times are vulnerable to extinction in bad times. HSI, therefore, encourages resource redirection rather than looking for a portion of a total net resource increase. Funds allocated to HSI and the disciplines it integrates frequently simply rise and fall proportionately with the fluctuation of the organization's budget. This comes from the belief that HSI is important, but no more so than any other activity contributing to the systems acquisition process. This belief is not above questioning as fiscally sound. In bad times, HSI may be one of the few areas where *increased* investment is warranted. In what other area can something be logically expected to produce more with less?

Education is absolutely essential to HSI. All people involved in the process from the top to the bottom must understand the concepts. Specialists are needed in certain areas, but to be successful HSI cannot, for example, rely solely on human factors specialists. New strategies are needed to provide HSI expertise to meet the increasing demand.

As the availability decreases (and consequently costs rise) for higher skilled operational and maintenance personnel, emphasis will be placed on simpler design. Systems and products that can be operated and repaired by fewer people, by lesser skilled people, and/or people with lesser training will be in greater demand. It is not an impractical expectation for the military, and probably in many commercial areas as well, to demand HSI designs that will allow reductions in all three areas—manpower, personnel, and training (MPT)—together. Too often in the past, cost reduction in one of these areas has merely shifted cost increases to one or both of the others. For example, when the army wanted to reduce total number of people, costs went up in recruiting higher skills. If it now tries to reduce cost of recruiting and retaining high-quality individuals, it will find increased training will be needed to maintain performance effectiveness. Improvement in equipment design is the most practical way to get major net reductions in MPT costs. It is a continual challenge for HSI researchers and engineers to develop methods and technologies that can help the HSI practitioner and systems engineer design systems that fully consider such MPT issues.

1.5 TEN HSI PRINCIPLES

During the past decade, 10 HSI principles have been identified that, to the degree they are applied, seem to assure that large organizations will capture the performance, cost, and safety objectives they desire for their systems. Conversely, to the degree any of these principles are left out entirely or a few are followed only marginally, large organizations risk their systems not meeting their desired system objectives. Moreover, specific systems programs that have followed these principles have been extremely successful, while those that have made compromises have made marginal progress. In some cases, programs have been canceled for failure to meet the system objectives; and in these cases, almost always the principles have been poorly followed as well. Several of these 10 principles have an obvious similarity to the unique aspects listed in Table 1.3. The main difference is that the HSI aspects are primarily stated in terms of special characteristics and benefits inherent in an organization that applies HSI—but no attempt is made to use them as criteria for building an HSI program or in assessing the program effectiveness—as is the purpose of the 10 principles.

The following 10 principles are crucial to effective HSI:

1. Top-level leadership
2. Focus on human-centered design (HCD)
3. Source selection policy
4. Organizational integration of all HSI domains
5. Documentation integration into procurement process
6. Quantification of human parameters
7. HSI technology
8. Test and evaluation/assessments
9. Highly qualified practitioners
10. Education and training program

1.5.1 Top-Level Leadership

Many programs in the past have attempted to bring greater focus to the human element in systems procurement using a bottom-up approach. Using this approach, organizations with human factors responsibilities and capabilities are assigned the responsibility to support other system design, development, and deployment activities. Historically, the bottom-up approach has had little positive effect on systems procurement. This is because the human factors disciplines operating in a support mode will find very few of the other HSI principles being applied throughout the systems acquisition organization. The HSI approach is completely reversed by having top-level leadership as its number one principle, meaning the leadership must infuse HSI throughout the organization, making HSI part of its culture, much in the Deming (1986) style that introduced total quality management in the commercial sector. Sponsorship of HSI by top-level leadership assures the organization adopts and continuously sustains the other nine HSI principles. This infusion should be done through implementing regulations with roles and responsibilities for HSI throughout the organization, actively encouraging HSI participation in top-level decision processes, providing wide-scale HSI education and training programs, and adopting HSI assessment, testing, and evaluation activities. Top-level sponsorship does not mean that large funding levels must be devoted to make the program successful, but it does mean that the advocacy is so visible that the nine other principles have a chance of being adopted. Without support from the highest management levels, the required organizational changes needed for effective HFI will not occur. If top-level sponsorship is withdrawn, support for the other principles will gradually wither.

1.5.2 Human-Centered Design Focus of Systems

This principle encourages the concept of defining a "system" more broadly than the hardware and software that industrial companies build. Procuring organizations should specify their requirements for a system in such terms as to include operators and maintainers as an inherent part of the "system." These requirements, which include the human element, should be translated quantitatively throughout the design, development, and testing processes in systems engineering measures of effectiveness and performance. Numerous examples of system failures in the past have been caused by failure to define a system in this broader sense. A very good illustration of how neglecting this principle of defining the system to include people is found in the U.S. Army's Stinger missile system. When the Stinger missile system was designed with a "probability of kill" at a certain level (without applying the HCD principle), the army found actual performance in the hands of the soldier was only one half of that expected. The designed performance was .6 PK (probability of kill), but actual performance (when the operator was included in the PK calculation) was only .3 PK. The designed performance had assumed human performance to be perfect and did not take into account the skill and training level of the operator. If the system probability of kill had been defined as "including the human operator," the procurement process would have been drastically different and training less costly.

1.5.3 Source Selection Policy

When the decision makers' attitude is "equip the man" rather than "man the equipment," the entire emphasis changes on what is actually being procured. For example, if in a military procurement the focus is on extending the capability of a fighter rather than fitting the fighter to a weapon, this creates a method of industry competition that is far more effective in cost and performance. To be successful, however, this concept has to reward those contractors who produce a better design at lower cost. This is done primarily by awarding contracts to those who demonstrate the best understanding and approach to designing and developing a system that will perform to the procuring activities performance requirements. When technologies and cost are close among competing proposals, HSI should be the discriminating factor in awarding the contract.

To help assure HSI can be a major factor in contract award, source selection policy for systems procurement should state that HSI evaluation factors will have the same *visibility* as technical and cost factors (as a major area) and will be evaluated in all *other relevant areas* as well. This source selection policy is a unique evaluation criterion requirement not specified similarly for any other factor. The HSI evaluation must not only show how well the contractor understands the HSI process (visibility) but also show that the contractor will use HSI technology and disciplines in the design of his equipment (other relevant areas).

1.5.4 Organizational Integration of All HSI Domains

A single focus for all HSI domains is necessary if any of the domains is to have substantial influence upon the procurement process and ultimately the quality of the product being procured. This single focus of the domains is the first integration step of the double-integration process (Fig. 1.3). The organizational integration principle can be a very difficult requirement for organizations to accept because the domains tend to be spread throughout large organizations within suborganizations that often have very little communication with one another. In 1986, the army chose the personnel organization (its DCSPER) as its integration center. The personnel organization became the representative of all six domains, even though manpower and personnel were the only domains specifically assigned to the DCSPER.

Although this decision worked well for the army, it is not necessary for HSI programs to have the domains integrated by personnel organizations. In fact, in some cases, the personnel organization may not be the best. The point and method of integration is highly dependent upon the implementation strategy for the organization as a whole. Regardless, expertise from each of the HSI domains should be provided to any system acquisition program with the idea of providing a common focus for HSI to the various systems engineering and systems integration working groups.

1.5.5 Documentation Integration into Procurement Process

The HSI model envisions a double-integration process, with the first integration taking place by bringing all the human factors domains together as described in principle 4 above. The second integration applies the information from the first integration directly into the procurement process. The HSI management tool for this principle for the DoD is the HSI Plan (HSIP) (U.S. Army, 2001). The HSIP is seen as the critical interface document feeding information into all other procurement documents and being fed by them. The quality of information in the HSIP depends on the quality of personnel assigned to the system joint working groups (SJWGs) and the tools and systems information available to the SJWGs.

1.5.6 Quantification of Human Parameters

The HSI process allows representation of all human factors domains in order to prescribe goals and constraints for the system being procured. Since the human is part of the system and the system is being designed to certain quantifiable specifications, the human aspects (to the degree possible) must be described quantifiably as well. Human parameters include data both from the perspective of the human as a measurable entity having such characteristics as body size and information processing capabilities and from a human performance perspective such as time and error performance on tasks. The quantification of human parameters database includes all characteristics, measures, and techniques that exist to describe and quantify a variety of human factors categories including anthropometrics, sensation and perception, mental abilities, social skills, and physiological attributes. Other representative quantitative measures include the levels of chemical, biological, and physical stressors that may adversely affect health and safety. In a systems approach to design one of the first set of human parameters to be quantified and provided to the contractor is the TAD. The U.S. military has compiled performance data for each occupational specialty (based on skill level and training) such that basic tasks can be analyzed for proposed weapons system designs. The HSI research community has a very strong role in providing human performance data that comprises cognitive as well as physical performance recorded in human reliability and human error terminology. This principle and the one following represent all the science and technology activities being performed by HSI professionals throughout government, academia, and industry.

1.5.7 HSI Technology

Conceptually, there are three different types of technologies, tools, and techniques important to HSI. First, each domain has tools that are either unique to it or shares commonality with one or more of the other domains. *Task analysis*, for example, is common to all the domains. Anthropometric design tools, however, are primarily HFE tools, although personnel, system safety, and health hazards would find use for them, as well. But domain tools are not generally envisioned to be trade-off technologies. The second and third types of HSI technology are classified under trade-off technologies.

The first of the trade-off technologies is represented in Figure 1.3 as the first integration. With this technology, the six (or more) domains of HSI can be traded off among each other to give the optimal system performance and cost. For example, if the total system affordability includes life-cycle costs [driven primarily by manpower (M), personnel, (P), and training (T)], then methodology is needed to assess such issues as the number of people who will operate and maintain the system throughout its life cycle, the occupational specialty of the people, and the type and amount of training for these people. A proposed system design might show increased automation to replace physical tasks but still demand a large number of high cognition tasks from the human operator. Trade-off techniques could show the advantages and disadvantages from a number of possibilities. For example, the number of operators and/or their skill levels might be reduced through increasing training. Or the number of operators and skill levels might be reduced through further automation. On the other hand, it might be desirable to increase the number of people to offset expensive specialty training or the projected casualty costs shown by the safety, health hazards, or soldier survivability domains.

The second trade-off methodology is used to trade off system capability against affordability based on HSI as an entity. For example, fewer systems requiring fewer personnel could be procured if the reliability of each system were increased because of better human performance. In such an exercise, human factors engineering plays a leading role by searching for design solutions that will assure the desired system performance while attempting to reduce the constraints imposed by the other domains.

1.5.8 Test and Evaluation/Assessments

Many of the principles addressed above, particularly those associated with staff requirements, statements of work, source selection, and proposal evaluation are concerned with creating a specification that meets the system buyer's needs and provides high assurance that the best supplier is chosen to meet the buyer's expectations. The HSI principles provide high assurance that the buyer and supplier fully understand the goals and constraints imposed by all the human factors associated with the system being procured. For each stage of design and development, it is just as important that a process is in place to evaluate how well the supplier is meeting the buyer's expectations. The HSI principle is to *crosswalk* all human performance requirements stated (or inferred) in the statement of work (with specifications) and evaluated in the proposal with the test and evaluation (T&E) process, as documented in the T&E plans and assessment procedures. Progress is reported in the official system T&E reports and through independent HSI assessment reports.

Representative users participate in operational T&E. If the system with these users fails the operational test, then the supplier's equipment has failed, not the user.

1.5.9 Highly Qualified Practitioners

Perhaps the most important principle of HSI is the requirement to use highly qualified practitioners. On the buyer's side such individuals will be found as domain representatives for the system working groups, as writers of requirements for statements of work, as proposal evaluators, and as assessors for the T&E process. It goes without saying that the supplier should employ equally qualified individuals. This requirement is often overlooked, for example, when the federal government introduces a large program and the needed skills are not immediately available or affordable. Consequently, the organization is tempted to try to implement wide-scale changes with insufficiently qualified practitioners. Such attempts will fail to be successful on anything other than a sporadic basis. The issues raised by HSI are nontrivial and not easily solved simply by imposing constraints on the system developer. HSI cannot influence design in any significant way by imposing requirements that cannot be defended by individuals conversant with the technology or operational complexity of the system. *Checklists cannot replace the technical judgment of personnel possessing the requisite formal education and on job experience that the domains require*. Most of the tools and techniques used by the domains and as HSI trade-off methodologies are applied best by experts in their field.

1.5.10 Education and Training Program

The HSI principle for education and training is to provide some aspect of HSI for everyone in the acquisition process, including government, industry, and academia. The implementation of this principle may appear so difficult and expensive that the organization will, as with some of the other principles, be tempted to ignore it, hoping benefits can accrue by a few policy changes and that industry will have incentives to provide more user-friendly products. But, wide-sweeping education and training is considered one of the most important principles for long-term institutionalization of HSI. Even if all the policy and procedures changes are implemented, systems will not be produced routinely that are significantly better if others throughout the procurement process do not "buy in" to the importance of human performance. There is a natural tendency to resist change, and if the future HSI program means doing still more with less, the resistance will be even greater than usual. Education and training is needed, therefore, not only for the practitioners, but also for the rest of those involved in the procurement and systems development processes. Fortunately, the cost to implement this principle is not prohibitive. Government agencies must make some investment to continue to assure a viable education and training program, but most education for the nonspecialist can be achieved by small modifications to other courses. The systems program manager in the DoD, for example, can be exposed to HSI during his already required defense systems management college course work. A one-semester graduate course in HSI could be added relatively easily to existing graduate programs in academic institutions for industrial engineering, systems engineering, or human factors.

1.6 HSI PRINCIPLES APPLIED TO SYSTEMS ACQUISITION

While it is easier to define, develop, and deploy systems with strong HSI influence in organizations with high HSI maturity ratings, it is possible for a few select systems to have acceptable quality HSI programs, even though the organization as a whole is weak on HSI. The phenomenon of a good HSI program within a weak HSI organization is because of the influence some PMs can have with procuring individual systems. This means it is extremely important for HSI professionals to be able to sell individual PMs on the cost and performance benefits HSI can offer.

A recent army study on HSI success factors for army systems concluded all of the HSI principles for organizations can be applied to specific systems procured by organizations (Booher, 1999). This study is described in more detail in Chapter 18, but some of the features of the HSI principles when applied to specific systems are briefly discussed here.

One of the study tasks was to identify critical factors resulting in MANPRINT cost and performance benefits for army systems. Ten representative army systems were selected and reviewed in this study. Most of the study systems had been recently reviewed by the U.S. Army Audit Agency (1997) to determine how well MANPRINT had been implemented on its newest systems coming into the army's inventory. Table 1.4 lists the systems reviewed and indicates their status in meeting the army's acquisition objectives at the time of the review. Six of the systems could be considered successful; two were marginal because of difficulties meeting soldier requirements, within cost, schedule, and performance objectives; one was fielded with reduced performance acceptance (degraded); and the army canceled one (failed).

The army systems were then rated on importance to systems success using three rankings: A, critical; B, important; and C, not important. When the same 10 principles for organizations are looked at from a PM's point of view, the principles can be described as 10 critical factors for systems acquisition. Each of the HSI system factors applies the corresponding principle as described below.

Factor 1. Top-Level (TL) Leadership and Understanding This factor is the degree to which top-level management supports HSI concepts and practices for the specific system being developed. Top-level management includes the PM and the responsible decision makers he or she must report to in achieving program objectives. For large

TABLE 1.4 Systems Reviewed for MANPRINT Involvement

System	Army Objectives
1. Comanche Helicopter	Successful
2. Longbow Apache Helicopter	Successful
3. Javelin Antitank Guided Missile System	Successful
4. Multiple Launch Rocket System—Extended Range	Successful
5. Command and Control Vehicle (C2V)	Marginal
6. Family of Medium Tactical Vehicles (FMTV)	Degraded
7. Armored Gun System	Failed
8. Crusader Artillery/Resupply	Successful
9. Land Warrior	Marginal
10. NBC Reconnaissance System (NBCRS–Fox)	Successful

systems this factor is almost indistinguishable from principle 1 for the organization itself. For smaller systems, however, a few individuals can determine the strength of this factor. These individuals are those most responsible for the acquisition of small systems—the PMs themselves. Because of the rapid and controversial systems engineering trade-offs that often need to be made, it is important that the PM also understands HSI concepts and data as well as any other systems engineering concepts and data.

Factor 1 was found to be critical in determining system success or failure for 7 of the 10 systems evaluated. Top-level support and understanding was weak for the 2 marginal systems. Only in one case (Fox vehicle) was this factor considered unimportant to a successful program. (See Section 18.4.2 for the answer to this unusual finding.) Generally, where this factor is strong, the program is strong; and where it is weak, the program is weak.

Factor 2. Human-Centered Design (HCD) Strong emphasis on HCD begins in the requirements stages. This factor generally follows the trend set by the PM on factor 1. Where it tends to differ is for nondevelopmental systems. The HCD concept is still important but can never be as central as with a full developmental program. Seven systems showed this factor to be either critical or important. The two systems that ultimately became degraded or failed considered HCD important but were unable to solve important MANPRINT issues along the way. This factor was not important to the success of two small systems.

Factor 3. Source Selection (SS) Criteria Source selection criteria, which make HSI instrumental in determining who will win or lose a system procurement, is a necessary system success factor. Those army programs that were successful generally had strong MANPRINT source selection evaluation criteria. However, strong HSI source selection criteria without many of the other factors do not assure success. The marginal and degraded systems had adequate MANPRINT criteria. In other words, HSI source selection criteria are generally necessary but not sufficient to assuring a successful system.

Factor 4. Domains Integration (DI) The integration of all the domains during the acquisition process was a factor that was critical or important on all 10 systems. In marginal, degraded, and failed systems the fact that this domain was active ensured the MANPRINT issues were properly identified. Once properly identified, the issues could be addressed in some cases, well enough to save the system, although in at least one system, it was too late.

Factor 5. System Documentation Integration (SDI) The integration of MANPRINT into a system documentation process was a critical factor for 8 of the 10 systems. Adequate attention to this factor helped 6 programs to be successful. Weaknesses in system documentation integration made it a degradation factor for 3 of the systems. Once again the Fox vehicle was unique in that this factor was not important to its success.

Factor 6. Quantitative Human Performance (QHP) For people to truly be included as part of the system, designers must be able to quantify their performance. A person can be treated as a system component and participate in trade-off methodology if the performance parameters are quantifiable. In 9 of the 10 systems this factor was either critical or important. The only exception was one system with little human involvement.

Factor 7. HSI Technology (HT) HSI technology, which includes unique domain and trade-off methodology between domains, was critical or important for half of the systems. (See Fig. 1.3, the first stage of the double-integration process.) For those systems where several aspects are important to soldier performance but work against each other, trade-off methodology was essential. On the Javelin Antitank Guided Missile System, for example, a light-weight system is needed for single soldier portability, but many survivability characteristics needed by the soldier necessarily increase the weight. MANPRINT considers each of the domains, but frequently trade-offs among them will determine the best overall benefit to the soldier. Although the other half of the systems did not have trade-off issues among domains, this factor is still very important for aiding trade-offs between HSI and other systems engineering factors. (See Fig. 1.3, the second stage of the double-integration process.)

Factor 8. Test and Evaluation (T&E) T&E was the only factor critical to all 10 systems. It is the one factor that must be present no matter what has gone before. It is the final and most reliable assurance factor for the army that the soldier will receive a safe and effective weapon before going into battle.

Factor 9. Practitioners (PR) Skilled and available practitioners were critical to all systems except the one that did not have significant human involvement. Without this factor, several of the other factors could not be performed. [Notice, e.g., their importance to factors 4 (DI), 5 (SDI), 6 (QHP), 7 (HT), and 8 (T&E)]. Also factors 2 (HCD) and 3 (SS) need input from skilled practitioners.

Factor 10. Education and Training (ET) The HSI education and training are essential to assure practitioners are qualified. For 9 of the 10 systems this factor was either critical or important to system success. The ET of nonpractitioners is almost equally important. In those systems that were marginal, degraded, or failed, the lack of appreciation of MANPRINT by nonpractitioners was one of the primary reasons for their deficiencies.

Perhaps the most important finding from the study was that the 10 HSI principles provide 10 corresponding factors that are both necessary and sufficient for program management attention to assure system performance success. Each of the 10 principles when applied to specific systems has unique characteristics, yet considerable connectivity with each of the others. In some cases the elimination of only one factor [such as factor 1 (TL)] will cause many of the others to degrade. On the other hand, one factor may be reduced, and the effect will be to create greater demand on one or more of the other factors, resulting in a domino effect among the factors. For example, if a PM decides to reduce the number of people representing the seven domains [i.e., reducing influence of factor 4 (DI)], a decrease in numbers of skilled practitioners [factor 9 (PR)] is created, which means the available practitioners must be skilled on more than one domain, which means greater pressure is applied on education and training [factor 10 (ET)] to produce higher skilled practitioners.

1.7 HSI ORGANIZATIONAL MATURITY

Attempts to make wide, sweeping changes in government organizations that either design and operate or influence the design and operation of technology are not new. As early as the mid-1960s, the air force, navy, and Department of Transportation initiated major human factors programs (Air Force, 1967; Fucigna, 1968; Little, 1966). In the 1980s, the Nuclear Regulatory Commission recognized the need for a comprehensive human factors program (Hopkins et al.; 1982; Moray and Huey, 1988). And in the 1990s, the air force and navy attempted to implement but soon shelved their IMPACTS and HARDMAN programs.

Although numerous specific examples of positive human factors influence can be cited, it is fair to conclude that past attempts to incorporate human factors as a primary consideration in government policy for the procurement or regulation of the nation's technology have been marginal at best. Human factors continued in the late 1990s to be viewed as a contributor to or supporter of design and operations that had not yet reached an equal footing with engineering or operations disciplines. The challenge for HSI in the twenty-first century is not only to reach an equal footing with these disciplines but also to actually surpass them in certain aspects; especially in organizational decision making about the purpose and approach to systems integration.

1.7.1 Assessment of Army MANPRINT Program

The 10 principles provide a means to assess the organizational maturity of HSI programs. In the 15 years since MANPRINT was first introduced to the U.S. Army there has been significant opportunity to refine the processes and techniques that are important to the HSI concept and show historically how well the army as an organization has applied the MANPRINT model to its military systems. Because MANPRINT has been continuously in existence since its inception, it provides the opportunity to evaluate an HSI program over time.

Three assessments of the U.S. Army MANPRINT program are shown in Figure 1.4 (1989, 1994, and 1999). The army HSI program was evaluated for level of maturity on each of the 10 HSI principles. A five-point scale defined on the figure was used for level of maturity. The HSI professionals familiar with the army MANPRINT program, from its inception until the present, performed the assessments. Major armywide studies on the effectiveness of MANPRINT implementation were primary sources for the assessments (Peters and Perkins, 1991; U.S. Army Audit Agency, 1997; General Officer Steering Committee, 1998).

The maturity assessments show it is very difficult to achieve and maintain an excellent rating on any of the HSI principles. On the other hand, excellence on all the principles is attainable. By 1989, the army MANPRINT program had achieved excellent ratings on 5 of the 10 principles and good ratings on two others. Curiously, two additional principles (7 and 8) that were among the lowest rated principles in 1989 are rated good by 1999. Only principle 2 (human-centered design focus of "systems") never reached better than average for any of the evaluation periods.

The assessments also show how easily support for an HSI organization can degrade. Within the 5 years between 1989 and 1994, all five of the excellent principles ratings fell at least three levels. Source selection (principle 3) fell four levels, all the way to the bottom. This drop was clearly not because no value was added from HSI, but rather because of the

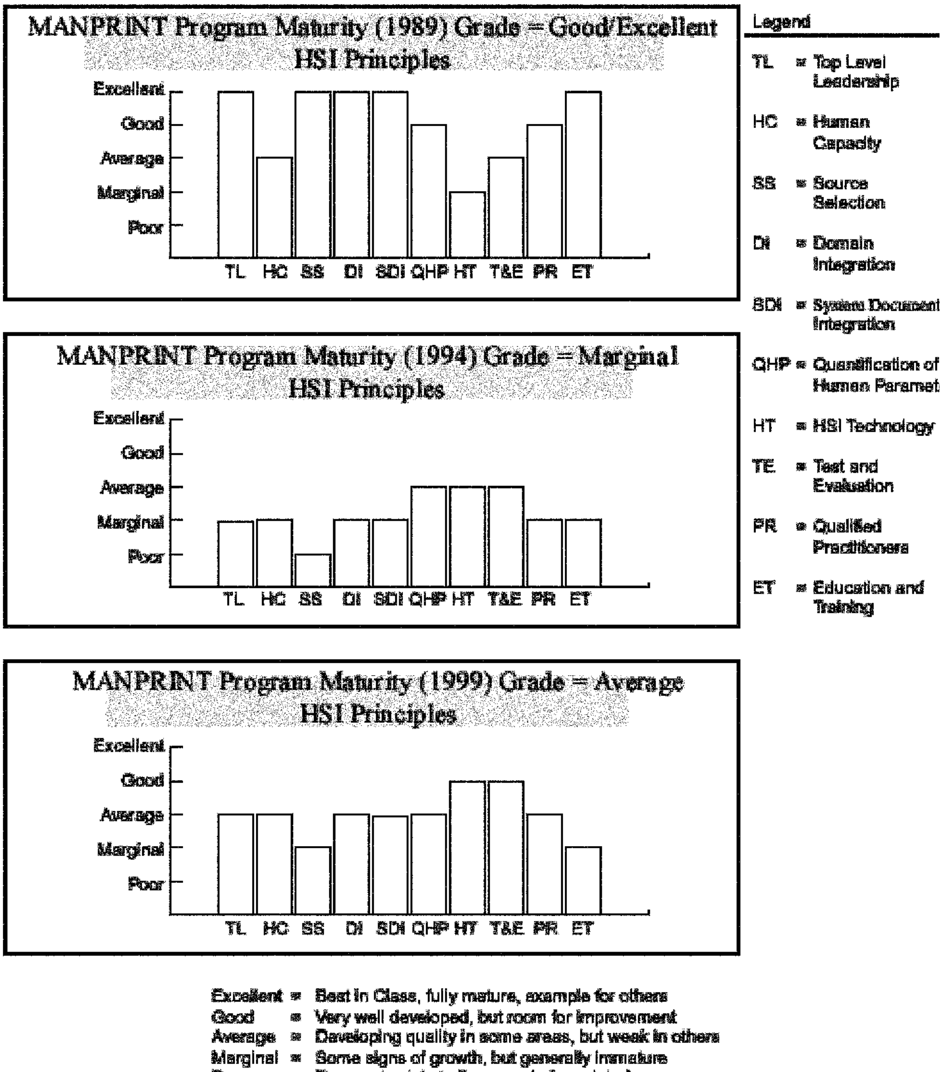


Figure 1.4 U.S. Army MANPRINT program maturity.

turbulence within the army in changing to new acquisition strategies while undergoing major downsizing with its acquisition personnel. In 1998, once it became recognized that HSI was essential to accomplishing the new army objectives of fighting multiple missions with a reduced force, the army leadership initiated a revitalization effort for HSI, such that the army was able to bring back most of the principles' maturity to average by the time of the 1999 evaluation.

Also as mentioned above, the army was rated good on two principles (HSI trade-off methodology and T&E), which have continuously improved since they were first rated in 1989. This improvement is fortunate since these two principles are particularly critical in the new systems acquisition environment. The new acquisition environment relies upon performance-based requirements, advanced simulation and modeling, and T&E measures of performance to reduce risk and to determine systems acceptance criteria. This approach simply cannot be made to work without increased emphasis on the human component in defining requirements, simulating operational systems and environments, and measuring system performance in operational environments.

All 10 principles need to advance in maturity, however, if an organization wishes to make maximum use of the HSI approach to systems acquisition. If any systems acquisition organization would place an emphasis on HSI today as the army did on MANPRINT in the late 1980s, there is little doubt that the organization could achieve an excellent rating on all 10 HSI principles.

1.7.2 Assessment of Other HSI Programs

By the end of the millennium, a number of other government organizations had started to implement HSI programs. The most notable was the Ministry of Defence for the United Kingdom, which had implemented an HFI program for all three of its major services. In the United States, the navy and air force had provided a renewed thrust to HSI, and the FAA had also made significant strides in its HFI and systems safety programs. Based on assessments from HSI/HFI specialists within the various organizations depicted, Figure 1.5 provides a snapshot view of the maturity of these four programs on the 10 HSI principles in the year 2000. All assessors were familiar with the army MANPRINT program, which was used as the baseline for comparisons.

Two major *overall* comparisons among organizations are useful from the assessments summarized in Figures 1.4 and 1.5. These are the other organizations compared to the U.S. Army and to each other. Compared to the U.S. Army, the UK program was rated the same as the U.S. Army in 1999 (average), but with the U.S. Army still ahead on several of the principles. The FAA (marginal) was one step below the U.S. Army and the United Kingdom but farther along than either the U.S. Navy or U.S. Air Force in 2000. Since these assessments were made, the greatest HSI improvement activity has been shown by the U.S. Navy, which if assessed in 2003, would likely receive at least a marginal overall rating.

To make significant HSI maturity progress equal to the U.S. Army and UK programs, the most critical principle for the other organizations is top-level leadership. As that rises, other weak principles can receive more attention. For the navy, the most urgent attention needed (after leadership) in 2000 was for source selection, domain integration, qualified practitioners, and education and training. The same four weakest principles applied to the U.S. Air Force and two of the same (source selection and domain integration) applied to the FAA. The other weak principle for the FAA (HSI technology) does not receive the same attention as either the U.S. or UK military because of fewer manpower, personnel, and training trade-off opportunities.[10]

1.8 DISCUSSION AND SUMMARY

Human systems integration is a technical and managerial concept with specific emphasis on methods and technologies that can be utilized to apply the HSI concept to systems integration. As a concept the top-level societal objectives of HSI are to significantly and positively influence the complex relationships among: (1) people as designers, customers, users, and repairers of technology; (2) government and industrial organizations that

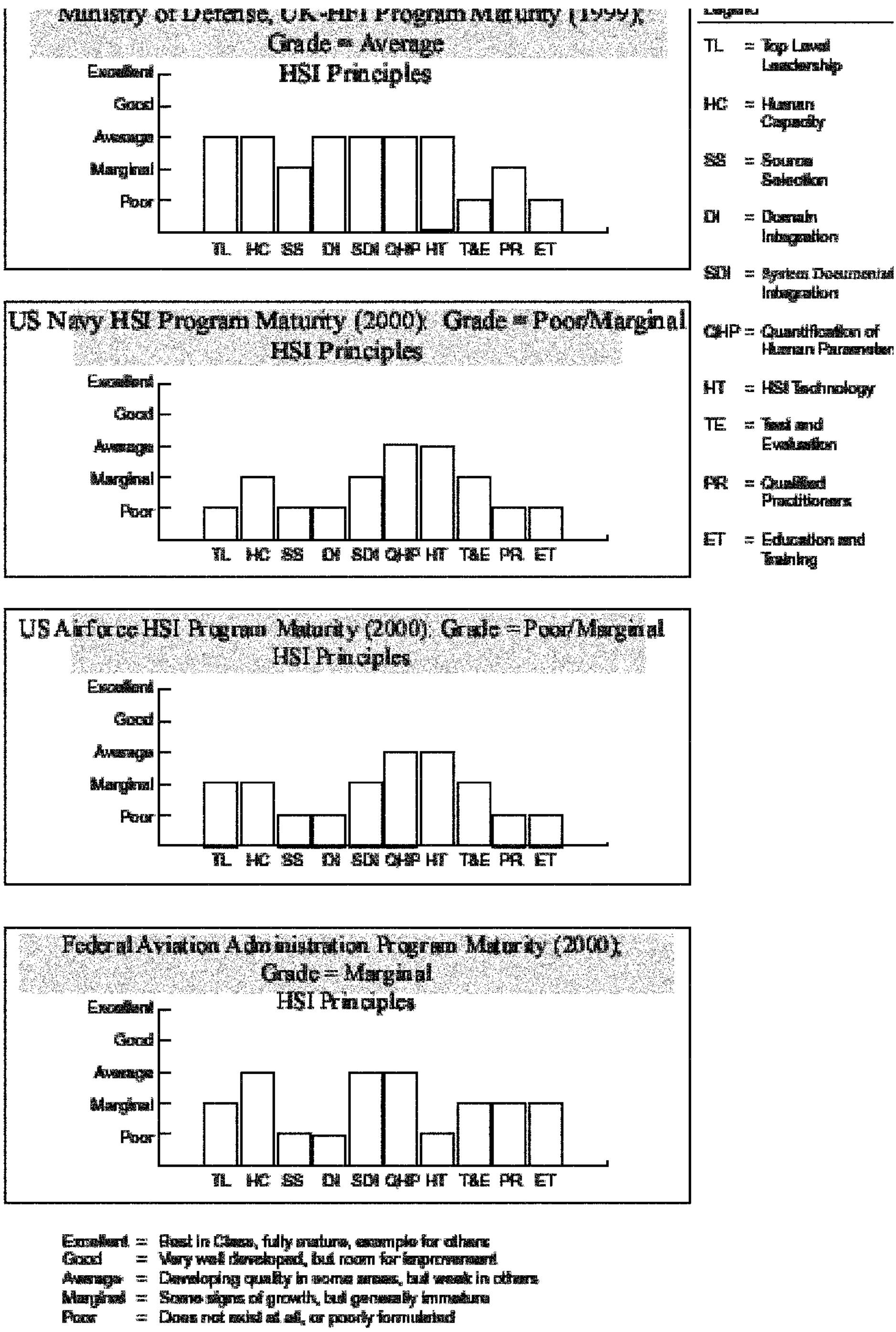


Figure 1.5 Non U.S. Army HSI programs maturity.

regulate, acquire, design, manufacture, and/or operate technology; and (3) methods and processes for design, production, and operation of systems and equipment.

Most of the technical and managerial advances suggested by the HSI concept can be accomplished within an overall systems integration philosophy that places a special emphasis on how its roles and technology can be included within systems engineering and systems management processes. As a concept, HSI is fully compatible with those systems engineering processes relevant to systems definition, development, and deployment and their life-cycle phases, as well as the systems engineering methods, tools, and technologies. As a top-level model, HSI brings two novel features to the systems engineering model. These are (1) the highly concentrated user focus on all aspects of the systems definition, development, and deployment stages and (2) the application of the human-related technologies and the HSI disciplines throughout the systems engineering management and technical processes. No system, product, or equipment inputs can be considered as having had an adequate consideration of the people component if it does not pass through the HSI process modulated with these two inputs.

As a unique concept for integrating people, organizations, and technology, HSI can offer a wide range of benefits to an organization. Too often, non-HSI individuals do not appreciate these potential benefits because the benefits have not been communicated in a way that reflects most directly on their particular role in the organization. For example, people who have high levels of responsibility for systems acquisition decisions should be interested in HSI performance measures that help assess quantitatively the human error risk with operational systems. This can be contrasted with those primarily concerned with operational processes within the organization. The latter might be more stimulated by the ability of the HSI professional to help them develop people-oriented procedures that utilize user-centered techniques such as functional and task analyses.

The applicability of HSI varies with sociotechnical systems complexity. Sociotechnical systems can range from very highly complex organizations (such as the DoD) to critical technological human–machine subsystems (such as an aircraft cockpit). The HSI process needs support from the highest levels of an organization but is best applied as a concept to specific technological systems such as an aircraft or a control room. As HSI develops technologically, it will also become more relevant to systems design of more complex sociotechnical organizations that comprise a number of technological systems working in unison, such as an aircraft carrier or a hospital.

The HSI concept has unique aspects not fully demonstrated with any other human factors approach to systems integration. Such HSI aspects as "people-oriented processes," "focus throughout the organization on competence and motivation," and "educating all people in the process" are the same characteristics found in high-quality-oriented organizations. The HSI concept is closely aligned to top-level management and organizational objectives and as such aids technology decisions that benefit people while meeting these objectives. Most human factors (HF) advances have focused on the development of technologies and disciplines, which, if utilized, could produce high-performance systems with low human error rates. However, HF concepts have not traditionally played a significant role in the organizational decisions about what systems the organization should acquire. Neither has HF tended to influence the top-level decision makers about their policies toward people and education throughout the organization. The HF concept has begun to provide decision makers with sound economic arguments for human factors designs centered on the user; but these arguments are focused almost entirely on customers with specific product roles, not those in top-level management or operational processes roles. As a discipline, HF is making great strides toward "multidisciplinary views of design," making the human component an "inherent part of the system," and the "quantification of people variables"; but it does so largely in a support role to the engineering processes. As such, HF is not likely to emphasize "resources redirection rather than net increases" for a system acquisition, provide trade-off techniques among the HSI domains in design decisions, or be seen as the primary technology advancement for the system being developed.

During the past decade, 10 HSI principles have been identified that, to the degree they are applied, seem to assure that large organizations will capture the performance, cost, and safety objectives they desire for their systems. Conversely, to the degree any of these principles are left out entirely or a few are followed only marginally, large organizations risk their systems not meeting their desired system objectives. Moreover, specific systems programs that have followed these principles have been extremely successful, while those that have made compromises have made marginal progress. If the 10 HSI principles for organizations are looked at from a PM's point of view, they indicate 10 critical factors for system acquisition. In analyzing 10 army systems, Booher (1999) found the HSI factors that correspond to the 10 principles are both necessary and sufficient for program management attention to assure system cost, performance, and schedule success.

The 10 HSI principles are a blend between technical and managerial features. Some (such as top-level leadership, source selection, and domains integration) are purely management and organizational factors that can be raised or lowered in maturity through policy decisions. Others (such as quantitative human performance and HSI technology) are primarily technical factors. These tend to progress at the rate science and technology progresses for basic human performance knowledge and techniques. But still others are combinations of managerial applications and technical developments (such as HCD, skilled practitioners, and education and training). As technology advances, the organization can speed or impede progress depending on how well it understands and supports maturity development on these principles.

The 10 principles provide a means to assess the organizational maturity of HSI programs. In the 15 years since MANPRINT was first introduced to the army, there has been significant opportunity to refine the processes and techniques that are important to HSI concepts and show historically how well the army as an organization has applied the MANPRINT model to its military systems.

By describing the HSI model and its principles, this chapter provides the first step of a new movement within both public and private systems acquisition organizations to implement and improve their HSI capability.

In the chapters that follow, I asked the authors and myself to answer two questions about their contribution that relate to the HSI philosophy presented in this introduction. The first question was which of the 10 HSI principles relates most directly to their chapter. The second question was which of the principles relates to secondary or related information in their chapter. The matrix in Figure 1.6 shows our consensus. Each chapter indicated with a heavy dot corresponding to a principle will provide amplifying information bearing directly on that principle. Each chapter indicated with a white circle corresponding to a principle provides secondary or related information for the principle. Chapter 2, for example, provides information that addresses organization and management change concepts directly related to principle 1. Each chapter should therefore help the reader better understand some of the guidelines for top-level leadership that are highly beneficial to implementing HSI within an organization. Secondary or related information

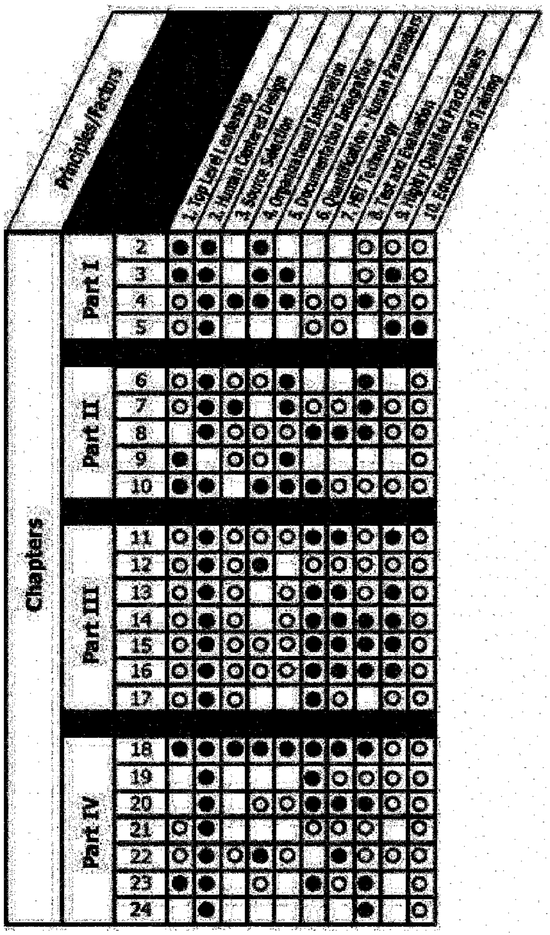


Figure 1.6 HSI principles by chapters.

will be found in Chapter 2 on principle 8 (measuring and evaluating organizational changes will indirectly aid systems acquisition processes) and principle 10 (if the guidelines for change are followed, the quality and amount of education and training devoted to HSI will increase).

1.9 BOOK OVERVIEW

The book organization is loosely modeled after that of the 1990 MANPRINT book. Chapters are categorized within four parts, but not meant to be restricted solely to the category where they are found. Any one of the chapters could provide valuable insight into each of the other parts. An attempt was made, however, to cluster chapter topics that provide information judged by the editor to fit best under the broad umbrella provided by each part as briefly described below. The book is constructed so that the reader can read from cover to cover, skip to parts, or read only pertinent chapters. The reader has an opportunity to decide on the relevance of chapter information before actually reading the full chapter. Each part briefly describes the chapters contained in the part, and each chapter begins with an introduction section.

Part I, *Organization, Management, and Culture*, discusses the engineering and management environments that affect HSI implementation, operation, and effectiveness. In particular it stresses those organizational, managerial, and cultural environments that procure, produce, and operate systems and equipment. To successfully apply HSI concepts, the organization's leadership, culture, and associated disciplines must at least tolerate, if not fully accept, the concepts. From the chapters included in Part I, the reader will find information that addresses the following types of questions:

- What is the role leadership must play for an organization that wishes to introduce HSI into its systems acquisition culture; particularly in motivating and managing change introduced by HSI concepts?
- What impact do cultural environments have upon implementation and operation of HSI programs?
- What are the roles and interfaces of HSI in systems engineering and management?
- What are key economic factors that drive decisions in the acquisition and systems engineering processes?
- What are the special needs and opportunities for HSI education and training for both the HSI professional and those other system acquisition stakeholders in an organization, newly introduced to the benefits of the HSI approach to systems integration.

Part II, *Systems Acquisition and Management Processes*, describes how HSI is involved throughout the major stages in acquiring a system, beginning with requirements determination (which have major personnel and training trade-offs), to system specifications (with extensive communication between the organization seeking a new system and the builder of the system), to system design and development, and, finally, to test, evaluation, and assessment of system performance. Part II includes:

- Descriptions of the systems acquisition model from both the government buyer's and the contractor seller's perspectives
- Guidance on how HSI requirements should be determined in the acquisition process
- Examples showing the importance of HSI system design trade-offs with personnel and training
- Descriptions of test and evaluation techniques that include HSI as part of system performance
- Special HSI issues associated with simulation architectures and procurement standards as applied in the modern acquisition process

Part III, *Methods, Tools, and Technologies*, describes the state-of-the-art for methods, tools, and technologies covered by the seven domains of HSI and those specially designed to integrate several domains. More specifically, Part III focuses on the description of tools, techniques, and technologies used by the HSI professional in the analysis and assessment of systems performance and integration issues. This part, more than any of the others, is designed to help the HSI professional acquire useful analysis and/or assessment information for system acquisition decisions. It addresses such questions as:

- Why conduct a particular type of analysis and why, or why not, employ a particular HSI method or tool?
- When should a tool, technique, or technology be used with respect to system development?
- What resources (time, money, computers, skills and qualifications of the analysts) are required for effective use of HSI methods and tools?
- What data are required to support a particular tool, technique, or technology?
- What are the critical interfaces among parameters and methods covered by the several domains?
- What methodologies are most applicable to cost–benefits analyses for HSI?

Part IV, *Applications*, gives us a wide range of examples that illustrate the methods and principles of HSI applied to systems from both the public and private acquisition processes. Many of the HSI systems applications presented in Part IV are drawn from military, aviation, and commercial environments that provide representative samples of the types of organizations, cultures, and technologies HSI professionals are likely to find themselves working in the future. Some of the more dramatic cost and performance benefits from HSI are demonstrated on major systems procurements such as those procured by large-scale public acquisition (DoD, NASA, FAA); but HSI can play an extremely important role in small systems developments such as appear with new commercial products, as well.

NOTES

1. The background is an updated version of the background provided in Booher (1990, pp. 1–2). Much of the original material is repeated here with kind permission of Kluwer Academic Publishers.
2. The Three Mile Island nuclear accident description opened the MANPRINT book in 1990. The last sentence still applies 10 years later.
3. http://www.swishweb.com/Disasters/Aircraft/disaster03a.htm.
4. Railway Accident Report, NTSB Number RAR97/02. Collision and Derailment of Maryland Rail Commuter MARC Train 286 and National Railroad Passenger Corporation Amtrak Train 29. http://www.ntsb.gov/Publictn/1997/RAR9702.htm.
5. http://www.swishweb.com/Disasters/Aircraft/disaster04a.htm.
6. Total U.S. motor vehicle fatal crashes in 1999 were 37,043 (*Traffic Safety Facts 1999*); total motor vehicle fatalities in 1999 were 41,611 (*NHTSA 37-00*). The number of U.S. Army casualties (deaths) in Southeast Asia from 1957 to 1997 was 38,201.
7. Quality experts frequently state that 20 to 40 percent of payroll costs can be associated with waste, failure, and rework (Crosby, 1979; Deming, 1986; Juran, 1987). The $600 billion estimate is based on 20 percent of labor costs per annum, around $3 trillion (1989) and the national debt around $6.5 trillion (1999).
8. In addition to systems engineering, the DoD regulation also includes HSI requirements in the section for support strategy (C2.8.5. HSI).

9. DoD 5000 was canceled on August 29, 2002. Changes in the DoD acquisition process regulations are frequent; so references such as this in the *Handbook* cannot be depended on as the latest official regulatory policy. However, as of the publishing date, the June 2001 DoD 5000.2R document still provided the most relevant guidance information for HSI in military systems acquisition.
10. The distinction between human factors technology and HSI technology is discussed in other chapters (see especially Chapters 8, 11, 12, and 13).

REFERENCES

Air Force Systems Command, Headquarters. (1967). *Handbook of Instructions for Aerospace Personnel Subsystems Design*, AFSCM 80-3. Washington, DC: Andrews Air Force Base.

Booher, H. R. (1999, May). *Acquisition Process Factors in MANPRINT*, Final Report for Army Research Laboratory, Human Engineering and Research Directorate. Reston, VA: Raytheon Systems Directorate, Instructional Systems Group.

Booher, H. R. (Ed.). (1990). *MANPRINT: An Approach to Systems Integration*. New York: Van Nostrand Reinhold.

Crosby, P. B. (1979). *Quality Is Free*. New York: McGraw-Hill.

Deming, W. E. (1986). *Out of the Crisis*. Cambridge, MA: Massachusetts Institute of Technology, Center for Advanced Engineering Study.

Fucigna, J. (1968). *Human Performance Development Program for the Naval Material Command*. Darien, CT: Dunlap and Associates.

General Officer Steering Committee (GOSC). (1998, July). *Report to the General Officer Steering Committee (GOSC) on the Army's Manpower and Personnel Integration (MANPRINT) Program*. Prepared for the Assistant Secretary of the Army (Manpower and Reserve Affairs). Washington, DC: Booz-Allen & Hamilton.

Hopkins, C. O., et al. (1982). *Critical Human Factors Issues in Nuclear Power Regulation and Recommended Comprehensive Long Range Plans*, Technical Report NUREG CR-2833. Washington, DC: Nuclear Regulatory Commission.

Juran, J. (1987). *On Quality Leadership*. Wilton, CT: Juran Institute.

Little, A. D. (1966). *The State of the Art of Traffic Safety: A Critical Review and Analysis of the Technical Information in Factors Affecting Traffic Safety.* Washington, DC: Automobile Manufacturers Association.

Moray, N., and Huey, B. (1988). *Human Factors Research and Nuclear Safety.* Washington, DC: National Academy Press.

Perrow, C. (1999). *Normal Accidents: Living with High-Risk Technologies*. New York: Basic Books.

Peters, J., and Perkins, M. (1991, May). *MANPRINT 2000: Program Assessment and Enhancement*. Science Applications International. McLean, VA.

Sage, A. P., and Rouse, W. B. (1999). *Handbook of Systems Engineering and Management*, New York: Wiley.

U.S. Army. (1990, May). *Manpower and Personnel Integration (MANPRINT) in the Materiel Acquisition Process*, Army Regulation 602-2. Washington, DC: Department of the Army.

U.S. Army. (2001, June). *Manpower and Personnel Integration (MANPRINT) in the Systems Acquisition Process*, Army Regulation 602-2. Washington, DC: Department of the Army.

U.S. Army Audit Agency. (1997, June 10). *Incorporating MANPRINT into Weapons Systems Development*, Audit Report: AA 97-205. Washington, DC: Army Audit Agency.

U.S. Department of Defense. (2001, June 16). *Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information Systems (MAIS) Acquisition Programs*, DOD 5000.2-R. Washington, DC: U.S. Department of Defense.