AFTERWORD

I INTRODUCTION

In 1997 Congressman Ike Skelton made an important statement to Congress on MANPRINT (reprinted in the Appendix). He was concerned that the turbulence of government "downsizing" and Department of Defense acquisition reform would eliminate an Army program which had all the features of exactly the kinds of programs that the nation's leaders should encourage—high performance, safety, and cost savings with new weapon systems developments. His statement not only had the effect of preserving the Army program, but also of encouraging the other branches of the military to seek out Human Systems Integration (HSI) benefits for their systems acquisition programs as well. Soon thereafter, as shown by the contributions to the *Handbook of Systems Integration* from both military and non-military sources, we found a growing interest to the degree that might be called a sociotechnical cultural revolution (at least among engineering and business communities) on how we should acquire and implement complex technological systems. This technological cultural revolution, which would focus all decisions concerning the acquisition of new systems on the people who must use them, is spreading not only throughout the military and aerospace industries, but is receiving consideration from other fields and endeavors which rely on complex systems to fulfill their missions.

The *Handbook* chapters present the state of the art for this new systems approach which begins and ends with fully integrating people, technology, and organizations for a common purpose which is almost always to promote the well being of the nation's citizenry whether at work, on the battlefield, in classrooms, or as patients. While one of the principal objectives of using the HSI approach is to increase the financial health of an organization, it seeks ways to accomplish financial goals without sacrificing the human resource upon which the success of the endeavor ultimately depends. According to Paul O'Neill's business philosophy while CEO of ALCOA, when business focuses on the safety, health, and well being of its people, business success will follow.[1] In the long run, this success could far exceed any short term gains an organization might be tempted to acquire at the expense of its people.

In ending his statement, Mr. Skelton posed a challenge to his colleagues that we would like to address here. He concluded:

> The possible applications for ... [HSI] go far beyond the military in our constantly evolving technological-based society... It would seem our medical and educational systems could benefit from a technological development and management process which focuses on the end user. One may wonder what a difference it would make if these systems were made to operate primarily for the doctor and the patient or the teacher and the learner rather than fitting these individuals to the system as an afterthought.

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TABLE 1 Comparison of Critical System Factors on Four Activities

Factors	Military	Health Care	Education	National Security
Users	Soldiers, Operators, Maintainers	Doctors, Nurses, Patients	Teachers, Students, Parents	FBI, CDC, etc. Fire fighters, Police, Civilians
Mission Issues	1. Weapons Systems acquisition 2. Manpower, personnel, training costs 3. Combat readiness	1. Health care quality and resource capacity 2. Health care costs 3. Supply of Health care professionals (manpower) 4. Emergency preparedness	1. Students' educational quality 2. Teachers' quality 3. Education Delivery systems and facilities 4. Education costs	1. Terrorism defense 2. Emergency readiness 3. Security Costs
Technology Complexity	Extremely high	Moderate	Low	High
Organizational Complexity	Extremely high	High	Moderate	Extremely high
Operational Complexity	Extremely high during war; moderate otherwise	Extremely high —Continuously	High	Extremely high

Note: Complexity ratings: Low, Moderate, High, Extremely high

Accordingly, we have picked three activities of high national interest that we believe have the potential to receive major benefits from applying the HSI approach to their systems decisions; particularly in making far better use of their resources than has happened in the past. They are health care, education, and national security. Table 1 provides a broad comparison of these three activities with military systems for five factors: users, mission issues, technological complexity, organizational complexity, and operational complexity. These five factors help provide a framework for evaluating the degree to which HSI benefits found in military systems might transfer to the other activities.

It is quickly seen that all four activities have costs issues associated with accomplishing their missions. One of the promises of HSI is that system performance objectives can be met with projected affordable costs. The problem with the health care and educational activities is that costs can increase exorbitantly while falling behind on meeting performance objectives. National security costs could be potentially unlimited without meeting desired objectives. None of the other activities has the level of technological complexity that the military requires, but all look to technology to assist in meeting their missions in a cost effective manner. For the organizational factor, only national security has the same level of complexity as the military. Military operational complexity is extremely high during war, but most of the time is fairly moderate. Similarly, depending on the level of threat, national security can range from moderately "alert" to extremely heightened states of emergency. The greatest daily operational complexity probably resides in health care because of the requirements to deliver a wide variety of highly specialized therapies for a large spectrum of illnesses under conditions which involve continuous, but unscheduled, patient emergencies. Further, like the military, the health care system must be prepared to deal with casualties of disasters. The operational complexity in education is high, primarily because of conditions placed on the education system by many disparate competing entities without common goals.

II HEALTH CARE

Healthcare is expensive, and national health expenditures in the United States continued to climb (at a rate of 6.9 percent, increased from 5.7 percent in 1999) in the year 2000, amounting to nearly $1.3 trillion and 13.2 percent of the gross domestic product (GDP). They are projected to total $2.8 trillion, grow at an annual rate of 7.3 percent, and reach 17.0 percent of the GDP by 2011.[2] Delivering state of the art medical care today generally requires the simultaneous and ongoing provision of many different, and often very specialized, services (various medical professional evaluations with treatment planning, diagnostic testing, monitoring, delivery of pharmaceuticals and other therapeutic interventions etc.). This necessitates a greater degree of teamwork than might have been necessary in the past (when there were fewer services and therapies to be rendered). Well reasoned, thoughtful application of medical knowledge to clinical conditions is a prerequisite of good care. However, clinical outcomes now, more than ever, depend upon a host of factors beyond good clinical judgment, some of which include the availability of timely, coordinated, safe and reliable services. With few exceptions, the delivery of medical care has become dependent upon a health care 'system' of services to provide our complex and technological standard of medical care.

In the recent, highly publicized Institute of Medicine report "To Err is Human: Building a Safer Health System,"[3] it was estimated that adverse events as a result of active medical errors (errors of commission) occurred among 3–4 percent of hospitalized patients. One in ten of these adverse events resulted in death, and at least half of these errors were thought to be preventable according to current standards of care. It has been estimated that 44 to 98 thousand deaths per year in the United States occur as a result of medical injury, with associated direct health care costs totaling 9–15 billion dollars a year. These estimates do not include care delivered outside of the hospital setting or instances where effective medical care may have been withheld (errors of omission in medical care are likely to represent a much larger issue for the effectiveness of health care delivery). Some have challenged the exact figures presented in the Institute of Medicine report, contending that the adverse event rate is overestimated.[4] Whatever the case, there is an increasing acknowledgement that medical errors do occur; they are often preventable; they are costly; and they significantly threaten the safety and quality of American health care. With the complexity of the healthcare enterprise, a systems approach to evaluating, managing and designing care processes seems logical.

The culmination of technological, organizational, and operational complexity for the health care system is best illustrated by a snap shot of any moment in a hospital environment. The following four exhibits describe a typical hour in the emergency room, the medicine floor, the surgery floor, and the administration office of an urban hospital.[5]

Exhibit 1 – Emergency room (ER) It’s 5 PM on a Friday during flu season. The ER is busy. One of the nurses scheduled to work this shift had injured her back lifting a patient the day before, and a receptionist called out sick. The ER manager was unable to find anyone who could cover this shift for them. The ER triages the people with flu symptoms to an urgent care setting. Today, this unit is overwhelmed. The ER will help to accommodate them when they can. However, the ER is unable to help those with more minor illnesses on this day, because it is full to capacity with a number of critically ill patients to care for.

One patient is a middle-aged executive who is having chest pain, and whose blood pressure suddenly drops. It becomes immediately clear that he is not having a heart attack but is suffering from a ruptured thoracic aortic aneurysm. The operating rooms are busy with other urgent and elective cases; the surgeons and anesthesiologists are all presently occupied.

Another patient is a young woman who suddenly fainted and is in a coma. She had been two blocks from a university hospital, but that hospital was presently so overwhelmed with patients that the ambulance had to be diverted to a community hospital. The patient had to be placed on a respirator, and testing revealed an intracranial bleed. The patient needed a level of neurosurgical care that would best be performed at a university hospital. The ER doctor called two different university hospitals, but neither had beds available in their neurosurgical intensive care units (ICUs), so could not accept the patient in transfer.

In another room is an obese woman who could not communicate or move her right side as a result of a previous stroke. A hired caregiver who brought her in reports the patient complained of abdominal pain. The caregiver could give some limited information about the patient’s past medical history, but was unable to list the patient’s medications or name the patient’s primary physician. In any case, medical offices were closing for the day, and without looking at the patient’s office record, the patient’s own physician, let alone a covering physician, would probably not be able to list the medications either. The caregiver reported that the patient had multiple previous hospitalizations at another local hospital, and received primary care in that hospital’s medical teaching clinic. The caregiver recalled that the patient had been previously hospitalized at this institution as well, however, a medical record could not be located. A medical technician is scrambling to find cables for a cardiac monitor, because another patient presents an irregular pulse and dizziness. Bloodwork is drawn and barcoded labels are placed on the specimen tubes. The labels are jamming in the bar code labeling machine, so another technician is trying to solve this problem. He is able to get them to print now, but the labels are slightly out of alignment, so the complete code is not being printed correctly. He’s still working on this.

There is a patient with a broken bone in another room. No one has been able to keep up with re-stocking the rooms, and the cast material specified by the physician has run out. Someone needs to go to the hospital’s central supply to get more. The police have just brought a disheveled, agitated and unruly patient to the ER for evaluation. He has a history of mental illness, and smells of alcohol. He has not been going to work and is now charged with assaulting his wife. The thoracic surgeons finished a cardiac bypass operation they had been involved with, and rush to the ER to take the man with the aneurysm to the operating room. The husband of the young woman with the intracranial bleed has also rushed to the ER. He is shocked and bewildered to see his wife on a ventilator. A nurse hurries to provide him with information and comfort. The ER doctor has done a physical exam, which required the help of two nurses to move and position the obese, stroke disabled woman with the abdominal pain. While the doctor documents the exam in the chart and is ordering studies, a nurse, with the help of a medical technician to hold the patient in position, is placing a urinary catheter with sterile preparation and draping to assess for bladder obstruction. Another nurse is preparing to draw blood from the patient’s arm. A respiratory therapist is administering nebulized treatments, begun in triage, to a patient with asthma in another room. The registrar is waiting outside this patient’s room to get the necessary information to register the patient, and create a chart. The doctor has already seen this patient, but will wait to document his findings once the chart is created.

A patient in another room presented with an upper gastro-intestinal (GI) bleed that seems to have stabilized, and is ready to be transferred to the medical intensive care unit (ICU). The ER unit clerk has been paging the ICU doctor who is listed as being on-call. There has been no answer. The patient will remain in the ER until an ICU bed can be made ready. The patient looks comfortable, is surrounded by family members, and is receiving a blood transfusion. His daughter is ringing the bell for his nurse, because he wants something to eat. In the medical laboratory, a laboratory technician is trying to scan the barcode label on a tube of blood. He complains that the way it was placed won't allow scanning because of the rounded surface of the tube. He enters the patient's information into his computer to create a new label and proceeds to peel off the previous label. If he has more than one label on the tube it won't fit into the centrifuge, which is a required step in the processing of specimens. He looses his grip on the tube. It falls to the floor and breaks open, with blood splattering on his clothes and elsewhere. It is 6 PM. The ER waiting room is still full. The unit clerk announces to everyone in the ER that the computer system used for patient registration, test requisition, test results reporting, and billing has just gone down. The ICU physician who is on-call pays a spontaneous visit to the ER to see if anyone needs help. This physician is not who was listed as on-call for this night. The unit clerk says hello, and takes a pen to correct the on-call list that had been faxed by the department of medicine.

Exhibit 2 – Medicine floor. Up on the medicine floor, a patient seems to be choking. A doctor is summoned, who inspects the airway and asks the nurse for a suction kit that can be hooked up to the wall suction unit. The nurse runs to the supply room, but says she doesn't regularly work at this hospital since she's an agency nurse, and can't find it. The unit clerk pages other nurses for help. Another nurse says that the suction units are no longer stocked on the floors and have to be ordered from the hospital's central supply. The doctor is getting angry and asks the nurse why such a decision had been made. She expresses similar frustration and says that the nurses had fought this decision when made two months ago by a hospital administrator. They decide that they have to break into a code blue cart, which is a locked cart of supplies for emergencies. It apparently costs hundreds of dollars to break into a code cart, but what else is there to do right now? Just then, another nurse comes running with an unused suction kit that she has taken from another patient's room. They suction oral secretions from the choking patient, who recovers. Everyone says they ought to write out an incident report, and they vow to, but right now they have too many other things to do.

A physician receives a call from a nurse to report that a diabetic patient had a dangerously low blood sugar measurement. She reports that the patient was given orange juice mixed with sugar to drink. The blood sugar was measured using a battery operated glucose meter. The physician asks what physical manifestations of the low blood sugar the patient showed. The nurse replies that the patient had no physical symptoms whatsoever, and was alert and oriented throughout. The physician suspects that the metered measurement was incorrect because the clinical status of the patient did not support a diagnosis of low blood sugar. A repeat blood sugar measurement is requested in one hour. The physician is called in one hour with a report that the blood sugar is now too high.

Exhibit 3. Surgery floor. On the surgery floor, a patient who came in for an elective hip surgery was being readied for discharge to home. The patient was an elderly woman with a number of chronic conditions for which she took a number of medications. One of her usual medications, for high blood pressure, was not specifically available in the hospital pharmacy. Another medication with similar pharmacologic properties had been substituted during her hospitalization so that she could continue to receive uninterrupted treatment for her hypertension. The surgery resident wrote discharge instructions as well as prescriptions for all the medications she had received from the hospital formulary. The patient assumed that the

substitution blood pressure medication was something new she had to take, since she was not familiar with its name. She had that prescription filled at the hospital outpatient pharmacy on her way out (instead of her usual pharmacy), and began to take the 'new' medication in addition to her usual regimen of medicines at home. Two days later she presented, as an outpatient, to her primary physician complaining of lightheadedness and fatigue. Her pulse and blood pressure were abnormally low. Fortunately, she had brought all her medication bottles with her for the appointment, making it a simple matter to determine that she was suffering from an overdose of antihypertensive medication.

Exhibit 4. Administration office. The hospital administrators are meeting to discuss strategic planning for the upcoming fiscal year. A few years ago, with excess hospital bed capacity, they had focused on attracting primary care doctors to the hospital community in an effort to boost hospital patient volumes. There weren't many gains in primary care doctors, yet, today, they find themselves dealing with hospital overcrowding. To make matters worse, most of the increases in hospital admissions have been medical admissions, which aren't reimbursed by payers (both private and public) as highly as surgical procedures are. The revenue stream has increased, but is becoming dominated by less profitable business. To make matters worse, this trend of increasing medical admissions is hampering the hospital's ability to accommodate the more profitable surgical business. With the hospital beds being filled with sick medical patients (for diagnoses like: pneumonia, congestive heart failure, emphysema etc.) there were fewer beds available to schedule patients for elective procedures (for example: joint replacement surgery, elective hysterectomy or gallbladder removal, cosmetic surgery etc.), which were increasingly being delayed, and sometimes cancelled. A few of the staff specialty surgeons have abandoned the hospital for free standing surgical centers. The administrators are not talking about expanding the number of beds at this hospital, because the beds are already there. A whole floor was shut down during the last decade because of previous downsizing. Even if they wanted to open this floor back up, they can't because, despite massive recruitment efforts, there aren't enough nurses available to staff them.

HSI Applied to Health Care

How can HSI help improve the health care system? There are a number of areas with common ground between the military HSI advances and applications to health care. For example consider costs containment, human and systems performance analysis and testing for delivery of complex services, patient safety, technological procurement and deployment strategies, dealing with manpower shortages, and achieving common organizational objectives.

When we look at Table 1, we see a different set of users from what HSI has focused in the military, but the idea of focusing on the user is still the driving concept. Doctors and nurses are skilled professionals whereas patients represent the diverse population of our society. The techniques for describing characteristics of the human, for conducting task analyses of work environments, and human-technology interfaces are covered throughout the *Handbook* in a number of chapters and need not be restricted to military personnel. Methods for analyzing costs of HSI applications and seeing their benefits in terms of safety and system performance are provided in Chapters 17 and 18. Federal Government personnel and manufacturers concerned with improving medical devices might read Chapters 7, 13, and 24 to better understand the processes for procuring products with a user focus.

TABLE 2 Health Care Priorities

HOSPITALS

Management and Organization:

1. Studies to determine most cost effective way for hospital network to a) meet increasing demands for patient services, b) reduce operations costs, c) improve medical outcomes, and d) increase delivery service effectiveness
2. Risk analyses to predict sources and effects of human and system error on patient care outcomes.
3. Development of data bases, data collection standards, and data evaluation processes for reliable health care delivery information used in decision making.

Operational Processes:

1. Mapping of current hospital processes and identification of resources to provide patient health care.
2. Identification of major impediments in current processes
3. Identify key areas to improve or redesign current processes
4. Provide user oriented measures of effectiveness for processes.

Product Design:

1. Technology requirements for hospital procedures and processes
2. Standards for medical devices development and usage.

FEDERAL GOVERNMENT

Management and Organization:

1. Laws, policies, and procedures that focus on safe, affordable, and effective health care practices and technology
2. National risk pool data to reflect projected costs of care; including analysis of demographics and access issues

Operational Processes:

1. Comprehensive human factors study of medical workplace and health care delivery system

Product Design:

1. Human factors criteria for safe and effective medical devices design and operation
2. Government sponsored medical research that focuses on design and development of new human factors technology; e.g., noninvasive surgery
3. Research and development of job performance aids for health care providers

MEDICAL DEVICE MANUFACTURERS

Product Design:

1. Develop and implement user centered design procedures
2. Integrate contributions from multiple skilled disciplines in human sciences and technology.
3. Apply human systems integration tools in the design and development of products.
4. Test and evaluate human performance, safety, and usability of products.

One of the greatest problems facing the health care system is the large number of disparate organizations that can be considered stakeholders in health care delivery. Hospitals, the federal government, health maintenance organizations, insurance companies, state governments, medical device manufactures, and universities/medical schools, the pharmaceutical industry, employers and patients are all part of the health care system. All of these organizations interact in ways to create the daily operational complexity in health care delivery. For leaders of health care organizations, the philosophy, cultural change requirements, and benefits of HSI are described in Chapters 1, 2, 3, 18, and 23. To better appreciate the HSI process for handling complex systems design, Chapters 4, and 6-10 are recommended reading. Two concepts are critical for success; these being 1) defining requirements for user involvement in all early decisions and 2) testing any ideas to be assured of their true value in the work environment.

For studies to determine tradeoffs among personnel, training and human factors design and systems performance see the methods described in Chapters 11, 12, and 13. For quantitative definition of users and their task environments see Chapters 19 and 20. For safety and health factors and methods, see Chapters 14 and 15.

It is realized that solutions to the health care crisis will need to create systems involving all the stakeholders, but to begin to help the doctors, nurses, and patients in a hospital environment we have reviewed three areas, the federal government, the hospital, and medical device manufacturers for priorities. Table 2 lists some of the highest priorities we would suggest for health care system improvement based on the HSI approach.

III EDUCATION

In FY 1996 our States and territories spent collectively over 255 billion dollars on elementary and secondary education. In FY 2000 that figure had grown to over 300 billion dollars (an increase of nearly 20 percent).[6] The Federal government, through the Department of Education, contributed another 40 billion in FY 2000 (which was a 33 percent increase over its FY 90 expenditures in constant dollars).[7] Yet in FY 2000 about 37 percent of fourth graders continued to read below a basic achievement level on the National Assessment of Educational Progress (NAEP) standardized test; a trend that has remained stable throughout the past decade.[8] Since the ability to read is such a critical skill that underlies most all of academic endeavors and our everyday life skills as well (from reading tax forms and insurance policies to instructions for operation of household items and even safe cooking) why do we seem unable to do better? Funding is always a consideration but the above statistics show that even with substantial increases in funding, success continues to elude the educational system.

The following two exhibits help illustrate the intricacies of the problem and why simply spending more money has not resulted in long lasting solutions for education.

Exhibit 5. First grade classroom. Mrs. Foster has thirty five children in her first grade class. This is her first day and their first day. They will begin to learn to read using simple familiar words and repetitive sounds that will enable them to “see” and “hear” the effects of different letters of the alphabet. Hence a sequence of letters C A T may be written or shown in a graphic display followed by the pronunciation. This sequence of letters may be followed by the sequence H A T and B A T. It will be an explicit assumption and expectation that the children have already learned to recognize the individual letters of the alphabet. Simple enough and straightforward it would seem. Still Mrs. Foster feels apprehensive.

Soon she discovers that many do not already know their ABCs. Also there is one child who seems to have a hearing impairment and yet another who has trouble “seeing” the letter sequence correctly. Even several of those who have the ability to see and say aloud “A B C “ when presented with the spelling and pronunciation of “CAT” appear puzzled on this first day of school. “C” simply does not sound like “CAT”. The problem becomes worse when she attempts to show and pronounce the word “S E E” since five of the children recently immigrated to this country and are more familiar with the Spanish “S I” looking and meaning something different. Some of the children are having trouble staying awake and two of the boys already appear likely to be disciplinary problems.

The school has just acquired new computers for the teacher and children to use in helping them learn to read, but there are no instructions provided with the computers. Mrs. Foster knows very little about computers and is especially unfamiliar with anything other than the reading programs, yet she is expected to use them to help with math and geography as well. The computers will sit unused for the next several months.

Several special sessions (during lunch and after the children go home) are called by the school principal to discuss administrative matters. At these Mrs. Foster learns she is to keep records on the students, noting their progress and shortcomings. She must also provide her own logistics support including identifying and acquiring supplies, equipment, and other resources. There will also be additional duties assigned as the year progresses.

In the afternoon, Mrs. Foster assesses her class for potential in developing writing skills. Quickly she becomes aware that Paulo and Mary are having a difficult time printing and she can sense their embarrassment. When she goes home that evening, although tired and a bit discouraged, she resolves to work harder tomorrow to keep up with the goals she has set for herself.

Exhibit 6. Efforts to improve the education system. Many efforts have been made to improve and reform our education "system" and new methods continue to be studied. One such major longitudinal study is reported by Berends et al.[9] in which the RAND Corporation gathered data on the project of the New American Schools (NAS), launched in 1991, which was designed to address whole-school reform. Approximately 185 schools partnered with special design teams in 14 separate districts throughout the nation. By 1995 over 500 schools had entered the project. The project initially consisted of theory-based new learning designs with no external intervention.

The RAND study investigators quickly discovered that external support for implementation of the designs would be required if the designs were to be implemented at all. Schools could not simply be "given" the programs without some guidance, help, and impetus to move forward. One of RAND'S major observations is that the learning designs were in a continuous process of adaptation often to the detriment of a major premise of the project, that of unification. Secondly, it was observed that barriers to achieving high degrees of implementation arose related to poverty, achievement, and school and district climate. School "capacity" to absorb the new learning designs proved to be an important factor. "Principal leadership (communicating expectations to the staff, securing critical resources for the school, talking with teachers about instruction) proved to be an important contributor across all studies." There was an indication that teachers bore a significant cost of the design reforms, particularly when other reforms were being attempted simultaneously. While student gains in mathematics and reading were observed in approximately 50 percent of the participating schools the findings suggested "that weak implementation will lead to weak impacts on student performance."

HSI Applied to Education

What do we know about HSI that can be applied to the problems faced by Mrs. Foster and her students? What kinds of help from an HSI perspective might a new look at education provide in the future and what are some of the major considerations that need to be taken into account with such a new look?

Broadly the principles of HSI can be employed to improve the educational system by:

- Developing educational programs, organizations, facilities, materials, and technology that are people focused as opposed to school or district focused.

- Placing emphasis on measurement, access, and utility of performance data.
- Developing educational strategies, models, and tools that are adaptable to local and individual needs.

HSI principles begin with a focus on the person rather than the institution or the technology. Table 1 shows these people to be primarily teachers and students. As with the health care system users, the *Handbook* techniques for describing the user characteristics, conducting task analyses, and defining human-technology interfaces can be useful for the education system users. Federal, regional, and local educators may read Chapters 7, 13, 22, and 24 to better understand the processes for procuring educational products with the user in mind. Methods for analyzing costs of HSI applications and seeing their benefits in quantitative versus subjective terms can be found in Chapters 17, 18, and 22.

Also as with the health care system, there are a large number of disparate organizations, including the Federal government, state and local school systems and boards, and parent teacher organizations that influence how any particular classroom will be utilized. From an HSI point of view all such organizations need a consistent and rational basis for deciding on how to design, staff, and operate a classroom. This means that suggestions and programs that affect the school organization and physical plant as well as educational methods and materials should be made focused first and foremost on the student, teacher, and parent. Decision makers for educational institutions may be stimulated from reading Chapters 1,2,3, 18 and 22 to consider the value of seeking a cultural change in education based on a user centered systems approach.

Next HSI urges the development and adoption of overall models and strategies that include the educational needs of the target audience; in this case it would be all the K-12 student population. To address this problem, a systematic approach will be required that can assess the traditional model of education and perhaps suggest alternative models of K-12 education to determine possible solutions at the national level. Successful programs such as Headstart indicate that a truly comprehensive model would apply even before students enter kindergarten.

No one "new" method or program (especially at the national level) will be able to address the complexities of providing adequate education for all. It is safe to say that schools, teachers, parents and students will need tools tailored to address unique regional and local requirements. These will need to be tested to assure they actually achieve the performance expected. Chapters 4, 6–8, and 22 describe the central two concepts (user requirements based on user involvement in early decision making and testing educational methods in the classroom) that are critical for success.

Perhaps the greatest contribution in the near term from an HSI approach would be in aiding educators to make better decisions about technology as an aid to learning. Many schools have embraced technology as a means of enhancing student education. Such programs can be very costly however, and few are adequate in helping all students learn. At best most have experienced varying degrees of success. In some cases, the programs may actually inhibit learning.

Developing and applying the right technology is important, however. (The chapters to read for more information on the process of developing technology from an HSI perspective are 12, 13, and 22.) For example, an "early up front needs analysis" can provide valuable insights and possible solutions, many of which may require application of technology. Design requirements for continuous, flexible, adaptation to student's immediate and changing needs may be imposed on any technology based solutions. Tools for assessment, collaboration and support can likewise be built into future solutions. Integration of schoolhouse, external environments and home, through distributed techniques made possible by technology can present continuous and expert support to all students.

Crawl/walk/run learning paradigms can be developed for individual students guided by continuous diagnostics. Individualized presentation of instruction based on sensory preferences and strengths or weaknesses can adapt to meet and support each student's learning style. Tools that permit collaboration of any two or all three of these groups with each other and with other peers can be very valuable in providing tailored, adapted learning and learning support activities for the student. A few recommended classroom educational tools are listed in Table 3.

TABLE 3 Classroom Educational Tools

Tools for teachers and students

- Tools of assessment evaluation and feedback for both teacher and students. (Diagnostics)
- Automated Management Systems (Record Keeping, Planning)

Tools for students

- Programs that can adjust using artificial intelligence (AI) to students' sensory preferences and strengths
- Computer software that employs voice recognition, speech synthesis software converting text to speech.
- Combination visual and audio programs with diminished cues capability that allow both machine and student to "show and tell."

IV NATIONAL SECURITY

After September 11, 2001 it is no longer possible in the U.S. to go about our daily activities with the same confidence we may have had before that date. Our national security from terrorist attacks is threatened in nearly every aspect of our society. Our transportation systems, communications, infrastructure, energy systems, air, water, centers of business and entertainment, even our homes are vulnerable – none is immune from the threat of terrorism.

The government of the United States has responded to the terrorist events of 2001 by heightening security across a broad array of industries (e.g., nuclear, aviation) and national assets, and has formed a new federal Department of Homeland Security. A 2002 report sponsored by the Brookings Institute[10] provides a four-point plan for enhancing national security against terrorist events that focuses on (1) perimeter defense at the border to prevent infiltration by terrorist and/or potential terrorist weaponry, (2) detection of internal threats and the securing of potential terrorist weaponry, (3) identification and defense of key sites within the country, and (4) providing those involved in responding to an attack that may nevertheless occur with the tools to effectively respond to and contain it. The proposed federal cost for the added security is around $45 billion annually compared to less than $20 billion in 2001.[11] State, local and private sectors would need to bear higher costs for homeland security as well. One of the most fundamental challenges will be structuring the federal government in ways that will make the responsible agencies capable of addressing national security threats efficiently and effectively.

The following two exhibits provide examples of the cross-organizational difficulties facing those responsible for preventing, preparing for, and reacting to terrorist acts.

Exhibit 7. Bioterrorism events. O'Toole provides a stark illustration of the extreme demands that would be placed on public health, safety, and defense resources in the event of a bioterrorist attack specifically, one in which the smallpox virus is used as the primary "weapon."[12] According to O'Toole's scenario, the smallpox virus is released by a terrorist group at a public ceremony attended by the vice-president in a major northeastern city. Although FBI informants later report there were rumors that "something happened" during this event, there is no awareness within the government of the smallpox release. Within two weeks, a small number of patients begin to present themselves at emergency rooms with signs and symptoms such as fever, backache, headache, chills, vomiting and influenza-like symptoms. For the most part, these patients are instructed to return home, rest in bed, take ibuprofen, and drink plenty of fluids.

Within several more days, these signs and symptoms begin to worsen. Of particular note is the appearance of vesicular rashes that are initially interpreted as indicating the presence of chickenpox. Further testing, based on recommendations from an infectious disease specialist, reveals the presence of the smallpox virus, and approximately two weeks after the initial release of the virus a contagious disease emergency is declared. At this point, a complex chain of events is set in motion involving the FBI, local police, the Centers for Disease Control, and local hospital administrators and healthcare personnel. Within hours of the emergency declaration, the issue has risen to the level of the National Security Council and White House, and has begun to attract the attention of local and national media.

O'Toole's detailed scenario goes on to illustrate the serious organizational challenges that arise as the nation attempts to respond to the crisis. The logistical problems involved in distributing limited supplies of smallpox vaccine to those most in need, identifying, locating, and isolating infected individuals, managing the flow of information to maintain public order in the face of rising public fear, concern, and civil unrest, and coordinating overall command and control activities at the national and local level are all highlighted in stark terms. Written to "stimulate review of institutional capacities for rapid communication and coordinated action in the wake of attack."[13]

Perceived shortcomings in the nature of the command and control structure needed to respond to a significant bioterrorist attack have been the topic of several recent articles.[14] Rosen et al. argue that current federal emergency response plans are well-suited to respond to "limited" disasters, but ill-suited to respond effectively to "unlimited" disasters.[15] The latter are defined as a disaster that spreads relatively spontaneously and indefinitely, last for periods of weeks to months. Rosen et al. cite a communicable bioweapon such as smallpox, plague, or influenza as an example of a man-made, unlimited disaster.

To illustrate their point, Rosen et al. cite results of two major exercises that simulated the release of bioweapons in the United States.[16] The first exercise, referred to as TOPOFF,[17] simulated the release of plague in the Denver area, and resulted in the collapse of the Colorado public health system after six days. The second exercise referenced by Rosen et al was the "Dark Winter" simulation, which included a scenario in which smallpox was released in Oklahoma.[18] The Dark Winter exercise resulted in the following major findings: (1) a bioterrorist attack on the United States would clearly threaten vital nation security interests, (2) current organizational structures and capabilities are not well suited for managing the results of such an attack, (3) there is no surge capability in the US healthcare and public health systems that could manage the results of such an attack, (4) managing the media response to a biowarfare attack would be a major challenge at all levels of government, and (5) containing the spread of disease will present significant ethical, political, cultural, operational, and legal challenges.[19]

Exhibit 8. Fire and police communications on 9/11/01. The events of September 11, 2001, revealed some clear deficiencies in the functional integration of the nation's sociotechnical defense assets. For instance, a long history of cultural distrust and animosity between the New York City Police and Fire Departments contributed directly to the occurrence of needless deaths and impeded effective performance of rescue operations. After the south tower of the World Trade Center had collapsed, police helicopters hovered in the air above the area of the remaining north tower. To the pilots and observers on board these aircraft, the imminent collapse of the north tower was apparent, and an immediate evacuation of all personnel was ordered.

"Those clear warnings, captured on police radio tapes, were transmitted 21 minutes before the building fell, and officials say they were relayed to police officers, most of whom managed to escape. Yet most firefighters never heard those warnings, or earlier orders to get out. Their radio system failed frequently that morning. Even if the radio network had been reliable, it was not linked to the police system. And the police and fire commanders guiding the rescue efforts did not talk to one another during the crisis. Cut off from critical information, at least 121 firefighters, most in striking distance of safety, died when the north tower fell."[20]

HSI Applied to National Security

A fundamental assumption of an HSI approach to national security preparedness is that an effective response to a large-scale terrorist event in the future will of necessity involve smooth, functional coordination between a number of different government and private sector entities. The success or failure of this response will largely be a function of the degree to which organizational and technical assets are designed (or redesigned) to effectively transmit the right information to the right people in support of the right response at the right time.

The observation of heroic human effort thwarted by the presence of technical and organizational shortcomings is an old story. Seldom, however, has it been as dramatically illustrated as it was on September 11, 2001. A very important point illustrated by this view of the events of 9–11 is that individual organizations can have all the well engineered, highly usable systems they want (though typically they do not) but if the demands of the situation call for effective interaction between organizations in terms of their personnel and their technology, then the technical assets of one specific group, no matter how well-designed, will almost certainly not be sufficient to overcome the more serious shortcomings of poor inter-organizational operability. Unfortunately (1) individual organizations all too often have technical systems that fail to effectively support human performance under emergency, high stress situations, even within their own limited domains (2) these systems are not interoperable with those of other organizations with whom they must cooperate in order to generate an effective response to an emergency and/or high stress event, and (3) the organizations themselves are often loathe to cooperate with one another due to cultural animosities.

If we might focus on a particular type of terrorist event, such as bioterrorism, it will be easier to illustrate the applicability of the HSI approach to national security. For example, an HSI approach to bioterrorism preparedness would focus first and foremost on the identification of current shortcomings (of the type listed above) in the nation's ability to respond to a bioterrorist event. These shortcomings are, in many respects, very similar to those that prevent the optimal operation of complex, multidisciplinary sociotechnical systems such as those in the military. (Because of this the *Handbook* in general appears directly relevant to the design of National Security systems. Also a special chapter on Personnel Survivability is included; it has little application to the other two activities reviewed here, but the threats and methods discussed in Chapter 16 bear directly on designing systems which most operate in response to such hostile events as might occur from bioterrorism.) Table 4 lists some of the most pressing priorities we believe need to be considered for bioterrorism preparedness and for which the HSI approach provides a realistic method to help assure the nation is prepared for such events.

TABLE 4 HSI Priorities for Bioterrorism Events

- Clear identification of the human-system performance requirements needed to successfully address a broad array of bioterrorist events. An analysis of this sort would be intended to illuminate key deficiencies, such as those described by O'Toole (1999) and Rosen et al (2002), in the nation's bioterrorism response capability, and to identify those that can be addressed by means of HSI principles and techniques.
- Identification of deficiencies in manpower capabilities, and formulation of a plan to provide "surge" capacity to the public health system in the event of a bioterrorist attack.
- Identification of human-machine/computer system deficiencies, including issues related to the interoperability of such systems across the diverse agencies that would be called upon to cooperate in response to a bioterrorist attack.
- Identification of deficiencies, bottlenecks, and other problems related to cultural issues occurring at the interface of difference agencies whose coordinated efforts will be required to achieve a successful response.
- Identification of training issues and development of a plan to train individuals and agencies in the necessary, coordinated activities.

Clearly there are other issues, those related to other HSI concerns and those of a more purely medical nature, which must be addressed to devise a successful bioterrorism response capability. HSI is not a panacea, and cannot successfully address all the problems that need to be resolved. However, an HSI approach to bioterrorism preparedness would provide an appropriate, coherent framework within which to pursue such a program in light of its overarching emphasis on human-systems performance objectives, and its emphasis on breaking down cultural and functional barriers that exist that between those organizations whose effective cooperation will be required.

IV SUMMARY AND CONCLUSIONS

If we examine HSI for its most distinctive features we can summarize them as follows:

1. HSI introduces organizational cultural change from one that makes people fit systems to one that makes systems fit people.
2. HSI introduces a safety culture for anticipating, preventing, and minimizing effects of system error.
3. HSI conducts risk and cost/benefit analyses to compare systems integration approaches with varying degrees of human performance considerations.

4. HSI provides ways to measure effectiveness of operational performance that includes human performance.
5. HSI provides the skills and tools needed to design systems that are user-oriented.

As we further examine the advances made with the HSI approach described in this *Handbook* and consider the three areas above of pressing national and international interest and urgency, we would like to leave the reader five thoughts on:

- Target Audiences
- Technology Needs
- Decision-maker Needs
- HSI Processes
- HSI resources

Target Audiences. The HSI target audiences for military and commercial systems are primarily operators and maintainers. The common aspect of the military audience with that of the health, education, and security systems is that all are professionals who work with our technical systems. For these individuals, there is almost a direct transfer of HSI knowledge to doctors, nurses, teachers, police, and fire fighters who also are professionals and must work with the systems of their trade. What is primarily different from the HSI audiences studied in the past and those of the three future arenas are the non-professional target audiences–patients, students, and every-day civilians going about their business where our technological systems are imposed upon them for better or worse. It is with these latter audiences, the ultimate reason for health, education, and security systems that the greatest needs exist for furthering HSI knowledge.

Technology Needs. Advances in technology will continue to be one of the primary forces driving our sociotechnical culture into the future. The HSI approach simply provides processes and methods to help assure technology is selected, designed and implemented in such a way that it makes the most of what the decision-makers, designers and implementers intend. When people are the central focus of technology design and usage, system performance can be enhanced, systems can be used more safely, and overall system resources can be conserved.

Decision-maker Needs. In all the activities considered by the *Handbook* contributors, the keys to system improvements are in the hands of decision-makers leaders who can decide to apply the processes and methods of HSI. To the degree leaders of organizations decide to implement some of the concepts outlined in the *Handbook*, many of the benefits promised by the HSI approach can become reality for their organizations. The two most important decisions for all the activities discussed are 1) defining requirements for new systems in terms of the human user and 2) testing the usefulness of the systems in performance terms. Decision makers need to be aware, however, of the HSI approach and its benefits and methods presented in terms that can be understood economically. Providing the economic case for HSI tailored to decision-maker criteria is the greatest challenge for the systems engineering and human systems integration communities.

HSI Processes and Methods. When decision-makers understand HSI concepts and see the benefits applicable to their activities, they will need something specific to apply. This *Handbook* presents the state of the art for HSI processes and methods and as such is recommended as the primary guidance document for this purpose.

HSI Resources. The quality of HSI implementation is dependant upon the availability and utilization of HSI professionals. As with the *Handbook* for processes and methods, the contributors are good sources for additional information on locating qualified HSI professionals. Additionally the Human Factors and Ergonomics Society with over 5000 members is a good source for identifying individuals skilled in various aspects of HSI. The U.S. has over 60 academic institutions for human factors and ergonomics. As the number of systems engineering and operations research institutions who teach human systems integration increase, the availability of HSI professionals will also increase. There are currently sufficient HSI resources to meet current demands. The challenge will be to meet increases in demand as more decision-makers join the HSI sociotechnical cultural revolution.

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NOTES

1. Paul O'Neill was key note speaker at the forum, "Developing a National Policy Agenda for Improving Patient Safety" convened by American Hospital Association, Joint Commission on Accreditation of Healthcare Organizations, and the National Patient Safety Foundation, held at National Press Club, Washington, DC July 15, 1999.
2. Source: Centers for Medicare and Medicaid Services, formerly the Health Care Finance Administration http://cms.hhs.gov/statistics/nhe/projections-2001/highlights.asp.)
3. Kohn, L., Corrigan, J., and Donaldson, M. (Eds.) (2000). *To Err is Human: Building a Safer Health System*, Washington DC: National Academy Press.
4. See for example, Sox Jr. H. and Woloshin S., (Nov-Dec 2000) "How many deaths are due to medical error? Getting the number right," Eff Clin Pract 3(6):277-83; Hayward, R. and Hofer, T. (Jul 25, 2001). "Estimating hospital deaths due to medical errors: preventability is in the eye of the reviewer," JAMA 286(4):415-20.
5. Hospital examples drawn from professional experiences and observations made by C. Booher, M.D. during a study, "Patient Centered Systems Analysis in a Hospital Setting" for the Food and Drug Administration; Center for Devices and Radiological Health Order No. FDA 269689-00-99-GH02. Final Report July 7, 2000.
6. Source: Website; US Department of Education, National Center for Educational Statistics (NCES); original source: US Department of Education, National Center for Education Statistics, Common Core of Data, "Early Estimates of Public Elementary/Secondary Education Survey," 1999-2000 and "National Public Education Financial Survey", 1995-96 through 1997-98.
7. Source: Website; US Department of Education, National Center for Educational Statistics (NCES); original source: U.S. Department of Education: Office of the Under Secretary, unpublished data, and National Center for Education Statistics, compiled from data appearing

in U.S. Office of Management and Budget, Budget of the United States Government, fiscal years (FY) 1982–2001 (selected years); National Science Foundation, Federal Funds for Research and Development, FY 1980–2000 (selected years); and unpublished data obtained from various federal agencies.

8. Source: Website; US Department of Education, National Center for Educational Statistics (NCES); original source U.S. Department of Education, NCES. (2001). The Nation's Report Card: Fourth-Grade Reading 2000 (NCES 2001499).
9. Source: Mark Berends, Susan J. Bodilly, Sheila Nataraj Kirby, Facing the Challenges of Whole-School Reform: New American Schools After a Decade (Santa Monica, CA.: RAND, MR-1498-EDU, 2002).
10. O'Hanlon, M.; Orszag, I.; Daalder, I.; Destler, I.; Gunter, L.; Litan, R.; and Steinberg, J. (2002). *Protecting the American Homeland,* Washington, DC: Brookings Press.
11. Ibid.
12. O'Toole, T., (2001), Smallpox: An attack scenario, *Emerging Infectious Diseases*, 5, 540-546.
13. Ibid, p. 540.
14. For examples, see Kun, L.G., & Bray, D.A., (2002), Information infrastructure tools for bioterrorism preparedness, *IEEE Engineering in Medicine and Biology*, 21(5), 69-85; Popovich, M.L., Henderson, J.M., & Stinn, J., (2002), Information technology in the age of emergency public health response, *IEEE Engineering in Medicine and Biology*, 21(5), 48-55; Rosen, J., Grigg, E., Lanier, J., McGrath, S., Lillibridge, S., Sargent, D., & Koop, C.E. (2002), The future of command and control for disaster response, *IEEE Engineering in Medicine and Biology*, 21(5), 56-68.
15. Op. cit., Rosen et al., 2002.
16. Ibid.
17. See also Inglesby, T.V. (2000), Lessons from TOPOFF, *The Second National Symposium on Medical and Public Health Response to Bioterrorism Speaker Transcript*, Washington, DC. Available at: http://www.hopkins-biodefense.org/sympcast/transcripts/trans_ingl.html.
18. See also ANSER, (2001), "Dark winter: Summary." Available at http://www.homelandsecurity.org/darkwinter.index.cfm.
19. Op cit., Rosen et al, (2002); ANSER, (2001).
20. New York Times, July 7, 2002.