CHAPTER 21

Linking Human Performance Principles to Design of Information Systems

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21.1 BACKGROUND

In 1988, the U.S. Navy accidentally shot down Iran Air flight 655. Due to a trivial design decision, the naval computer did not provide a summary of crucial information about position, heading, and altitude on a single screen. Related information was displayed on different consoles, which made it difficult for the operator to interpret. The operator was under time pressure to diagnose the aircraft as friend or foe, which was mistakenly identified as a military flight.

In December 2001, a “friendly-fire” accident occurred in the Afghanistan war where 3 U.S. Special Forces soldiers and 20 others were injured. A 2000-pound satellite-guided bomb landed on a battalion command post instead of the Taliban post. A precision lightweight global positioning system receiver was used to calculate the Taliban’s coordinates for a B-52 attack. However, the controller did not realize that after he changed the device’s battery, the device was programmed to automatically display the coordinates for its own location rather than the enemy’s target location.

These are just a couple of examples illustrating how information systems have performed inadequately in the recent past, but the prospect of acceptable information systems performance is even more discouraging for the future. In a presentation of a concept for future military operations, Becker (2002) provides a bleak assessment of our readiness to respond (p. 54):

> We have an unmatched ability to gather information about the environment, the adversary, and ourselves, but this information is not always the critical information needed. Furthermore, we lack the collaborative planning and command and control systems to use this information to enable decision superiority. We have precision weapons that can hit an aim point with great accuracy, but our planning is limited in its ability to consistently produce the desired

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

> operational effect. Our services bring great capabilities to each domain, but continuing interoperability problems, insufficient joint training, and the lack of a fully coherent joint command and control system limit their ability to perform routinely and effectively in integrated joint action.

Why are we in this position? In 2000, a panel chaired by the Deputy Under Secretary of the Army (Operations Research) reviewed how the U.S. Army was acquiring information systems as part of the digitization program to modernize army operations. The assessment was initiated because the army's efforts to acquire information systems were behind schedule and had not resolved training deficiencies noted during advanced warfighting experiments. The charge to the panel was to review the current process and make recommendations for improvement. The panel looked at the acquisition process from requirements definition through testing and fielding.

Deficiencies noted by the army digitization review panel included a lack of horizontal integration across information systems and between information systems and weapon platforms [U.S. Department of Defense (DoD), 2000b]. These deficiencies were noted for all echelons. Information systems were being acquired to support requirements within battlefield functional areas such as artillery, maneuver, and intelligence, with little attention given to integration across functional areas, within the army, or across the services. This finding extends to a lack of interoperability with other government agencies, multinational partners, and the international community, which may be especially problematic in current operations in Bosnia-Herzegovina (B-H), Kosovo, and Afghanistan. The panel suggested that additional work should be invested in integration efforts, developing a capstone requirements document to outline the *system-of-systems* requirements, defining the information processing and transport requirements in an operational architecture, and developing joint training methods. In short, a comprehensive system-of-systems approach was recommended.

The panel noted that requirements were often refined during early user testing, but while recognizing the importance of user input, especially in developing tactics, techniques, and procedures (TTPs), there was a need to synchronize user refinements with system-of-systems requirements identified by system and program managers. The panel concluded that a system-of-systems view must be maintained, that while the effectiveness of each system was important for battlefield success, it was clearly not sufficient. Further, a spiral development process was required such that users were involved with developers in a develop–refine–develop process. The spiral development process should facilitate the systematic development and testing of TTPs, system-of-systems operational architectures, training methods and tools, and system refinements.

How people, teams, and human organizations use and adapt to new technology, procedures, organizational structures, and environmental complexities remains at the heart of the system-of-systems performance issue. Greater understanding of the relationship among the human, the technology, and the mission and a systematic assessment framework are required. Without these things it is difficult, if not impossible, to judge the relevance and utility of emerging information systems and to guide combat developers in design and integration of information systems to meet the complexity that will be inherent in future operational requirements.

In light of the above, how can information systems be acquired that meet the needs of the military command-and-control decision makers? How should the military acquisition system account for human performance? Can the findings from human performance research help guide the design and delivery of information systems? Our motivation in writing this chapter was to answer these questions.

The purpose of this chapter is to identify the major issues, concepts, principles, guidelines, and tools of human performance that are relevant to information systems design and operation. This is accomplished by reviewing the U.S. Army's *cognitive engineering of the digital battlefield* project and the U.S. Navy's *tactical decision-making under stress* project. These projects are briefly described below. Examples from the projects are used throughout the chapter to illustrate the concepts derived from them. The human performance data from these projects are considered along with the state-of-the-art literature on human performance to provide guidance for information systems designers and decision makers.

21.1.1 Cognitive Engineering of the Digital Battlefield

In the latter part of the twentieth century, the U.S. Army became heavily involved in the acquisition of information technology to "digitize the forces." The concept was that information technology would improve *situation awareness* of own and enemy forces for *more timely and accurate decision making* and improve battlefield performance. Initially, situation awareness tended to be considered as synonymous with information acquisition, with relatively less effort devoted to understanding how commanders and teams would actually use the information to make decisions and to assessing the implications for doctrine, organizations, training, leadership, and soldiers. A focus on the technology rather than the human was due in part to the significant technical challenges that needed to be solved and in part to limited understanding of the importance of the interaction between the human and the computer. A lack of scientifically valid, relevant, and practical methods to assess human performance in battle command further interfered with efforts to examine the interdependencies among the human, the technology, and the mission. Very quickly, however, it became apparent that human performance issues had to be considered if information technology was to have the intended effect.

The impact on performance of an army research and development focus on the data-driven, information management aspects of battle command has been documented in numerous reviews of the army's digitization process (U.S. Army Audit Agency, 2001; DoD, 2000a,b; Grynovicki et al., 2001). Creating automated devices has generally been much easier than using them. New automation has often failed to produce expected gains because system designers treated the operator as just another switch or sensor. Regarding operators as mechanical components simplified system design but overlooked the active and highly complex nature of human information processing (Beck et al., 2002).

The Army Research Laboratory Human Research and Engineering Directorate (ARL HRED) in collaboration with the Army Research Institute (ARI) planned and executed the cognitive engineering of the digital battlefield science and technology objective (CE STO) to improve army battle command through integration of the human dimension in information system acquisition. This five-year research program was designed to close the gap that was growing between the army's ability to generate and distribute megabytes of data across the battlefield and the soldiers' ability to cognitively assimilate and translate these data into situation awareness for effective decision making or common ground for adaptable, distributed teamwork. This work was aimed at developing models of human performance to guide investments in information technology and methods and tools for assessing and improving command decision making and teamwork.

While the gap still exists, the concepts in decision making and teamwork defined during the course of the CE STO have promoted innovation in training and information system design, helping the army realize the potential of digitization. Specific areas of investigation included leader and team learning for adaptable performance; collaborative decision making by multinational and dispersed teams; visualization techniques for timely decision making in uncertain, rapidly evolving situations; and methods for assessing human performance in battle command and comparison of alternative systems, organizations, or procedures.

Defining features of the CE STO were reliance on a practice-centered approach to research using both theory and application to define and test solutions (Woods and Christoffersen, 2001); collaboration among researchers from the government, academia, and industry; and use of military experts to implement and validate proposed solutions. Methods of inquiry ranged from highly controlled laboratory experiments to field studies, with each area informing the next in a spiral process of iterative advances in science and application.

21.1.2 Tactical Decision Making Under Stress (TADMUS)

Several incidents led to the launching of the TADMUS program. First was the USS *Stark* incident. The USS *Stark* commander failed to identify an enemy ship allowing his vessel to be hit by two missiles from an Iraqi *Mirage* on May 17, 1987. Thirty-seven crew members lost their lives. Several months later, the USS *Samuel B. Roberts*, shortly after being commissioned, struck an Iranian mine. The ship was repaired and survived. The investigations of these two incidents pointed to problems in system displays and crew training.

One of the most salient examples of the need for TADMUS was the *Vincennes* incident mentioned above. Rear Admiral Fogarty (1988), who conducted the investigation and published the report on the incident, identified several contributing factors to the accident in his official report about the incident. The incident was ultimately attributed to human error, in general, by the official Fogarty report (Collyer and Malecki, 1998). The accident was blamed, in large part, on operator stress, task fixation, and unconscious distortion due to expectancy bias and scenario fulfillment. Klein (1989) and others expanded on the findings and said blaming human error was too simplistic. There were certain factors reported by Fogarty that could not be filed under the heading of simple human error. For example, inadequate displays led crew members to believe the aircraft was descending rather than ascending. Systems then available, such as the *AEGIS* (the Navy's most sophisticated battle management system at the time), were often ambiguous in identifying the position and intentions of aircraft.

The TADMUS objectives were to define what problems navy tactical teams face—from designing tactical decision-making performance measures to determining the effect of stress on tactical decision making and, lastly, to developing and then testing principles for training, decision support, displays, and simulation. TADMUS scientists accomplished this by applying notions from several different research areas, including human–computer interaction, human factors, and naturalistic decision making to the design of training, performance measurement, and decision support systems (see Cannon-Bowers and Salas, 1998).

21.1.3 Chapter Overview

The CE STO and TADMUS programs produced a large amount of data on human performance and information systems. Selected findings from these two research programs are summarized and used to illustrate

- human performance issues in information systems operations,
- human performance concepts and principles applicable to information systems, and
- guidelines and tools for information systems design.

21.2 HUMAN PERFORMANCE ISSUES

Table 21.1 lists eight of the most troublesome issues facing human systems integration (HSI) in information systems operations. Each of these issues will be described in this section.

21.2.1 Learning *How* to Think, Not *What* to Think

The U.S. Army is moving from a battlefield approach that emphasizes planning to a more flexible, execution-based focus. Operational transformation is being spurred by advances in information technology with the promise of nearly perfect situation awareness and by the increased breadth and complexity of missions military leaders and teams must be prepared to address (e.g., warfighting, combating terrorism, peacekeeping, humanitarian assistance). They are expected to rapidly assess, continually monitor, and appropriately adapt in evolving, ambiguous situations. A level of expertise not generally seen across the force structure will be required, and an innovative training approach is needed to help these men and women develop their thinking skills earlier and more thoroughly.

Learning how to think, not what to think, means practicing to be adaptive. Immersion in multiple, realistic, challenging, and cognitively complex situations and iteration, performance assessment, and scaffolding are key elements of an adaptive learning model developed by Ross et al. (1999). The adaptive learning model was applied and refined in a series of Army experiments (Lussier et al., 2000; Ross, 2000), and while the tenants of adaptive learning are theoretically sound and intuitively appealing, the process is not well

TABLE 21.1 Human Performance Issues in Information Systems

• Learning *how* to think, not *what* to think
• Leader mindsets constraining flexibility
• Difficulty managing uncertainty
• Degraded situation awareness
• Problems with team coordination
• Inadequate information filters
• Abuse, misuse, and disuse of automation
• Inadequate human performance assessments

supported by currently available training technologies or information systems. Efforts to use the adaptive learning model to design and evaluate training methods and tools and to define requirements for information systems have been initiated, but additional work is required to link the resulting methods, tools, and systems to adaptable operational performance.

21.2.2 Leader Mindsets Constraining Flexibility

In applying the adaptive learning model, the army CE STO study team worked with an active-duty army unit as they prepared for and then completed a one-year deployment as the sustainment force (SFOR), multinational division north [MND(N)] in B-H. The CE STO study team found a *warfighting mindset* to be a primary barrier preventing adequate preparation of the unit for peacekeeping prior to deployment (Klein and Pierce, 2001; Pierce and Klein, 2002; Pierce and Pomranky, 2001). The investigators noted that a warfighting mindset tended to limit diversity in team decision making, was uncomfortable with ambiguity, and did not promote training in the peacekeeping art of negotiations, persuasion, and influence (see Example 21.1).

Leader mindsets are also a problem with the selection of technology. Because of this, technological barriers were seen in the use of systems designed to support decision making in major theater-of-war conflicts, tracking enemy and friendly forces, and developing and executing warfighting solutions such as movement to contact or defense in sector. It is evident in our sociotechnical culture that technology and engineering thrusts are preferred over human-centered ones by the acquisition community. This "technology mindset" is not unique with information systems. Information systems, however, because of the need for rapid changes and complex human–machine and human–human communications, quickly reveal failures in total system performance due to poor designs for human performance.

Example 21.1 SFOR Peacekeeping Activities A primary mission of the army is to fight and win the nation's wars. Given this requirement, some within the army leadership have perceived peacekeeping as a detractor from that mission. Because of this mindset, time devoted to deployment preparation was strictly controlled in the deploying SFOR unit. In addition, personnel continued to rotate into and out of the unit less than 30 days before deployment with training events rarely including intact unit teams. Key team members from civil affairs, multinational forces, and the international community were grossly under-represented throughout the predeployment training cycle. The result was a lack of under-standing of the roles and functions of team members in peacekeeping that was difficult to overcome once deployed.

Although SFOR unit actions were predominately nonlethal, designed to maintain the steady state to allow freedom of movement and support the nonviolent return of displaced persons to their prewar homes, training and operational planning continued to emphasize high threat events such as how to respond to criminal activities and violent demonstrations. One of the final training events, the mission rehearsal exercise was a complex series of interrelated events designed and orchestrated by the exercise developers to introduce unit personnel to a range of potential threats. Few opportunities to learn or plan for high probability functions and practice interpersonal skills such as negotiations, persuasion, and influence were provided. This focus reflected a force protection philosophy and an assumption that a warfighting mindset would assure the safety of the unit for the first 30 days of deployment and that the functions and tasks specific to peacekeeping could be learned on the job. Our observations in B-H of deployed forces and interviews with selected leaders and teams generally revealed that this philosophy was not fully supported, although most believed that preparation and planning to handle crisis events were required, but not to the exclusion of training for the more likely events. Further defining or measuring success, which was key to learning and commitment, was difficult for the unit once it had deployed. *The unit practiced what they were good at—using force to respond to threats.* The unit did not fully appreciate the novelty and ambiguity—the uncertainty—inherent in adapting warfighting skills to a peacekeeping mission until after deployment.

21.2.3 Difficulty Managing Uncertainty

Within the military, the rise in uncertainty is due in part to the loss of a defining peer threat in the breakup of the Soviet Union and the emerging more ill-defined asymmetric threats as well as the advances in technology, especially information technology and the data deluge that has resulted. The latter cause is due in part to a focus on information acquisition rather than technology to support decision makers in their interpretation and use of information. Often, in the case of uncertain environments, tactical leaders have tended to overplan. Overplanning involves trying to anticipate all the possible situations the unit is likely to face, defining appropriate responses in as much detail as possible, and maintaining resources to implement plans and contingency plans. [See Lipshitz and Strauss (1997) for a review of coping with uncertainty in the field.]

In the SFOR environment, many military leaders advocated a strategy of “tactical patience” to manage uncertainty. The notion was to delay action, or in the words of one highly experienced senior mentor, to “not rush to failure.” In peacekeeping, situations were thought to develop more slowly than in warfighting. In observing the unit and interviewing key decision makers, the CE STO study team suggested that applying a strategy of tactical patience might have encouraged overplanning and interfered with unit adaptability.

Managing uncertainty by withholding decisions or actions is problematic to army operations on at least two levels. The first is the tendency for inaction to move the team from a proactive to a reactive stance, perhaps missing opportunities to influence or control situations. The second concern in applying a strategy of tactical patience is the false assumption that uncertainty can be reduced if the team waits long enough. This is not likely in highly ambiguous situations, where uncertainty exists not only in what is happening but also in how best to respond. If the task is cognitively complex or novel, there is no guarantee that the decision makers will know the best response (Beck, 1997). Tactical patience may have been due to poor preparation in peacekeeping skills and a lack of decision support systems.

As stated previously, information systems have been designed to primarily address the acquisition of information rather than the interpretation or use of that information in decision making or teamwork. Further, this has primarily been the acquisition of information for warfighting, not peacekeeping, and certainly not to enable adaptability. Procuring systems for information acquisition in warfighting provides only a small portion of the situation awareness requirements.

21.2.4 Degraded Situation Awareness

Situation awareness is defined as a global representation of the current and future situation. Decisions about what actions to be taken are byproducts of the situation awareness that precedes the selection of that action (Hutchins, 1996). The *USS Stark*, the *USS Vincennes*, and the Afghanistan friendly-fire incidents all took place when operators were under stress and in degraded situation awareness conditions. The *Stark* commander failed to identify an enemy; the *Vincennes* operator mistakenly detected an enemy action from a nonthreatening aircraft; and the controller gave a B-52 the coordinates for the friendly location rather than the enemy's target location under conditions where none of them was adequately aware of the true situation before making his decision. The fault for such degraded situation awareness may be any number of things—from faulty, too much, or too little information; lack of training; or poor design of displays—but when the decision maker is not fully aware of what is going on, the consequences are often tragic.

21.2.5 Problems with Team Coordination

Uncertainty and situation awareness were considered from the perspective of the individual; however, many performance failures are not the result of a lack of individual skills or machine failures, but, rather, are caused by the inability of team members (human or automated) to coordinate their actions (see Example 21.2). The empirical literature is filled with examples that illustrate the importance of team functions. For instance, Terborg et al. (1976) discovered that only 3 percent of the variance in the performance of land survey teams could be attributed to differences in individual skill levels. Similarly, Jones (1974) reported that measures of individual skills only accounted for 35 percent of the success of basketball teams. This leaves most of the variance to be explained by teamwork and other factors such as coaching.

Example 21.2 Aircraft Disasters from Teamwork Breakdown Some of the most graphic examples of the need to understand group process variables come from examinations of aircraft disasters. In 1978, a flight crew became preoccupied with a minor mechanical problem, allowing the airplane to run out of gas. The U.S. National Transportation Safety Board (NTSB, 1979) attributed the crash to a breakdown in teamwork. Poor teamwork may also have led to the crash of an Air Florida jet into the Potomac River bridge in 1982. As the plane awaited takeoff, the copilot repeatedly, but deferentially, reminded the captain of dangerous ice accumulation. The NTSB (1982) report implied that the disaster might have been averted if the copilot had more forcefully conveyed his misgivings to the captain. Analyses of multicrew aircraft accidents (Cooper et al., 1979; Foushee, 1984) have clearly established that communication and coordination failures contributed to most crashes.

21.2.6 Inadequate Information Filters

In the design and acquisition of information systems for military applications, problems of situation awareness especially within and between teams are highlighted in the lack of system interoperability. Interoperability includes the integration of information systems into networks with filters and communication strategies that either promote or hinder team performance. The team's approach to information filtering determines what data are transmitted and what data are not transmitted. Filtering systems are designed to provide decision makers with access to relevant information and prevent the passage of unimportant information. The process of setting filters demands an understanding of the relationship between data and performance (Beck, 1997). Any minimally effective filtering system must pass vital data and exclude the most extraneous data. Most filtering controversies concern the treatment of information that is neither critical nor extraneous. This large middle ground of information could be of value to decision makers but is of secondary importance. Permeable filters send both primary and secondary information to decision makers. Restrictive filters transmit only critical or primary information. The most appropriate filter, permeable or restrictive, will be determined by the situation. Filtering strategies that work well in one situation may have catastrophic effects on performance if the amount of data or the environment changes.

Social conditions within most organizations promote permeable filters. Most people want as much information as possible before making important decisions (Cialdini, 2000). There is also evidence that most people have an inflated view of their skill at processing information (see, e.g., Carver et al., 1980; Zuckerman, 1979). Thus, it is reasonable to hypothesize that many military commanders tend to overestimate their information processing capacities, often asking for more data than they can efficiently analyze (Beck, 1997). In observing a unit conducting their mission rehearsal exercise prior to deployment to B-H, the commander was observed to order his subordinates to tell him everything and he would decide what was and was not important. This order was in response to the commander's perception that a key piece of information was not passed and his recognition that the novelty and ambiguity inherent in a peacekeeping mission made defining his critical information requirements more difficult. He quickly became overloaded with data and had to reexamine his decision requirements!

21.2.7 Abuse, Misuse, and Disuse of Automation

Advances in information systems have increased the role of automation in teamwork. This evolution in user system interaction was recognized by Halpin (1984) and described in a three-stage process. In the first stage, users monitored systems, without an ability to interact with or control the data presented. Interactive computer systems led to the second phase, which was characterized by more user control of what data were displayed. The third stage heralded the introduction of the computer as an interactive partner or team member. Guidelines for human–system collaboration, however, have lagged behind the capability. For example, automation is not always the best option for improving system performance. Automation can improve efficiency, performance, and system productivity. Automation can also reduce workload and operational costs. However, people do some things better than machines. In some circumstances, human expert ability greatly surpasses that of automated systems. One such area is in adaptive performance. People, especially experts who have experience with a number of different situations, can display enormous flexibility (or adaptability) in performance.

Parasuraman et al. (2000) have developed a four-stage model to guide automation decisions in design. The model includes full automation to manual operations in information acquisition, information analysis, decision and action selection, and action implementation. Parasuraman and Riley (1997) refer to the automation of functions that should not be automated as abuse. Human operators can become *complacent* and rely too heavily on automated systems if they are *highly reliable but not perfect.* Complacency results when operators overtrust a system (Parasuraman and Riley, 1997). By not requiring human operators to be actively involved with a system, the operator may be convinced that the system will not fail, especially if it had not failed in the past. The Three-Mile Island nuclear power plant accident is an example of what can happen when operators misuse automation. Mistakes resulting from misuse or overreliance on automation are one of the causes of automation disuse or underutilization.

Dzindolet et al. (2001b) considered the Battlefield Combat Identification System (BCIS) acquisition (see Example 21.3) within the context of the literature on *automation reliance*. In a series of experiments, they examined the impact of system reliability on reliance and found that more reliable automation did not necessarily produce greater reliance or better performance by human–machine teams. The relationship between decision maker and decision aid was much more complex with cognitive biases toward and against automation and self-serving biases affecting reliance (Beck et al., 2002).

In subsequent work, the impact of trust and motivation on automation use decisions was added to define a comprehensive model of cognitive, social, and motivational influences on automation use decisions (Dzindolet et al., 2001a, 2002). Field reports have been collected indicating that trust in automation is affecting reliance, especially as battle intensity increases. Despite apparent acceptance of automation in training, in actual combat or during highly realistic battle rehearsals, there has been a tendency for soldiers to turn off their automation. They were not fighting as they were trained—their objectives had changed. In training, soldiers work to improve processes, often including integration of automation. In combat, priorities change. Automation that is hard to use or does not clearly provide an advantage to the individual over manual operations will be discarded (Beck, 1997).

Example 21.3 Battlefield Combat Identification System The BCIS was proposed to assist in vehicle-to-vehicle identification, and the Combat Identification for the Dismounted Soldier (CIDS) performed a similar function between individual soldiers. The concept was that a system able to identify other friendly systems would reduce fratricide. The BCIS provided the ability to "interrogate" a potential target by sending a microwave or laser signal that, if returned, identified the target as a "friend." Unanswered signals produced an "unknown" response. Early limited user tests of the BCIS indicated that it did indeed increase the ability of soldiers to identify friendly vehicles and reduce fratricide. However, the results were not supported by more realistic assessments in advanced warfighting experiments (Grynovicki et al., 2001) in which fratricide, even with the BCIS, continued to be a significant problem. Further, the literature on collaboration between humans and automation indicates that human operators do not appropriately rely on automated decision-making aids, depending, instead, on the situation, they may underutilize (disuse) or overly rely (misuse) on these aids (cf. Parasuraman and Riley, 1997; Dzindolet et al., 1999). In the case of the BCIS, receipt of an unknown response from an unanswered signal presents two potential dangers. The first is that the commander's dilemma will remain unresolved, slow his reaction to threat, and increase the chance of his own destruction. The other hazard is that soldiers, especially during battle, will be too quick to treat an unknown signal as an enemy. If that happens, the BCIS could increase fratricide.

21.2.8 Inadequate Human Performance Assessments

Assessing human performance in HSI requires new measurement approaches. In laboratory-based research, cognitive scientists typically measure such simple features of behavior as response time, accuracy of the response, or type of response. However, as cognitive engineers examine complex behavior in fields of practice, these simple measures may not accurately reflect the behavior. In other words, to study cognition in the wild (e.g., Hutchins, 1996), HSI investigators must first create and validate new methodological approaches. These new methods must represent the complex behavior in a way that accurately reflects the behavior and that also makes the data comprehensible and useful for making inferences about the cognitive processes underlying the behavior.

21.3 HUMAN PERFORMANCE CONCEPTS AND PRINCIPLES

Recognizing some of the major issues facing HSI in the operation of information systems, we now turn to those concepts and principles of human performance that show the most promise toward helping develop information system design guidelines. There are four major concepts derived from army and navy research-and-development (R&D) studies that can greatly aid in establishing how HSI can enhance information system design and use:

- adaptive performance,
- situation awareness,
- information presentation, and
- performance assessment.

Table 21.2 lists a number of theoretical and empirically based human performance principles. Categorized under the four concepts, 10 human performance principles are described in this section.[1]

21.3.1 Adaptive Performance

What Is Adaptive Performance and Why Is It Important? Military leaders and teams must have the training and technology required to respond to the full spectrum of military missions. These missions range from warfighting to peacekeeping and humanitarian assistance, with the continuum characterized by complexity and ambiguity. Although there is a core set of military skills that are required across the spectrum, each point along the continuum requires specific knowledge, skills, and abilities (KSAs). An overarching skill is adaptability or the ability to rapidly assess the situation and make the right decisions based on that assessment, monitor the situation for changing requirements, and respond appropriately. In addition, advances in information technology continue to challenge adaptive decision makers and teams with more and more, often unprocessed, information received more quickly than ever before.

Decision making has and will likely remain primarily a human responsibility. With advances in sensor and information technologies, decision uncertainty will shift from knowing what is happening to understanding the situation and knowing what to do. The situations are too varied, and the variables are too many to prescribe behavior or to rely on automation. Information systems certainly may be designed to better support their use, but command decision making demands expert leaders and teams who expect and prepare to respond to change.

P.1 Learning to Be Adaptive Requires Practice Learning to be adaptive is different from overlearning (Driskell and Johnston, 1998). Overlearning refers to skills

TABLE 21.2 Human Performance Principles

Adaptive performance
P.1. Learning to be adaptive requires practice.
P.2. Adaptability is a way of managing uncertainty.
P.3. User and computer adaptability is a social activity.
Situation awareness
P.4. Situation awareness is affected by time and operator involvement with the system.
P.5. Shared situation awareness promotes team adaptability.
Information presentation
P.6. Decision support systems should be designed to work within the constraints of cognitive processing capabilities.
P.7. Individuals rely on heuristics to make decisions and the decisions contain biases.
P.8. Method of communication used affects workload and performance.
Performance assessment
P.9. Improvement in system performance requires knowing what to measure and how to measure human performance.
P.10. Human performance must be assessed as part of system performance.

that were deliberately overtrained beyond initial proficiency often to reduce errors, especially under stress. Overlearned skills can actually lead to rigid responding, the antithesis of adaptability. Ross (2000) described the process of learning to be adaptive as one in which the learner is allowed to grapple with tough problems and to learn to appreciate ambiguity and disequilibrium as part of the learning process, receiving guidance only as necessary to move to a higher level of understanding. This type of guidance or feedback is given in the form of scaffolding, allowing the learner to move from one level of understanding to the next. Feedback enhances—but does not replace—the intellectual struggle. Researchers have proposed that individuals and teams can learn to be adaptive through this dynamic process of immersion, iteration, performance assessment, and scaffolding. Researchers across the services have begun development of training tools designed to promote adaptability.

P.2 Adaptability Is a Way of Managing Uncertainty It is commonplace for organizations to assert that they want to encourage their teams to be adaptive as a way of managing uncertainty (Klein and Pierce, 2001). Uncertainty and the need for adaptability have always been a part of military operations. As described previously, however, information technology has changed what the military does and how it is done, increasing the need for adaptability. The choice has become not whether or not the team should be adaptive but rather how well or quickly the team will adapt.

P.3 User and Computer Adaptability Is a Social Activity Cognition must be examined within the larger sociotechnical system in which it is embedded. Within this system, the smallest team is the user and the computer. Social psychology therefore may be applied to the acquisition of information systems. As examples, social psychology concepts that should be considered in information system acquisition include diffusion of responsibility, social loafing, social facilitation, collaborative debate, trust, and coordination (see, e.g., Beck and Pierce, 1996). Adaptation occurs in the context of transactions; adaptation and adaptive responses are dynamic, evolving, and dependent on the situation. In human–computer collaboration, adaptability is a requirement for both the human and the computer.

21.3.2 Situation Awareness

Decision making in naturalistic environments consists of "what is going on?" and "what do you do about it?" *"What is going on?" refers to situation assessment. "What do you do about it?" refers to actually choosing what action to take*. These decisions reflect situation awareness (Hutchins, 1996). Therefore, human performance researchers and designers must concern themselves with the process of situation assessment and awareness.

P.4 Situation Awareness Is Affected by Time and Operator Involvement with the System *Time is important in establishing awareness of the current and future situation*. Past and present information is critical to establishing situational awareness in both teams and individuals (Hutchins et al., 1996). Users need the past to understand the present, and past and present events are used to predict the future. The user must also be aware of changes over time, which may tax working memory.

Situation awareness can lead to increased performance if the operator is involved with the system (Niessen et al., 1999). In designing systems, work schedules, and work tasks, vigilance and its demands on human operators must be taken into consideration. Human performance research demonstrates that human operators must be involved with the operation of the system, even with automation, in order to perform successfully and consistently. Situation assessment is based not only on anticipation of future events but also on the evaluation of further information processing requirements.

P.5 Shared Situation Awareness Promotes Team Adaptability In interacting with the environment, others, and the artifacts of technology, people form internal, mental models of themselves and the things with which they are interacting. These models provide predictive and explanatory power for understanding the interaction. Mental models are important cognitive tools for human factors (Langan-Fox et al., 2000). An individual's mental model in large part determines how they behave and how they will react to novel, ambiguous situations. Teams have shared mental models that help them predict and coordinate their behavior. Shared mental models that include an understanding of the situation, the team's resources, and the other team members' roles and needs improve team effectiveness by permitting implicit coordination to occur (Entin and Serfaty, 1999). This is especially important during periods of high workload. One way to form adaptive teams is to ensure all systems and displays have common capabilities to increase the likelihood of a shared mental model. Although it is sometimes difficult to determine what is "common," if done successfully, teams or dependent individual operators are better able to visualize the mission as a whole, which leads to better and shared situational awareness. Goals, resources, plans, actions, and progress reports can be shared to improve shared knowledge and mental models.

21.3.3 Information Presentation

The information processing capabilities of humans should be a primary factor in designing displays. The way the data are presented (e.g., size, color, and organization) has an impact on human performance. If critical data are displayed outside of the operator's normal scan area, then they may not be perceived. If a display presents data across time or relies on the operator to track several pieces of data, then the operator's short-term memory capacity may be exceeded and key data may be forgotten. If systems are designed without taking these limitations into account, then operators may not be able to use the system. However, when human capabilities are folded into the design, positive outcomes such as increased accuracy, fewer errors, and less time needed in interaction with the system can result. Designing to support operator pattern recognition may reduce information processing and memory overload and may provide users with more time to make decisions about emerging problem situations.

P.6 Decision Support Systems Should Be Designed to Work within Constraints of Cognitive Processing Capabilities Decision support systems may reduce cognitive workload of the user by reducing the amount of information processing that must be done, by reducing working memory requirements, and by assisting users by properly allocating the limited cognitive resources that they have available. Unfortunately, however, decision support systems are often created to provide operators too much data and not enough information. Operators are often given data that are raw and must be processed and evaluated in order to be helpful (Morrison and Moore, 1999). The extra processing required can increase workload and distract the user from the task at hand. Information must be presented in a way that is appropriate to the given situation and not add to the workload of the user.

Human performance can be improved by providing decision support that does not require dependence on previous contact data and a vast amount of information obtained in past training and experience (Hutchins et al., 1996). By providing users with more information in order to support their decision making, users with limited attentional capacity, often found in complex situations, have the tools to perform better. This enables users to rely on recognition rather than recall, which has traditionally been found to be better and less demanding.

P.7 Individuals Rely on Heuristics to Make Decisions and Decisions Contain Biases Diagnoses begin as an initial provisional hypothesis is formed and more evidence is sought to either confirm or disprove it. We use heuristics to help us find the "true" state. Heuristics help save cognitive resources and enable human operators to make rapid decisions. However, heuristics may contain biases and direct us away from the true state.

In the work related to the BCIS described previously, these biases were further described as appraisal and action biases. Appraisal biases occurred when operators misjudged their own competence relative to an automated alternative. People misused automation aids when the perceived utility of the aid was overestimated and disused aids when the perceived utility was underestimated. Self-serving biases, an illusion of control of chance events, and the availability heuristic have all been used to explain disuse. The bias toward action was observed in operators who accurately assessed the reliability of both team members but chose to ignore the automated aid even though probability of success would be less. The result was nonrational automation use decisions (Beck et al., 2002). There is some evidence that expertise may encourage disuse (Sheridan et al., 1983). Experts believe they have less need for decision aids and so ignore potentially useful information. Analyses and knowledge of heuristics and biases can help direct training, procedural guidelines, and design guidelines.

P.8 Method of Communication Used Affects Workload and Performance

There is an optimal amount of perceptual information that can be attended to. Perception of information is optimum when enough is presented to stimulate attention but not so much as to cause cognitive overload. Users should not be required to take in too much perceptual information at once. If the human capacity for perceptual information is exceeded, the result can be a decrement in performance. Perceptual load also affects haptic tasks. Excessive amounts of visual, auditory, or tactile information can lead to failure to process most, if not all, of the information provided.

When an individual is required to do too many tasks at once or when task demand is too high, there is high workload. Performance declines during periods of very low and high workload (Beck, 1997). Performance is optimal with some, but not too much workload. This principle is based upon the idea that task performance is based on the amount of resources available to dedicate to the task.

When a person is aroused, the manner in which attention is distributed depends on what attentional resources are available. This principle is based on the Yerkes–Dodson law (Yerkes and Dodson, 1908) and the inverted-U shape of the arousal function. Systems that must be operated during times of increased arousal must compensate for decreased performance by the user. It is accurate to say that a little arousal is a good thing, but too much can cause a decline in performance.

The function describing the actual relationship between the amount of information received and the value of that information is also curvilinear (Beck, 1997). At first, *increments in the quantity of information received leads to better performance, until an inflection point is reached. Thereafter, further increases in the amount of information causes a decrease in team performance*. Deterioration in the performance of either an individual or team resulting from excessive information input is referred to as cognitive overload. The old premise that more information is better has proven false. The quantity of data that can be processed without exceeding the inflection point will depend on a variety of factors, including the size and skill of the team and the communication links between teammates.

Different users or operators require different levels of detail, fidelity, and depth of information. Some operators need overview data that are concise and provides them with the essential but general information. Some only need recommendations for action. Others need more detailed discussions of issues in order to operate effectively. Some operators require orders and directions. A user's duties and standing within the team and the organization often determine what type of information is needed. Information presented so that the viewer can rely on pattern recognition rather than recall has traditionally been found to be better and less demanding.

The method of communication used affects performance. Some multimedia presentations of information result in better performance of human operators on memory tasks (Najjar, 1998). Verbal information leads to better memory of small amounts of information. Text appears to be better for remembering information for longer periods of time. However, if an operator's visual channel is already occupied, verbal information is better.

Graphic presentations reduce the mental computation required of users to complete a task. The proverbial expression “a picture is worth a thousand words” is certainly true for human processing of display information. Users have been found to easily understand “cartoon” graphics (Moore and Averett, 1999), and graphic presentation has been found to be preferable to text-based presentations. One reason is that graphic presentations allow users to skip mental steps when performing a task. Instead of having to visually compare mental images, users can use the graphic on the screen to make their decision. The image is already generated for them. Users can use the perceptual processes that are less demanding by looking at the screen. This saves the user cognitive resources to devote to more logical operations.

Color-coding conventions reduce errors in communications. Most systems offer users definable color settings. However, if each system within a network has different coding conventions users may not be able to read, see, or understand each other’s displays (Moore and Averett, 1999). This failure between users can lead to many errors because of missed or misunderstood communication of information. Research recommends following human factors guidelines regarding colors and using common color settings across systems, thus enabling free and open communication of ideas. Based on that same idea, researchers have found that operators need to share a common picture across systems and units (Moore and Averett, 1999).

21.3.4 Performance Assessment

Adequate assessments of human performance need to be based on reliable, valid measures of performance. In the CE STO research program to improve command decision making and teamwork, the study team worked under the premise that “you could not improve what you could not understand and you could not understand what you could not measure.” Two principles of performance assessment were found most beneficial to information systems assessments.

P.9 Improvement in System Performance Requires Knowing What to Measure and How to Measure Human Performance The CE STO study team first observed warfighting exercises to assess who was making what decisions and how and then went on to conduct critical decision interviews and to describe battle command processes based on their observations and interviews. Their descriptions were operationalized in human performance models of battle command (Knapp et al., 1997a–c; Middlebrooks et al., 1999; Plott, 1999; Wojcik and Plott, 2001). These models included a depiction of the functions and tasks performed, the flow of information, and the decisions made by personnel within a command organization using various types of information systems and under different environmental conditions. Model outcomes included workload, information bottlenecks, and decision quality. This process is being refined to explore human-system performance in future concepts.

P.10 Human Performance Must Be Assessed as Part of System Performance Advances in simulation systems have enabled the use of synthetic task environments to assess human performance as a part of system performance. Human performance metrics are being developed to focus on the human system within the larger mission and ensure that neither the human interface nor the technical capabilities of the system drive acquisition decisions; rather it is the interaction among the soldier, the system, and the mission—the system of systems—that is considered.

21.4 GUIDELINES AND TOOLS FOR SYSTEM DESIGNERS

With an understanding of the major issues, concepts, and principles of human–system performance in information systems, we can now focus on recommended guidelines and tools for information systems acquisition and design. Organized under the four categories below, these guidelines and tools are summarized in Table 21.3

- acquisition process decision recommendations;
- tactical decision making—aiding and support;
- adaptability design for training and operations; and
- performance assessment.

21.4.1 Acquisition Process Decision Recommendations

For cognitive engineering to have the greatest impact on information system acquisition, it must be integrated throughout the acquisition cycle. As described in other chapters, this includes such things as describing the user during requirements determination and determining automation and human–system interface needs. We add the need to design for adaptability as a top-level recommendation. The acquisition of information systems requires a sociotechnical approach in which the information system is considered a team member within a system of systems. This approach supports the use of HSI to assure the success of information systems in meeting the expectations of the designer and the requirements of the user.

G.1 Describe the Users Understanding the intended users is the first step in system design. Factors such as level of expertise, culture, cognitive ability, and personality should be considered when designing systems. User profiles provide information about user capabilities and limitations. Cognitive task analyses (CTAs), help determine what the user needs from the system to ensure that the system supports the major task sequences. Other important information needed to describe the user is education and reading level and the experience they have in performing the job.

T.1 Cognitive Task Analyses The CTAs are conducted to understand and define the cognitive requirements of individuals and teams on jobs and tasks (see Schraagen et al., 2000; Vincente, 1999). This is done mainly through interviews and observations. One specific way to conduct CTAs is through a *knowledge audit*, which uses structured interviews, often in connection with other CTA methods (Klein and Militello, 2001). Related to CTA are manpower, personnel, and training (MPT) trade-off analyses, analyses that may also be used to describe the user. (See Chapters 8 and 11 for MPT trade-off analyses.)

G.2 Determine Automation Needs It is critical that automation should not be utilized without carefully considering its drawbacks. *Automation should not be used*

TABLE 21.3 HSI Information System Guidelines and Tools

Guidelines	Tools
	I. Acquisition Process Decision Recommendations
G.1 Describe the users	T.1 Cognitive task analyses (Chapters 10, 20); MPT trade-off analyses (Chapters 8, 11)
G.2 Determine automation needs	T.2 Function and allocation analyses (Chapters 10, 13, 20)
G.3 Determine human–system interface needs	T.3 Task and workload analyses (Chapters 10, 13, 20)
	T.4 Breakdown analyses
G.4 Design for adaptability	
	II. Tactical Decision Making—Aiding and Support
G.5 Design for how users view tasks	
G.6 Design automation to improve team performance	T.5 Automation use decision model
G.7 Design a common shared picture for teams	
G.8 Display states of uncertainty	T.6 Advanced tactical architecture for combat knowledge systems (ATACKS)
G.9 Rely on experts in special circumstances	
G.10 Design displays to present tailored information and support operator pattern recognition	
G.11 Design displays to provide feedback and active practice	
	III. Adaptability Design for Training and Operations
G.12 Apply adaptive learning design requirements.	T.7 Advanced cognitive understanding simulation (ACUSIM)
	T.8 Think like a commander (TLAC)
	T.9 Simulations for adaptability (SFOR Adapt)
G.13 Utilize naturalistic decision-making concepts	T.10 Embedded decision and team performance measures
G.14 Apply team training Strategies	T.11 Team dimensional training (TDT)
	T.12 Team adaptation and coordination training (TACT)
	T.13 Stress exposure training (SET)
	T.14 Stress inoculation training (SIT)
	IV. Performance Assessment
G.15 Apply human performance models	T.15 Command, control, and communications tactically reliable assessment of combat environments (C3 TRACE) (see also Chapter 11, IMPRINT)

TABLE 21.3 (***Continued***)

Guidelines	Tools
G.16 Utilize simulation-based training and assessment methods	
G.17 Measure individual and team processes	T.16 The behavioral observation booklet (BOB) T.17 Anti–air warfare team performance index (ATPI) T.18 Anti–air teamwork observation measure (ATOM)

simply because it can (Wickens and Hollands, 2000). Human factors research has shown that completely automated systems often leave the user with nothing to do except to monitor the system, which may lead to decrements in attention and reduced operator vigilance in monitoring problem situations. Operators may get lost within modes (Sarter and Woods, 1995) or overly trust the automation and assume that problem situations are being handled by the automation (Parasuraman and Riley, 1997). Users may not be able to problem solve or troubleshoot if they do not understand where they are in the system, or if a function has been automated, users' skills may deteriorate and they may not be able to take manual control back from the system. Generally, performance is better if operators play an active role in using the system, with automation supporting their needs, rather than operating a highly automated system.

T.2 Function and Allocation Analyses Chapters 10, 13, and 20 describe function and allocation analyses that are useful in determining system automation needs.

G.3 Determine Human–System Interface Needs Advances in information system technology have increased the likelihood that individuals and teams will rely on technology as if it were another team member (Halpin, 1984; Noah and Halpin, 1986). Without an understanding of how teams operate, information systems may be designed to be bad team members allowing breakdowns in performance to occur. A breakdown occurs when the user becomes aware of the system, rather than being able to focus on the task at hand (Scrivener et al., 1993). Questions such as "What is that thing doing now or why is it doing that?" exemplify the breakdown.

T.3 Task and Workload Analyses Chapters 10, 13, and 20 describe task and workload analyses that are useful in determining human–system interface needs.

T.4 Breakdown Analyses Breakdown analyses are geared to identify, diagnose, and remedy breakdowns between user and task, user and tool, user and environment, and user and user. In addition to the user and tool breakdowns, the communication breakdowns Scrivener et al. (1993) proposed as most likely between user and user can be applied to better understand user and information system interactions.

G.4 Design for Adaptability A top-level recommendation for information systems is to design for adaptability. The system design should be adjustable for different users' needs, including expert, novice, and any other users with different capabilities and needs who are intended to use the system. *Adaptable systems are usable by both novices and experts*. Novices and experts have different mental models, experience, and access to information on which to base their decisions (Kalyuga et al., 1998; Schlechter et al., 1998). Further, individuals can be novices in one area and experts in another. However, displays and system features can help novices perform more comparably with experts. By providing novice users with additional (text) information, they will have access to information similar to that held by the experts. In addition, training and tasks can be designed to reflect the level of expertise of the operator. A proper adaptive design can ensure all users' needs are met. Further, when the system is adaptive to all user needs, each user will have a more accurate mental model and more accurate expectations of system performance (Duncan et al., 1996).

21.4.2 Tactical Decision Making—Aiding and Support

Decision making involves the process of detecting a pattern of cues in a situation, assessing what is going on, choosing a response for dealing with it, and determining the degree that the response successfully dealt with the situation. Further, the consequences of decisions in tactical situations are great, and the decision-making process is often performed under time stress. Ignoring the information requirements of operators or how they need that information to be presented can be catastrophic. Users read displays to gather information in order to make decisions. By understanding the user's task, the designer ensures that systems are built to support operators in their decision making. Specifically, HSI drives what and how information is displayed, based on the criticality and frequency that the operator needs information. Decision makers must be able to access the information they need, when they need it, where they need it, and in the form they need it to make effective decisions (Morrison et al., 2000).

G.5 Design for How Users View Tasks System design should be based on how users view tasks and how they learn, explore, navigate, and predict future system states (Morrison et al., 2000). When the user's mental model is incorporated into system design, the result is more accurate expectations and greater understanding of what the system is doing at various points in time.

G.6 Design Automation to Improve Team Performance Automated decision aids must be designed as collaborative systems, and the impact of automation on other team members must be considered. For example, the high incidence of fratricide during Operation Desert Storm led Secretary of Defense William Perry to charge the services to enhance their capabilities to distinguish friendly, enemy, neutral, and noncombatant (Doton, 1996). The army responded to the Secretary's challenge by developing combat identification devices to identify friendly vehicles and individual soldiers. However, as described previously, in operation these devices did not deliver the expected gain in performance. The system was not designed to consider the biases of the human decision maker.

T.5 Automation Use Decision Model A *comprehensive model of cognitive, social, and motivational influences on automation use decisions* (Dzindolet et al., 2001a, 2002) grew out of the research on automation reliance. This model has been applied in the laboratory and has provided evidence that *training decision makers to better understand when aids were likely to make a mistake encourages more appropriate automation use* (Dzindolet et al., 2000). St. John et al. (2000) propose a "trust-but-verify" strategy with a two-stage model of conditional trust and qualitative verification. Conditional trust involved knowing when the automation should be trusted, and qualitative verification uses the automation as a guide or even an input to manual decision making. Findings on automation reliance must be validated in the field as a next step. While laboratory findings are consistent with anecdotes from the field, the model needs to be tested under stressful, battlefield conditions to determine how stress will interact with automation use.

G.7 Design a Common Shared Picture for Teams In tasks that require teamwork, it is important that the system support team performance. To accomplish this, the system should support the team members' ability to monitor each other and to create a common picture across the team—a shared mental model (Salas et al., 1997). This picture can then help team members see the same problem situations, so that all team members have a common understanding. Further, it may facilitate the ability to predict what other team members should be doing at different points in time. In large, distributed, tactical teams, it is even more difficult to monitor what other units and team members are doing. Common displays that compile relevant information can increase the chances that all team members are seeing a common problem situation or share a team mental model. A good team mental model may enable team members to anticipate the information needs of other teammates and engage in implicit coordination by "pushing" information rather than waiting for it to be "pulled" via time-consuming requests (Entin and Seraty, 1999). Implicit coordination occurs when team members have an awareness of the roles and functions of other team members to include their information needs and are able to predict and respond in a timely manner to those needs. Common displays enable a shared team mental model and implicit coordination.

G.8 Display States of Uncertainty Various presentation methods have been considered with an objective to reduce or at least understand the impact of *cognitive biases on decision making* (Barnes et al., 2000b). The ultimate purpose of decision aids or visualization techniques is to increase the commander's ability to understand the battle dynamics, consider options, make decisions, and predict outcomes. As evolving systems become more sophisticated, the display of states of uncertainty and the concomitant cognitive biases will require innovative cognitive engineering solutions. Findings from this preliminary work are being used to design aids to enhance situation awareness in nonconventional situations such as B-H, Kosovo, and Afghanistan with a goal of increasing understanding of historical trends, political changes, ethnic conceptions, and changing perceptions of various combatant and noncombatant groups (Zacharias and Hudlicka, 2001).

T.6 Advanced Tactical Architecture for Combat Knowledge System (ATACKS) The ATACKS provides a simulation environment to evaluate new visualization concepts for commander and staff decision-making. The ATACKS operates on a standard personal computer and is composed of visualization tools and decision support drivers (Suantak et al., 2001). The visualization tools portray three-dimensional standard and nonconventional military symbols, important terrain and urban features, and realistic animated behaviors for the objects depicted. Decision support has been demonstrated using genetic algorithms as well as more conventional rule-based algorithms. The ATACKS is applicable to both a major theater of war and support and stability operation (SASO) environments and is being used to evaluate visualization and decision-aiding tools for the Army Future Combat System (FCS).

G.9 Rely on Experts in Special Circumstances Overall, though, it is important to remember that since all possible circumstances cannot be anticipated, even with the advantage of decision support, the *expert's abilities* and intuition are indispensable (Hutchins et al., 1996). In some circumstances, human expert ability surpasses that of technology or automated systems. One such example is flexibility, especially for experts who have experience with a number of different situations. Automated systems simply do not have the capabilities to exhibit adaptability, creativity, and commonsense knowledge that are an important part of human performance. Furthermore, human operators are much more able to incorporate experience online, use analogical reasoning, and maintain a broader focus than machines. Experts are even more adept at incorporating these capabilities into their performance.

G.10 Design Displays to Present Tailored Information and Support Operator Pattern Recognition After designers understand what information is required, the next step is to ensure that it is presented in a way that can be perceived and remembered. Displays should illustrate data in a way that operators can use to make decisions. The data that are displayed should be useful, in that raw data should be analyzed and condensed so that patterns in the data are clear and calculations and analysis are minimized. Performance will be negatively impacted if the display does not match operator needs, information processing capabilities, and expectations.

A good display design provides relevant information tailored to the situation rather than data that require interpretation (Morrison and Moore, 1999). Operators are often given raw data that must be processed and evaluated in order to be helpful in decision making. The extra processing required can increase workload and distract the user from the task at hand. Information must be presented in a way that is appropriate to the given situation and not add to the workload of the user.

In addition, system design should support user tasks and capabilities. In many cases, users may not be able to glean pertinent information from a large number of system inputs and outputs. Designing to support operator pattern recognition may reduce information processing and memory overload and may provide users with more time to make decisions about emerging problem situations (Klein, 1997).

G.11 Design Displays to Provide Feedback and Active Practice Embedded system features should include *active practice and feedback*. Practice is essential for effective learning, but other tools, such as feedback, are also necessary (Johnston et al., 1997; Ross et al., 1999). Feedback should be provided to ensure human operators and teams understand their performance to avoid repeating mistakes and errors. Feedback should be given relatively quickly after an action to ensure it is understood and applied. Feedback, when used effectively, is also good for such affective components as morale and efficacy. Systems and training should include a feedback component for human operators and teams. Feedback and active practice encourage adaptable performance.

21.4.3 Adaptability Design for Training and Operations

Information on adaptive learning, naturalistic decision making, and team training are useful in developing design requirements for adaptive systems. The following guidelines and tools are recommended for adaptability design for training and operations of future information systems.

G.12 Apply Adaptive Learning Design Requirements Practicing to be adaptive in multiple, realistic, challenging, and cognitively complex situations enhances learning to think adaptively. To meet the challenge, adaptive learning models have been developed (see Ross, 2000; Ross et al., 1999; Lussier et al., 2000).

The multiple training tools developed under the CE STO were based on the same underlying model of learning and are complementary, with the primary difference being the mission focus, which varied across the spectrum from warfighting to peacekeeping and humanitarian assistance. Using a student-centered process, learners improve through sustained exploration and practice geared to their unique requirements. The following simulation tools for adaptive learning were developed under the CE STO.

T.7 Advanced Cognitive Understanding Simulation (ACUSIM) A training tool for battle staffs, ACUSIM provides a forum for staff officers and staff teams to plan and execute battle operations with embedded performance tips, available online coaching, and faster than real-time implementation (Ross, 2000).

T.8 Think Like Commander (TLAC) The Army Research Institute developed TLAC to promote deliberate practice of thinking skills required for command in warfighting and responding to threatening situations that could be encountered in small-scale contingencies and peace enforcement (Lussier et al., 1997).

T.9 Simulations for Adaptability (SFOR Adapt) This is a program of instruction that includes two automated tools, facilitation guides, and performance measures. The automated tools are PC-based and Web-hosted. It was developed to prepare soldiers for SASO, a general and inclusive term for operations other than war, including peace enforcement, peacekeeping, and humanitarian assistance. It is characterized by cooperation between military forces and civilian agencies working together to establish or promote regional stability (Pierce and Pomranky, 2001).

G.13 Utilize Naturalistic Decision-Making Concepts Naturalistic decision-making concepts, such as recognition-primed decision making and explanation-based reasoning should be considered in training and information system design to improve decision-making performance, especially in novel situations.

Recognition-primed decision making assumes that people form a new but tentative representation when confronted with a novel situation. The representation or hypothesis is based on past experiences that seem to be similar to the present situation. This representation contains observed situation data and is the basis for future expectations about what will happen. Incoming data can confirm the representation and enforce people's observations. If incoming data conflict with the current representation, additional data are gathered to refine or dispel it.

Explanation-based reasoning is another, less common form of decision making that involves the selection and evaluation of plausible hypotheses. This decision-making process is often employed when the situation is novel and ambiguous. As in recognition-primed decision making, explanation-based reasoning is quick, concise, and done online. Both strategies are improved by team training in realistic situations.

T.10 Embedded Decision and Team Performance Measures Measurement of team processes and performance is important for providing team members with feedback and represents a critical component of the adaptive learning model and event-based practice. *Event-based practice* is an approach to training in which practice is embedded within the task environment, and training objectives, exercise design, performance measurement, and feedback are linked (Cannon-Bowers and Salas, 1997; Dwyer et al., 1997, 1999; Johnston et al., 1997). A scenario is designed with cues and events that cause individual and team tasks to be performed. Measures of individual and team performance are derived from these events and embedded within the scenario.

The TADMUS and CE STO researchers have used embedded decision and team performance measures to examine situation awareness and team adaptability. Performance is improved by providing teams an opportunity to practice in various situations and environments and learn skills that increase the team's ability to confront novel situations. Decision and team performance measures may be embedded in training tools or information systems. An event-based approach to training with embedded decision and team performance measures facilitates the development of naturalistic decision-making skills and expertise.

G.14 Apply Team Training Strategies A number of training strategies are currently available:

- team dimensional training (TDT),
- team adaptation and coordination training (TACT),
- stress exposure training (SET), and
- stress inoculation training (SIT).

T.11 Team Dimensional Training This involves the teaching of teamwork skills and knowledge through guided self-correction (Smith-Jenstch et al., 1998). In guided team self-correction, a facilitator works to keep discussions focused, keep the climate positive, facilitate active participation through encouragement, facilitate self-correction through modeling effective feedback between team members, and provide instructions on how to give constructive, useful feedback. This facilitator is provided with a debriefing based on the focus of that particular self-correction exercise that outlines specific questions that can be asked to encourage useful team discussions. Self-correction gives team members a guide to how they should interact and what topics should be discussed while enforcing shared knowledge structures and mental models.

T.12 Team Adaptation and Coordination Training This strategy was developed to enhance a team's ability to adapt their coordination strategies to changes in workload and stress. It uses the intermediate feedback loop from the theoretical framework for team adaptation (Serfaty et al., 1998), which contains adaptive coordination skills. It entails the training of adaptive skills, coordination skills, and team exercise of shared situation assessment procedures that apply to the appropriate situations. In research, TACT was found to alter communication patterns according to the training strategies used. Teams who were trained with TACT have exhibited implicit coordination (i.e., team members' ability to maintain performance even under high stress and workload when team members cannot really communicate) (Entin and Serfaty, 1999) and more adaptability (Cannon-Bowers and Salas, 1998).

T.13 Stress Exposure Training This is an integrated model of stress training comprising three stages of training: (1) information is provided regarding stress and its effects, (2) behavioral and cognitive skills are acquired, and (3) skills are demonstrated in an environment that approximates the real-world setting (Driskell and Johnston, 1998). It was influenced by a cognitive-behavioral approach to stress training.

T.14 Stress Inoculation Training This is designed to provide coping skills after stressful situations. It emerged from research regarding cognitive and affective research on cognitive behavior modeling (Meichenbaum, 1996). It attempts to increase familiarity with the environment and boost confidence in a team's ability to learn.

21.4.4 Performance Assessment

Models and simulations provide a forum for the assessment of human performance in concept evaluation and training. Using models and simulations, system designers have a unique opportunity to base HSI decisions on human performance data that approximate performance in the "real world" but allow for more control of implementation and environmental conditions. Based on task analysis and performance data, designers can uncover and correct errors early in system acquisition. Performance assessment can provide designers information to improve HSI and operators with tools to improve performance for future interactions with the system. The importance of models and simulations to HSI and training is captured in the notion that you cannot train what you cannot understand and you cannot understand what you cannot model.

G.15 Apply Human Performance Models Task network models provide a method to efficiently conduct "what if" analyses to further concept exploration and derive the most valuable alternatives for assessment in the more costly, less well-controlled synthetic environment. Applications include the development of task network models to examine the impact of digitization on brigade command and control (Knapp et al., 1997a–c) and command and control of fires and effects (Plott, 1999; Wojcik and Plott, 1999). Building on this work, task network models are being developed to define requirements for both the future combat system and the unmanned combat, armed rotorcraft. Human performance modeling technologies can be employed to understand how to design *decision support systems* to optimize information flow and human performance (see Zachary et al., 2001).

T.15 Command, Control, and Communications Tactically Reliable Assessment of Combat Environments (C3 TRACE) This builds on other human performance models developed by the Army Research Laboratory [e.g., Improved Performance Research

Integration (IMPRINT)]. It allows a user to evaluate and propose high-payoff operational and system architectures for use in human-in-the-loop experiments. Human performance data captured during the experiments are then used to refine the model for use in an interactive cycle of model–test–model. The C3 TRACE has been refined through several applications to include an interface that supports what-if-type analyses by the user community. It may also be used to highlight potential workload or performance challenges to drive changes in system or organization design or training.

G.16 Utilize Simulation-Based Training and Assessment Methods When using simulations for training, operators are often provided unstructured practice supported by somewhat general after action reviews that are separated in time from task performance. This method of practice does not provide detailed information about common errors or tasks that are taking up unreasonable amounts of time. Timely, relevant feedback is a critical aspect of human performance that is often overlooked by system designers. Both training theory and empirical testing have supported the value of providing performance feedback to operators (Cannon-Bowers and Salas, 1997).

The HSI tools listed in Section 21.4.3 for adaptability design for training and operations are unlike most simulation techniques. For example, these tools provide a cost-efficient platform that individuals and teams can use to practice decision making and teamwork to master the advanced learning stage for adaptable performance. The products allow learners to practice in cognitively complex and immersive, synthetic task environments with process- and outcome-based performance feedback available throughout the process and tailored to the needs of the learner. The products are usable by colocated or distributed teams.

G.17 Measure Individual and Team Processes Several measures are available to evaluate individual and team processes. Three in particular are

- the behavioral observation booklet (BOB),
- anti–air warfare performance index (ATPI), and
- anti–air teamwork observation measure (ATOM).

T.16 Behavioral Observation Booklet This is used to *measure individual processes within teams* in order to evaluate how team members perform on task-specific jobs (Hall et al., 1993). It is formatted like a critical incident report, with events and expected actions listed. An observer marks whether or not the expected action was taken by the individual team members.

T.17 Anti–Air Warfare Team Performance Index This provides a measure of outcomes of teams using an anchored rating scale. Raters evaluate outcomes based on a scale of 0 to 3 (Zachary et al., 1991).

T.18 Anti–Air Teamwork Observation Measure In ATOM, 11 teamwork behaviors are categorized under 4 major dimensions. Raters record detailed information regarding team performance during a scenario using an ATOM work sheet that contains a time line with prescripted events. For a final score, raters give each event a rating based on their detailed notes (Johnston et al., 1997).

21.5 CONCLUSION

The primary conclusion that may be drawn from this chapter is that processes for acquiring information systems must be revised to capitalize on rapid advances in automation and to meet emerging requirements, especially in the area of adaptable performance. Examples were presented that demonstrated both the weakness of the current approach in information system acquisition and the importance of an approach that considers the interaction among the human, the technology, and the mission, especially when designing systems for use in highly uncertain, dynamic, and information-rich environments. Vincente (2002) stated that adaptation to change and novelty will be the primary role of the human in system performance as more "routine activities that are well understood, and which can be reduced to a set of rules or an algorithm are increasingly automated with computer technology" (p. 62). The implications of this evolution in automation to the design of information systems have been highlighted throughout this chapter.

We reviewed human performance issues in information systems operations, defined human performance concepts and principles applicable to the design of information systems, and derived or identified guidelines and tools to improve information systems design. The result of our review was a framework to move from automating the routine to designing for adaptable system performance. Based on this framework, we began the work of defining methods and identifying technology to aid in the process. The framework evolved during two R&D programs in which theory was applied to training and system design to improve battle command decision making and teamwork using research methods that ranged from the laboratory to field experiments but emphasized the importance of a multimethod, iterative approach.

Based on this work, we know with some confidence how to model and measure battle command performance (see Grynovicki et al., 2001; Knapp et al., 1997a–c; Middlebrooks et al., 1999; Plott, 1999; Wojcik and Plott, 2001), to design and deliver training (see Ross et al., 1999; Salas and Cannon-Bowers, 2001), to optimize human–computer interaction (see Dzindolet et al., 2002; Parasuraman and Riley, 1997; Parasuraman et al., 2000), and to use visualization aids to increase situation awareness and improve decision making (see Barnes et al., 2000a,b). Our challenge now is to use and expand the framework and our knowledge of human performance, to test and refine proposed tools, or to develop tools where none are indicated and to use the framework in collaboration with users and technologists to design and field the next generation of information systems promoting adaptable system performance.

NOTE

1. The 10 human performance principles discussed in this chapter should not be confused with the 10 HSI principles of Chapter 1.

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