

Human Systems Integration in Army Systems Acquisition

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18.1 BACKGROUND

MANPRINT (Manpower and Personnel Integration), the U.S. Army's human systems integration (HSI) program, has been identified as one of the most promising programs ever developed by the military for providing effective human systems performance. (Minninger et al., 1995; Skelton, 1997). This has been supported by other studies [U.S. Army Audit Agency (AAA), 1997; Booher, 1997; 1998; General Officer Steering Committee (GOSC), 1998] that show the vast range and depth of influence that HSI has had upon the army systems whenever its methodologies have been applied. Generally, performance improved, safety increased, and costs were avoided.

In spite of these impressive results, the HSI practitioner often finds it difficult to convince program managers of the full value of the HSI discipline. Part of the difficulty is that the HSI concept is not fully appreciated, even among many practitioners, so the positive benefits that could accrue for a program are never presented in a way that convinces decision makers HSI can make a significant (and affordable) difference in achieving their objectives. Another difficulty is that very few systems throughout the defense and commercial sectors have actually been quantitatively documented for performance and cost benefits resulting from HSI. Finally, it must be realized that the acquisition world has changed such that strategies that worked with past systems may not work with future systems.

This chapter is designed to help the HSI practitioner better formulate arguments that will be convincing to program managers of the need for HSI on future systems. Set within the framework of those HSI factors identified in the literature (Booher, 1996–1999; GOSC, 1998) as crucial organizational and technical principles to the success of HSI programs, the specific army applications provided here should help the reader better understand the importance of the factors and their interactions to a successful systems acquisition

program. A large number of specific examples are provided as supporting evidence for the value of HSI in terms program managers can appreciate such as (1) technology advancements, (2) acquisition process efficiencies, (3) system design enhancements, (4) safety increases, and (5) returns on investment.

18.2 HSI SYSTEM SUCCESS FACTORS

A recent army study on HSI success factors identified critical factors important to achieving MANPRINT cost and performance benefits for army systems acquisitions (Booher, 1999). Ten representative army systems were selected and reviewed in this study. Table 18.1 lists the systems reviewed and indicates how well they had met the army's acquisition objectives at the time of the review. Six of the systems were 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 one was canceled by the army (failed). Since the study, one of the two marginal systems (the command-and-control vehicle) has also been canceled.

Factors Identified Booher (1999) concluded that 10 HSI factors (listed in Table 18.2) can account for MANPRINT success (or failure) on systems procured by the army. The 10 principal organizational and technical factors hypothesized from the literature as critical to the success of past MANPRINT programs were verified with analyses of the representative systems. Without exception, all of the major development systems adequately adopted all 10 factors. No new top-level factors were identified, and none of the 10 identified were shown to be consistently unimportant on past systems. Consequently, these 10 factors are considered the broad factors that have made MANPRINT successful in the past. The specific examples, which follow in the next two sections, show a large number of examples on army systems that support Booher's conclusions.

TABLE 18.1 Systems Reviewed for MANPRINT Involvement

System	Category	Army Objectives
1. Comanche helicopter	ACAT I—full	Successful
2. Longbow Apache helicopter	Major—mod	Successful
3. Javelin Antitank Guided Missile System	ACAT I—full	Successful
4. Multiple Launch Rocket System—Extended Range	Major—mod	Successful
5. Command and Control Vehicle (C2V)	ACAT I—full	Marginal
6. Family of Medium Tactical Vehicles (FMTV)	Major—NDI	Degraded
7. Armored Gun System	Major—NDI	Failed
8. Crusader artillery/resupply	ACAT I—full	Successful
9. Land Warrior	ACAT II	Marginal
10. Nuclear, biological, and chemical (NBC) reconnaissance system (NBCRS—Fox)	ACAT III	Successful

Note: ACAT=army category; ACAT I is highest cost and priority; ACAT II is intermediate cost and priority; ACAT III is relatively low cost and priority; NDI=nondevelopmental item; less than full-scale acquisition process.

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TABLE 18.2 HSI System Success Factors

1. Top-level support and understanding
2. Human-centered design
3. Source selection
4. Domains integration
5. System documentation integration
6. Quantitative human performance
7. MANPRINT technology
8. Test and evaluation integration
9. Practitioners, skilled, available
10. Education and training: (a) practitioners and (b) nonpractitioners

18.3 HSI FACTORS: EXAMPLES FROM ARMY SYSTEMS

The 10 HSI factors can be better appreciated by examining a number of specific examples from 15 army systems (including the 10 systems in Table 18.1). Figure 18.1 is a summary of the HSI factors illustrated by specific system examples in this section. This section is designed to provide a collection of examples arranged by the 10 HSI system factors. The reader who does not need this level of detail may skip to the next section.

Factor 1: Top-Level Support

Description 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 program manager and the responsible decision makers he or she must report to in achieving program objectives. Because of the rapid and controversial systems engineering trade-offs that often need to be made, it is important that the program manager also understand HSI concepts and data as well as any other systems engineering concepts and data.

Systems	HSI Factors									
	1.TSP	2.HCD	3.SS	4.ODI	5.SDI	6.QHP	7.MT	8.T&E	9.PR	10.ET
1. Apache Automatic Target Handover System (ATHS)			x							
2. Apache Longbow		x				x				
3. Armored Gun System (AGS)	x	x							x	x
4. Comanche Helicopter	x	x	x	x	x	x	x	x	x	x
5. Command and Control Vehicle (C2V)					x	x			x	x
6. Crusader Artillery System			x			x	x	x	x	x
7. Family of Medium Tactical Vehicles (FMTV)					x				x	x
8. Fox NBC Reconnaissance Vehicle						x	x	x	x	x
9. Javelin Antitank Guided Missile System				x						
10. Land Warrior								x		
11. Lightweight Howitzer							x			
12. Line of Sight - Forward Heavy (LOS-FH) missile system						x				
13. Singer Missile System			x			x				
14. T-800 Engine			x		x					
15. Multiple Launch Rocket System-Extended Range	x			x	x			x		

Figure 18.1 Systems by HSI factors.

Example 18.1 Comanche Management The Army's Comanche is being developed as a lightweight, twin-engine helicopter capable of performing armed reconnaissance and light-attack missions. From the beginning, the Comanche has had a number of ambitious goals including

1. to push the state of the art by incorporating the latest aircraft technologies to enhance its performance in complex missions in a wide range of environments (i.e., night, nap of the earth, and adverse weather conditions),
2. to be one of the most supportable aircraft in the world,
3. to have increased safety measures for aircrew survivability,
4. to achieve the added performance features without unduly increasing operations-and-support (O&S) costs over that to maintain the current reconnaissance and light-attack helicopter fleet.

It was realized by army leadership that the challenges to meet the ambitious performance goals would require major changes in the acquisition and design processes. This was especially true regarding the emphasis to be placed on the human design component. Through the MANPRINT approach, HSI methodology was inserted in the earliest stages of requirements development and carried throughout each subsequent stage of the acquisition process. The Comanche report (Minninger et al., 1995), which documents the results of the program's human-centered approach, is based on a five-year record keeping effort by both the winning contractor, Boeing-Sikorsky, and the Comanche Program Office. These results are without question some of the most impressive ever reported on a major weapon system acquisition.

Example 18.2 Armored Gun System (AGS) Leadership Top-level army leadership supported the MANPRINT concerns for soldier performance and survivability, but both government and contractor's program managers did not pay sufficient attention to these concerns until too late in the program. The AGS was designed from a hardware perspective, and crew performance and soldier survivability were at best afterthoughts. However, because MANPRINT reviews were given top-level visibility, the poor application of HSI was highly contributory to the program cancellation in 1996.

Example 18.3 Multiple Launch Rocket System—Extended Range (MLRS-ER) The MLRS-ER is an example of a system considered to have relatively simple human interfaces and low manpower, personnel, and training demands, thus suggesting little need for a strong HSI program. However, analyses of this system (AAA, 1997; Booher, 1999) show this system had a good MANPRINT program and was successful with applying several of the HSI factors, in particular: 1.0 for top-level management and organization support, 4.0 for domains integration, 5.0 for system documentation integration, and 8.0 for test and evaluation integration. The MLRS-ER shows that even for a system that appeared to have few human performance issues, HSI top-level support (along with at least some of the other HSI factors) is still necessary for system success.

Factor 2: Human-Centered Design

Description Strong emphasis on human-centered design (HCD) begins in the requirements stages. This factor 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.

Example 18.4 Army Stinger Missile System Numerous system failures have occurred in the past because a system was not defined to include the human. For example, when the U.S. Army Stinger Missile "system" was designed with a "probability of kill" at a certain level, it did so without applying this factor. As a result, the army found actual performance in the hands of the soldier was only one-half of that expected. The designed performance has 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 significantly different.

Example 18.5 Armored Gun System Design From the beginning, this program did not have an acquisition strategy favorable to making the soldier part of the system design. For example, although expected to fight in the desert and tropical environments with nuclear, biological, and chemical (NBC) gear, none of the escape hatches was wide enough for large soldiers to exit, even without NBC gear, and most of the soldiers could not exit quickly enough if wearing NBC gear. Also, the AGS crew could not be expected to perform well in the cramped and poorly designed workspaces. Driver head clearance when wearing the helmet with the hatch closed was less than 1 inch, so that they would routinely bang their head during motion, and if slumped to avoid the banging, the drivers' field of view was reduced and possibly eliminated altogether. These were only a few of the large number of HSI problems identified by the MANPRINT practitioners.

Example 18.6 Comanche Cockpit The crew station design for the Comanche allows the aircrew to set priorities for information criticality at specific points during the conduct of missions. This is unlike previous cockpits where the information was presented in predetermined menus. Overall, the sequence of tasks required to perform mission functions was greatly reduced with this human-centered approach. For example, a sequence for target reporting that previously required 34 procedural steps in the older aircraft (OH-58D) was reduced to only five steps in the Comanche.

Factor 3: Source Selection Policy

Description 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 is a unique evaluation criterion requirement not specified similarly for any other factor. This is because 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 or her equipment (other relevant areas).

Example 18.7 Comanche Contractor Selection The source selection evaluation criteria used in the Comanche program represented a radical departure from past acquisition programs. For example, MANPRINT (including training) was made a separate evaluation area with the same weight as reliability, availability, and maintainability/integrated logistics support (RAM/ILS). MANPRINT and ILS were combined under the same review team so that MANPRINT/ILS had the same weight (35%) as technical. This was made known to industry during the request-for-proposal stage, showing that the government was serious about its commitment to the soldier. With such weighting factors, a contract could be won or lost based on HSI understanding and the proposed approach using HSI methodology.

Early in the competition it was discovered that even more important to effective design (once industry was convinced the government was serious about HSI, which was communicated by showing the major area emphasis) was the additional emphasis on MANPRINT

within the technical evaluation criteria. A very high percentage of the technical evaluation areas were also evaluated as having either strong or moderate MANPRINT implications.

The two competing contractor teams were required to commit contractually to the achievement of MANPRINT, supportability, system performance goals, and the overall affordability of the Comanche program. MANPRINT objectives (and HSI methodologies that demonstrated feasibility) tended to both ease the overall manpower requirements for the system and to make more efficient use of available projected manpower than had been done in the past. Because of the unique emphasis in source selection on HCD, MANPRINT/HSI requirements were clearly communicated to the contractor. The contract statement of work (SOW) required the contractor to seek ways to incorporate HSI principles into the operation, support, and maintenance of the aircraft. By adopting HSI objectives as an inherent part of engineering design and development, the contractor was able to integrate soldier capabilities and limitations into the design with an affordable investment. As it turns out, Boeing-Sikorsky won the contract primarily because it received higher MANPRINT/ILS and operability scores than its competitor.

Example 18.8 Apache Automatic Target Handover System (ATHS) On the Apache product improvement program (PIP) for ATHS, MANPRINT was one of only two evaluation factors. MANPRINT was 50 percent of the source selection weight and technical was the other 50 percent. The purpose of the ATHS was to automate the function of "handing over" the target once identified and selected by the pilot to the lock-on of the target for delivery of a Hell Fire missile. MANPRINT was evaluated so heavily because of the critical interface with the human operator in the cockpit. As it turns out, this MANPRINT design for the pilot caused a large unanticipated maintenance manpower increase. The wiring in the Apache was so confusing due to the new and old wiring being interwoven that it was estimated that troubleshooting difficulties would require manpower increases costing about \$1 million per year. Since MANPRINT is concerned with total system costs, it required the old wiring to be removed. There was great resistance from the program manager, since the Apache program would be paying around \$4 million to remove the old wiring as part of the PIP. However, due to the high source selection weighting of MANPRINT, the old wiring was removed. Still another unexpected result came from this issue being resolved in favor of reduced manpower—this time it was additional warfighting capability, which was a windfall for the program manager. The removal of the old wiring reduced the aircraft weight by 16 pounds. This reduced weight translated to either a saving on fuel consumption of \$170,000 per year or 14 additional 30-mm rounds that could be carried. The end result of a high MANPRINT source selection factor for the army was improved system target hit capability (the original intent of the PIP) and \$16 million cost avoidance (spread over 20 years) in maintenance manpower—all while reducing aircraft weight.

Factor 4: Organizational Integration of All HSI Domains

Description A single focus for all HSI domains is necessary if any of the domains is to have substantial influence upon the system being procured. It is important that expertise from each of the HSI domains be provided to the various systems engineering and systems integration working groups. The results of a common focus of all HSI domains to a system acquisition can differ widely from system to system and from feature to feature within a system. Sometimes the domains can provide different perspectives that tend to reinforce each other and, once understood by the program manager, seem to be additive in meeting system objectives. At other times, a domain recommendation may be perceived by the program manager as so low in trade-off decisions that it can only survive with the help of the other domains. In some cases, the domains may create major conflicts for the system

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because of the differences required among the domains themselves and may not be resolved without compromises among the HSI requirements.

Example 18.9 Comanche Rotor System Design The Comanche PENTAFLEX rotor system design provides an excellent lesson learned for industry on the unexpected benefits that can accrue when HSI recommendations are adopted. The Boeing-Sikorsky design team had originally considered a rotor blade design that met government specifications but one for which MANPRINT and ILS contractor personnel had raised maintainability and transportability concerns. Because the team was still in competition with McDonnell Douglas, it was reluctant to expend extra design resources where they were not required by government specifications. Nevertheless, by bringing the full focus of the domains together on this issue, MANPRINT/ILS persevered, and the team decided to develop a new modular design that was easier to maintain, reduced the potential for installation error, and eliminated close-fit tolerance for transportability. The amount of additional effort for the MANPRINT analyses, test and evaluation, and drawing change was 395 man-hours, likely costing the contractor something well below \$50,000. However, when a life-cycle cost analysis was conducted later, approximately \$150 million was calculated as avoided due to this design improvement. These savings would come primarily from manpower requirements reductions in skill and numbers due to easier and less maintenance on the rotor system and reductions in transportability times.

Example 18.10 Comanche Tail Rotor Weight Trade-off During early design the technical advantages of the "fan-in-fin" composite tail rotor (FANTAIL) for flight efficiency were recognized. Moreover, crew and aircraft survivability were also increased with the new FANTAIL design. During the trade-off analysis the FANTAIL design was found to be eight times safer than that of the traditional rotor design. A shroud was added to protect ground crew from the tail rotor. It was known that in the past unprotected tail rotors have contributed to many avoidable accidents on the ground. This was significant for MANPRINT design influence because the shroud added extra weight, which would not have been accepted in the weight trade-off decisions if the safety domain had to argue its case alone. However, because of MANPRINT bringing together the voice of safety, maintenance, and flight operations, weight offsets in other areas allowed the increased weight for ground personnel safety.

Example 18.11 Javelin Antitank Guided Missile System The Javelin is an excellent example of a system where manpower versus soldier performance and survivability create conflicting expectations from MANPRINT. The Javelin Weapon System will replace the Dragon as the army and marine corps primary medium Antitank Guided Missile System. Javelin is a man-portable, shoulder-fixed antitank weapon capable of defeating modern and future threat armor. Major improvements over the Dragon are increased range and lethality, increased gunner survivability, reduced launch signature and effects, and reduced maintenance and support requirements. The Javelin program has understood well the role of the soldier in the total system performance. A major difficulty with the Javelin has been conflicting human performance parameters. The weight of the Javelin has always been too heavy for a one-man portable system. Yet one of the domains (soldier survivability) has required increased weight for gunner survivability. The one-man portable requirement has forced technology to reduce weight while providing the survivability advantages. Still another domain, human factors engineering, has added improved human performance features to the system accuracy that increase weight as well. All seven MANPRINT domains participated in the MANPRINT Joint Working Group (MJWG) and relied on the system MANPRINT management plan (SMMP) to bring together issues to effect design and development. A weakness pointed out by the army audit was that the MJWG did not have tasking authority to get issues tested and resolved. (Booher, 1999; AAA, 1997)

Factor 5: System Documentation Integration

Description The second integration step of the HSI model applies the information from the first integration directly into the procurement process. The HSI management tool for this principle for the Department of Defense (DoD) is the HSI management plan (HSIMP). The HSIMP 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 HSIMP depends on the quality of personnel assigned to the system joint working groups (SJWGs) and the tools and systems information at their disposal. Some of the critical documents that the HSIMP feeds are the operational requirements document (ORD), request for proposal (RFP), and test-and-evaluation plan (TEMP).

Example 18.12 T-800 Engine Contractor Request for Proposal Major advances in maintainability with reductions in manpower, personnel, and training (MPT) were demonstrated in the T-800 engine as a direct result of the government inserting limitations in the RFP. The RFP stated that the design was to have no increase in skills or manpower numbers. This clause was added late in the procurement bidding process but was accepted by industry competitors at "no cost to the government." As a result, impressive design improvements were provided. An early notable example was requiring only six tools for the T-800 organizational maintenance when 136 tools were needed for similar functions on the predecessor engine. *Note that the HSI approach was not to require a reduction in tools, but rather to set limits on the MPT that could result from the contractor's design.*

Example 18.13 Command-and-Control Vehicle (C2V) The C2V (now canceled) was to be an improved armored, tracked combat vehicle that would house and transport command-and-control equipment and staff personnel. The improvements desired were (1) speed and mobility to keep up with Abrams tank and Bradley vehicle, (2) conduct operations on the move, and (3) geographic dispersion of command and control. The command-and-control systems in the vehicle would be highly digitized equipment providing a central role for the future battlefield. Several human performance issues were identified as unique to this new equipment. Most importantly, these comprised performance of cognitive tasks and team performance under noise, vibration, and motion. Motion sickness was especially troublesome for many individuals during operations on the move and presented a major human limitation that was not fully considered in the requirements stage. Had this been fully explored, it is likely the requirement for conducting operations on the move would not have been made. This combined with the other human cognitive performance issues while in motion made one of the most important features of the new vehicle—operations on the move—no longer feasible.

Example 18.14 Family of Medium Tactical Vehicles (FMTV) The FMTV was singled out by the AAA (1997) as the only program reviewed that did not have MANPRINT properly integrated into the acquisition process. The FMTV is a nondevelopmental item consisting of both the 2½-ton (light medium tactical) and 5-ton (medium tactical) vehicles. Compatible trailers with capacity equal to the prime mover are also included in the FMTV. The system was designed to provide for large reductions in supportability need, to enhance capability and performance, and for multiple and flexible use. Although none of the 10 factors was adequately applied, it is an especially good example of how a program should *not* conduct system documentation integration. The AAA (1997) report found such concerns as: deficiency in documentation to support MPT; MANPRINT issues and concerns were reactive instead of proactive; and the SMMP never addressed issues and concerns. The SMMP prepared at the beginning of the program was not updated to include new issues and concerns found from the prototype hardware (i.e., the SMMP never addressed issues and concerns representing the actual hardware). As a result, the FMTV was fielded with a large number of design flaws. For

example, two soldiers are needed to change a tire; female soldiers cannot assemble the electric crane on the $2\frac{1}{2}$ -ton truck; and it lacks protection from small arms and fragmentation and has vulnerability to blast overpressure and shock injuries. Other deficiencies include: inability to withstand effects of chemical agents and decontaminates, inadequacy of seat belts and crew seat comfort, poor rollover protection, poor brakes, and high potential for additional training and military occupational specialties (MOSS). Some of the problem may have been because of the newness of MANPRINT. The FMTV program was initiated in 1986 prior to a full understanding of the MANPRINT philosophy by Tank & Automotive Command (TACOM) and the U.S. Army Training and Doctrine Command (TRADOC) systems manager (TSM). In this case both the user and the developer did not understand how to integrate MANPRINT requirements to affect the acquisition process.

Factor 6: Quantitative Human Performance

Description 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 should be described quantifiably as well. 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 quantitatively for proposed weapon system designs. The 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.

Example 18.15 Stinger Missile System Probability of Kill In the early 1980s a test was conducted with different skilled soldiers on performance with the U.S. Army Stinger Air Defense System. The Stinger was designed to be held, aimed, and fired by the infantry soldier. The design specification was for a system capable of being fired by the soldier at the enemy aircraft with a probability of kill (aiming, firing, and hitting) 6 out of every 10 enemy aircraft fired upon. Thus, the probability of total system performance was $P_s = 0.6$. Total system performance reliability was $P_s = P_c + P_h$, where P_c is missile component probability and P_h is human operator probability. The accuracy of the missile components themselves (P_c) was 0.6, so the gunners' performance would have had to be error free ($P_h = 1.0$). However when actual gunners were tested, it was found that even the best gunners made errors with the system such that the actual system performance reliability with superior gunners was not 1.0 but rather 0.402 (0.67×0.6). The average gunner was lower still, having a reliability of 0.51, thus making the total systems performance with them $P_s = 0.306$. In other words, the actual performance the army could expect with its air defense system was only about one-half of what it was designed to do. The requirements document should have stated, "The total systems performance reliability, including the gunner performance reliability, must be $P_s = 0.6$."

Example 18.16 Line of Sight-Forward Heavy (LOS-FH) Missile System MANPRINT was introduced in the middle of a program's acquisition process. The LOS-FH was one of those programs. The program manager showed the difference on the program as an example of the increased emphasis on human performance quantification. Before MANPRINT, crew members would be asked questions that provided subjective answers. For example, on one occasion the program manager asked, "How did you feel about information displays used in engaging targets?" Four sample crew member responses were as follows:

1. "Screen was too small and dim."
2. "I feel good about it."

3. "Things were just going too fast."
4. "That thing kept losing track."

The resulting database was comprised largely of subjective unquantifiable performance data.

After MANPRINT, the LOS-FH collected human performance data differently. Table 18.3 shows quantified human performance data for two contractor candidates for the system.

Example 18.17 Command-and-Control Vehicle Human Performance Quantification of human parameters was an extremely important factor for the C2V. Many of the difficulties with human task performance under noise and motion would not have been identified as early as they have were it not for this factor. Quantitative data for human performance were used to both identify important MANPRINT issues and make design recommendations to improve performance. Some of these efforts included analyzing individual and team performance tasks while the vehicle is in motion, assessing the effects of various shift scenarios, identifying special knowledge requirements' impact on crew members, and recommending design changes to reduce noise.

Factor 7: HSI Technology

Description The HSI technology includes three different types of technologies, tools, and techniques: (1) domain unique or common technology shared by one or more domains, (2) technology that allows trade-offs among domains, and (3) technology that aids trade-offs between system capability and affordability. The HSI technology in the hands of highly qualified practitioners will allow better design and development decisions with future systems.

Example 18.18 Comanche MANPRINT Quantitative Trade Analysis MANPRINT technology has been productively used in several critical decisions for the Comanche program (Minninger et al., 1995). During the concept exploration phase of the Comanche program (then called LHX, for light-helicopter experimental), a HARDMAN (hardware-versus-

TABLE 18.3 LOS-FH Human Performance Data

Event	Candidate A		Candidate B	
	Recoverable Error	Engagement-Ending Error	Recoverable Error	Engagement-Ending Error
Detect	6	57	8	94
Acquire	0	4	1	6
Identify	19	9	24	5
Identify-friend-of-foe (IFF)	33	0	135	0
Tracking	13	25	0	10
Ranging	0	0	0	0
Fire	0	34	0	31
Slew to cue	1	1	4	0
	72	129	172	146

manpower) comparability methodology (HCM) study was conducted to provide early estimates of MPT requirements and associated training costs for a family of light helicopters compared to predecessor systems. The HARDMAN results supported the light-helicopter concept as vastly superior for MPT affordability.

The Systems Laboratory, Army Research Institute, employed the crew workload model, a new MANPRINT tool at the time, to determine the degree to which automation would aid one- and two-person crews to conduct the intended missions. The crew workload model demonstrated that without the automation planned for LHX both one- and two-crew cockpit positions were overloaded an excessive number of times for the missions intended. The missions could not be accomplished with either size crew. However, even with automation, the one-person crew was overloaded in 10 critical events. Only a two-crew model with automation predicted no overloads for the LHX missions. The decision to adopt a two-seat design was therefore based on MANPRINT analysis for superior mission performance. This was an important decision, because not only were more flight crew required but also more maintenance personnel. The HARDMAN analysis showed that the two-seat configuration would require 12 percent more maintenance support than the single-seat version due to the additional cockpit equipment.

Altogether, however, a major net reduction of MPT was projected for the army. The manpower capabilities (MANCAP) model (one of six HARDMAN modules) was used to predict about a 25 percent reduction in manpower requirements (primarily maintenance) in the light-infantry division with the introduction of LHX. As manpower requirements became less, so did personnel requirements. For example, MANPRINT analysis showed it would be possible to consolidate maintenance-related MOS from 13 to 4. Still another finding was that the reductions in manpower and numbers of MOS allowed the MPT resource requirements to be reduced on an average of 27 to 39 percent compared to predecessor aircraft.

While showing the overall reductions in MPT requirements was important, still other uses of the MANPRINT technology were demonstrated that utilized HARDMAN's ability to represent the complexity of MPT trade-offs. In maintenance manpower, for example, depot maintenance increased 16 percent for the two-level maintenance concept. (This increase was partially offset by an estimated 6 percent reduction in manpower due to improvements in reliability, availability, and maintainability). Further complexities were revealed for actual operations. While the overall light-helicopter manpower and personnel were less, distribution of personnel was critical since workload requirement could be expected to increase at the unit level. The increases in unit workload were due to increases in operational tempos of the aircraft within the units operating the light helicopter compared to the aircraft it would replace.

Example 18.19 HSI Modeling and Simulation Program New human figure modeling tools are continually being advanced as part of the HSI set of tools to answer such questions as workspace layout, egress, and access to equipment in new or modified designs. The advanced human figure models work in combination with advanced simulation methods seeking to reliably predict system mission performance. The Comanche, Crusader, and Fox case studies (Section 18.4) show the importance of HSI to the capability and validity of those simulations directed to questions on system performance, speeded-up acquisition processes, twenty-first-century training techniques, and outcomes in warfighting scenarios.

The HSI modeling and simulation program currently available at the Human Research and Engineering Directorate (HRED) provides a conceptual "build," "test," and "evaluation" that can be performed well before a system is built. Various pieces and their integration on real programs have been demonstrated in the case studies. The human figure model, HARDMAN III, and distributed interactive simulation of small crews were applied to the Fox, whereas HARDMAN III and distributed interactive simulation (DIS) at the Janus level were successfully applied to the Crusader.

Example 18.20 Lightweight Howitzer Human Figure Modeling and Improved Performance Research Integration Tool (IMPRINT) The Human Research and Engineering Directorate developed and applied new MANPRINT/HSI technology to the SM777, 155-mm, lightweight, towed howitzer to increase system safety, usability, and efficiency while avoiding costly redesigns and reducing the total cost of ownership. An early HSI evaluation identified numerous operator interface concerns that were corrected with inexpensive fixes. The integration of HSI methods included human figure (HF) modeling, task network models, and a fast azimuth shift tool (FAST). The HF modeling was used to correlate reported operator discomforts with specific crew postures interfacing with the prototype design. Subsystem design alternative related to hand wheels, trails, spades, and fire control were evaluated with the HF modeling effort. Task network models were generated with the IMPRINT for various response functions. The task network modeling results were used by the joint program manager for requirements risk reduction, the training community for crew drill optimization, and the prime contractor to conduct real-time design trade-offs on over two dozen subsystem alternatives. The FAST was used to reduce crew burden and function time for conducting the bold-shift function. The concept and design were rapidly implemented into the final howitzer design.

Factor 8: Integrated Test and Evaluation

Description Human systems integration test and evaluation are the final and most reliable factors to assure that the soldier will receive a safe and effective weapon before going into battle. This factor begins by assuring all human performance requirements are fully included in the measures of effectiveness (MOEs) and measures of performance (MOPs) for the test-and-evaluation plan for the system. It is completed when representative users successfully perform the system during the operational test and evaluation (T&E).

Example 18.21 Crusader Training and Testing Simulator Experiment At its best, HSI integrated T&E is a continuous activity taking place throughout the system design and development process. The Crusader illustrates how HSI can play a central role in reducing the costs of operational T&E and make training and testing more effective for complex warfighting environments. As an example, Pierce (1996) describes a battlelab experiment where HSI was applied to a combined training and testing simulator for the Crusader operating in a digitized battlefield (see Section 18.4.1). The battlelab experiment showed the value of the simulator as both a trainer for field artillery collective training and as a means of testing alternative Crusader tactics, techniques, and procedures (TTPs).

Example 18.22 Land Warrior MOEs and MOPs The Land Warrior program provides a good illustration of the way MOEs and MOPs tie soldier MANPRINT requirements into the T&E program. The T&E requirements will vary over time, but a snapshot of a Land Warrior draft of MOEs/MOPs in 1997 (see Table 18.4) provides the basis for an example of integration with soldier survivability MANPRINT requirements. A few critical issues for the program are broken down into several criteria, then further broken down into MOEs, and finally each MOE comprises a list of MOPs. For Land Warrior there were three critical issues each broken down into criteria ranging in number from 3 to 7. Each criterion has its MOEs described. For critical issue 3 (survivability), the number of MOEs ranged from 4 to 6. Each MOE was further broken down into MOPs. For example, for critical issue 3, Land Warrior had MOPs ranging in number from 3 to 9 for the various MOEs related to that issue.

TABLE 18.4 Land Warrior T&E Issues, Criteria, MOEs, and MOPs

<i>Critical issue 1:</i> Effectiveness. Is Land Warrior (LW) operationally effective?
<i>Critical issue 2:</i> Suitability. Is LW operationally suitable?
<i>Critical issue 3:</i> Survivability. Is LW survivable on the modern battlefield?
<i>Criterion 3.1.</i> The LW soldier/infantry squad/platoon survivability on the modern battlefield must be equal to or greater than baseline soldier/infantry squad/platoon.
MOE 3-1-1 Difference in detectability of a LW soldier/unit and a baseline soldier/unit in an operational environment (as stated in ORD para xx)
MOP 3-1-1-1 Probability of detection due to light by range by mission by soldier/squad/platoon.
<i>Criterion 3.2.</i> Determine LW impact on protection afforded a dismounted soldier engaged in close combat.
MOE 3-2-1 Ability of basic body armor and the modular plates to meet weight goals, dimensions, protection level, and compatibility requirements (as stated in ORD, para xx, and LW spec, para xx)
MOP 3-2-1-2 Ratings of the fit and comfort associated with wearing body armor with and without front and rear plates
MOP 3-2-1-8 Coverage of plates of vital organs in the torso region for the 5th to 95th percentile male soldier

Example 18.23 Fox Vehicle T&E The Fox vehicle case study (see Section 18.4.2) illustrates the ability of HSI to improve the effectiveness of operational T&E for nonmajor systems. By using an HSI model such as HARDMAN III (newer version called IMPRINT) to obtain operational estimates of measures of performance and effectiveness, the T&E procedures can be conducted much more efficiently.

Factor 9: Practitioners

Description Successful systems need to use highly qualified practitioners on the government side as domain representatives for the system working groups, writers of requirements for SOWs, proposal evaluators, and assessors for the T&E process. Skilled HSI practitioners also need to be employed by the supplier in the research, development, test, and evaluation (RDT&E) of the system. Such individuals need to be conversant with both the technology and operational complexity of the system. Most of the tools and techniques used by the domains and as HSI trade-off methodologies are best applied by experts in their field. Because of the short supply of highly qualified practitioners in HSI, two questions that need to always be asked in assessing program success on this factor are as follows: (1) Were qualified practitioners available? (2) Were the practitioners utilized effectively?

Example 18.24 Crusader Crew Workload Research Highly qualified practitioners were both available and utilized effectively on the Crusader. The depth and quality of contributions possible from qualified HSI practitioners are well illustrated by the experience of Pierce (1996). Pierce describes how HSI practitioners using HARDMAN III technology answered system critical research questions on Crusader crew characteristics early in systems design (see Section 18.4.2). The HARDMAN analysis provided design recommendations for optimal crew size for both the Advanced Forward Artillery System (AFAS) and the Forward Area Resupply Vehicle (FARV). It also found the best combination of the Armed Services

Vocational Aptitude Battery (ASVAB), area composites, ASVAB area cutoff scores, and MOSs that would allow enhanced mission performance while not restricting the availability of qualified personnel.

Example 18.25 Practitioners on Other Successful Programs

A. Comanche Highly qualified practitioners were available and utilized by both the government and industry. In the government, skilled personnel represented each domain such that a team approach was used. This was true somewhat in industry as well, however; human factors engineering (HFE) and safety were the most heavily utilized in working with ILS personnel in a concurrent engineering environment. Government practitioners tended to specialize in their domains. When the first army acquisition milestone decision meeting for Comanche was held, more than 200 issues were identified from the practitioners of the six domains.

B. Fox Practitioners from HRED using both HFE and MPT domain tools were available but were not utilized appropriately until the program was in danger of being canceled from the adverse operational and test results.

C. Lightweight Howitzer Practitioners were available and fully utilized on this program. The practitioners were fully qualified to conduct an early HFE evaluation, to apply human figure modeling to operator interfaces, to generate task network models using IMPRINT, and to develop, fabricate, and evaluate FAST while applying it to a new howitzer design.

Example 18.26 Practitioners on Marginal and Failed Programs

A. FMTV The specification/purchase description for the FMTV addressed only HFE requirements in general (i.e., MIL-STD 1472 requirements). There was no specific requirement for MANPRINT, thus automatically leaving out five practitioner domains. Practitioners for all domains were generally available but not utilized.

B. AGS Highly qualified practitioners were available and utilized by both government and industry, but AGS leadership attempted to keep them from voicing their concerns to top leadership. The MANPRINT leadership was able to override these attempts and get the practitioners' concerns to the top army decision makers.

C. C2V This program started during a period when MANPRINT was receiving reduced emphasis at the top levels. Consequently, inadequate resources were provided for MANPRINT translating to an inadequate number of qualified practitioners being consistently provided for the C2V program. However, qualified practitioners were able to identify and attempt to solve a number of human performance issues for the program. This program did not attempt to hide the MANPRINT issues as did the AGS, but the human performance problems identified were determined too difficult to overcome.

Factor 10: Education and Training

Description Human systems integration education and training are essential to assure practitioners are qualified. Moreover, it is important to provide some aspect of HSI for everyone in the system acquisition program, in addition to the practitioners, in order for them to understand the value of HSI in meeting overall system performance, cost, and schedule. Three different levels of HSI education and training are provided. Level 1 is advanced education through formal degree programs in academic settings. Level 2 is specialized practitioner training provided by government or industry short courses. Level 3 is HSI awareness training for nonpractitioners provided as part of government and industry training either in specialized HSI short courses or as part of other courses for non-HSI personnel. (See Chapter 5 for a complete discussion of HSI education and training.)

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Example 18.27 Education and Training in Successful Programs

A. Comanche All three levels of MANPRINT education and training were fully covered on the Comanche program. Most of the domains had practitioners with advanced degrees who worked issues for all the domains on both the government and industry sides. Specialized MANPRINT training was provided for civilians, military personnel, and industry personnel who participated on the Comanche. Most government individuals associated with the acquisition process but who were not practitioners were trained by the army on the MANPRINT concept.

B. Crusader As with the Comanche, all three levels of MANPRINT education and training have been provided to participants on the Crusader program.

C. Fox MANPRINT and its tools did not receive appropriate visibility among the nonpractitioners. It took being evaluated as "unsuitable" and "ineffective" to gain the necessary visibility.

The fact that highly successful programs in the past have had all three levels of HSI education and training helping to develop knowledge, skills, and abilities for practitioners and knowledge for nonpractitioners suggests a high priority for all three levels to assure success in future systems.

Example 18.28 Education and Training in Marginal and Failed Programs The FMTV, AGS, and C2V represent degraded or failed army programs spanning 15 years of MANPRINT. The FMTV was introduced at about the same time MANPRINT was introduced. Then AGS came into the acquisition about the middle of this time period, and the C2V has come most recently. In each of these programs, it was not the lack of available educated and trained HSI practitioners that contributed to their failure. In fact, in two of the cases, it has been the voice of HSI practitioners that has been heard that has helped to eliminate the programs before they were made into problems for the soldiers. The major problem has been nonpractitioners, either within the program or higher in the army acquisition leadership, not fully appreciating the importance of HSI to program decisions. This suggests that the top priority to avoid system failures in the future is increased emphasis on education and training for nonpractitioners involved in the acquisition process.

18.4 CASE STUDIES OF SYSTEM BENEFITS

The review of army systems and HSI application has revealed a number of beneficial results that should be especially attractive not only to the HSI practitioner but also to the non-HSI practitioner to better understand the value of HSI in systems engineering and management terminology. Four systems have been studied in detail as case studies by Booher (1997) from this point of view. The systems comprise two aviation systems, Comanche and Apache; one NBC reconnaissance vehicle; and the army's advanced howitzer system, Crusader. Selections from these four case studies are presented here as examples of program benefits in terms of acquisition process efficiencies, system design improvements, casualty reduction, and cost avoidance.

18.4.1 Acquisition Process Efficiencies

Two examples of major systems acquisition process efficiencies are provided below: the Comanche acquisition process and the Crusader battlelab experiment.

Comanche Acquisition Process The Comanche program provides the best-documented example of HSI influence on the systems acquisition process. The Comanche philosophy was to focus on maximizing the army aviation's battlefield influence by fielding a *totally integrated* weapon system with the appropriate mix of quality soldiers, hardware, and software. To achieve a "total system," as opposed to an "equipment-oriented" perspective, HSI principles were applied to the design and development of the Comanche aircraft. Inherent in such a philosophy of a total system's view was the crucial concept that the soldier is not added to the system but that the soldier (whether aircrew member, maintainer, or support personnel) is an integral part of the system.

This total systems philosophy required a new organization and management process that horizontally integrated the widely disparate MANPRINT, supportability, engineering, and cost disciplines. The horizontal integration of discrete development processes encouraged the breakdown of traditionally organizational barriers and facilitated interaction outside those barriers. In this way, effective design decisions could be made that reflected all participating disciplines. This, of course, is the intention of the modern acquisition improvement concepts with integrated process teams (IPTs). The Comanche program went beyond this, showing that the IPT was most effective because MANPRINT was provided a prominent status. In fact, for integration across disciplines, only the focus on the soldier permitted a true integrating strategy.

Minninger et al. (1995) highlight a number of management initiatives driven by and/or compatible with HSI principles:

- concept exploration and advanced modeling/simulations,
- concurrent engineering (integrated concept teams/integrated process teams),
- source selection and MANPRINT,
- continuous acquisition and life-cycle support (CALS),
- Comanche supportability initiative,
- HFI quantitative trade analyses,
- TRADOC system manager—forward, and
- pilot vehicle interface mechanization and specification.

Several of these initiatives described below illustrate the major influence HSI methodologies had upon the Comanche acquisition process.

Concept Exploration and Advanced Modeling/Simulations Long before the current Comanche program during the concept exploration stages for the LHX program, advanced modeling and simulation activities were initiated through the Advanced Rotocraft Technology Integration (ARTI) Program. Pilot workload issues were considered early on as a potential limiting factor to the LHX concept. Advanced simulation was utilized in the study of pilot tasks using a wide-field-of-view helmet-mounted display, electro-optical systems, and very high speed integrated circuit (VHSIC) electronics. Human-driven analyses, computer simulations, and physical mock-ups were used to improve and assess the effectiveness of the aircraft's total system performance. At the time, an important manpower issue was one- versus two-pilot cockpit and a critical training issue was simulation fidelity.

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A MANPRINT analysis of pilot tasks was used to reduce the risk of the LHX developmental program and prove the feasibility of a single-pilot scout/attack helicopter as well as general cockpit and architecture design. In order to meet the single-pilot objective, the state of the art had to be pushed to the maximum. As an absolute minimum, not only did human engineering requirements have to be incorporated into the aircraft architecture but also the majority of in-flight functional activities had to be automated. The automated features included detection, recognition, identification, and prioritization of targets; management of noncritical flight control functions; navigation; automatic location reporting; and mission and flight status. The technology thrust was to provide this critical real-time information within the pilot's field of view looking outside the aircraft, so he or she would not have to look down at the control panel. The HSI research showed this was feasible by using sophisticated heads-up/eyes-out displays integrated into the pilot's helmet. The helmet-mounted display also could provide forward-looking infrared (FLI) imagery for target identification and acquisition. The cockpit design also incorporated two integrated multipurpose displays mounted in the control panel.

As part of the modeling and simulation efforts, performance and work loading data were obtained from HSI real-time simulations of flight dynamics, external visual scenes, and responses of mission equipment packages. Flight tests in modified aircraft verified the HSI simulation findings that a pilot could use helmet-mounted and multipurpose displays while performing normal flight tasks.

Source Selection See Example 18.7.

HFI Quantitative Trade Analysis See Example 18.18.

TRADOC System Manager—Forward Prior to the downselect of the contractor team to complete development of the Comanche, the army provided teams of TRADOC soldiers to support the contractors. These teams were composed of aviators and maintenance personnel selected for their experience and ability to communicate "user" information to the contractors during the design phase. Following downselect of the prime contractor, a team of soldiers were provided to the contractors on site as an extension of the Comanche TSM; it became known as the TSM-forward. The TSM-forward was a unique concept in that it was neither a part of the Defense Plant Representative Office (DRPO) or part of the Program Manager's Office (PMO). The objectives of the TSM-forward were to address and prioritize user operational and MANPRINT concerns during the demonstration/validation (DEM/VAL) prototype and subsequent engineering and manufacturing development (EMD) phases. The presence of the TSM-forward in the contractors' facility allowed user's issues and concerns to be identified in a timely manner. As an example, TSM-forward activities with the IPTs reduced the time period to turn around design changes between contractor and government. In one instance, a rotor design change that would routinely have taken 12 months for contractor/government approval was completed in 30 days.

Integration with Advanced Systems Management Other new systems management initiatives (e.g., total quality management, concurrent engineering, integrated logistics support) created an environment for Comanche design and development that was compatible with the human-centered approach. As a direct result of these efforts and changes in the acquisition process, more than 500 design improvements were approved to aid in system performance and logistics. These improvements were accomplished while

demonstrating projected cost avoidance of \$3.29 billion in manpower, personnel, training, and safety. Additionally, 91 fatalities and 116 disabling injuries would be avoided.

Crusader Battlelab Experiment The experiment on Crusader (Pierce, 1996) was conducted in a first of a kind *synthetic environment* comprising real and simulated systems in a complete battlelab environment. The real systems included such tactical digital systems as the Advanced Field Artillery Tactical Data System (AFATDS), Initial Fire Support Automated System (IFSAS), and Fire Direction System (FDS). The simulations were at two levels: the maneuver battle using the DIS-compliant version of Janus and the support processes simulated by the target acquisition and fire support model (TAFSM). World Modeler, an interpreter, created the interface between the two simulations. The Janus simulation was staffed by interactor and player staffs using Crusader scenarios. Crusader characteristics were played in the TAFSM, and soldiers from field artillery units were used to generate and process fire missions, resupply missions, and *tactical coordination and movements*. The HSI personnel at the HRED Ft. Sill Field Element led the experiment to demonstrate the feasibility of the synthetic environment playing war games of complex battle scenarios with full soldier performance data, including battle staff performance.

Forty battalion-level staff from a field artillery unit participated in the battlelab experiment. The scenario selected represented an artillery battalion performing a direct-support role for an attacking brigade and its three task forces. The principal offensive operation was a movement to contact that included a reconnaissance, hasty attack, obstacle breaching, forward passage of lines, and deliberate attack by the maneuver forces. In the experiment, personnel were assigned roles for the maneuver element, the battalion tactical operations center, and each of six platoon operations centers. The event stream was those events that make up a complete command-and-control cycle, including fire mission processing; survivability and tactical displacements; and resupply planning, coordination, and execution. The TAFSM performed fire support officer functions and disseminated instructions to players in tactical message format.

The study examined implications of Crusader systems on command-and-control processes using the event stream. The training/test purpose of the synthetic environment exercise was to stress the unit command-and-control system, to determine what levels of fire support activity stress this system, and where the system is likely to break when these levels of activity occur. The level of activity was varied through fire missions, movements, platoon operations center performance, and the scenario.

Two principal questions about Crusader performance were asked of the first battlelab experiment:

1. Can the Crusader deliver effective fires to defeat the projected threat?
2. Can Crusader ammunition resupply system support the battle (operations tempo OPTEMPO)?

The answer to both questions was in the affirmative, but the experiment provided greater specificity about the relative importance of certain TTPs as well as equipment capabilities and limitations. For example, to deliver effective fires, it was discovered that additional command-and-control processors were required at battalion and platoon. The techniques for "shoot and move" were not only confirmed as sound but were also shown

necessary to enhance Crusader survivability against counterfires. Additionally, potential fratricide situations were uncovered and tactics were developed to avoid fratricide. Also, for the assurance of effective fires, the experiment found it critical to define specific tactical and technical fire control roles and responsibilities for the platoon centers.

For the resupply system to support the battle OPTEMPO, the experiment confirmed the need for "pooled" resupply vehicles at the platoon level. It was also found that the pooled condition allowed the resupply vehicles operational cycle (rearm, hide, resupply) to keep up with conditions of increased fire mission processing.

The battlelab experiment showed the value of the simulator as a trainer for field artillery collective training and as a means of testing alternative Crusader TTPs. Because of HSI involvement, unit performance can now be observed in the various battle games for systems as complex as the Crusader operating in a digital battlefield. Shortfalls, gaps, and improvements in the warfighting doctrine can be evaluated and used by the army to propose new doctrine for systems such as the Crusader upon fielding.

18.4.2 System Design Improvements

Eleven examples of system design improvements from HSI are provided below from the four case study systems: Comanche, Crusader, Apache Longbow, and Fox.

Comanche System Design Improvements The Comanche aircraft has been designed to be the most sophisticated helicopter ever built. It incorporates state-of-the-art technology throughout every component and subsystem of its design. Apart from those disciplines advancing helicopter technology itself, HSI is one of the most important disciplines contributing toward making the Comanche system a highly capable, operable, and supportable weapon system. Figure 18.2 illustrates several of the design features most notably influenced by the MANPRINT design team. The crew station design, the T-800 engine, and the box structure design are selected for further discussion below.

Crew Station Design Early simulations and modeling, lessons learned, and user inputs allowed the cockpit truly to be designed from the pilot outward. The objective of the crew station design process was to blend the airframe, computers, sensors, and crew into a low-workload, low-error-rate, high-situation-awareness, and quick-reaction cockpit. The Comanche Human Factors Engineering Group used the army's task analysis/workload (TAWL) methodology to perform analyses of the operator tasks. As a result of the TAWL analyses, designers were able to meet the following crew station design objectives:

- Reduce the number of sequential tasks required to perform mission functions.
- Ensure human performance demands from design do not exceed human performance capabilities.
- Ensure task performance times are acceptable for the mission.
- Ensure that the controls and displays provide adequate interface information to accomplish mission tasks.

More specifically, the TAWL and TAWL Operator Simulation System (TOSS) assisted the design team to simultaneously combine critical target acquisition and attack data with critical flight control data. This information can be displayed to the aircrew through the



MANPRINT Design Influence on the Comanche

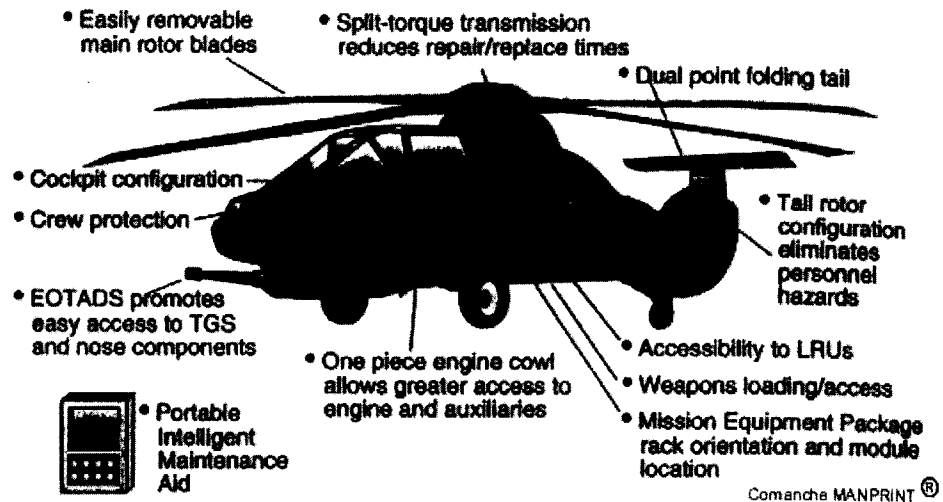


Figure 18.2 Comanche design improvements.

tactical situation display (TSD) mounted on the display panel or the Helmet Integrated Display Sighting System (HIDSS) attached to the crew member's helmet.

T-800 Engine The T-800 engine was the first army development program in which the MANPRINT process played a major role. MANPRINT's visibility allowed ILS and RAM programs to be more effective in influencing the design process and also provided for the integration of soldier capabilities and limitations with system development. During the design and development process, widely varying HSI tools (analyses, models, and mockups) were utilized to improve, validate, and assess the effectiveness of the T-800 system. Benefits were extensive in the areas of MPT as a result of government limitations in the RFP stating the design was to have no increase in skills or manpower numbers. The engine had an extensive number of improvements based on the MPT limitations. The modular design eliminated the need for scheduled overhaul; the elimination of the need for torque wrenches reduces both the number of tools required and the level of maintenance. In designing the engine to be more maintainable, it had become more reliable as well. The increased reliability and maintainability not only decreased the maintenance per operating hour but also reduced overall training burden by as much as 40 percent for comparable engines of the current aircraft fleet. Some of the other many benefits to the T-800 from HSI have been documented by Howington and Goldthwaite (1989), by Booher (1990), and in a 1993 case study held in the army MANPRINT headquarters office (DAPE-MR)

Box Structure Design Driven by MANPRINT access requirements to helicopter on-board components, especially in a field environment, an entirely new load-bearing structure was designed for the Comanche. The new box beam structure is a graphite-

epoxy composite material that allows more than 50 percent of the exterior skin to have access doors and panels. Mission equipment packages (MEPs) are accessible for maintenance and/or inspection in a field environment. Several of the access panels open at convenient locations to serve as work platforms, thus eliminating the need for separate ladders or special work platforms. The design and placement of aircraft components, built-in access doors, and convenient work platforms make it possible for fast turnaround of maintenance and loading tasks. By partitioning the Electro-Optical Target Acquisition and Designation System (EOTADS) sensor functions, a 40 percent life-cycle cost avoidance in supply stockage is projected. Loading of the 20-mm gun can be accomplished by one person loading from the side of the aircraft. The feature of adjustable weapon bay doors allows missile ordnance loading in less than 13 minutes with only two personnel.

Crusader System Design Improvements As the Comanche, the Crusader has had a number of system design improvements generated by HSI practitioners. One of the best documented examples is how MANPRINT affected the manpower and personnel design decision for the artillery and resupply systems. At the time, the Crusader was called AFAS-FARV. The general question for HSI was whether the 13B MOSs with regular training, using the AFAS-FARV under sustained operations, could accomplish their mission.

Three specific manpower and personnel questions were asked of the practitioners with their HARDMAN analysis:

1. What is the optimal crew size for the AFAS and the FARV?
2. What combination of ASVAB area composites and area cutoff scores for the AFAS and the FARV results in enhanced mission performance while not restricting the availability of qualified personnel?
3. Is there a basis for selecting an appropriate MOS for the AFAS and the FARV?

To address the crew size question, the HARDMAN analysis team looked at performance of different crew sizes two, three, and four under different environments (Desert Storm, tropical, NE Asia-Korea) under a range of scenarios (standard, rapid fire, direct fire; degraded operations and FARV upload-manual and automatic). The crew's performance was also examined for effects of special stressors such as mission-oriented protective posture (MOPP) gear, continuous operations, heat, cold, humidity, wind, and noise.

Two of the most significant conclusions on crew size were as follows:

1. With the exception of two-man FARV crews with automatic upload, only three-man crews could perform mission requirements accurately under any of the conditions examined.
2. Automatic upload was essential for FARV. Even a four-man crew could not meet mission performance times in the manual mode. The automatic upload showed either two- or three-man crews consistently met mission performance times.

However,

3. In a desert or tropical environment and after 48 hours of continuous operations, the FARV two- and three-man crews made 40 percent more errors than the four-man crew.

To answer the personnel questions, three-man crews for both AFAS and FARV were assumed. Fewer environments and scenarios were examined and continuous operations were held below 48 hours. Two area composites, field artillery (FA) for the 13B MOS and operations and food (OF) for the 13M MOS were considered. The ASVAB cutoff scores examined were 85, 95, and 105.

The findings supported the following ASVAB area conclusions:

1. For the AFAS—FA for 13B MOS and OF for the 13M MOS perform about the same in normal operations, but the OF area composite crews produced about 34 percent fewer mission aborts than FA-selected crews. The area cutoff scores recommended therefore were FA 95 and OF 85 or OF 95. For the FARV—Increased aptitude was not significant in improving performance.
2. Although the OF area composite teams could perform adequately with lower cutoff scores and better under continuous operations, the difference was not so great as to select a 3M MOS specialty for Crusader. Utilization of personnel from both MOSs could increase the availability of qualified personnel. For the AFAS the standard 13B MOS can perform adequately, so long as the cutoff score is 95.

Apache Longbow Design Improvements Irving et al. (1994) report on a McDonnell Douglas helicopter systems MANPRINT cost savings study conducted on the Longbow Apache. The study covered the four previous years in which the Longbow Apache MANPRINT team participated in the EMD phase where issues were raised throughout the concurrent engineering process. Those issues that were not readily resolved were labeled as problems, issues, and concerns (PICs). An item could become a PIC from recommendation by the army, by failure to comply with documented company or military standards, or by continual refusal by a designer to comply with user-friendly design practices without acceptable rationale. At the time of the study 161 PICs had been documented and 86 had been resolved. Five of the resolved PICs were selected for detailed analysis and are presented as items here as illustrative of typical HSI design issues and methods of resolution.

The five items selected for HSI analysis were (1) seat stroke interference, (2) extended forward avionics bay (EFAB) contour, (3) rotor head access, (4) tail rotor rigging pin, and (5) data rate adapter mounting. The rotor head access and the EFAB contour related to design deficiencies that could have caused loss of life and aircraft had they not been resolved. The remaining three were concerned with maintainer access to components and fasteners and the time and costs involved with difficulties in access.

Seat Stroke Interference The Apache is equipped with crash-survivable seats that "stroke" (collapse) during a crash to absorb energy in order to reduce injuries to crew members. The original design for the Longbow Apache included new brackets for the left consoles of both crew stations that reduced the clearance on the left side of the seats and interfered with the stroke. As a result of HSI, the depths of the control panels on the left side were reduced and the Apache Longbow brackets were redesigned to allow the seats to stroke identically to those in the fielded Apache (AH-64A).

Rotor Head Access In order to access the rotor head, Apache maintainers have a habit of standing on the engines, the infrared jammer support, and catwalk door hinges. These

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practices have led to injury and maintenance-induced damage in the AH-64A Apache. A review of lessons learned from the AH-64A brought this issue into the MANPRINT analysis process. The analysis found the Longbow Apache Environmental Control System (ECS) structure would be exposed to damage when used by mechanics as steps and handholds.

As a result of HSI recommendations, the ECS support structures were redesigned to incorporate a work platform. The new platform not only provides maintenance access to the rotor head components but also provides protection to ECS components. The analysis of frequency of repair in the rotor head area showed Apache maintainers might need to access the rotor head area over 92,000 times throughout the fleet life cycle.

EFAB Contour The Longbow Apache avionics bays were enlarged over the predecessor system, causing designers to redesign for changes in airflow. On the right side of the aircraft, a fairing was constructed to improve airflow over the top of the wing. Unfortunately, the new design created a safety hazard. If during flight, a foreign object were to be directed down the top of the EFAB, the object would likewise be directed toward the engine inlet and sucked into the engine. The faster the forward aircraft's air speed, the more likely the ingestion of the foreign object. If this were to occur during nap-of-the-earth, an engine failure could result in loss of aircraft and flight crew. As a result of the HSI effort, the fairing was eliminated and replaced by a smaller fairing that diverts air and foreign objects under the wing and outboard rather than into the engine.

Tail Rotor Rigging Pin The proposed rigging of the tail rotor flight controls was difficult to access. The maintainer had to insert a pin in the flight control package located below the pilot crew station right console. Two ECS components, a fan, and an evaporator had to be removed to access the rigging pin hole. Also, an additional maintainer MOS was required for removal of ECS components. The human factors redesign was to relocate the fan and evaporator slightly aft to allow access for the rigging pin, eliminating both the access problem and the second maintainer.

Data Rate Adapter Mounting Line-replaceable units (LRUs) mounted below the Longbow programmable signal processor are tightly packed. Data rate adapters (DRAs) mounted in this area with fasteners facing inboard could not be removed without first removing adjacent LRUs. By fastening the DRAs to a sheet metal bracket that mounts to a shelf with fasteners facing outward, maintenance was eased.

Fox Vehicle HSI Modeling Illustrated in Figure 18.3, the Fox vehicle (formally the XM93E1, NBC Reconnaissance System) provides one of the clearest examples to date of how the integration of HSI technology from different domains can provide vastly superior results over nonintegrated applications of the same technology.

The Fox is designed to move over terrain possibly having NBC contamination, pick up and analyze the samples, and determine the nearest "clean" area. The Fox was originally designed for operation by a crew of four without consideration for female anthropometrics. The army wished to field the Fox as quickly as possible as an army category (ACAT) III nondevelopmental item (NDI) but with some changes in field operations. The changes included (a) reducing the crew from four soldiers to three soldiers, (b) replacing contractor maintenance with army logistics support (i.e., the soldier), and (c) adding standoff detection capability (an additional soldier task). From a workload perspective, it was

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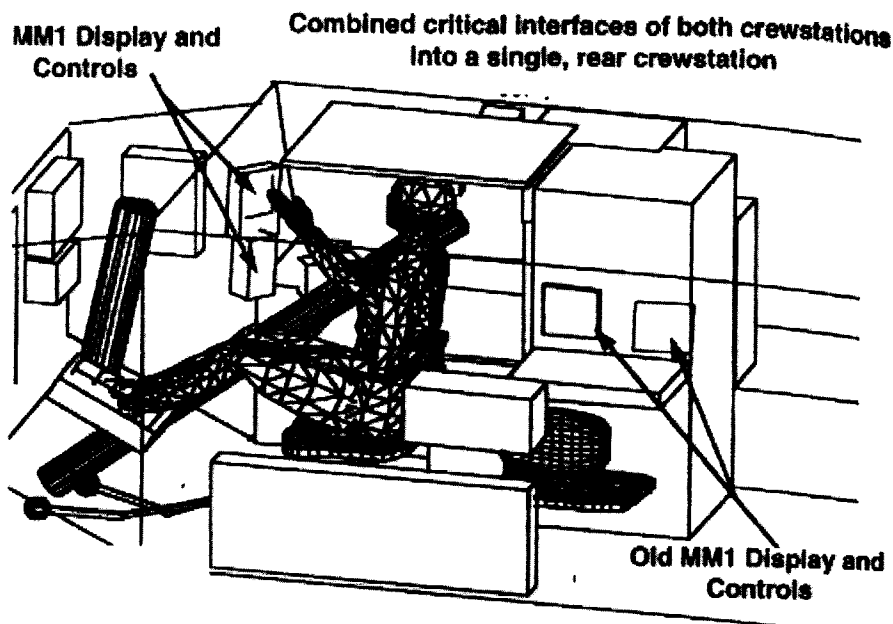


Figure 18.3 Fox vehicle.

apparent right away that the Fox without design modification would have a serious problem with crew workload. The soldier maintenance and standoff detection would increase the tasks, which would be distributed among fewer soldiers. An excessive workload determination was subsequently confirmed by the Operational Evaluation Command (OEC), which gave the Fox an initial outfit T&E (IOT&E) assessment of "unsuitable and ineffective." The Fox program manager requested HRED of the Army Research Laboratory to assist in making this vehicle effective and affordable. McMahon (1996) describes the strategy utilized by HRED to design a solution based on two different types of HSI modeling capability: a workstation human figure modeling and a HARDMAN III task network modeling.

Human Figure Modeling The original four-person crew had two positions at the front of the vehicle, one on the right side and one at the rear. In order to eliminate one of the crew, a workstation design change was required to combine two positions into one. It was decided that the rearward positions could be combined into one by combining the man-machine interfaces. Anthropometric-sized human figure models were created for each of the Fox crew stations. The human figure models of the rear stations showed how the old controls and displays (MM1) for the seat on the right could be combined into a single, rear crew station. The human figure model was also exercised to verify that the design was within the field of view and reach envelope of a 5th percentile female operator.

HARDMAN III Task Network Modeling The human figure modeling provided confidence that the two crew stations could be combined into one. It was still a question,

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however, whether the three crew members would be able to meet mission requirements that included movement to a starting point, taking a spectrum, and then finding the near-side clean area. To accomplish these mission functions, the rear crew member must continually interact with a spectrum monitor, a probe, and sampler wheels. The Operational T&E Command (OPTEC) was not convinced that the functions could be satisfactorily accomplished under conditions of stress and fatigue over long periods of time. The OPTEC test scenario was 24 hours a day for five days a week over two to three months. This test was of such an extent that it was estimated by the program manager to cost between \$2 and \$4 million, an amount sufficiently large to cancel an ACAT III program. However, OPTEC would allow certain performance model estimates to supplement the operational test and evaluation. By using the HARDMAN III (MAN-SEVAL) model, previously accredited by OPTEC, to obtain system performance estimates, the actual test was reduced to a much more affordable test—4-hour missions, 8 hours a day, for only two to three weeks.

The HARDMAN III model was set up to analyze the Fox operations with inputs on mission definition, crew performance time data, and task workload estimates. Mission definition was stated in terms of functions and subfunctions derived from the Fox mission crew drills. Performance time data came from the Fox IOT&E of fiscal year 1994. The workload assignments for visual, cognitive, psychomotor, and auditory tasks came from subject matter experts using McCracken-Aldrich scale values.

The HARDMAN model verified that the Fox human factors modifications (HFMs) would meet performance requirements in all mission functions. In fact, the overall mission time for HFM showed a 20 percent reduction from the original mission time. It was determined that the modifications not only allowed one soldier to do the combined tasks previously done by two but also improved the soldiers' ability to interact with the monitor, probe, and sampler wheels.

HSI Tools Interaction The Fox vehicle demonstrated three significant points about the application of HSI technology. First, HSI technology can make a program successful, even if it is one where only relatively small design modifications are possible. Second, the Fox clearly illustrated that HSI man-machine interfaces and workspace layouts are necessary when attempting to reduce manpower without creating excessive workload. Third, Fox demonstrated the importance of utilizing widely varying HSI tools from the different domain to help the program manager achieve the program mission. The human factors interface technology helped design the optimum solution but would not have been adequate to forego the OPTEC expensive test scenario without the HARDMAN task network modeling. On the other hand, if only network modeling had been done to the original design, little more would have been shown than that OPTEC was correct—that the workload was too excessive to conduct the mission.

18.4.3 Safety Improvements

Although safety improvements through HSI design were inherent in all of the case study systems, the Comanche provides the best documented example of how HSI can reduce military casualties.

Comanche Casualty Reduction It is projected that use of the Comanche rather than the OH-58 A/C and AH-1F aircraft will avoid 91 soldiers' deaths over a period of 20 years.

Similarly, use of the Comanche will avoid at least 116 disabling injuries. Nine years of accident/incident data reported to the U.S. Army Safety Center was reviewed for events causing personnel deaths and disabling injuries in the older aircraft. During this period there were 26 AH-1 and 39 OH-58 related fatalities (i.e., fatalities that safety analysis showed could have been prevented by improved design). Also during the 9-year period, there were 23 AH-1 and 63 OH-58 related disabling injuries. Some of the incident types and corresponding design improvements are listed in Table 18.5.

18.4.4 Cost Benefits

Three of the systems, the Comanche, Apache Longbow, and Fox, provided clear investment and benefits costs *that could be directly attributed to HSI activities*.

Comanche Cost Avoidance Minninger et al. (1995) fully document their assessment of cost avoidance due to MANPRINT/HSI. Although MANPRINT attributes were closely linked to other disciplines such as ILS and RAM, it was not always possible for the analysis to identify those savings due directly to HSI. However, the cost avoidance documented in that report was entirely from the MANPRINT domains of MPT and safety. It was also recognized that it was the MANPRINT approach with the focus on the soldier and communication to industry through its acquisition process that significantly changed the design process for the contractor. The cost avoidance assumptions and details of the cost avoidance estimate rationale are provided in Appendix B of Minninger et al. (1995).

The Army Manpower Cost System (AMCOS) model was used to quantify cost avoidance due to the contributing factors of MPT that follow from such items as reduction of number of MOSs, reduction in maintenance levels, and reduced training requirements. The contributing factors for the Comanche were compared to the predecessor systems OH-58 and AH-1 being replaced with the Comanche. In order to standardize comparisons,

TABLE 18.5 Incident Type and Design Improvements

Incident Type	Design Improvements
• Aircraft collisions	• Improved outside visibility • Two pilots for all current missions
• Aircraft crash	• Improved night vision capabilities • Improved situational awareness • Ground proximity warning system • Improved airframe crash survivability
• In-flight break-up	• Strengthened composite airframe • Improved rotor system prevents mast bumping
• Engine failure	• Monitoring systems warn of impending failure • Engines can operate 20 minutes after loss of oil • Multiple engines
• Loss of tail rotor effectiveness	• Fantail system does not limit flight envelope • Fantail can operate after loss of a blade
• Ground accidents	• Work platforms built into the airframe • Fantail shrouded with added safety bars

identical operational tempos were used for the Comanche and the predecessor systems. It is important to recognize that the systems being replaced would not only require the higher MPT costs but would be unable to perform many of the new capabilities provided by the Comanche. Other analyses such as those described above in determining fielding requirements showing a 25 percent reduction in overall maintenance requirements are not reflected here, because those analyses consider the full MPT needed to make complete use of the Comanche's capabilities.

Safety and soldier survivability estimates were based on safety center mishap data and consideration of those specific Comanche design improvements aimed at eliminating design deficiencies of the Kiowa and Cobra aircraft that safety analyses show could have been prevented by design changes.

The cost avoidance figures due to HSI were broken down into four categories. Manpower showed that 32 percent of the predecessor manpower costs will be avoided in the Comanche equating to \$2.67 billion. Personnel and training together will avoid 33 percent of predecessor personnel/training costs or \$440 million; safety, health hazards, and soldier survivability costs avoided equate to \$180 million. *The total Comanche cost avoidance due to HSI is \$3.29 billion.* Since the total costs for MANPRINT on the Comanche (past and projected) is \$74.9 million, the return on investment over 20 years is 4390 percent.

Apache Longbow Cost Benefits Irving et al. (1994) report that 80 of the 86 resolved PICs were judged capable of objective analysis for determining quantifiable cost savings or cost avoidance for their customer. The study team felt the five PICs discussed above were a good representation of the range of HSI impacts on the Apache.

Seat Stroke Interference Using historical data for class A mishaps, the cost avoidance for the seat stroke interference design correction led to an estimated savings of \$2,610,000, not including the loss of crew productivity or the incalculable loss of aviator's lives. This deficiency was resolved by making minor changes to one control panel and a single bracket at a nonrecurring cost of less than \$10,000.

Rotor Head Access The work platform recommendation for the Apache ECS support structures redesign came as a cost-effective solution to avoid maintenance-induced damage. Assuming the expensive blower or transition duct could be damaged by maintenance personnel to the extent that they would need to be replaced 2 percent of the time, cost avoidance of replacement parts alone (not including aircraft downtime or man-hours to make the repair) would be about \$4,577,000. The fleet implementation expense for the maintenance platform will be about \$568,000, a return of 8 times the investment.

EFAB Contour To avoid the potential hazard of a foreign object being sucked into the engine because of the EFAB contour, HSI recommended a design that diverts air and foreign objects under the wing and outboard rather than into the engine. This hazard was resolved with a nonrecurring cost of approximately \$10,000, with a cost avoidance of over \$10 million.

Tail Rotor Rigging Pin The HSI redesign of the fan and evaporator location to allow access for the rigging pin, which eliminated both the access problem and the second

maintainer, was made with an implementation cost of \$8000 and reduced manpower costs by about \$300,000.

Data Rate Adapter Mounting The small change of a bracket that mounts to a shelf with fasteners facing outward cost about \$4000 to install but allowed cost savings of over \$76,000.

For the five PICs alone the design and implementation costs were \$600,000, but the study team found a \$16.8 million cost avoidance over the life cycle of the program. They concluded this only represents a small fraction of the total cost savings/avoidance to be realized by the army throughout the Longbow Apache life cycle. The investment in MANPRINT for the entire full-scale development is \$2.7 million. Allowing for implementation costs, the five PICs alone will provide a return 5 times (500 percent) the investment into HSI for the program. But if one were to extrapolate to all 80 PICs, the return would amount to over 20 times the same investment, not as high as the Comanche, either in total dollars saved or return on investment, but a number well worth the investment.¹

Fox Cost Benefits The Fox vehicle demonstrates a number of HSI lessons learned and quantitative cost benefits not realized before. First, as an ACAT III program that is NDI, only relatively small modifications are possible. The Fox clearly demonstrated that HSI human-machine interfaces and workspace layouts are necessary when attempting to reduce manpower without creating excessive workload. Second, Fox demonstrates how widely varying HSI tools can be used to achieve the program mission. The human factors interface technology helped design the optimum solution but would not have been adequate to forego the OPTEC expensive test scenario without the HARDMAN task network modeling. On the other hand, if only network modeling had been done to the original design, little more would have been shown than that OPTEC was correct—that the workload was too excessive to conduct the mission. Finally, not only was the program saved, but it was also done in a very cost-effective manner *that was reflected in the PM budget in the near term*. The estimated cost to the PM for the HFI analyses (which were completed in 60 days) was \$60,000. The operational test savings were \$2 to \$4 million.

18.5 HSI FACTORS AND FUTURE WEAPONS SYSTEMS ACQUISITION

There are several difficulties facing the army leadership with a decision to revitalize the old MANPRINT process and apply it to future army systems. Although factors can be identified that were successful in the past, it is fair to question how well these factors will translate to new systems, considering that many of the acquisition processes have changed. For example, it is not known what effect acquisition reform changes such as using integrated concept and process teams or elimination of coordination documents like the system MANPRINT management plan will have on future systems. Additionally, the effect of reducing the numbers of practitioners representing the individual MANPRINT domains may provide a new personnel and training issue that was not a problem in the past.

A second task in the study by Booher (1999) was to evaluate the critical HSI factors for applicability to systems being procured now and in the future under the DoD acquisition

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reform practices. Starting with the baseline information for the 10 systems in Table 18.1, Booher reanalyzed the 10 HSI success factors in view of 8 relevant acquisition reform factors (ARFs):

- R1. rapid acquisition process (RAP);
- R2. increased NDI, COTS (INC);
- R3. reduced emphasis on SMMPs, MJWGs (RSM);
- R4. greater reliance on battle labs, simulation, and modeling (BSM);
- R5. ICTs, IPTs, Integrated T&E (INT);
- R6. fewer practitioners (FPs);
- R7. fewer nonpractitioners (FNPs); and
- R8. greater reliance on total system performance (TSP).

Table 18.6 presents the results of a matrix analysis conducted for the 8 ARF factors and the 10 HSI success factors. The HSI success factors for past systems were judged whether they would have been significantly influenced by an ARF, positively (+), negatively (-), or with no change (nc).

The results of the analysis of HSI success factors with the interactions of the ARF are summarized in Table 18.7. The two most important findings were as follows:

1. Two of the acquisition reform factors either have positive or no effect on all the HSI success factors. These are R4 (battlelabs, modeling, and simulation) and R8 (total system performance). MANPRINT is conceptually consistent with front-end decision making that uses human performance data. To the degree that R4 and R8 include human performance parameters on the domains of MANPRINT, better performing and cost-effective systems will be produced.

2. Six of the eight reform factors have a negative effect on many of the HSI success factors. In particular, success factors 4 (domains integration), 5 (system development integration), 6 (quantitative human parameters), 9 (practitioners), and 10 (education and training) are most negatively affected by the reform factors.

Booher (1999) made the following conclusions regarding the HSI success factors' role in future systems acquisition:

1. In general, the 10 success factors for past systems appear to be the same factors that should be part of the process for all army systems of the future.

2. The reform factors provide no basis for the proposition that reduced attention to any of the factors will result in systems successes in the future. Although greater utilization of battlelabs, simulation and modeling, and total system performance are highly compatible with some of the HSI success factors, this does not offset the extremely negative effects of most reform factors on most of the success factors.

3. No tailoring of factors for future systems can be recommended beyond that shown in the HSI success factors. The problem is really how to achieve satisfactory results in the future under seriously degraded conditions. The best solutions appear to be increased emphasis on strong HSI policy for requirements, source selection, and test and evaluation;

TABLE 18.6 Acquisition Reform Factors Analysis Matrix

Success Factors	Acquisition Reform Factors							
	(1) RAP	(2) NDI	(3) SMP	(4) BSM	(5) INT	(6) FP	(7) FNP	(8) TSP
1. Top-level support	-	-	nc	nc	nc	nc	nc	nc
2. Human-centered design	-	-	nc	+	nc	-	n	+
3. Source selection	nc	nc	nc	nc	-	-	-	+
4. Domains integration	-	nc	-	nc	-	-	-	nc
5. System documents integration	-	nc	-	nc	-	-	-	nc
6. Quantitative human performance	-	-	-	+	-	-	-	+
7. Trade-off methodology	nc	nc	nc	+	+	+	+	+
8. Test and evaluation integration	+	nc	nc	+	+	nc	nc	+
9. Practitioners, skilled, available	-	-	-	nc	-	-	-	nc
10. (a) Education and training (Practitioners)	-	-	-	nc	-	-	nc	nc
10. (b) Education and training (nonpractitioners)	-	-	-	nc	-	nc	-	nc

TABLE 18.7 HSI Factors and Acquisition Reform Factors Interaction

Factor 1. Top-level support and understanding: Most of the acquisition reform factors have little influence on the importance of this factor. The same emphasis from the top will be critical to MANPRINT success on future systems. However, reform factors 1 (rapid acquisition process) and 2 (more NDI/COTS) can have a negative effect because of the pressure to have less coordination and examination of issues at the top levels.

Factor 2. Human-centered design: This factor will be influenced in several different ways by the ARFs. The rapid acquisition process and more NDI/COTS can be negative for the same reasons as factor 1. Human Centered Design is most influential when considered early in developmental programs, but both these reform factors can act against considering the human in the requirements stages. Fewer practitioners is a negative influence, particularly at the U.S. Army Training and Doctrine Command (TRADOC), again by having fewer informed people to pay adequate attention to user requirements early. Two positive acquisition reform factors, however, are RF-4 (greater attention to battle labs, simulation, and modeling) and RF-8 (total system performance). These provide data and acceptance criteria that are favorable to a human-centered design.

Factor 3. Source selection: This factor is negatively influenced by three reform factors: RF-5 (integrated teams), RF-6 (fewer practitioners), and RF-7 (fewer non practitioners). This is because each of these reform factors reduce personnel, which means fewer people to fully attend to source selection criteria development and evaluation. As with human-centered design, total system performance (RF-8) helps offset the negative effects of reduced personnel.

Factor 4. Domains integration: There are no positive aspects of acquisition reform to offset the extensive negative aspects of having inadequate representation from all the MANPRINT domains. *This is a serious problem, considering that this factor was the one factor that was critical or important on all 10 systems evaluated.* It was often this factor that discovered MANPRINT weaknesses in systems such as the AGS and FMTV.

Factor 5. System documentation integration: As with the domain integration factor, there are no offsetting benefits of acquisition reform that directly and positively make up for the negative impact of weak inputs to the systems documentation for a system.

Factor 6. Quantitative human performance: Most of the reform factors have a negative effect on this factor. The reform factors of rapid acquisition and emphasis on NDI/COTS provide tendency to gloss over human performance requirements. The reduction in SMMPs and MJWGs, and integrated teams combined with fewer personnel reduce the likelihood of incorporating important quantitative data on human performance. Similar to factor 2, the two positive acquisition reform factors, RF-4 and RF-8, provide data and acceptance criteria that are favorable to quantitative human performance.

Factor 7. MANPRINT technology: This factor, along with factor 8, are the only HSI success factors that are positively affected from acquisition reform. Five of the eight ARFs show positive influence on this factor. This is because this factor (and the next) most closely coincide with the best intentions of acquisition reform. With emphasis on simulation and modeling and total system performance, MANPRINT technology is indispensable for assuring systems will perform as designed. Although it is always desirable to have more personnel, this factor is the major one to assure informed decisions can be made with fewer people.

Factor 8. Test and evaluation integration: This is the one factor that must be applied as the last assurance that operational systems will perform as projected. Providing similar benefits and no negatives as HSI factor 7, it is one of the only two factors positively influenced from the rapid acquisition process. This is because T&E soldier performance considerations must now be fully integrated into the earliest stages of system concept and development. Under the old process, T&E of soldier performance could be left to the end.

(continued)

TABLE 18.7 (Continued)

Factor 9. Practitioners, skilled, available: Along with HSI factors 4 and 5, this is one of the most seriously degraded success factors resulting from acquisition reform. This problem is the most central of all the MANPRINT problems, negatively influenced by six of the acquisition reform factors and negatively affecting six other success factors.

Factor 10(a) Education and training—practitioners: This factor is negatively affected by most of the acquisition reform factors, because of the increased burden on education and training of those practitioners that are left. The few practitioners left in the human factors engineering domain must be trained to do TRADOC MPT domains; to participate in more MJWGs; and to provide T&E integration. Additionally many of these practitioners are supposed to do human performance research and develop MANPRINT technology, crucial to HSI factors 2, 6, and 7.

Factor 10(b) Education and training—nonpractitioners: This factor is negatively affected by most of the acquisition reform factors, because of the increased burden on education and training of individuals in the acquisition system who can be helpful to MANPRINT. Individuals not responsible for MANPRINT can reduce the obstacles impeding the HSI process through better understanding the value of HSI to help meet system performance needs.

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18.6 SUMMARY AND CONCLUSIONS

The army's experience with HSI/MANPRINT over the past decade is described in two ways. First is a description and explanation of the relevance of each of the 10 HSI factors that the literature and a recent study by Booher (1999) have shown to be crucial to army weapons system success. Thirty-four specific examples from 15 army systems are used in this chapter to describe the HSI success factors. We conclude that 10 HSI factors (listed in Table 18.2) have been major contributors to army systems success (or failure) in the past.

Second is a report of four case studies of army systems (Comanche, Crusader, Apache, and Fox) conducted by Booher (1997) that documents the benefits of HSI to these systems in terms of acquisition process efficiencies, system design improvements, casualty reduction, and cost avoidance.

18.6.1 System Benefits from HSI

The four case studies and the other army systems examined for this chapter show the vast range and depth of influence that HSI has had upon the army systems whenever its methodologies have been applied. Generally, performance improved, safety increased, and costs were avoided. The findings of the case studies are summarized for contributions and lessons learned under (1) technology advancements, (2) acquisition process efficiencies, (3) system design enhancements, (4) safety increases, and (5) major returns on investment.

Technology Advancements The Comanche program demonstrates that technologies across the board are advanced rapidly through the influence of HSI. Not only were the human-machine interfaces advanced to take advantage of the state of the art, but literally the entire engine and airframe construction was advanced by the focus on the soldier philosophy. The HSI technology itself is advanced by research focused on an operational environment and the human technology organizational interfaces. New human figure modeling tools such as those employed on the Fox vehicle are continually being advanced as part of the HSI set of tools to answer such questions as workspace layout, egress, and access to equipment in new or modified designs. Critical to the new digitized battle is the HSI advancement in simulation. Human systems integration is the crucial link to the confidence required to make simulations reliable for the environments being simulated. Such simulations cover a vast array of needs for the Objective Force Army. The Comanche, Crusader, and Fox case studies show the importance of HSI to the capability and validity of those simulations directed to questions on systems performance, speeded-up acquisition processes, twenty-first-century training techniques, and outcomes in warfighting scenarios.

Acquisition Process Efficiencies The Comanche illustrated the numerous desirable acquisition processes that were made to work effectively due to HSI influence:

- Advanced modeling and simulation applied to cockpit, engine, and airframe design at early stages of development.

- Unique source selection process—human systems factors evaluated as a separate major area *and* integrated throughout all other areas.
- Human-centered technologies and disciplines drove critical decisions throughout the design process.
- TSM-forward concept—utilized actual Army operators and maintainers to communicate “user” needs and concerns to contractors at contractors’ location.
- System performance defined to include operators’ and maintainers’ performance as well as equipment performance. This definition carried through operational T&E measures of system performance.

The Fox vehicle case study shows that the benefits to the acquisition process are not limited to new systems. The HSI modeling program can be applied anywhere from milestone O up to milestone IV. The Fox vehicle also shows the major benefits to nonmajor systems as well the ability of HSI to improve the effectiveness of operational T&E. The Crusader illustrates how TRADOC can utilize HSI to evaluate operational concepts, improve the criteria for reducing costs of operational T&E, and make training and testing more effective by integrating real and simulated systems in a complete battlelab environment.

System Design Enhancements The case studies indicated clearly that HSI can be applied to enhance system designs appreciably regardless of the stage of development or how large the system is. Longbow Apache HSI made over 160 critical design improvements for the period evaluated. The ACAT-III Fox vehicle could not have performed its mission if HSI had not designed a new workstation. These two systems were, however, modifications of existing systems, so the HSI potential was limited. To appreciate the full impact of HSI potential on system design, the Comanche is without comparison. A few of the improvements are listed in Table 18.8.

TABLE 18.8 Significant Comanche HSI Design Improvements

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- State-of-the-art crew station design decreasing pilot workload while increasing mission performance.
 - Superior modular main rotor blade design with reduced acoustic vibration, automatic rotor tracking, reduced maintenance, greater transportability, and an approximately \$150 million manpower life-cycle savings.
 - Tail rotor designed to be eight times safer than conventional designs.
 - Portable maintenance aid laptop computer to diagnose systems failure, accumulate critical flight and maintenance data, and replace all technical publications.
 - Line-replaceable modular design for mission equipment packages for functional partitioning and diagnostics capability.
 - Central-box main structure that acts as primary load-bearing carrier for high structural integrity and allows exterior skin with 50% access panels.
 - Enhanced drive train with 73% fewer parts than Blackhawk and 62% less than Apache.
 - T-800 modular engine design with increased reliability and 40% reduction in maintenance man-hour requirements.
 - Tool set with only 50 tools compared to over 150 for other helicopters, with only 22 of the 50 peculiar to Comanche.
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Safety Increases Safety was greatly improved by the MANPRINT teams on both the Comanche and the Apache. The Comanche showed 91 lives saved and 116 disabling injuries avoided from HSI designs compared to the predecessor aircraft. The Apache study did not calculate the number of lives and disabling injuries avoided, but two of the five PICs, if they had not been corrected, would have undoubtedly contributed to unnecessary loss of lives and/or disabling injuries.

Major Returns on Investment The three case studies with quantitative analysis of costs and savings make an interesting comparison (see Table 18.9). The Comanche offers both the greatest return on investment and total costs avoided. The Apache Longbow provides a very commendable savings and return on investment. Both Comanche and Apache returns are spread over 20 years. The advantage of the investment in the Apache is that the investment was considerably smaller and the return began earlier as the Longbow started fielding in FY 98. The Fox vehicle is perhaps the most interesting for considering the future army with few new major systems and major modifications. Systems like the Comanche and the Apache represent an acquisition system of the past, not the future. Program managers and training and doctrine system managers should be aware of the tremendous advantages that HSI offers to the smaller but far greater number of systems that can be improved for soldier use as well as saving resources in the near term. The Fox showed that programs can save considerable operational test and evaluation funds if HSI disciplines and technology have played a role in design, modeling, and simulation.

18.6.2 HSI and Future Systems

There is every reason to believe that similar benefits from HSI shown with the case studies and the other army system examples can be derived with future weapon systems. We conclude that the 10 HSI success factors for past systems should be made part of the process for military systems acquisition of the future. However, the HSI factors will be more difficult to implement with future weapon systems. Although the utilization of battlelabs, simulation and modeling, and total system performance are highly compatible with two HSI factors (HSI technology and test and evaluation integration), a majority of the reform factors have strong negative effects on most of the HSI success factors.

In view of the projected negative effects of acquisition reform on most of the HSI success factors, it is recommended that the highest priorities for future HSI acquisition organizations should be (a) increased emphasis on strong HSI policy for requirements, source selection, and test and evaluation; (b) increased funding of HSI science and technology; (c) increased funding of HSI practitioner systems support; and (d) increased education and training of both practitioners and nonpractitioners.

TABLE 18.9 Major Returns on HSI Investment

System	Cost Savings (\$)	Investment (\$)	Return on Investment (%)	Time (years)
Comanche	3.29×10^9	74.9×10^6	4390	20
Apache Longbow	268.8×10^6	12.3×10^6	2180	20
Fox	$2-4 \times 10^6$	60,000	3300	1

NOTE

1. Extrapolating the 5 PICs to 80 increases the cost figures by a multiple of 16. Assuming the 5 PICs are a good representation, $(16.8 \times 10^6) \times 16 = 268.8 \times 10^6$; and $600,000 \times 16 = 9.6 \times 10^6$. Combining total design change costs, (9.6×10^6) , and MANPRINT costs (2.7×10^6) gives 12.3×10^6 . Dividing savings by costs (268.8×10^6 divided by 12.3×10^6) equals 21.8, or 2180% return on investment.

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