CHAPTER 11

Manpower, Personnel, and Training Integration Methods and Tools

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11.1 INTRODUCTION: WORKFORCE CHALLENGES

A key concept in personnel staffing and systems integration is determining, acquiring, training, and retaining the proper number of people with the right skills for the jobs required to operate and maintain systems. Traditionally, most organizations attempt to match the number and skills of people necessary to meet acceptable performance at minimum cost. More recently, organizations have begun to recognize that the introduction of new technology—ranging from information technology, process monitoring and control, and robotic manufacturing to weapons technology—can significantly increase the difficulty of maintaining a proper mix of numbers and skills of people in the workplace. Some technology may help to reduce numbers and skills required as well as reduce the workload (both physical and mental) on employees. In other cases technology may, through its sophistication, cause an increase in the need for, and therefore the cost of, skilled individuals to operate the systems. Also, technology may not reduce workload but simply shift it from physical workload to mental workload. The technology–people tradeoff in the workplace is a job design issue that can be addressed via the human systems integration (HSI) approach. The primary objective of this chapter is to describe the state of the art for HSI methods and tools particularly useful for analysis and assessment of manpower, personnel, and training (MPT) issues on system design and development programs.

The complexity and universality of the workforce problem facing organizations that procure, manufacture, and use systems and products can be appreciated from the following overview of workforce challenges facing the military, other government activities, and commercial industry.

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11.1.1 Military Manpower and Personnel

The military is facing serious manpower and personnel challenges as we enter the twenty-first century. Problems in meeting recruitment quotas due to competition from industry and college and an increasing sophistication of equipment equate to a need for soldiers with skills and aptitudes in advanced technologies. Also, jobs must be performed within the environment of a battlefield "office," which is further complicated by stressors such as long-term operations, fatigue, night operations, temperature extremes, protection against the nuclear–chemical–biological threat, noise, precipitation, crowding, rough terrain, and fear of the enemy strength. Now with an ever-increasing use of computing power on the battlefield in weapon, vehicle, and communication systems, warfighters must also cope with operating and maintaining complex systems and dealing with an information-rich tactical environment. Decision making will need to take place under conditions of high cognitive workload, perhaps to the point of "information overload," coupled with information uncertainty and time pressure. Special consideration is required to match the skills required to successfully perform these challenging jobs with the skills and abilities that the warfighters possess.

Simply throwing technology at the problem is not the solution. This notion is aptly stated in *SAILOR 21: A Research Vision to Attract, Retain, and Utilize the 21st Century Sailor*: "Many in Congress, the Department of Defense, and the Navy believe that if we have newer, bigger, more high-tech weapons systems, we don't need to worry about people. These new technologies may require fewer people, but those same people must be more capable, able to learn more, faster, and perform a much broader range of tasks" (Keeney and Rowe, 1998, p. 5).

11.1.2 Government Workforce

In spite of recent moves to reduce the federal workforce, the federal government is still the largest employer in the United States. The vast majority of the workforce is employed under the executive branch (about 98 percent) and is mostly distributed across 14 cabinet departments and 90 independent agencies. The U.S. Office of Personnel Management (OPM) reported in March 1999 that the executive branch employed nearly 2.8 million civilians. Of that number, 918,000 were in the Department of Defense. The remainder, slightly less than 2 million, are distributed among the other government cabinet departments and agencies.

There are significant differences between the federal working force and the workforce as a whole. In particular, almost half of all federal workers perform professional or managerial jobs. This rate is nearly twice as high as the remainder of the U.S. workforce, in which the largest group of workers is engineers, including chemical, civil, aeronautical, industrial, electrical, mechanical, and nuclear engineers.

The outlook for federal employment is bleak; it is projected to decline by 9 percent through 2008. Due to the competitive benefits and perceived stability of federal employment, this will translate to particularly aggressive competition for the remaining jobs. While this will lessen somewhat the pressure to recruit new employees, concerns about retaining high-quality workers will increase in order to maintain a desirable skill and experience balance across the workforce. In sharp contrast, 707,000 new government jobs are expected to arise in state and local government, reflecting growth in the population and its demand for public services.

These statistics describe the pressures in achieving a manpower and personnel balance in the government workforce that supports dynamic adjustment in the mix of quantities and skill levels needed for each job.

11.1.3 Commercial Workforce

There were about 7 million business establishments in the United States in 1997, providing close to 128 million jobs. This workforce is projected to reach nearly 150 million by 2008, not including approximately 12 million self-employed workers. Commercial organizations, including manufacturing, service, and financial organizations, are diverse and have a wide variety of manning and personnel challenges and must align with the vast range in workforce demographics. Broad disparities in age, experience, education level, and even motivation require a correspondingly broad range of manning and personnel policies. There are also some similarities to the federal sector and military: Recruiting is typically needed to replace workers in existing jobs, rather than to fuel employment growth.

While the operational environment of the military is much riskier than the environment typically experienced in commercial industries, nonmilitary organizations can also have unique challenges. A good example of this is a university hospital in California that was required to define and justify the skill levels of its medical staff before it would be considered for grant funding (Hager et al., 1998). Addressing manpower and personnel issues and selecting employees that are qualified and prepared for the jobs in a fast moving technological society is a nontrivial effort, and dealing with the gaps between the skills employees have and those that they need is quite difficult.

11.1.4 Meeting the Workforce Challenges

The solution to these identified skill-requirements gaps in industry is similar to the solutions pursued by the military and government in that if the selection process does not succeed in supplying the needed skills and aptitudes, the gap must be filled through implementing a training solution, a materiel solution, or a process reengineering solution. Training solutions are fairly easy to understand in an industrial setting because the structure of skills and abilities by worker specialty is not usually as rigid as in the military (although some labor unions do have similar structures). In industry, however, procuring training often requires extensive effort since competitive forces typically do not support sharing training courses across employers.

Materiel (i.e., equipment) solutions include adjusting the system and equipment to be simpler to use or including job aids that provide advice or assistance on the most challenging tasks. This solution is probably the most commonly used in response to addressing manpower and personnel gaps. One example from the commercial world is the advanced automated call centers that involve a wide range of speech recognition and automated message generation capabilities. Another example is the advanced production management systems installed in many production facilities that include robotic and electronic machine control tools. These tools have not only decreased the need for manual, low-skill tasks but also have allowed artificial intelligence techniques to replace some of the decision-making effort that used to require highly experienced worker involvement.

Process reengineering solutions can encompass the other types just discussed but can also extend to rethinking an existing process in order to improve it. Many examples of successful business process reengineering (BPR) efforts can be found in the literature

(Malhotra, 1998; Caron et al., 1994). One specific case is of a major consumer bank. In order to increase its competitive position, this bank instituted an effort to examine the flow of work inside its organization. In this study, bank managers recognized that no part of the process or the organization was "sacred" and that a well-done BPR effort had to have license to examine and question every aspect of the work flow (Grover et al., 1995). Every step of the process flow was examined to ensure that it added value to the product or service, and that it was performed as efficiently as possible. In this case, jobs were redesigned in order to streamline existing processes, impacting staffing, training, and selection policies.

The above examples are typical illustrations of how MPT issues affect government and commercial organizational decisions for systems and product acquisition. In the following sections, discussion of MPT domain factors, with the emphasis on the military, along with examples of the analysis and assessment methods currently available, are presented to illustrate how HSI technology can help address MPT challenges relevant to a wide variety of organizations. At the end of the chapter, a number of challenges for HSI technology are identified.

11.2 MANPOWER, PERSONNEL, AND TRAINING DOMAINS

A primary function of the various HSI tools and techniques developed to date is the integration of HSI domains, which generally refers in particular to the interaction of manpower, personnel capabilities, and training, and also human factors engineering. Figure 11.1 along with the following description illustrates the basic system integration model for HSI:

> A particular system design concept determines the human tasks that are required to operate, maintain, and provide logistical support to the system. The tasks in turn drive the requirements for quantitative manning, required characteristics and innate abilities of personnel, and needed training. Human performance is the product of the interactions of tasks with manpower, personnel, and training. The combination of human performance with the system design, in terms, for example, of lethality, mobility, vulnerability, reliability, maintainability, and availability, drives system performance. —Hay Systems, 1991, pp. 1, 3

In this section we describe the MPT domains individually and address the distinguishing elements of analysis for each element. A further guide to MPT issues and risks is via an electronic booklet developed by the U.S. Army Total Personnel Command and available at https://www.perscomonline.army.mil/DCSOPS/DCSOPS_MANPOWER.htm.

11.2.1 Manpower

The manpower domain focuses on establishing the number of people needed to operate, maintain, and support the system. These numbers include military and civilian resources.

Typical Issues and Questions in the Manpower Domain While considered the most costly, manpower is perhaps the easiest domain to define and understand. It solely concerns the number of people and does not attempt to describe the people. In HSI language this is often referred to as the "spaces" problem, whereas considerations relating

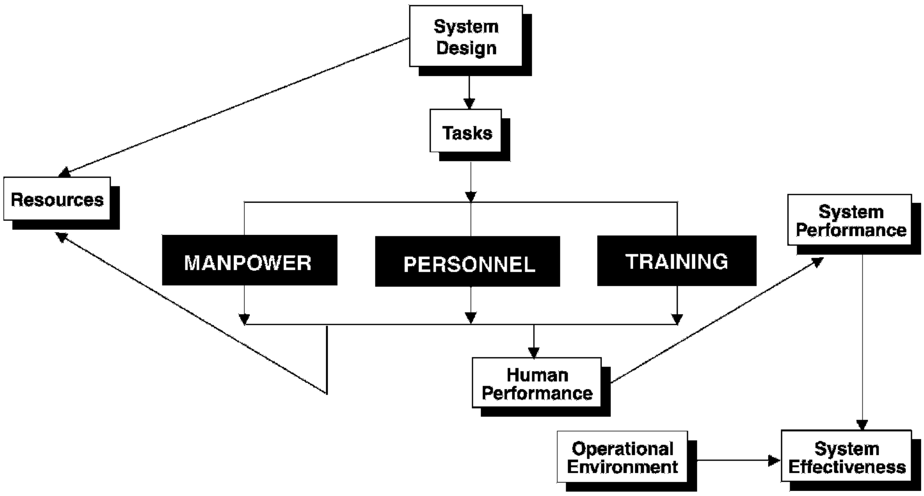


Figure 11.1 MPT domains within a system structure (Hay Systems, 1991).

to the characteristics of the people are often referred to as the "faces" problem. This latter challenge belongs to the personnel domain.

A sample of the questions that can be answered by a manpower analysis include:

- How many maintainers do I need at each maintenance level in order to achieve the required system availability?
- Do I need two operators in my new system, or will advanced levels of automation allow me to reduce the crew size to one?
- Will the new concepts for bolt-on armor enable my crew to be able to transition an air-dropped vehicle to battle-ready status in less than one hour?
- Does the system require round-the-clock or sustained operations?
- Has special test equipment been identified that will require maintenance?
- Do sufficient human resources exist in the units that will receive the new system to conduct operations at the identified tempo?
- How many semiautonomous robotic systems can a single operator control? Or, conversely, how many operators are required to control a single robot?

In order to address each of these questions, we must use some method of estimating how much work needs to be done and dividing it by how much work a single person can do. The solution to this equation is the number of people you need. While this sounds extremely simple, both the numerator and the divisor can be difficult to estimate with precision. The remainder of this section provides examples of techniques that have been used to successfully assess these values.

Manpower High Drivers A high driver is anything about the system that is resource intensive and could lead directly or indirectly to system performance problems. The system characteristics that drive manpower requirements are all linked to the amount of attention that a system needs in order to remain operational. The common element across all types of manpower analysis is the system's operational tempo. The operational tempo specifies the intensity and number of missions that must be performed by the system. This value drives operational, maintenance, supply, and support requirements of the system.

Manning requirements, as shown earlier in Figure 11.1, are driven by system design, but those requirements must be evaluated within the full operational context. For operational manning requirements especially, that context is described as MET-T (mission, environment, terrain, and tactics.) Those factors drive the frequency, difficulty, and criticality of task performance. In a battlefield context, the speed and accuracy of task performance are crucial. Making even a small error can have serious consequences.

Maintenance manpower requirements are driven by operational tempo as well as component reliability (i.e., how often the system must be repaired), maintenance concept (i.e., how many spares are available), and combat damage levels. Additionally, the shift lengths of the maintenance crew and the availability of special skills across each shift matched with the operational mission schedule can play a large role in determining maintenance manpower requirements. The notion of the operator-maintainer, while appealing, bears special consideration since both sets of drivers must be included in the process of manpower requirements determination.

Support manpower requirements are driven by the geographic relationship between the supply unit and the operational unit, as well as the physical requirements of the tasks. For example, if each round of ammunition must be manually loaded and is a two-man lift rather than loaded via an automated process, this will have a dramatic effect on support manpower requirements. Likewise, if resupply is required frequently and the distance to the ammunition storage point is great, then support manpower requirements are again increased.

Regardless of the specific manpower element of interest, it is clear that there is a strong and direct relationship between system design and manpower requirements. This provides the basis for the HSI community's need to apply manpower analysis tools very early in the weapon system acquisition process. It is through this process that the HSI community can influence system designers to implement design elements that reduce manpower requirements, leading to a more affordable system.

Key Manpower Analysis Elements In the military environment, reaching an understanding between "what do we need" and "what can we have" for numbers of personnel (manpower) is an important part of the early planning process. An equally key determination is identification of the *bill payer* for manpower slots (i.e., the spaces). In a zero-sum environment, if a new or revised system is to add people, then the cost involves paying for these new slots by taking away from elsewhere. This consideration requires that a comprehensive manpower analysis system necessarily include force-level assessments. This is equally important for operators, maintainers, and support manpower.

The analysis elements for operational manning requirements typically begin with a classic task analysis. First, the functions that the system must perform in order to accomplish all of the missions in the operational requirement are identified. Once this is done, the functions can be decomposed into subfunctions and then allocated to people or machines. Once they are allocated to people, these subfunctions become operational tasks and form the basis for a detailed, job-oriented task analysis. This type of task analysis delineates the step-by-step process that must be performed to achieve a function, the estimated performance parameters (e.g., time, accuracy, workload) for the steps, and the consequences of incorrect performance. Once this information is gathered, the individual tasks and groups of tasks can be analyzed in order to determine where workload, or effort, peaks during the mission and function processes. These peaks can drive the work allocation among crew members and, thus, can determine the operational crew size required to successfully achieve the missions. Specific methods for performing this analysis are described later in this chapter.

Assessing the force-level implications of operator crews is usually straightforward. Once crew size for a single system is established (using comprehensive task analysis and workload modeling techniques discussed in Section 11.2.2 and Chapter 13), crew ratios (i.e., the number of crews per single system) are used as multipliers to extend the operational crew requirement to the various unit levels.

The analysis of maintenance manning requirements requires linking performance of maintenance tasks to system reliability data. An example of a comprehensive maintenance analysis tool is the Improved Performance Research Integration Tool (IMPRINT) developed by the Army Research Laboratory Human Research Engineering Directorate (Archer and Adkins, 1999; Archer and Allender, 2001).

IMPRINT predicts manpower requirements by simulating the maintenance requirements of a unit as the systems are sent out on missions, then to maintenance (as required), and then placed back into a pool of available systems. This process must continue for a significant period so that components with high reliabilities have an opportunity to fail, providing a realistic sample of maintenance requirements. There are, of course, a number of complexities involved in this process. For instance, when a system comes into maintenance, it is prioritized and scheduled for repair based on the pools of maintainers with specific specialties available in the particular maintenance level needed. Therefore, if the manpower pools are very tightly constrained, the maintenance will take longer, since fewer repairs can be performed in parallel. This will have an adverse effect on the system availability. If the system is not available to be sent out on other missions, it will actually accrue less usage because it is in maintenance, rather than performing missions on the battlefield. Oddly enough, this will result in less maintenance over time since the components are not accruing as much wear and tear. Other issues that affect the manpower required to maintain a system include spare availability, combat damage, maintenance shifting, and the criticality of individual component failures.

The process of developing a maintenance analysis, running it, and analyzing results is analogous to designing, executing, and analyzing an experiment. In this vein, the first step is to determine the questions that analysis must answer. A comprehensive maintenance manpower analysis capability can answer questions such as:

- How many people of each specialty are needed in order to meet the system availability requirement?
- Which pieces of equipment (i.e., subsystems) are the high drivers for maintenance?
- How should each organizational level be staffed?
- How sensitive is the maintenance manpower requirement to the failure rates of individual components?

After defining the questions that need to be answered, the dependent and independent variables must be selected. After these items are determined, the analyst is equipped to conduct a study that is designed to address the relevant questions.

To conduct an IMPRINT analysis of the maintenance man-hour requirements to support a particular system, four basic activities must be performed:

1. Prepare a description of the maintenance requirements for the system by specifying the following information for each component system:

    a. How often the component needs to be maintained (i.e., rounds fired, time operated).
    b. The type of maintenance task that needs to be performed (remove and replace, repair, inspect, troubleshoot, etc.).
    c. The type and number of maintainers that are needed to perform the maintenance task, including selection of specific soldier specialties.
    d. How long it will take to perform each maintenance task.
    e. Whether the maintenance is scheduled or unscheduled.
    f. The maintenance organizational type at which the task needs to be performed; up to three levels of organizations can be specified including factors of geographic dispersion.
    g. Whether a contact team could perform the maintenance.

2. Build a simulation scenario that defines the conditions that will be used for the system being modeled and the amount of usage the components in each system will incur. Usage can be described in time or distance units and also as the amount of ammunition fired, which permits greater simulation fidelity. Missions that are relevant to the scenario will determine system usage and probabilities for combat damage. Each scenario can contain multiple missions.

3. Define the unit configuration and support parameters for each scenario. These parameters include:

    a. Operational crew (per system)—This is an optional parameter and the information defaults to an empty set of operational crew members.
    b. Maintenance shift manning (size, type)—This parameter defaults to the minimum possible shift manning, as well as one shift per day that is 8 hours long. IMPRINT calculates the minimum shift manning by examining each maintenance task to find the minimum number of people in each specialty that will enable any given task to be performed.
    c. Spare parts (availability, wait times)—This is also an optional parameter and is specified at the subsystem level. This parameter defaults to 100 percent availability and a zero wait time.

4. Assess the results after executing the simulation for a sufficient number of scenario days so that both low- and high-reliability parts have a chance to fail. IMPRINT provides reports that identify the direct maintenance man-hours needed to achieve a specific reliability and availability or readiness level for the input parameters described in the previous three elements. These man-hours are converted into "bodies" by considering the required crew sizes to perform individual tasks and the annual maintenance man-hour availability at each organizational level. IMPRINT also outputs reports to help assess the subsystems and specialties that are "high drivers" in terms of maintenance requirements, so that users can evaluate trade-offs between reliability, maintenance concepts, manning, and operational capability.

If IMPRINT is used to evaluate the maintenance requirements for a proposed new system in the acquisition cycle, the component maintenance parameters can be entered from scratch, a system design, or contractor-provided logistics and reliability data [e.g., from a Logistics Support Analysis Report (LSAR)]. However, it is more likely that an analyst would begin by copying maintenance parameters from a similar library system and then modifying existing components and/or adding new components to reflect the system being evaluated. It is also possible to use IMPRINT for a different purpose, such as to address unit or organizational design questions. In this case, the analyst will probably copy a library system and use it as is. In this manner, the analyst can use the same components and maintenance actions and modify only the types of maintainers, maintenance levels, or other parameters for the existing components.

As mentioned above, the maintenance analysis also requires a mission schedule or operational profile. This information is used to determine the intensity of the scenario. The intensity, or operating tempo, drives the distance the system travels, the number of rounds each weapon system fires, and the number of operating hours that are accrued during each day of the scenario. This information, in turn, controls when the individual components will fail. Often, data that help define the operational profile are available in the operational requirements document (ORD), test and evaluation reports of a similar predecessor, system, or from subject matter experts (SMEs). If data elements exist for which there are no sources, multiple analyses can be performed using the most likely and worst-case values for these elements. The analysis can then be performed iteratively to determine how sensitive the maintenance manpower results are to the variability of these data items. If the results are not very sensitive to the values in question, then it is probably not necessary to invest more resources in finding better data. If the results are very sensitive, then it is important to improve the quality of the data, or to provide a decision maker with information on the most likely and worst-case results.

Once optimal maintenance manning decisions are made through an analysis process such as the one described, they are added to the operational and supply manpower requirements at the force level, and the total is used as a basis for calculating any necessary additional directed manpower. Directed manpower is usually ratio-based. That is, it is a proportional allotment of manpower slots needed to account for other support personnel (e.g., chaplains, administration). A system's total manpower burden can then be expressed in terms of numbers of people by specialty and organizational level.

11.2.2 Personnel

The personnel domain focuses on assessing the types of people needed to operate, maintain, and support the system. The experience, aptitudes, and physical characteristics can all be used to describe the personnel requirements.

Typical Issues and Questions in the Personnel Domain In conducting a personnel staffing capabilities assessment for decision makers, the HSI analyst typically looks for "disconnects" between what the system is supposed to do and the capabilities of the men and women who will operate, maintain, and support that system. Example issues and questions facing military organizations and decision makers in the procurement process when personnel capabilities and new technology do not connect include:

- Do the skills of the target audience match up with the system requirements?
- Will the system be usable for the target audience?
- Does the new system require jobs that:

  a. Are difficult to recruit because of high entrance requirements?
  b. Are difficult to retain because of ample public-sector opportunities?
  c. Require a Top Secret security clearance?

The remainder of this section describes the U.S. Army's method of assessing personnel staffing capabilities that would be required for a system being planned or revised.

Personnel High Drivers One very useful result of a personnel staffing capabilities assessment is to project as early as possible what likely *high drivers* will occur with the system when it is implemented in the organization. Typical items include requirement of specialty personnel, time constraints for system development, high physical or cognitive workload requirements, an undefined or hard to define target audience, and a wide-scoped target audience.

Elaborated by Headley (in press) and illustrated in Figure 11.2, the personnel capabilities assessment model follows a four-step process in determining high drivers. Headley derived the process from guidance provided by a number of sources (Guerrier et al., 1991; U.S. Total Army Personnel Command, 1991; Herlihy et al., 1990; Archer and Adkins, 1999).

Steps 1 and 4 of Figure 11.2, although important and often time-consuming, are obvious and need little discussion here. To aid in step 1, beneficial contacts, documents, and web sources for military systems and personnel background information are provided by Headley (2002) and Herlihy et al. (1990). For step 4, the end result of the assessment methodology, the primary feature to appreciate is that it is a formal report that states the MPT issues with associated *concern, major*, or *critical* ratings and that when these ratings

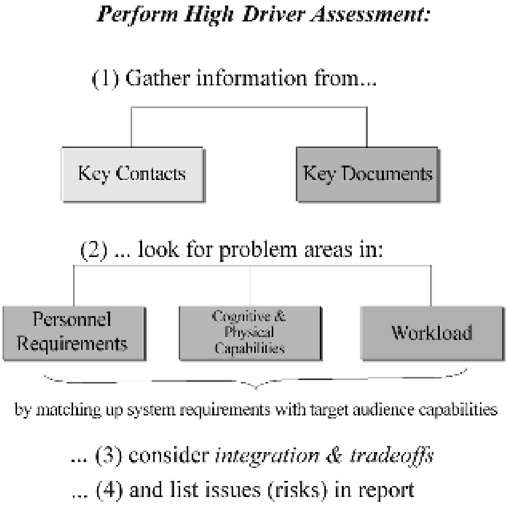


Figure 11.2 Key steps in performing personnel staffing assessments.

are determined by an organization that has an acceptable level of HSI maturity (see Chapter 1), a system will not be allowed to continue in the acquisition cycle until major and critical issues are resolved (Headley, in press). Step 2 is described in the section immediately following, and step 3 is elaborated for manpower, personnel, and training in Section 11.2.4.

Key Personnel Analysis Elements Any organization that wishes to improve its capabilities through the introduction of new technology must consider the personnel staffing capabilities needed to operate and maintain the technology and determine whether the personnel costs of this capability is affordable. Criteria to make this judgment include the skills of people needed to perform the jobs and tasks both generated and eliminated by the new technology. Assessing whether the required capabilities are available and affordable is a difficult task and cannot be done effectively with large, complex operations such as military systems acquisition without decision aids.

Critical information in determining personnel requirements is found in describing the *target audience*, which includes the types of systems used, key statistics on the personnel pool, and descriptions of relevant occupational specialties. Given the typical constraints of no increases in personnel, no newly created specialties, and no increase in training burden, designing for usability by a defined audience is important. Sometimes the target audience is narrow and easily defined, such as an infantryman. But for some systems, the user community is vast and the ORD may include the term *general-purpose user* (GPU). An example of a true GPU system would be the Army Distance Learning Program, which is building digital training facilities (CD-ROM courses, two-way televised instruction, e-mail, etc.). Any soldier or Department of the Army employee is potentially a student in such a classroom. As a result, the digital training facilities can be designed with this very broad target audience in mind. Note, however, that even with a very focused target audience, when the mission broadens, as with the U.S. Army's vision for the Objective Force Warrior, and the skills and abilities required also broaden, the description of the target audience is still essential and, in fact, may need to be filled in with greater detail.

Key statistics describing the active enlisted personnel that comprise typical enlisted operators and maintainers can be found in a U.S. Army study (Department of the Army 1997):

- 50 percent are in the age range 21 to 29; 94 percent in the range 17 to 39; median age is 26 years.
- 96 percent of the enlisted force have high school diplomas.
- Average years of service is eight.
- 15 percent are females.
- The most frequent rank is that of specialist (E4), comprising 25 percent of the enlisted force.

Many systems are meant for operation by both genders. This is especially important to know from a design point of view if anthropometrics is a key factor, necessitating designing for the "5th percentile female to the 95th percentile male" soldier on stated parameters. However, users on some systems will be all males, as will be the case for those specialties closed to women. This exclusion is due to the Direct Combat Probability Coding Policy, which proscribes that jobs routinely exposed to direct combat are off limits to women. Currently, 40 U.S. Army jobs are closed to women for this reason; example jobs are infantryman, armor crewman, cavalry scout, M1 Abrams tank turret mechanic, and combat engineer (Department of the Army, 1999).

The armed services place great emphasis on recruiting and retaining the proper skill base to attain operational readiness. Given that the state of the skill base is always in some degree of flux, there is a need to examine how the available base will tie in with the quality of training and usability of the system interface. Some jobs are typically hard to fill, especially those requiring the smarter soldiers (e.g., intelligence analyst) as defined by high entrance exam scores. This consideration gains importance in filling the need for more "digital warriors," that is, soldiers with basic skills in operating and maintaining computerized systems and also higher cognitive abilities for complex multitasking and attention management. The U.S. Army's Office of the Deputy Chief of Staff for Personnel routinely maintains a list of the top 25 recruiting priorities for entry-level soldiers. An HSI analyst can use this list to identify high-demand and low-supply skills.

Cognitive and Physical Requirements Entry into most workplaces in our society requires meeting certain standards. For jobs, whether in the academic, business, or military communities, an applicant is expected to possess or have the potential to acquire selected skills and abilities. The military requires meeting strict standards in these areas:

- Educational
- Medical
- Height, weight, and size characteristics
- Moral
- Physical requirements
- General muscular strength and endurance and cardio-respiratory fitness
- Strength requirements for performance of job-specific physically demanding tasks
- Aptitudes related to job requirements

Of particular note to the HSI analyst is that an applicant for a given job must meet specific aptitude criteria, as established in Army Pamphlet 611-21, "Military Occupational Classification and Structure." (Department of the Army, 1999). Examples of requirements for two army jobs from this document are:

11B Infantryman	96B Intelligence Analyst
• A minimum score of 90 in aptitude area "combat" • Color discrimination of red/green • Occasionally raises and carries 160-pound person on back. Frequently performs all other tasks while carrying a minimum of 65 pounds, evenly distributed over entire body	• A minimum score of 105 in aptitude area "skilled technical" • Eligibility to meet requirements for top secret security clearance and sensitive compartmented information access • Occasionally lifts 37 pounds and carries 50 feet as part of a multiperson lift

Cognitive aptitude comes into play for recruiting, training, and interface design of systems. The cognitive aptitude component is stated in the form of a minimally acceptable score on 1 of 10 *aptitude areas*. In the examples above, the cutoff score for an *infantryman* is 90 on the aptitude area *combat*, and the cutoff for an *intelligence analyst* is 105 on the area *skilled technical*. Aptitude area scores are derived from scores earned on subtests of the recruiting test battery called the Armed Services Vocational Aptitude Battery (ASVAB). The better the performance on this test, the more jobs for which one is eligible. In addition to the aptitude area scores that are specific for different job categories, ASVAB subtests are used to derive the more general Armed Forces Qualification Test (AFQT) score. Four ASVAB subtests (arithmetic reasoning, mathematics knowledge, word knowledge, and paragraph comprehension) contribute to the AFQT. As stated by the Office of the Assistant Secretary of Defense (1999), the AFQT score is representative of:

- General measure of trainability
- Predictor of on-the-job performance
- Primary index of recruit aptitude

Test scores on the AFQT have been shown to be predictors of military performance. In one study, performance on tasks pertaining to communications networks highly correlated with the average AFQT score of three-soldier teams (Winkler, 1999). Another study found consistent predictability between AFQT scores and performance on a number of written and hands-on tests by soldiers in missile-system-related job series (Horne, 1986). Modest correlations were found between ASVAB scores and vehicle identification performance (Heuckeroth and Smith, 1990).

Prior to induction, recruits are rated according to a physical profile made up of six factors: physical capacity, upper extremities, lower extremities, hearing, and ears, eyes, and psychiatric (PULHES). These categories are shown in Table 11.1.

Each U.S. Army job lists a profile for these physical abilities on a scale that ranges from 1 (high level of medical fitness) to 4 ("medical conditions or physical defects of such severity that performance of military duty must be drastically limited"; AR 40–501; Department of Army, 1998). For induction the practical limit is a 2 on any given ability for most U.S. Army jobs. Most jobs have a *physical demands* rating that indicates the level of body strength needed to perform the tasks. For example, the infantryman rating is "very heavy," which is defined as "lift on an occasional basis over 100 pounds with frequent or constant lifting in excess of 50 pounds" (Department of the Army, 1999). A legal specialist's job is rated as "light" ("lift on an occasional basis a maximum of 20 pounds with frequent or constant lifting of 10 pounds"). The analyst should assess whether physical tasks marked for a given job are within the already set rating.

TABLE 11.1 Some Examples of Required Fitness Levels

Ability	Infantryman	Recruiter	Cavalry Scout
Physical capacity or stamina	1	1	1
Upper extremities	1	3	1
Lower extremities	1	2	1
Hearing and ears	2	2	1
Eyes	2	2	2
Psychiatric	1	1	1

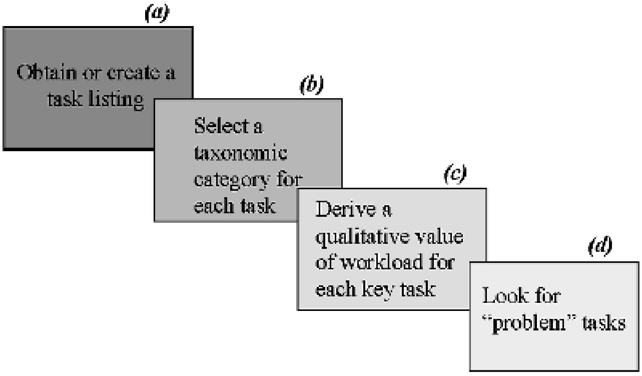


Figure 11.3 Strategy for task workload assessment.

Task Workload Workload is a measure of the amount and quality of effort required to perform a set of tasks and is used here to refer to workload involving perceptual, cognitive, and fine motor processes rather than gross motor abilities. Many theories exist that define the unit of workload measurement and the threshold of workload that is acceptable. However, most theoreticians agree that one or more tasks of a job could cause high cognitive or physical workload such that overall system performance is affected. Solutions to high workload could be job redesign, interface redesign, or increased crew size (the latter, of course, is typically to be avoided).

Figure 11.3 illustrates typical procedures for identifying high workload tasks. These are conventional task analyses exercises and can be found discussed more fully in Headley (in press) and Chapters 10, 13, and 19.

As illustrated in step (b) in Figure 11.3, it is helpful to classify a given task by the channel(s) (visual, auditory, etc.) required. This categorization aids later diagnosis of how to alleviate a high workload condition. For example, if visual workload is high at the same time that auditory workload is low, the HSI analyst should consider whether some visual information can be converted to auditory cues, possibly through a speech synthesis system. SMEs are a good source for these data. Three convenient taxonomies are listed in Table 11.2.

TABLE 11.2 Workload Taxonomies[a]

VACP Model[b]	NASA TLX Model[c]	SWAT[d]
Visual	Mental demand	Time load
Auditory	Physical demand	Mental effort load
Cognitive	Temporal demand	Psychological stress load
Psychomotor	Performance	
	Effort	

[a] Abbreviations: VACP, visual, auditory, cognitive, psychomotor; NASA TLX, National Aeronautics and Space Administration Task Load Index; SWAT, Subjective Workload Assessment Technique.

[b] McCracken and Aldrich (1984).

[c] Hart and Staveland (1988).

[d] Reid et al. (1989).

A final note about the key personnel analysis element of task workload and cognitive requirements has to do with the capability to examine this in detail. For task workload, the effort required to perform a task is rated. Similarly, the cognitive skill required to perform a task can be rated. Such ratings are important for both personnel and training analysis and one well-known approach, the Job Assessment Software System (JASS) (e.g., Knapp and Tillman, 1998) is briefly described in Section 11.2.3. Another approach is available within IMPRINT, where an abbreviated taxonomy of nine task types is used to describe individual tasks. For each task, when an operator is assigned to perform the task, a specific U.S. Army military occupational specialty (MOS) is also selected. Along with that MOS selection comes the associated ASVAB-based aptitude area and AFQT scores. If a proposed task or set of tasks is suspected to require a different set of skills and abilities than those generally available with that MOS, an analysis can be conducted. For example, in order to evaluate whether an increase in personnel abilities is required, and if so, how much of an increase, a higher score cutoff is selected and the resulting effect can be determined at the level of the individual task performance time and accuracy or aggregated at the overall system mission level. However, it may also be the case that a particular task type does not benefit from an increase in ability level, in which case, no appreciable effect is seen and some other approach to bridging the personnel-performance gap such as training must be examined.

11.2.3 Training

The training domain is concerned with assessing the likelihood that the stated system instructional plan will provide personnel with the job skills and knowledge required to properly operate, maintain, and support a system. Notice that this domain addresses the training *re-quirements* for a system and does not typically include the development of training methods and techniques per se. (Note, however, that this distinction is blurred when the system being developed is itself a large-scale training system such as the U.S. Army's Combined Arms Tactical Trainer.) Often training requirements are presented in terms of gaps or differences between the current training program and the new system. Once this is accomplished, this information can be used to determine the training needs for the new or modified system.

Typical Issues and Questions in the Training Domain In conducting a training requirements assessment for decision makers, the HSI analyst typically looks for "disconnects" or "leap aheads" between how the selected operators, maintainers, and support crew are currently prepared to perform their jobs and what they must do for the new system. Example issues and questions facing military organizations and decision makers in the procurement process when current training plans and new technology do not connect include:

- How do the current knowledge and skills of the target audience as provided by the current training [i.e., program of instruction (POI)] match up with the tasks the crew members must perform on the new system? What is the basic ability to attain the skills that will be trained?
- Does the new system require jobs that:

  a. Are hard to train because of high aptitude requirements?
  b. Are expensive to train because they are unique?
  c. Are difficult to train because experienced performers do not exist?

The remainder of this section describes the U.S. Army's method of assessing training requirements that would be required for a new or modified system.

Training High Drivers Historically, the training burden implications of a new or modified system have been overlooked or underestimated. One reason for this is that the bill payer for training is not always the system developer, which indirectly influences the developer to use training as a panacea for usability problems. One very useful result of the training domain of HSI is that it requires a detailed assessment of training requirements early in the design process, to include the tasks and equipment elements that are contributing to the requirement.

High drivers that emerge as a result of a detailed training requirements assessment will likely fall into three general categories—the frequency, difficulty, and criticality of task performance. If a task is performed with a high degree of frequency, even if it is a relatively easy, not cognitively demanding task, it is a training high driver. Tasks also may be deemed high drivers if they are inherently difficult; for example, if they require high cognitive skill and will be performed under time pressure. Or it may be that some aspects of task performance are hard to remember, say a task with a large number of substeps that must be performed in sequence without a memory aid. [See Rose et al. (1985) for a detailed discussion.] Other possible high driver tasks are those that will be performed under high physical workload or stress or performed as a part of a team. These sorts of tasks are critical, yet difficult or costly to train. Finally, tasks are training high drivers if they are critical to the overall mission.

Key Training Analysis Elements Unfortunately, analysis tool development to support the training domain has received less attention than either the manpower or personnel domain. This is probably due in part to a dearth of empirical data to support quantitative, performance-based analysis. Training-related data are more likely to pertain to the effectiveness of a training method or technique rather than to training requirements determination.

Analyses conducted to support this domain provide important data necessary to ensure that a system can be successfully fielded within the schedule and the life-cycle cost constraints. The results of this element of the HSI analysis process provide the inputs for the training development process. In most system designs, this particular element of the analysis will focus on tasks and functions in which new and unique skills and knowledge are required of the users—those "leap ahead" requirements.

The training analyst accepts as input the knowledge, skills, and abilities (KSA) elements attached to each task and the equipment required to perform each task. These KSAs encompass the cognitive and physical workload aspects identified to support the personnel domain, and extend to broader considerations of task performance. One tool that has been successfully used to identify KSAs needed to perform new tasks is the U.S. Army's JASS (Knapp and Tillman, 1998; Barnes et al., 2000a). The individual skills and abilities in the JASS taxonomy are shown in Figure 11.4 (see Fleishman and Quaintance, 1984, for foundational work on JASS categories).

A typical training analysis process is shown in Figure 11.5, in which each task is scored using benchmarks aligned to basic performance skills (e.g., communication, analysis, information processing, gross motor, fine motor, etc.). The tasks are then assigned to a targeted specialty. The current POI for that specialty and the personnel characteristics drive the KSA profiles for the soldiers. The two profiles can be directly compared across the eight major categories of skills yielding skill gaps (i.e., skill categories for which the

Cognitive Skill and Experience Clusters

Communication	Conceptual	Reasoning	Speed-Loaded
1. Oral Comprehension	5. Memorization	13. Inductive Reasoning	19. Time Sharing
2. Written Comprehension	6. Problem Sensitivity	14. Category Flexibility	20. Speed of Closure
3. Oral Expression	7. Originality	15. Deductive Reasoning	21. Perceptual Speed and Accuracy
4. Written Expression	8. Fluency of Ideas	16. Information Ordering	22. Reaction Time
	9. Flexibility of Closure	17. Mathematical Reasoning	23. Choice Reaction Time
	10. Selective Attention	18. Number Facility	
	11. Spatial Orientation		
	12. Visualization		

Perceptual-Motor Ability Clusters

Vision	Audition	Psychomotor	Gross Motor
24. Near Vision	31. General Hearing	34. Control Precision	41. Extent Flexibility
25. Far Vision	32. Auditory Attention	35. Rate Control	42. Dynamic Flexibility
26. Night Vision	33. Sound Localization	36. Wrist-Finger Speed	43. Speed of Limb Movement
27. Visual Color Discrimination		37. Finger Dexterity	44. Gross Body Equilibrium
28. Peripheral Vision		38. Manual Dexterity	45. Gross Body Coordination
29. Depth Perception		39. Arm-hand Steadiness	46. Static Strength
30. Glare Sensitivity		40. Multi-Limb Coordination	47. Explosive Strength
			48. Dynamic Strength
			49. Trunk Strength
			50. Stamina

Figure 11.4 JASS categories.

allocated tasks exceed the skill levels currently supplied by the training and selection criteria for that MOS) and high driver tasks (i.e., specific tasks that cause unique or exceptionally high skill levels). The skill gaps become training or possibly personnel selection challenges. The high driver tasks become design and integration challenges.

This approach enables the HSI analyst to assess training impacts very early in the system design process so that training development can address unique needs of the new or modified system and can progress in parallel with the system integration process. It provides a clear link between the tasks that are driven by technology selections and integration decisions and the skills needed to perform those tasks. Finally, it compares those skill requirements to skill availability in selected MOSs and identifies skill gaps, many of which become training requirements and can be passed on to the training development team.

11.2.4 Trade-offs Among Domains

The HSI initiative helps an analyst identify issues within separate domains that affect system design and development. However, much of the value of HSI is in how it identifies issues that interact across domains. For military applications, this notion is directly stated

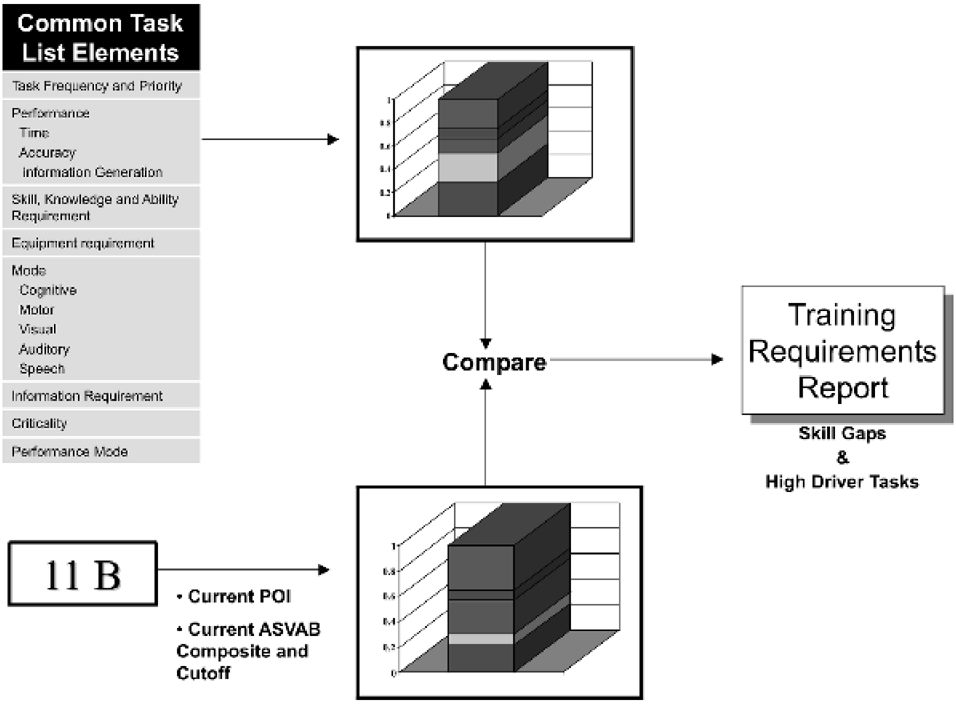


Figure 11.5 Task data drive skill requirements and enables direct comparison to POI and personnel aptitude data to reveal specific training or selection needs.

in the Military Handbook *Human Engineering Program Process and Procedures* [MIL-HDBK-46855A; (U.S. Department of Defense, 1999)]: "With few exceptions, the MPT areas are predominant sources of life cycle cost of major systems. Since initial MPT constraints limit design, while equipment, software, and task design place demands on MPT resources, it is imperative that the HE and MPT communities harmonize their work from requirements-setting to total system design and evaluation" (p. 23).

Frequently, domains interact with one another such that successful resolution of a high driver in one domain might cause a significant negative impact in another domain. Acceptable manpower limits, the aptitudes and characteristics of user personnel, the training burden, the design, and acceptable performance criteria must all be considered together. For example, take the interaction between manpower and personnel. If manpower requirements go up (more people are needed), personnel quality will go down. Similarly, when the human factors engineering of a system is poorly done, the training requirement will increase. The multiway trade-offs among training, personnel, and equipment design are often a major HSI consideration in minimizing the effects of high drivers. For example, if a relatively poor design were locked in place, and the target audience were relatively unsophisticated in terms of the system at hand, then the only variable to manipulate is training in order to assure acceptable performance. In the remainder of this section, we describe some of these trade-offs in more detail in order to set the stage for a subsequent discussion on MPT integration tools.

Table 11.3 highlights the principal areas of trade-off applicable to the manpower and personnel capabilities domains (see also Dynamics Research Corporation, 2000). The three examples below illustrate more specifically the variety and importance of making proper trade-offs in design decisions:

Trade-offs between Aptitude-Training-Performance Often the most desirable system design desired is one that allows acceptable system performance with low-aptitude operators and minimal training. However, this outcome is seldom possible even with financial resources available to assist the design effort. If the system design results in a more complicated system than expected, but not enough high-aptitude operators are readily available, then enhancing the training package might be required. As shown in Figure 11.6, different combinations of aptitude and training can result in different design concepts.

TABLE 11.3 Trade-off Areas

Areas	Comment
• Operators versus automation	Functional allocation of task to people or equipment
• Aptitude versus training	Lower aptitude people have greater training requirements
• Aptitude versus decision aids	Relationship between aptitude and best use of decision aids
• Design versus target audience (5th–95th percentile)	Consider cost and increase in personnel availability between a 10–90 versus a 5–95 percentile design
• Manpower versus built-in test/built-in test equipment	Embedded diagnostics can reduce maintenance times and personnel required (but, consider cost and reliability of equipment)
• Design versus manpower	System's design influences workload that in turn influences numbers of operators and maintainers
• Design versus aptitude	More complex tasks that are not automated will require higher aptitudes in order for them to be performed at required level
• Maintenance manpower versus support manpower	Watch for trade-offs that reduce burden in one area but end up increasing burden in other areas
• Manpower versus training	Using maintenance as an example, if specialist positions are required, training time goes down but overall manpower is increased; if generalist positions are planned (e.g., a suite of systems is to be maintained by one specialty), then the number of positions is decreased, but training time will likely need to be longer
• Manpower versus aptitude	Fewer personnel with high aptitudes may be required to perform a given set of tasks to time and accuracy standards; but, such people may be in limited availability
• Personnel characteristics versus safety	Example: A visual warning in red is required; a constraint now exists to allow only operators who are not color blind
• Health hazards versus personnel characteristics	Army constraints of operator's capabilities (e.g., strict visual requirements) reduce risk also reduce the availability of the personnel pool

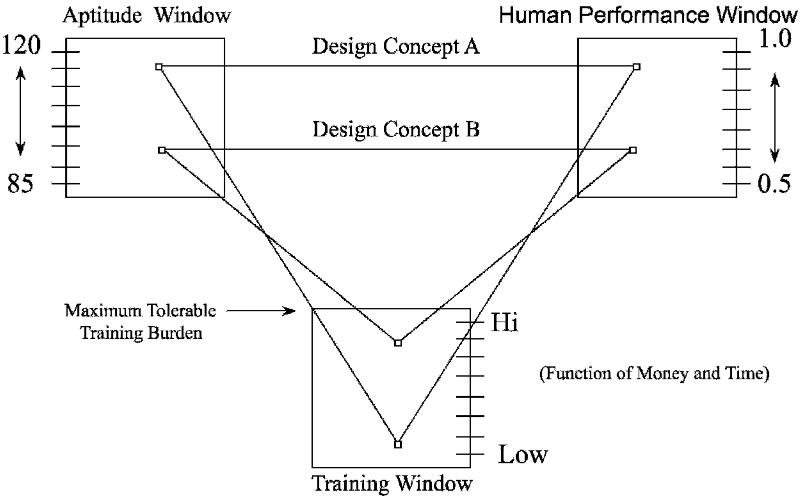


Figure 11.6 Aptitude training, and performance trade-offs (adapted from Guerrier et al., 1991).

Computer Systems Achieving usability of automated information systems is typically accomplished through balancing an interaction of the quality of screen designs (i.e., navigation, consistency, layout, labeling, etc.), the type of training required, and the background the target audience brings to the system. Unlike the standard practice of the mid-1980s when a box of software included a paper user's guide, today much commercial-off-the-shelf (COTS) software is shipped without the manual; rather, a reduced set of useful information is embedded in the software. This is often, but not always, successful. When successful, this achievement is due in part to designing to the low-skill end of a wide target audience (i.e., the least common denominator); therefore, the more usable the product the greater the potential for increased sales.

Military software is often customized and built for a more specific user group. It may also be more complicated than a typical COTS product. Therefore, it is important to consider how the interface, operator aptitudes and experience, and required training interact. Three minimally acceptable scenarios for combinations of the three factors are shown in Figure 11.7. Poor interface design will likely require both complex training and a smart target audience. Conversely, an excellent interface design may allow simple training and a "not so smart" target audience. If the interface design is medium quality, it is possible to have a more medium training and medium target audience combination for acceptable usability.

Aptitude Areas The importance of aptitudes to the HSI analyst is that some skills are hard to obtain and therefore are constantly in high demand throughout the military. Thus, there is a relationship between aptitude area and recruiting, training, and retention. This relationship is made all the more dramatic if an aptitude area cutoff score is changed to either bring smarter personnel into a given job to handle added complexities of a new system (i.e., cutoff is *raised*) or to bring more people to the job (i.e., cutoff is *lowered*). The following is likely to happen for each of these two scenarios, respectively (concepts taken from Warner and Knapp, 1999):

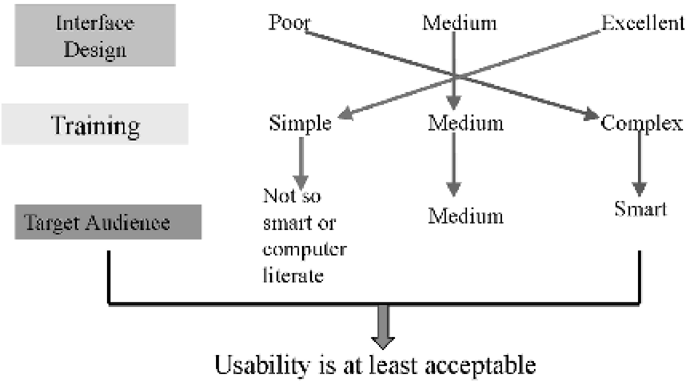


Figure 11.7 Three scenarios for domain trade-offs in automated information systems.

- A higher aptitude area cutoff score will result in higher quality graduates of an advanced training course. Also, because of the higher caliber student, the number of academic drop-outs will be fewer. However, the total number of graduates for the aptitude area will not be as many because the number of qualified recruits for entry into the school will drop.
- Lowering an aptitude area's cutoff score means more personnel will be qualified to enter the class, and as a result the graduating class will be larger, but the training expense incurred will be greater due to the cost of many academic drop-outs and of additional material that might have to be presented.

With a better understanding of the high-level personnel capabilities considerations provided by HSI assessment methodology and seeing the types of personnel data needed to exercise the tools useful to HSI analysts, we can now review the status of MPT systems integration tools that have been developed by the U.S. Federal Government (primarily military services) and other countries.

11.3 MPT SYSTEMS INTEGRATION TOOLS

Most systems integration tools have been developed for use in military systems acquisition. Each military service has a slightly different perspective on MPT integration, borne of their different missions and the different environments in which they operate, and sometimes capitalizing on different research findings. This has led to the separate development of analytical tools and techniques that support the differences in service organization focus. In this section we have selected a tool from each of four different organizations [U.S. Army, U.S. Air Force, U.S. Navy, and UK Ministry of Defence (MoD)] in order to highlight the various similarities and differences with the major HSI integration tools. This is not intended to be a complete discussion of the tools, techniques, and technologies currently available or being developed for HSI.

11.3.1 U.S. Army

The U.S. Army took the early lead in HSI tool development and recognized that the power of these tools lay in their ability to support quantitative, unambiguous trade-offs. The U.S. ARL-HRED has been active in performing HSI analysis on a variety of systems and has sponsored recent work in this area. ARL-HRED developed a modeling and analysis tool named IMPRINT. The IMPRINT tool grew out of common U.S. Air Force, Navy, and Army MPT concerns identified in the mid-1970s. These concerns centered about two key questions: How to estimate MPT constraints and requirements early in system acquisition and how to enter those considerations into the design and decision-making process.

To address these questions, the U.S. Navy first developed the HARDMAN (hardware vs. manpower) comparability methodology (HCM). The U.S. Army then tailored the manual HCM, which became known as HARDMAN I, for application to a broad range of weapon systems and later developed an automated version, HARDMAN II. In HARDMAN I and II, however, there was no direct link between MPT and performance. To directly remedy this shortcoming, the U.S. Army began the development of a set of software analysis modules in the mid-1980s (Kaplan et al., 1989). This set of modules was called HARDMAN III, and although the name was the same, it represented a significant advance in the field through using a fundamentally different approach for addressing MPT concerns than previous methods. It provided an explicit link between MPT variables and soldier–system performance. IMPRINT is essentially an integrated and refined version of HARDMAN III in the Windows environment.

The mechanism for the MPT performance link is task network modeling provided by the commercially available Micro Saint task network simulation modeling engine, PC software designed for describing and analyzing task networks. The modeling capability offered in IMPRINT can be further characterized based on three distinctions (Law and Kelton, 2000): (1) static versus dynamic, (2) deterministic versus stochastic, and (3) continuous versus discrete. A static model does not address system effects over time, whereas a dynamic model represents a system as it changes with time. A deterministic model does not represent any probabilistic or random elements, whereas a stochastic model does encompass random elements and produces output that contains random error. A discrete model refers to instances where the variables characterizing the system change instantaneously at separated points in time. A continuous model is the converse, with variables that change continuously with time. In some instances, systems can be treated as either discrete or continuous, depending on the objectives of the analysis.

Using these definitions, IMPRINT can be described as a dynamic, stochastic, discrete-event modeling tool. When certain assumptions hold, namely, (1) that the system of interest can be adequately described by task activities and networked sequencing, (2) that dynamic processes and random variability are of interest, and (3) that any continuous tasks can be fairly transformed into discrete tasks, then IMPRINT is an appropriate tool to use to represent and analyze soldier–system performance.

The basic modeling capability in IMPRINT requires the decomposition of a system mission into functions, which, in turn, are decomposed into tasks. The functions are linked together into a network describing the flow of events. The network can include various types of branching logic such as parallel branches, probabilistic branches, and repeating branches. Within each function, the tasks are sequenced using the same types of branching logic options. At the task level, estimates of task performance time and accuracy means and standard deviations are input along with the consequences of the failure to perform a

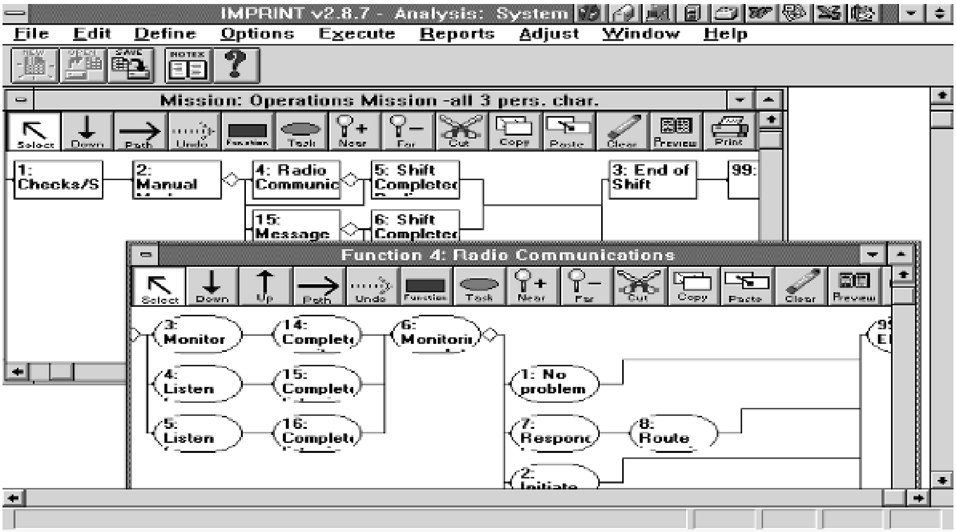


Figure 11.8 Sample IMPRINT screen.

task accurately enough. The available failure consequence options are: (1) no effect, (2) total mission abort, (3) repetition of that or some other task, or (4) subsequent degradation of some other task. The data entered are assumed representative of performance under "typical" or baseline conditions. In addition, standards of performance can be entered to provide benchmarks for performance adequacy at the mission, function, and task levels. A sample IMPRINT screen depicting both the function and task level networks is shown in Figure 11.8.

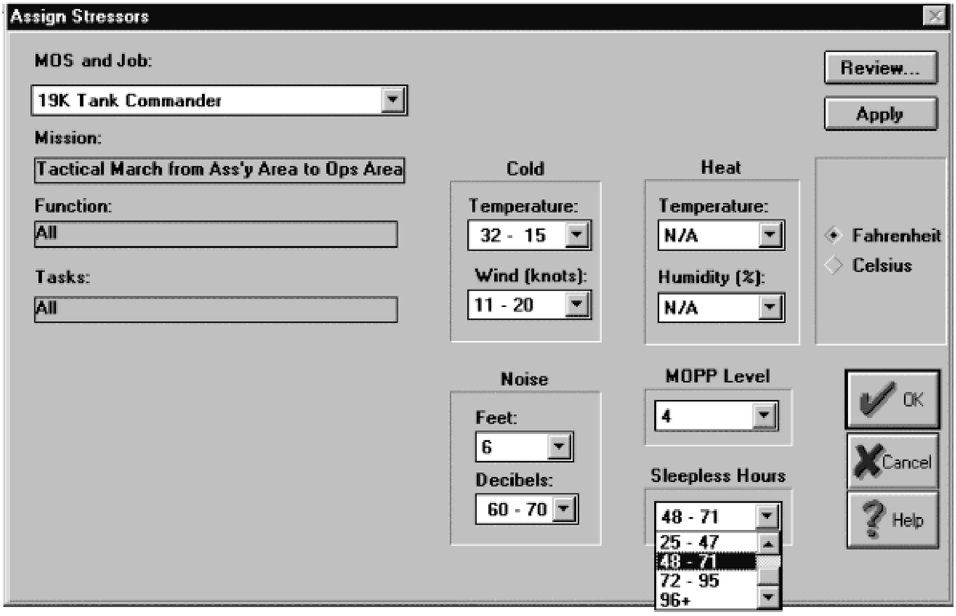
IMPRINT executes a mission model task by task by first drawing a task time from the distribution as defined by the mean and standard deviation input for each task. Then it calculates the probability of success for the task based on the accuracy inputs. Next it determines, for this instance, whether there is an accuracy failure. After checking for a given task, IMPRINT proceeds through the task and function networks in accord with the established branching logic and analyzes the output according to the standards. When the model execution is completed (which can consist of several repetitions), reports of estimated performance at each of the three levels are generated along with the comparisons to the standards. Although any given model and its associated assumptions must be scrutinized, this approach is particularly useful for comparisons across systems or system conditions.

Several aspects of IMPRINT are unique. First, IMPRINT provides a method through which users can assess the effectiveness of the performance (i.e., "how successful was our system") as well as the more traditional efficiency assessment (i.e., "how busy were the soldiers" and "how many soldiers do we need"). The question of "how busy" can be answered in greater detail by using the embedded mental workload scales, either a straightforward assessment of visual, auditory, cognitive, and psychomotor workload channels or an assessment using a more advanced scale that includes a calculation of single task demands and intertask conflicts.

Second, IMPRINT includes specific algorithms to assess performance under diverse environmental conditions. Recall that the task performance data entered in the baseline model are assumed to represent performance under “typical” conditions. The embedded environmental stressors automatically adjust performance to account for the changes expected under different levels of the stressors. Currently, IMPRINT includes five environmental stressors: (1) protective clothing (i.e., mission-oriented protective posture, or MOPP); (2) heat; (3) cold; (4) noise; and (5) hours since last sleep (see Fig. 11.9). The application of a stressor will result in either less accurate task performance, longer times to complete the task, or both. Stressors may be applied to an individual task or to all the tasks assigned to a particular job or MOS for the mission. When the model is rerun, the new, or “stressed,” task performance time and/or accuracy are used as the task estimates that are “rolled up” in the task, function, and mission reports are compared against the standards. Importantly, the results can also be compared with the baseline model predictions. [See Archer and Adkins (1999) for more complete documentation.]

The third unique aspect of IMPRINT is embedded data to enable users to adjust performance based on personnel characteristics (i.e., ASVAB scores) of the performing soldiers. This capability is a key element of the integration analysis, for it ties the variables from the personnel HSI domain into the system performance prediction.

IMPRINT is truly an integration analysis tool. Manpower (the number of crew members), personnel (the aptitudes of those soldiers), training (frequency and recency of practice for tasks), and human factors engineering (the design of the crew station) are all well represented in the total system performance estimate. A number of applications of IMPRINT to system acquisition and design issues provide ample evidence of integrated HSI analysis (Allender, 2000).



MOS and Job: 19K Tank Commander

Mission: Tactical March from Ass'y Area to Ops Area

Function: All

Tasks: All

Cold — Temperature: 32 - 15

Wind (knots): 11 - 20

Heat — Temperature: N/A

Humidity (%): N/A

● Fahrenheit

○ Celsius

Noise — Feet: 6

Decibels: 60 - 70

MOPP Level: 4

Sleepless Hours: 48 - 71

25 - 47
48 - 71
72 - 95
96+

Figure 11.9 Environmental stressors.

11.3.2 U.S. Navy

The U.S. Navy has a unique HSI problem to solve. Since most of its platforms are shipboard systems, the operators, maintainers, supply, and support personnel are typically the same sailors, most of who live on the system. This difference, coupled with recent emphasis on dramatic reductions in crew size and increased concern about each sailor's quality of life, has driven the U.S. Navy to focus on properly allocating tasks between crew (either aboard the system while underway or in port) and automation devices. This emphasis has driven development of tools that are attentive to the skills required by new equipment and faithful representation of sailor training and selection considerations in order to determine whether those skills are likely to be available.

The Systems Engineering Analysis Integration Tool (SEAIT) is a small business innovative research (SBIR) project managed by NAVSEA Dahlgren, Dahlgren, Virginia. The purpose of SEAIT is to evaluate the effects of reduced shipboard manning on ship design, system performance, and cost. A primary strength of this tool is that it supports a flexible analysis approach through which a system designer can apply varying levels of fidelity to the analysis of manning and automation alternatives. The scope of the functional analyses includes shipboard operations, unplanned corrective maintenance, and support functions. The tool allows for evaluation and trade-off analyses of ship manning during both normal and emergency or special conditions for a variety of operational activities (e.g., underway in open water, entering port, heavy weather, man overboard, fire, combat operations). A unique and innovative capability of this discrete event-based simulation tool is a module that solves for the best crew manning strategy based on the user's goal.

The SEAIT tool assists designers in assessing the impact of reduced manning levels on performance in various dimensions of the systems. These include the levels of automation required, the allocation of tasks to human operators of the system, the workload of the reduced crew, and subsequent risk associated with degraded performance due to excessive workload and other performance stressors. Users of SEAIT evaluate and trade-off these factors to determine the ultimate affordability of the new system. Costs associated with a new system are limited to the dollar cost of developing the system, including new automation, and the manpower costs of the required crew.

Several aspects of SEAIT make it unique among HSI tools. In SEAIT, users are prompted to provide limitations regarding crew size and the flexibility of voyage functions and also for the analytical goal (i.e., minimize number of jobs, minimize hardware cost, minimize skill gaps between existing and new jobs). SEAIT will run multiple iterations of the task network model in order to find the solution that best accomplishes the goal, within the constraints.

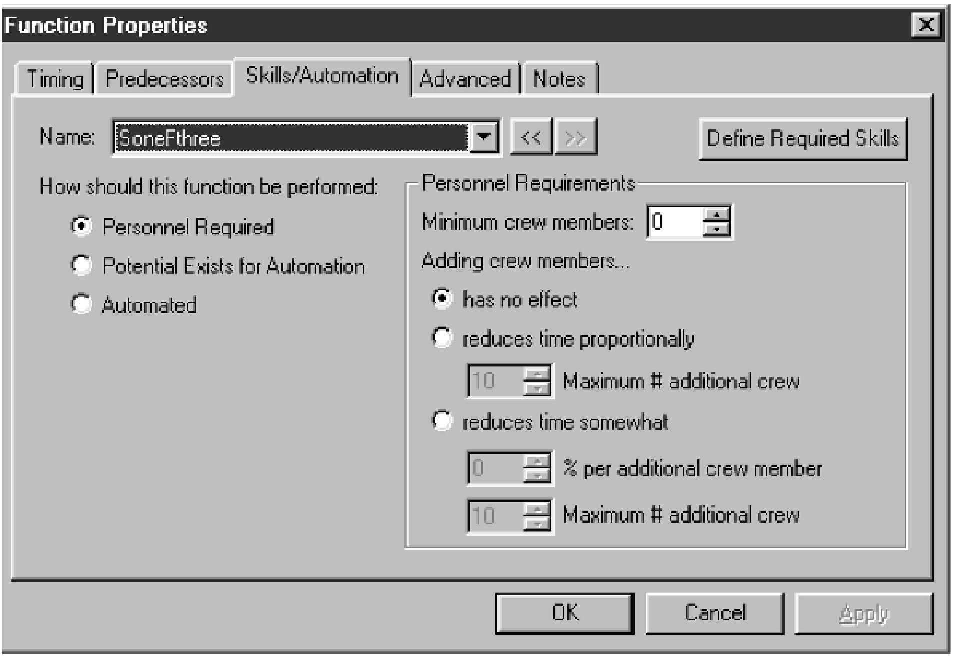
The SEAIT tool incorporates a method through which users can specify the types and levels of skills necessary to perform tasks. These skill scales are taken from work by Fleishman (Fleishman and Quaintance, 1984) and were originally included in a tool developed for the U.S. Army and discussed earlier in this chapter, JASS. The SEAIT method contains the JASS skill taxonomy as a library table that provides information on the skills and their levels that are available within the navy personnel inventory. These embedded data allow SEAIT to perform three tasks. First, the tool can help users allocate tasks appropriately through providing guidance to the user when tasks are assigned to jobs, by listing all the existing jobs that contain the requisite levels of the necessary skills. Second, SEAIT can allocate tasks to jobs "on the fly" whenever competing (parallel) tasks exceed available crew members for specific jobs. Finally, SEAIT can determine whether a task has a unique skill (i.e., one that is not available in the crew). This task would then be a candidate for redesign, automation, or possibly a training solution.

The interface available to users behind the Skills/Automation tab is shown in Figure 11.10. If users indicate that this function will not be automated, they can use the Define Required Skills buttons to change the list of skills attached to each function. If users click on the Define Required Skills button, the interface shown in Figure 11.11 is presented.

When users add required skills to a function or task, they can select the skills they want from the complete list or from skill categories (e.g., Communication). The list is presented in a spreadsheet interface and includes a description of the skill. Once they select a skill and click on the Score Skills button, the interface shown in Figure 11.12 is displayed.

The Assign Skill Levels interface helps users determine the level of a skill needed for the function or task. As shown in Figure 11.12, the skill scale name and description are displayed on the interface. Below these, the benchmarks for this skill scale are shown, with scores ranging from 0 to 70. For example, “Understand a lecture on navigation in space” is assigned a score of 63 from a maximum possible 70 under the category Oral Comprehension. Users can move the slider on the scoring scale to set the score, or alternatively, can type in a score in the text box underneath the scale. The control at the bottom left of the screen lets users move through the skill scales and score them without returning to the previous screen and selecting them individually from the list of skills.

Skills and required levels are combined and assigned to tasks by the SEAIT discrete event simulation engine. This engine generates a composite of the skill requirements over time by each crew member of the system. Figure 11.13 provides an example of this type of



Name: SoneFthree

How should this function be performed:

● Personnel Required
○ Potential Exists for Automation
○ Automated

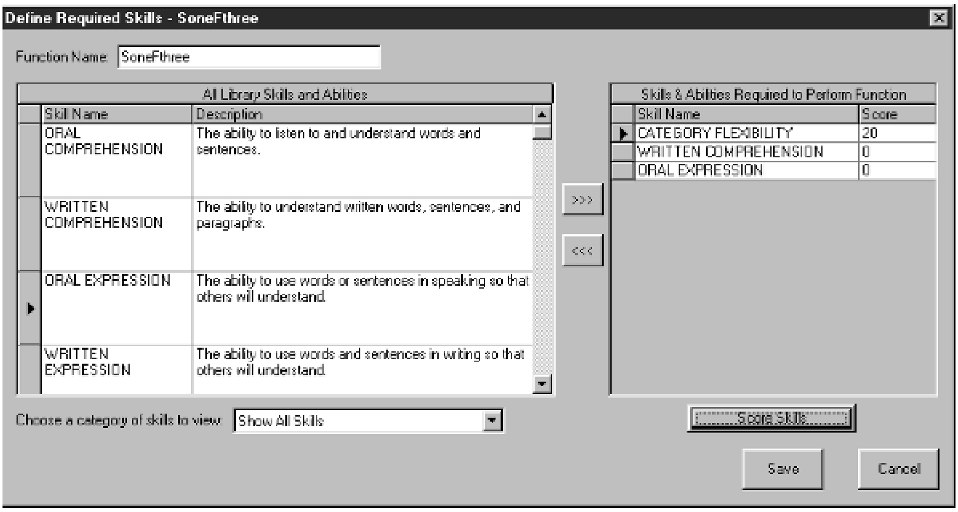
Personnel Requirements

Minimum crew members: 0

Adding crew members...

● has no effect
○ reduces time proportionally
10 Maximum # additional crew
○ reduces time somewhat
0 % per additional crew member
10 Maximum # additional crew

Figure 11.10 SEAIT Skills/Automatic tab.



Define Required Skills - SoneFthree

Function Name: SoneFthree

All Library Skills and Abilities

Skill Name	Description
ORAL COMPREHENSION	The ability to listen to and understand words and sentences.
WRITTEN COMPREHENSION	The ability to understand written words, sentences, and paragraphs.
ORAL EXPRESSION	The ability to use words or sentences in speaking so that others will understand.
WRITTEN EXPRESSION	The ability to use words and sentences in writing so that others will understand.

Skills & Abilities Required to Perform Function

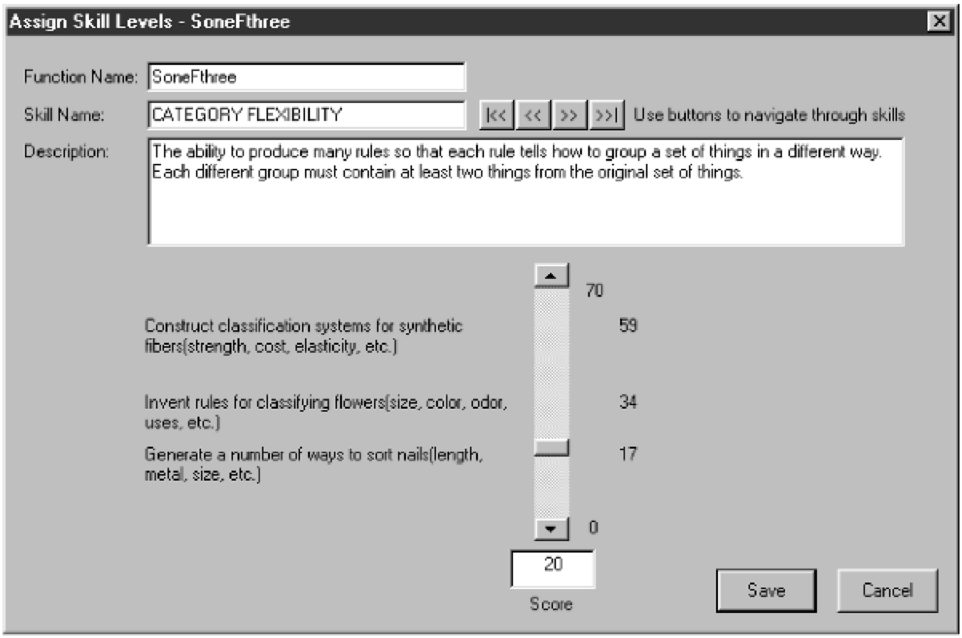
Skill Name	Score
CATEGORY FLEXIBILITY	20
WRITTEN COMPREHENSION	0
ORAL EXPRESSION	0

Choose a category of skills to view: Show All Skills

Figure 11.11 SEAIT Define Required Skills.

output. This result can be used to determine whether a specific set of tasks or operational requirements combine to drive the skill requirements of the system and to help the user identify fruitful task allocation or automation strategies.

SEAIT became available in late 2000 and includes some system data from fielded ships. Follow-on plans include significant augmentation and integration with other U.S. Navy analysis environments.



Assign Skill Levels - SoneFthree

Function Name: SoneFthree

Skill Name: CATEGORY FLEXIBILITY

Use buttons to navigate through skills

Description: The ability to produce many rules so that each rule tells how to group a set of things in a different way. Each different group must contain at least two things from the original set of things.

Construct classification systems for synthetic fibers(strength, cost, elasticity, etc.) 59

Invent rules for classifying flowers(size, color, odor, uses, etc.) 34

Generate a number of ways to sort nails(length, metal, size, etc.) 17

Score: 20

Figure 11.12 SEAIT Assign Skill Levels.

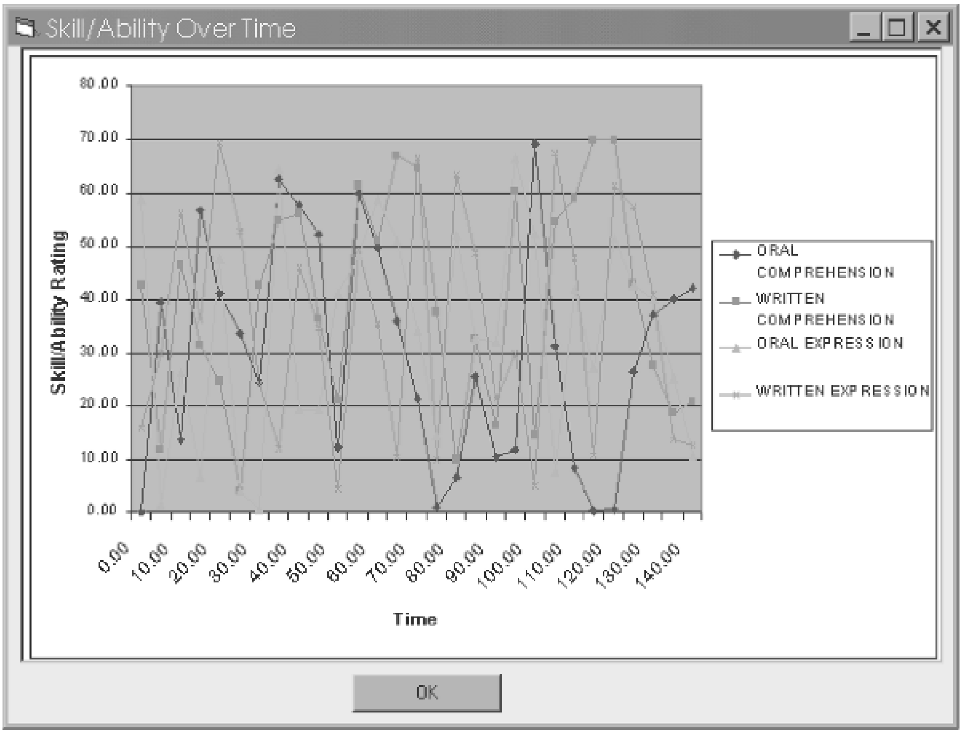


Figure 11.13 SEAIT output example.

11.3.3 U.S. Air Force

U.S. Air Force tool development has traveled a slightly different path than the other services. While the U.S. Army and the U.S. Navy have typically considered the maintenance and operational HSI analysis of a system together, the U.S. Air Force has tended to separate the analysis of the maintenance requirements of the system from the operational requirements. This is partly attributable to the traditional organizational divisions of the analysts and to the different emphasis of the two analytical requirements for aviation systems. The need for weapon system maintenance is driven by equipment reliability under various operational scenarios. The resulting maintenance task performance then leads directly to sortie generation rate, one of the most important and highest visibility readiness measures in the air force. Air force operators are exceptionally highly trained and skilled personnel. Unlike the other services, the operator crew (i.e., pilots, copilots, navigators) performs very little maintenance, so there is little overlap in terms of resource limitations and workload requirements. This reduces the requirement to consider the two sets of tasks in the same analysis.

The tool that best characterizes the U.S. Air Force's MPT integration effort is the Manpower, Personnel, and Training Decision Support System (MPT DSS). The MPT DSS helps analysts conduct the complex MPT analyses required to support Department of Defense (DoD) HSI requirements. MPT DSS provides a non-simulation-based analytical environment that has several unique capabilities.

MPT DSS is composed of a number of tools that communicate through a central database, enabling users to maintain data integrity and a clear audit trail of data elements and their resulting outputs as the design for the analyzed system matures. This design also enables the software to direct users toward specific tools that fit their analytical goal and level of expertise.

One of the most unique elements of MPT DSS is its ability to allow users to import MPT data from existing databases. Through a tool called the database integration (DBINT) tool, users can import data from the logistics composite model (LCOM), the comprehensive aircraft support effectiveness evaluation (CASEE), F forms 611/612 training cost data, U.S. Navy (USN) catalog of navy training courses (CANTRAC), and the programmed technical training manpower standards (PTTMSs). This helps the user begin to populate the analysis with reliable data. While this ability is powerful and useful, it does create a maintenance requirement for MPT DSS in order to stay current with updated data formats of the external data sources.

The individual analysis tools of MPT DSS are designed to address reasonably separable aspects of the HSI analytical picture. As the user progresses through the tools, the inputs and the outputs are integrated into the master database in order to support the trade-off capability that is central to an integration tool.

The tool elements of MPT DSS can be placed into three categories. The first category contains tools that help the user develop a representation of the system design.

Database Integration (DBINT) helps users import the data needed to conduct MPT analyses.

System Definition Systems (SDSs) help users refine the equipment and tasks to be included in the MPT analysis. The LCOM and CASEE methods provide existing aircraft work unit codes and maintenance task reliability and maintainability data.

The second category includes six tools used to perform selected, somewhat domain-specific analysis.

Manpower Estimation (ME) helps users determine the direct maintainer manpower required to support a squadron.

Force Structures (FS) help users aggregate squadron manpower and calculate indirect manpower within an organization structure. The FS categorizes and outputs manpower as specified by the Manpower Estimate Report and includes various cost categories.

Training Task Analysis (TTA) helps users identify the tasks that require training, determine the instructional setting in which the tasks should be trained, and determine the time required to train each task adjusting for skill and knowledge similarity.

Training Resources and Requirements (TRR) help users define operator and maintainer courses including length, training devices, and comparable cost.

Life-cycle Cost (LCC) applies standard cost factors, including inflation, to the MPT resources generated by the other tools to produce the MPT portions of LCC.

The third category includes three tools that are used to support comparison and trade-off analyses between versions of an analysis and across domains. Three tools have been designed to combine the results of the individual analysis tools into an overall assessment of the system.

The high driver tool identifies the parts of the weapon system that are the major contributors to a key measure of effectiveness. For example, the high driver tool can rank order equipment items in terms of the maintenance man-hours they require.

The comparison tool allows users to compare MPT analysis results between different versions of the same system. The comparison tool presents differences in both tabular and graphical reports.

The trade-off tool helps users conduct trade-off and sensitivity analyses of key MPT parameters. The trade-off tool can vary two parameters systematically, rerun the analyses needed to assess their impact on a particular measure of effectiveness, and graphically depict how variations in these parameters impact the measure of effectiveness.

The MPT DSS central database maintains a representation of the input and output associated with each process. During the trade-off analysis process, this representation allows users to change MPT parameters and automatically rerun the analyses needed to assess impacts on key measures of effectiveness.

Originally developed for U.S. Air Force (USAF) systems, the MPT DSS has been expanded to include the analysis of U.S. Navy (USN) and U.S. Marine Corps (USMC) systems to support the Joint Strike Fighter Program Office (JSFPO). The USAF has also played a leading role in meeting the challenge of integrating human performance models (HPMs) with other constructive simulations. The Air Force Research Laboratory/Human Effectiveness Directorate (AFRL/HED) supports research development for the air force in the areas of human/system design. AFRL/HED is leading the development of a methodology and a suite of computer simulation tools to evaluate crew system designs from the perspective of crew performance as they affect weapon system mission effectiveness. The capability will allow users (e.g., system program offices, industry, etc.) to impact design decisions much earlier in the acquisition process in ways that historically have only happened later in the design phase. Being able to affect the design of crew interface and associated aircraft subsystems (avionics, weapons, etc.) much earlier permits greater inclusion of human factors and crew systems engineering trades.

The software tool currently being developed by the USAF is called Combat Automation Requirements Testbed (CART). CART helps analysts, operation researchers, and engineers develop HPMs that are realistic in their behaviors and can also interact with external mission and engineering-level simulations. Rather than begin anew, AFRL/HE built upon the U.S. Army's proven IMPRINT human performance modeling environment. There were two major modifications made to IMPRINT that provided this new capability. The first was goal orientation, and the second was integration with external simulations.

Based on Jens Rasmussen's abstraction hierarchy concepts, the hierarchy of goal-to-task is key to CART's translation of real-world actions and events into usable operator models (see Fig. 11.14). CART permits the user to decompose a mission (i.e., destroy a time–critical target) into high-level goals (threat evasion, attack a target, etc.). Once these goals are established, the user can create a series of high-fidelity operator tasks that support each higher level goal. Creation of the lower level tasks in the model can be based on real-world experience, engineering analysis, interviews with SMEs, or simply assumptions about how the operator will interact with the crew interface (should a physical form not yet exist). As the task network model is being built, users can input key performance features such as time, accuracy, variability, etc.

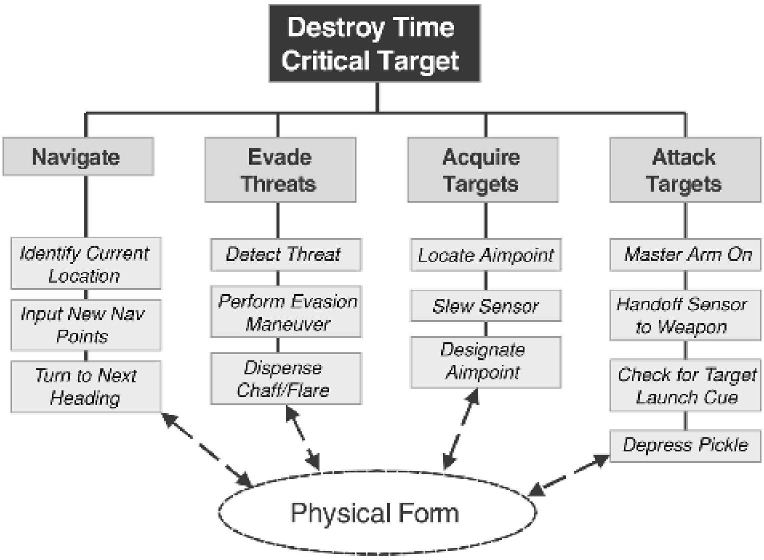


Figure 11.14 CART goal orientation.

The second major extension to IMPRINT under the CART program was the addition of a network communication interfaces (NCI) layer or "sockets" that permit data to be exchanged with an external simulation running in parallel but outside of the CART simulation. In this mode, the external simulation passes target location, threat identification, and other key environmental factors to the task network model built by the CART user using the NCI. The task network model in CART "perceives" the real world through a set of crew interfaces (displays, audio) and visual cues that have also been modeled. Based on the user's construction of the task network model, the interaction between the HPM and the external simulation will vary—much like real pilots under different environmental conditions. The variability within and between the external simulation and the CART model can be measured whereby validation of the operator model becomes straightforward. In practice, AFRL has demonstrated the efficacy of the CART software to faithfully represent operator tasks in highly dynamic time-critical targeting missions.

By using these features (goal orientation and integration with external simulations), CART users are able to create realistic models of human behavior while avoiding the costs associated with fabricating and running cumbersome human-in-the-loop simulations. In effect, this capability provides the acquisition community with a tool that relates the effect that operator performance has on system lethality and survivability.

11.3.4 Other Developers (Non-U.S.)

The Integrated Performance Modeling Environment (IPME) is an integrated environment of models intended to help the human factors practitioner analyze human system performance. IPME builds from a discrete event modeling environment similar to that embedded in IMPRINT but adds modules to expand the descriptions of selected aspects of human behavior. The development of IPME has been a collaborative development effort among the United Kingdom's Defense Evaluation Research Agency's Centre for Human

Sciences (DERA CHS), Canada's Defense and Civil Institute for Environmental Medicine (DCIEM), and Micro Analysis and Design Inc. (MAAD).

The IPME uses a process-oriented modeling approach and builds upon an SME's accounting of how operator activities are organized or may be organized to meet operational objectives. Operator responsibilities and goals can be recorded at a high level of abstraction (such as "prepare for mission") that can be decomposed into a hierarchy of functional blocks (such as "prepare met brief") until the analyst has reached a level of granularity (such as "read current weather map") appropriate to study a given problem.

The key IPME features are:

- *Environment Model* The analyst can model environmental factors or what behavioral scientists refer to as performance-shaping factors. These include environmental variables such as temperature, humidity, time of day, etc.
- *Operator Characteristics* Operator traits and states are simulated. Traits are variables such as mental ability, susceptibility to motion sickness, time since trained, etc. States are variables such as fatigue, hunger, etc. The operator state is dynamically updated during a simulation. Therefore, each operator in the simulation can have unique characteristics.
- *Performance-Shaping Functions (PSFs)* These user-defined functions dynamically modify individual operator task "time to perform" and "probability of failure" values. These PSFs define how performance-shaping factors (environment variables or operator characteristics) affect operator performance. The PSFs are linked to individual tasks through a task taxonomy allowing one PSF to be dynamically applied to any similar task in a model. Since PSFs can use operator states as expression variables, simulations can be built that have two operators performing the same task type with different, and therefore more realistic, "time to perform" and "probability of failure."
- *Prediction of Operator Performance (POP) Scheduler and Workload Measurement* A new algorithm for estimating operator workload developed by the British Centre for Human Sciences has been built into IPME and can be used to evaluate when operator task demands exceed capacity (Farmer et al., 1995).
- *Information Processing (IP) Scheduler* The IP scheduler is a new scheduling approach that establishes an "operator load" rather than a "task load." The operator load is defined as execution of the tasks that *can* be simultaneously completed within a human's resource capacity. Thus, the scheduler emulates expected human performance under loaded conditions. The IP mode of IPME establishes time criterions, structural and resource contention, and human memory limits for each task. As the simulation executes, a time pressure is calculated for each operator within the simulation based upon the slack time established for task execution. For simultaneously executing tasks, the scheduler determines if there are conflicts between structural resources such as hands, vision (fovea and peripheral views), and cognitive conflicts. In addition, it emulates the concept of prospective (or short-term) memory limits and the resulting effects from task overloading and attention distractions. These features produce realistic human behaviors, both for simulation-based acquisition and training applications.

- *Measurement Suite* Through a measurement suite, the user is able to set up experimental runs using independent variables that can be set to different initial values for each experimental run. Multiple experimental runs can be defined *and* multiple simulation runs (or iterations) can be specified for each experimental condition. Blocked experimental designs are supported.

The IPME is based on the proven Micro Saint simulation engine with the human operator simulator (HOS) extensions. It is a discrete event Monte Carlo simulation engine with a graphical user interface (GUI). The GUI provides a drawing space where network diagrams defining man and machine tasks are constructed using visual components. Network element sequence is defined by connecting model components with mouse point, click, and drag operations. Micro Saint supports several types of human decision models and queues to allow the representation of complex operations.

The HOS extensions provide a mechanism to define a workspace associated with a task network. This workspace can contain work zones or work surfaces, operators, and positional markers. Work surfaces can contain work controls with which the operator would interact. These controls can include things such as keyboards, mice, dials, knobs, etc.

IPME contains a simple socket protocol to allow passing variable information from external applications. External applications can be processing anywhere from which a connected socket can communicate. This means the IPME simulator can interact with other simulators on the same machine, or other machines connected via an intra- or internet.

IPME continues to have new features added under collaborative funding. The Canadian DCIEM continues to transition its simulated operator loading evaluation (SOLE) methodologies into the IPME environment. The final target is to have a complete human factors analysis capability that implements methodologies consistent with MIL-HDBK-46855A (Hendy and Farrell, 1997). The Centre for Human Sciences continues to advance the capabilities of the IPME simulation tool.

11.3.5 Summary of Tool Characteristics

The tools considered in this chapter are summarized in Table 11.4. They are IMPRINT, SEAIT, MPT DSS, CART, and IPME. The following five basic characteristics of each tool are included in the table: (1) principal purpose, (2) features supporting MPT requirements analysis, (3) additional analytic and data capabilities, (4) platform, and (5) distribution. It should be noted that many of these tools are still in active development, and the features are changing in order for the tools to continue to meet user needs. One particularly fertile area is in the development of links between these tools and other analysis tools and databases. The development of standards such as high-level architecture (HLA) have fueled this work and will eventually provide a cost-effective method for the tools to share algorithms, methods, and data.

11.3.6 Technical Gaps and Emerging Technologies

Although admittedly not quite perfected, and, unfortunately, not even in every-day use, the MPT tools available today are far more than simple manpower calculators or training days

TABLE 11.4 Summary of Tool Features and Capabilities

	IMPRINT VACP	IMPRINT Advanced	IMPRINT Maintainer	SEAIT	MPT DSS	CART	IPME
Proponent							
	Army	Army	Army	Navy	Air Force	Air Force	United Kingdom
Principal Purpose							
Level of analysis	Individual & small team (systems of systems in development)	Individual & small team	Single system type/force-wide roll-up	Navy manpower analysis ship-wide	Air Force & Navy aircraft maintainer manpower	Individual & small team	General modeling & individual performance
Acquisition phase	All	Postconcept	All	All	Postconcept	All	All
HSI domains	MPT & HFE (performance)	M & HFE	MPT	MPT	MPT	MPT & HFE (performance)	MPT & HFE (performance)
Manpower Requirements Analysis Features							
Analysis of staffing or team composition	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Embedded workload algorithm	McCracken-Aldrich	Wickens' MRT	Utilization	Busy/not busy	Utilization	McCracken-Aldrich	POP and IP/PCT, VACP, W/Index
Dynamic operator assignments	No	Triggered by workload overload	Triggered by utilization	Triggered by workload overload	Triggered by utilization	Triggered by task environment	Available through user-defined simulation expressions

Embedded stressors	Sophisticated noise, heat, cold, MOPP, sleep deprivation	User calibrated soldier quality, fatigue	Sophisticated noise, heat, cold, MOPP, sleep deprivation	No	No	Sophisticated noise, heat, cold, MOPP, sleep deprivation	User defined
Embedded shift work and circadian rhythm	No (Circadian algorithm in development)	No	Shift definition	Limited – work week/ overtime tracking	Shift definition	No	No
Personnel Requirements Analysis Features							
Performance variation by personnel quality	Yes, by ASVAB score	User defined	Yes, by ASVAB score	No	Yes	Yes, by ASVAB score	User defined
Skill requirements estimation	Yes – detailed	Yes – limited	Yes – limited	Yes – very detailed	Yes	Yes – detailed	Yes – limited
Training Requirements Analysis Features							
Performance variation by frequency of practice	Yes (sophisticated algorithm in development)	User defined	Yes	No	No	Yes	User defined
Training resource requirements estimation	No	No	No	No	Yes	No	No
Additional Analytical & Data Capabilities							
Task analysis data used as input	Yes	Yes	Yes & logistics data	Yes	Yes	Yes	Yes
Sample models	Army-specific models	Army-specific models	Army-specific models	Navy data elements	May be available on request	Air Force models also available	Limited set of military & commercial models

(*continued*)

TABLE 11.4 (*Continued*)

	IMPRINT VACP	IMPRINT Advanced	IMPRINT Maintainer	SEAIT	MPT DSS	CART	IPME
Number of task decomposition levels	Unlimited	Two	N/A	Two	N/A	Unlimited	Eight
Performance time distributions	Normal, gamma, lognormal	Normal, gamma, lognormal	Normal	Normal, gamma, lognormal	Normal	Normal, gamma, lognormal	Normal, gamma, exponential, rectangular, lognormal
Automated task accuracy & failure consequences	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Embedded human performance micro models	Yes	Yes	No	No	No	Yes	Yes
Link to cognitive modeling architecture	Yes	No	No	No	No	Yes	No
Representation of work center (x, y, z coordinates affect model outcome)	No	Can be implemented manually	No	Can be implemented manually	No	Can be implemented manually	Automated
Automated optimization techniques	No	No	No	Limited	Trade-offs, high drivers, comparison	No	No

Automated data collection	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Measurement suite to support experimental designs	In development	In development	In development	No	Version comparison capability	No	Yes
Graphical point & click model building interface	Yes	Yes	N/A	Yes	N/A	Yes	Yes
Animation	Task network	Task network	N/A	Task network	N/A	Task network	Task network
Debugging/ tracing capability	Yes	Yes	No	Yes	Yes	Yes	Yes
Simulation to simulation communication	Yes, HLA compatible	No	No	No	No	Yes, HLA compatible	Yes
Life-cycle cost	No (link to tool provided)	No	No	No	Yes	No	No
				Platform			
Windows 2000	Yes	Yes	Yes	Yes	N/A	Yes	HFAT only
Unix–Sgi	No	No	No	No	N/A	No	Yes
Linux	No	No	No	No	N/A	No	Yes
				Distribution			
Availability	Immediately	Immediately	Immediately	12/00	Not currently available	Immediately	Immediately
Limitations	Free to U.S. govt. and contractors	Free to U.S. govt. and contractors	Free to U.S. govt. and contractors	Free to U.S. govt. and contractors	N/A	Free to U.S. govt. and contractors	Free to UK govt. and DCIEM

estimators. *The "so-what" question has been answered*. The effect of MPT factors on task and system performance has been firmly established. IMPRINT, for example, has been used to apply stochastic, task network modeling, and mental workload assessments to a number of systems, resulting in significant system design impacts (see Allender, 2000, for a summary). At the same time, the need for MPT integration and assessment continues to grow in both breadth and depth.

Fortunately, research results and new technologies are now becoming available to address these expanded MPT integration and assessment needs. The HSI community is building on advances in computing technology and human performance modeling techniques (Laughery and Corker, 1997). In 1998, Pew and Mavor published their comprehensive review of the state of human behavior modeling in the military, which has proved to be a touchstone for both the modeling and the HSI communities. In the Human Systems Integration Technologies, Tools, and Techniques Symposium (2000), sponsored by ARL-HRED, the discussions of emerging expectations were all discussions of what modeling can offer: "Cognitive Modeling: Does HSI Need a Brain?," "Integration of Models: Is It the Holy Grail?," "Team Modeling: Can Human Teams be Engineered?," "High-level Architecture (HLA) and HSI: Do They Need Each Other?," and "Joint HSI: Are the Models Color Blind?" In addition to these advances came the formal recognition from the defense community that an authoritative representation of human behavior is essential for military simulations (U.S. Department of Defense, 1995). In this section, a few of the key advances that support expanded MPT integration and assessment needs are highlighted.

Computers and Computing Techniques Advances in computing have boosted and will continue to boost the performance of MPT integration tools. Computers are faster, and at the same time, faster computers are more accessible. On the "low end," the latest PC technology, which is actually quite powerful, sits on virtually every HSI practitioner's desk. On the high end, for example, the ARL's Major Shared Resource Center lists dozens of high-performance computers and programming languages that are available to government and government-affiliated researchers, either on-site or via remote access.

Somewhat distinct from the variety and number of available computers are what might be termed computing techniques coming from the fields of computer science, artificial intelligence, and mathematics. For example, in their review, Pew and Mavor (1998) singled out neural networks as having particular promise for the representation of human behavior. Both neural networks and genetic algorithms, in addition to their surface "biological" or "physiological" appeal, have potential for human behavior representation in that they "learn" or "evolve" in ways that may reasonably represent learning, although both also require large amounts of data to feed or train the software. Bayesian networks are another way to represent learning and growth and can be used in two ways of interest here for: embedded decision-aiding or embedded within another modeling environment to represent an aspect of cognitive processing (e.g., Anderson and Lebiere, 1998). Another development is agent-based programming, and while the uniquely defining characteristics are still being debated within the computer science community (Bradshaw, 1997), for our purposes here, suffice it to say that agents are another way to structure software that may be value added for simulating human–human or human–system collaboration. [See Zhang et al. (2001) for an example of tactical operations staff collaboration.] While only a few techniques are mentioned briefly here, detailed descriptions abound in the scientific literature and even in the popular press.

Cognitive Modeling The requirement to understand and predict soldier–system performance has expanded beyond the classic sort of task analysis where a task is generally an observable unit of behavior that takes seconds to minutes, even hours, to perform. Now, there is a need to know not just *what* the tasks are but *how* they are performed. System developers and designers need to know what cognitive mechanisms are invoked as a part of task performance. For example, displaying information on a helmet-mounted display does not simply increase the amount of information available to a soldier. The change in technology changes the perception, memory, and processing of the information as well as the kinds of errors associated with it. Therefore, truly understanding the MPT implications of a system requires an understanding not only of the obvious and observable interface features but also the cognitive interface and resulting cognitive demands.

Cognitive modeling capabilities, originating with academic research, are maturing to meet this need (Pew and Mavor, 1998). The 2001 International Conference on Cognitive Modeling even included a special panel on government interests and opportunities in the area (Gluck et al., 2001). The U.S. Air Force has sponsored the Agent-based Modeling and Behavior Representation (AMBR) project that examined several cognitive modeling approaches all modeling the same task of air traffic control (Gluck and Pew, 2001). The National Air and Space Administration (NASA) has initiated a human error modeling effort utilizing a number of cognitive models to describe and predict pilot errors with current equipment and practices as well as planned future equipment enhancements. The U.S. ARL has recently conducted work in-house using the Atomic Components of Thought-rational (ACT-R) cognitive modeling architecture (Anderson and Lebiere, 1998) to model aspects of soldier behavior (e.g., Kelley et al., 2001).

Among the most well-known cognitive modeling architectures are the ACT-R (Anderson and Lebiere, 1998), Executive-Process/Interactive Control (EPIC) (Meyer and Kieras, 1997), Soar (Laird et al., 1987), and COGnition as a NEtwork of Tasks (COGNET) (Zachary et al., 1992); but also include the various versions of the HOS (e.g., Hood and Allender, 1993) or goals, operators, methods, and selection rules (GOMS) concepts (e.g., Card et al., 1983). Whereas task network modeling, such as is resident in IMPRINT, is essentially atheoretical with respect to cognition, cognitive modeling approaches typically derive from a specific theoretical basis. ACT-R grew out of research in basic learning and memory and the findings in that research are "built-in" as constraints on the modeling. The development of EPIC drew on work in perception and psychomotor skills; Soar can be considered a product primarily of the artificial intelligence community with its reliance on rule-based productions; and COGNET combines several aspects of psychology and the more applied approach of task analysis. A fundamental concept of HOS was to take "laws" of the basics of human performance and make those available to aggregate into larger descriptions of performance. Fitts' law pertaining to reaction time is a classic example.

As development has continued on individual cognitive modeling approaches, some aspects of that development have drawn from other approaches. For example, ACT-R now includes a perceptual-motor component in ACT-R-PM. Another aspect of development has been to address the software interface, the "ease-of-use" question. Training classes are offered routinely for COGNET, ACT-R, and Soar and changes to their interfaces are being considered to enhance usability. In sum, there are cognitive modeling tools available to the HSI community that can provide significant predictive and explanatory power even though they are not yet turn-key operations.

Decision Modeling Human decision making has been considered within the HSI context most simply by using flow diagrams or operational sequence diagrams to show possible decisions, and, more robustly, by using task network modeling. Within task network modeling, both decision variability and the time to make a decision can be addressed. While both diagrams and network modeling are useful, there are limitations, at least in the current formulations.

One way in which limitations in decision modeling have been addressed is by bringing the outside world in. Links to other simulations have increased the richness of the available decision environment. Specifically, this means that the scenario against which a model runs does not have to be preset within the model. The CART program described earlier was a significant advancement in this regard. The goal orientation capability implemented in CART permits modeling of decision-making strategies as goal switching with the "triggers" for switching goals coming from events in another simulation. A test of the CART methodology in a Joint Strike Fighter testbed reported by Hoagland et al. (2001) showed very good correspondence between the model-in-the-loop decision making with respect to use of controls and displays and that of actual pilots-in-the-loop in the same simulation.

Many of the outcome measures of human performance modeling are predictive of efficiency, that is, the time to perform. One effort (Wojciechowski et al., 2001) recently expanded the effectiveness measures to include quality, where decision quality is determined as a function of information quality, operator factors such as fatigue, experience, training, stressors, and team performance. This framework has been implemented in a field artillery sensor-to-shooter model and has shown great promise as a way to provide a measure of decision quality and the resulting influence on overall system performance over and above the more typical efficiency measures.

Recognition-primed decision making (RPD) (Klein, 1989) has been suggested as a more appropriate way to represent the way humans actually make real-world decisions than criterion weighting, pure memory strength, or adherence to predefined strategies. Recently progress has been made to represent the RPD approach via modeling, such as the effort reported by Warwick et al. (2002) where task network and cognitive modeling capabilities are combined with the promise of increased descriptive and diagnostic power.

Model Integration and Model Federations The recent growth in model integration and the advances in model federations have been motivated by all of the developments just mentioned in this section. Computing advances have made it possible for different models to "talk to each other" and share information more easily. This includes military model communication standardization efforts such as distributed interactive simulation (DIS) and high-level architecture (HLA). The increasing desire, or need, to include accurate and appropriate representations of human cognitive and decision-making behavior in military models and simulations—and the reality of having to do it cost effectively—require assembling models using the best of what is available and reusing models across multiple environments.

One example of model integration is found in Lebiere et al. (2002). In that effort, IMPRINT and ACT-R were integrated in order to capitalize on the strengths of IMPRINT for modeling task sequences with flexible branching logic and the richness of ACT-R for representing the influence of memory limits and competing information on decision making. Craig et al. (2002) report on a CART (or IMPRINT)-ACT-R integration, again building on their individual strengths, although via a slightly different communication protocol. This sort of "hybrid" integration holds great promise.

The appearance of human behavior representation in large-scale military combat models and simulations is not new. The Conference on Computer-Generated Forces and Behavior Representation has been meeting since 1992. However, what is new is the escalating emphasis on a *truly* authoritative representation of psychologically plausible behavior as opposed to, say, simple movement rates. Within the CART program, Hoagland et al. (2001) built a model of a pilot that "flew" and reacted to targets in a jet fighter simulation, a simulation that could also be run as soldier-in-the-loop. This federated, model-in-the-loop configuration was used to evaluate design and tactics options. The U.S. Army's Joint Virtual Battlespace (JVB) federation has funded the integration of Micro Saint–based models of a robot controller and of a field artillery staff for the purpose of helping to evaluate Future Combat Systems (FCS) concepts. In this way, an accessible, standalone human performance modeling environment can take inputs from other models and simulations, which stimulate and affect the human performance model—including cognition, decision making, and the actual goal-oriented behavior of the human model—and in turn, the human performance model can exert an influence on the course of the overall, federated simulation, that is, on the combat outcome.

11.4 COMMERCIAL APPLICATIONS

There is tremendous pressure in commercial industry to reduce the cost of delivering products and services. As with the military, a key factor in product cost is manpower cost. Therefore, competitive advantage can be gained through reducing the numbers of people needed in the process, or through reducing the skills required by the workforce, while maintaining target production levels. The techniques used in industry to attain this reduction often include some version of the four-step process described in Section 11.2.2. Unlike the military, however, the documentation and requirements process does not have a common structure across companies, even within the same industry. While this is not surprising, the sharing of techniques is also thwarted by the need for companies to protect proprietary information for competitive purposes. However, one common element across firms is that the manpower and personnel questions are addressed by a combination of the human resources, facilities planning, and technical staffs.

While the level of analytical power brought to the questions varies widely between companies; in general, a well-structured approach is typically used when a firm is considering a change that could affect staffing. In this process, the first step is to reach a detailed understanding of the system in which the work is being performed. The second step is to identify viable alternatives. The third step is to test those alternatives in a realistic environment. And finally, the selected improvement must be implemented. In this section, we will discuss two examples describing how this process was successfully conducted.

11.4.1 Example 1: Automation and Manpower Trade-offs

Gates Rubber is a large manufacturing corporation that produces rubber products for the automotive industry. Many years ago, they recognized that their production throughput could probably be improved and they began a process of updating their traditional manufacturing facility from a straight-line production process to a cell-based manufacturing process (Harshell and Dahl, 1988). They hoped that this would allow them to maximize the utilization of large pieces of capital equipment, such as cranes and ovens. However, there were many unanswered questions that they wanted to examine before making this dramatic change. First, they needed to understand how much the new process would increase throughput. This would enable them to assess the financial payoffs of the new equipment purchases. Second, as a unionized organization, they needed to understand the manpower and personnel implications in order to fulfill their obligations to their workforce. Finally, they needed to perform detailed analysis that would allow them to balance their production line through the removal of bottlenecks.

To address these questions, Gates Rubber embarked on an analytical process. Because many of their questions needed to be answered in relative terms, as to how much the new process was different from the existing process, the first part of the process was to develop a reliable and accurate baseline of the existing process. As with many manufacturing organizations, Gates Rubber possessed very detailed records of how much time each step in their existing process would take. These records of time were collected using a combination of empirical data collection and motion–time–method (MTM) techniques. Collectively, these data became their labor standards upon which negotiations with union personnel regarding staffing levels were based. Because of these existing data, it was a relatively simple process to benchmark the existing manufacturing production data, providing a reliable basis to which the manpower and personnel implications of the changes could be compared.

This information was used to develop a discrete event simulation model of the baseline process. This type of simulation is commonly used in industry, and most industrial engineers have some knowledge of these simulation techniques. In this case, the simulation model was constructed using Micro Saint, which is based on a task network modeling approach.

To develop the baseline models, a flow diagram was constructed that described the flow of the product through the manufacturing line. This diagram was complicated because the current product mix consisted of 40 different product types, resulting in different flows through the line, depending on the orders that were being processed in a given batch. Figure 11.15 shows a portion of the baseline task network.

Each node in the flow diagram represented a step in the manufacturing process. Associated with each step was performance information, such as the time it took to perform the step, the requirement for resources or manpower, and the potential for rework.

Once the model was fully populated, it was executed against a production schedule. In this way, the same process could be tested against different product mixes, lot sizes, and manning and personnel solutions. As the model ran, an animated depiction of the manufacturing floor could be viewed, as shown in Figure 11.16. This animation allowed the design team to quickly evaluate bottlenecks in the process, manpower problems, and flow rates. Additional output from the baseline model consisted of data files that provided a record of product throughput and manpower utilizations that were used to assess the allocation of workload among the manufacturing staff resulting from the baseline layout.

The next step in the process was to identify viable alternatives that could potentially increase or maintain production throughput while decreasing cost. Ideas were collected using a wide range of techniques, from management-driven initiatives to suggestions from floor production staff. Many alternatives were considered, which ranged from changes in automation levels, to reengineering of the process itself (through a reorganization of the

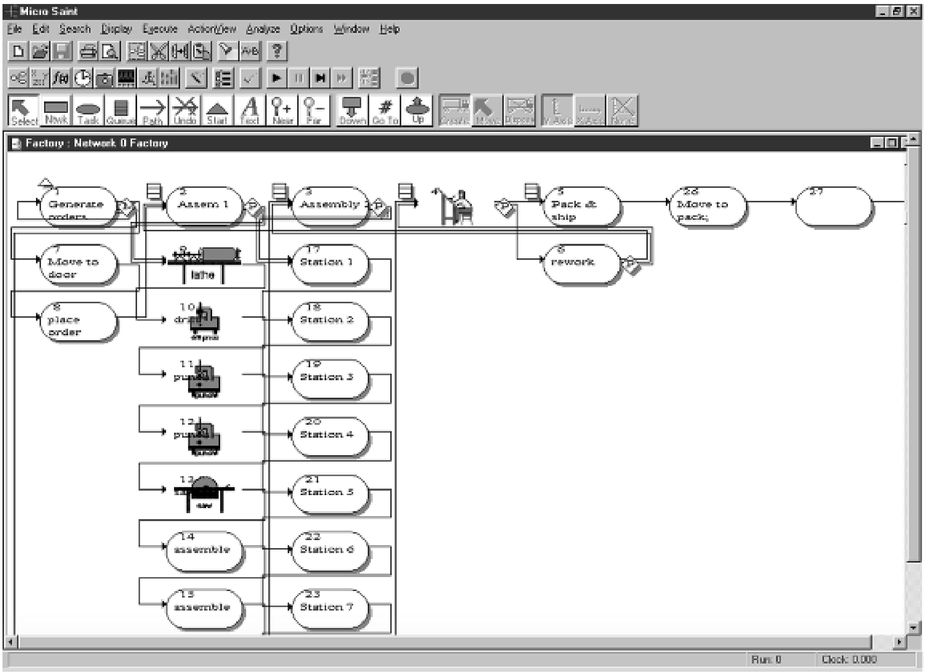


Figure 11.15 Gates Rubber baseline task network.

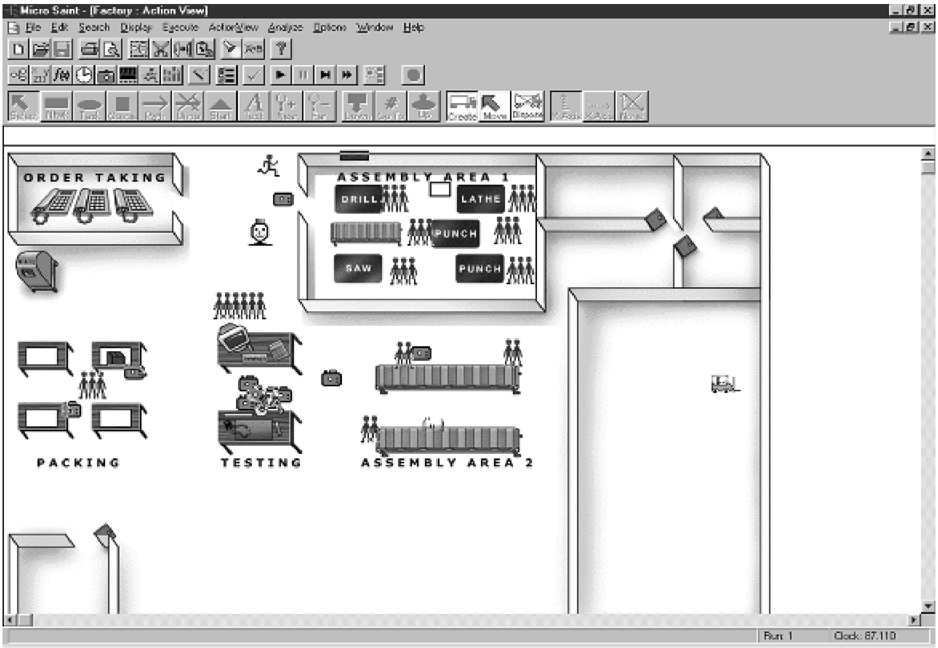


Figure 11.16 Dynamic view of the Gates Rubber manufacturing model.

production stations and adjustment of the work-in-progress levels), to implementing advanced automation that could reduce motor and cognitive workload levels. Each of these alternatives was described in terms of how they would affect the existing process in terms of time, worker involvement in the process, and potential rework levels.

Next, the project team developed simulation models that would compare each of the alternatives to the existing process. The output of the discrete event simulation model provided measures of worker utilization (i.e., how "busy" each worker was throughout the shift), the number of tasks that required highly skilled work, and a prediction of the throughput of the process. Pay rates, fully loaded with overhead and fringe benefit amounts by experience level for each worker, were combined with the cost of each alternative process to generate a prediction of the cost per unit of the product for each alternative. This output provided quantitative, unambiguous comparisons of the effects of trading off manpower and personnel adjustments against materiel solutions, and clarified for the project team the facts associated with making these decisions in a system that is controlled and operated by humans.

One less obvious benefit of the work was that the entire team gained a detailed understanding of the system, illuminating many other areas that could potentially be improved. This project did not attempt to discover the "optimal design" for the cell. Rather, it only identified one of an entire family of solutions that would work. Later studies were conducted of other production line alternatives to support trade-off analysis based on operator utilization balanced against operator costs, training, and skill levels. These studies were also designed so that machines and capacity could be traded against the cost of the equipment, the operator training and installation requirement, and the processing time. Optimization was measured using cost–benefit analyses that balanced labor and facility costs against production rates.

The final step in this process was to implement the chosen change to the production line and to attempt to validate the data predicted by the simulation model. This step was critical in that it would determine whether the use of simulation to evaluate process alternatives was trustworthy and could be used for additional reengineering studies. The validation process was extremely successful, and showed that the predicted measures were within 96 percent of the production levels experienced on the newly redesigned production line.

11.4.2 Example 2: Health Care

To stay competitive in the service industry, it is becoming more and more critical to accurately predict customer need while remaining cost efficient. At the same time, the market demands instant, high-quality service and support. Nowhere is this challenge more apparent than in the health care industry. Health care professions must find ways to become more efficient and effective in order to keep up with varying patient needs.

One of the determining factors for health care facilities is the need to properly plan staffing of new or renovated facilities. Prior to the 1980s the methodology used to assess manning needs was based on a ratio formula involving patient volume and length of stay. During the 1980s, a computerized model using probability theory and the Poisson mathematical formula became a popular method for determining obstetric bed need and associated manpower and personnel (i.e., numbers and types of care providers). Unfortunately, neither of these methods could incorporate the impact of scheduled procedures (inductions and caesarian births) or seasonal variability.

In the early 1990s, discrete event simulation became a popular method for attacking this problem. Since simulation can take into consideration the dynamic variability of patient arrival rates, length of stay, and service times, as well as the individual characteristics of the level of care needed for particular procedures, it would provide needed predictive accuracy and power.

Figure 11.17 shows a diagram of the top level of an obstetric model that has been used by Smith Hager Bajo, a health care consulting firm, to predict resource needs (Hager et al., 1998). Development of this model began with eliciting descriptions of the various scenarios that could impact staffing decisions from knowledgeable experts. These scenarios were used to develop a task network model of the medical process. The network is hierarchically organized, with the rectangles representing networks of tasks. The patient arrival rates are modeled using existing patient scheduling data, and the flow of each patient through the process is determined by stochastically generated patient profiles, representing historical procedure records.

This effort resulted in a simulation model that can be used as an analytical tool through which staffing requirements and the impact of training and skill levels on bed need can be assessed. Figure 11.18 provides sample output taken from a snapshot in time during the execution of a scenario in this model.

The obstetric model has been used by over 50 facilities since it was first developed. The projects have ranged from facility planning for bed need, to staffing analysis, to decision making regarding practice changes. Several users have documented significant savings in remodeling costs dues to the detailed analysis supported by this tool.

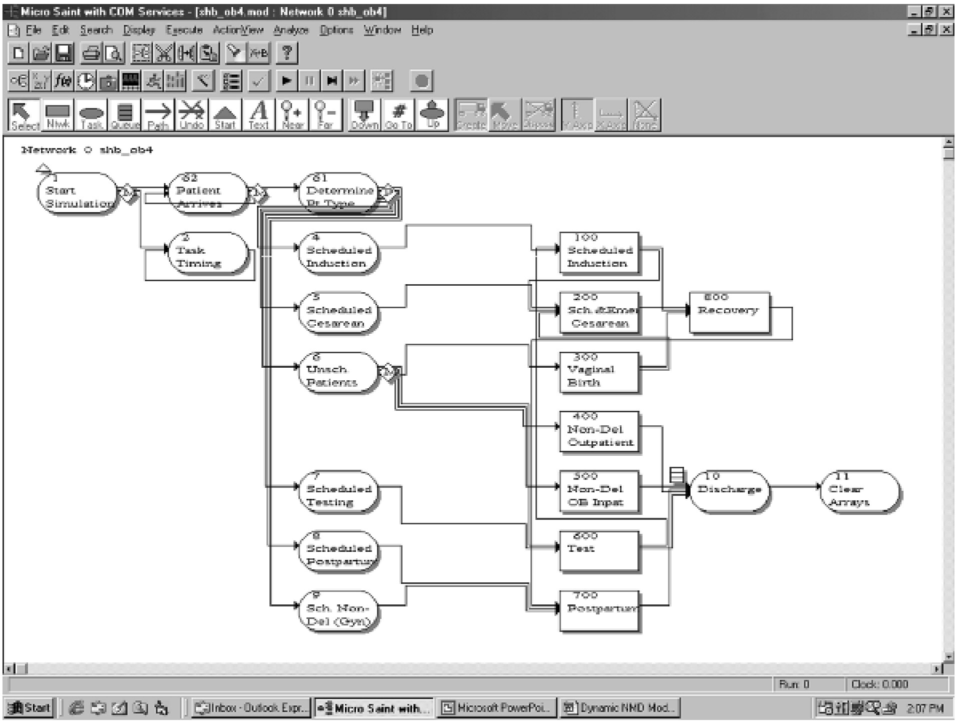
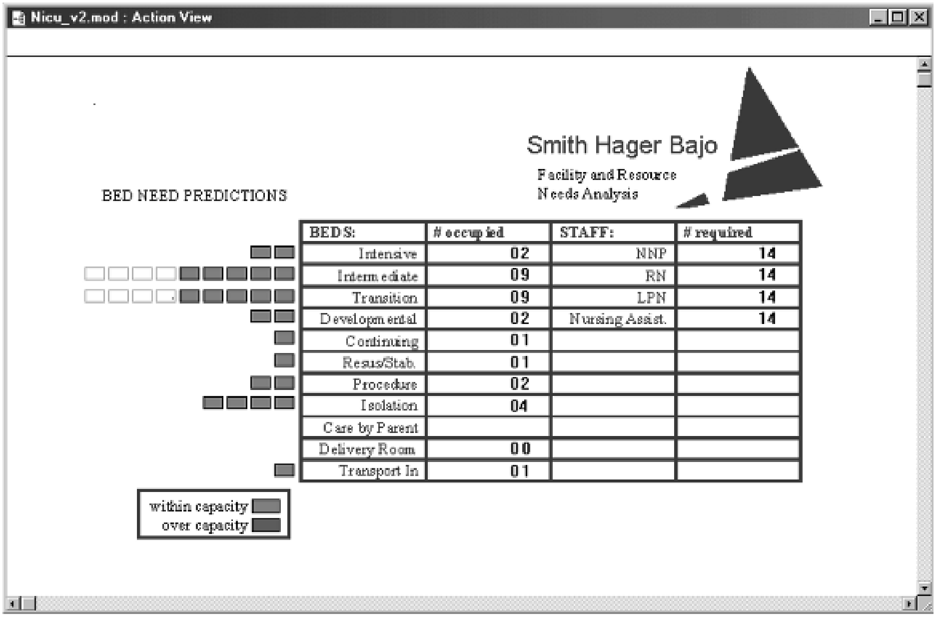


Figure 11.17 Obstetric model.



BEDS:	# occupied	STAFF:	# required
Intensive	02	NNP	14
Intermediate	09	RN	14
Transition	09	LPN	14
Developmental	02	Nursing Assist.	14
Continuing	01		
Resus/Stab.	01		
Procedure	02		
Isolation	04		
Care by Parent			
Delivery Room	00		
Transport In	01		

within capacity
over capacity

Figure 11.18 Sample outputs from the obstetrics analysis simulation tool.

11.4.3 Summary of Commercial Systems

Emerging systems are relying on advanced automation at an unprecedented level. Decision aids and adaptive automation devices are becoming common solutions to the challenge of decreasing personnel costs. However, the insertion of these technologies can dramatically change the character of the tasks assigned to the people in the system. It is necessary that designers influence system design with manpower and personnel considerations in order to ensure the people can operate, maintain, and support the system.

Commercial industry must attack issues very similar to those experienced by the military in which the role of humans within a system can be adjusted, with concomitant analysis of the resulting implications to system efficiency and effectiveness. Commercial organizations appear to have a very detailed grasp of the financial bottom line and use that grasp as the final objective measure of whether a solution should be implemented. Similar projects to the ones discussed in this section have been conducted across a variety of industries including banking, financial management, fleet vehicle maintenance, automotive production, airport and transportation center design, and food service. In each of these examples, similar questions had to be answered that addressed the role of the people in the system and how the roles impacted system performance and return on investment.

11.5 CONCLUSION: CHALLENGES FOR MPT INTEGRATION TECHNOLOGIES

Changes in military and commercial operational environments have contributed to the need to better understand how to take advantage of the increased information available in today's systems. The challenge is to attain this advantage in spite of the limitations in MPT resources and how they affect our capabilities to work with these systems. As designers respond by moving toward distributed, network-centric systems, the research and development (R&D) community must support that move by understanding the human's role in this new environment. Additionally, the R&D community must communicate in ways that designers and system engineers value so that the potential of these technological advances is not wasted.

As a conclusion, we provide a brief survey of some of the most pressing challenges for MPT integration technology development.

Challenge 1: To Better Understand the Role of the Human as a Component of a Robotic System Limitations in manpower and personnel as well as a continuing desire to reduce the exposure of humans to risky environments increase the interest in robotic systems. Because these systems are typically thought of as "unmanned," the implications of human interaction are often overlooked or undervalued. We must develop tools to help robotic system designers understand the payoff of instituting human-centered design processes into the control and maintenance of robotic systems.

Advanced robotic systems are typically endowed with task managers that provide the system with some level of autonomy (Endsley and Kaber, 1999). It is often difficult for the human controller to understand when to intervene in the robot's task and when to let automation take over. The level to which the human trusts the automation and understands the robot's limitations is a critical issue. Yeh and Wickens (2000) are just one team of many researchers who have done work to increase our understanding in this area. Alerting humans to the state of the system, levels of potential error and uncertainty, and possible remediation for automation missteps is a complex issue and must be accommodated by properly designed user interfaces and operator training programs.

It is important that we select robotic technologies, and implement decision-aiding systems (e.g., task managers, intelligent agents) in a thoughtful way, with an eye toward improving total system performance. This is an extensive challenge and engulfs many interesting research questions. Research in the areas of visual perception, multimodal displays, user-adaptive interfaces, and intelligent agents must all be conducted in order to ensure that we are making well-reasoned choices in the design of command and control interfaces for robotic systems.

Challenge 2: Engage in the Design and Development of Effective Collaborative Tools Tools that enhance the ability for distributed teams to collaborate and share a "common operating picture" have great promise. However, anecdotal evidence indicates that these tools have not yet lived up to their promise to reduce workload in times of stress and uncertainty.

Effective collaborative tools rely on vast streams of data and limited bandwidth places practical limits on the application of such tools (Darken et al., 2001). It is necessary that we develop an understanding of the trade-offs between hardware capability and the ability of humans to use information successfully so make wise choices in developing collaborative systems.

Challenge 3: Continue to Explore How People Make Decisions in Realistic, Complex, Stressful Environments Many researchers have made significant progress in developing an understanding of the decision-making process (Klein, 1998; Orasanu and Connolly, 1993; Zsambok, 1997). This understanding has been applied to a variety of operational contexts (Warwick et al., 2002; Peterson et al., 2001) to ensure that the theory makes sense in military environments. The promising results will allow us to design systems that provide a "decision-friendly" environment. This influence spans user interface development, job and task design, and training program development. This work must continue, and further, computational models of human decision making must be developed so that we can predict the decisions a human will make in particular situations. This will enable us to design systems that are error–tolerant.

Challenge 4: Intelligently Control Information Flow Digitization technologies and the increased data flow in everyday life, as well as on the battlefield, have increased the importance of applying visualization technologies in order to help people turn data into knowledge that helps them perform their tasks. Innovative work in this area is being performed (Barnes et al., 2000b) and should be continued.

In a related area, while technologies can be developed to help humans "see" more, problems with limited bandwidth, workload overload, etc. do not always enable them to "notice" more. It is theoretically possible to develop technologies that will augment cognition (Schmorrow et al., 2001). Instead of simply displaying video to a decision maker and allowing the decision maker to identify items on the video that require attention, rule sets and intelligent agents could be developed to "prescreen" the images so that the decision maker's attention is directed toward potential items of interest. Not only will this enhance performance, but it also simplifies many of the tasks associated with the perceptual challenges of a data-rich environment.

Challenge 5: Develop a Quantitative Understanding of the Links Between Training and Performance Some efforts have been made to understand the quantitative links between training and performance (Archer et al., 2002). This area of work is critical if MPT analysts are to make defensible trade-offs between numbers, quantities, and training levels of the humans in the system. As crew sizes decline and tasks become more cognitive in nature, gaps between the skills available to perform tasks that are increasingly complex will create training needs that must be well understood.

Challenge 6: To Continue to Work Toward "Speaking the Same Language" as Other Engineering Disciplines Significant leaps in human performance modeling techniques (Sargent and LaVine, 2000) have provided a way for HSI analysts to participate in large-scale distributed simulation efforts through integrating models of the soldier with models of other system components. The combined simulation places the human model in a realistic context, interacting with changes in the simulated environment, the operating tempo of other computerized components, including enemy forces, and to changes in the state of the system (e.g., sensor outputs, weapon status). The outputs of the composite integrated simulation system are measures of performance and effectiveness that inherently include the variability of the human. These improvements have enabled considerations of human capability to impact system design and have gained credibility for an MPT analyst's ability to provide design information early in the acquisition process.

While these recent advances have been quite successful, much work remains. We must continue to work toward improving the research base so that we can accurately predict the elements (or "first principles") of performance that are instantiated in high-fidelity human performance models. Particularly interesting work is being conducted in developing models of perception and cognition (Lebiere, 2001), and work in this area will improve the credibility of HSI analysts and the applicability of and acceptance for our products.

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