

Human Systems Integration in Expeditionary Medical Treatment Facilities

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Future Expeditionary Medical Treatment Facilities (EMTF) are expected to achieve the same effectiveness as current facilities while facing predictions of fewer personnel, personnel with lower initial qualifications, and growing sophistication of equipment. The present research aims to develop tools to improve the design of such facilities and equipment by providing Human Systems Integration (HSI) principles and design requirements. Specific aims are to identify the highest priority HSI technical challenges in next-generation facilities, assess the tradeoffs among the HSI technical domains related to the design of these facilities, evaluate candidate technologies that address the HSI issues, and develop HSI guidance.

Our approach takes the following steps: We started with an assessment of the state of the art in EMTF design, emerging technologies and important trends. This assessment was guided by an advisory panel consisting of medical personnel experienced with remote consultation and diagnostics, and service personnel with experience in EMTFs. We collected data from the research literature on reported HSI issues in EMTFs, supplemented by data collection through interviews and site visits. We also identified and analyzed emerging technologies that may impact EMTFs in areas linked to HSI in the near future. From these sources we have identified high-priority HSI issues and developed plans for an open, scalable, and flexible facility design to support HSI experimentation, with automated data collection capability. Future work will make use of the mockup and prototype design facility to investigate high priority HSI issues in EMTFs, analyze results, and develop actionable guidelines for future EMTF design with detailed descriptions and supporting data.

INTRODUCTION

The United States Air Force (USAF) operates and manages a worldwide healthcare system that includes the capability to provide integrated healthcare from forward deployed locations. The Air Force provides hierarchical levels of care, and provides transportation needed to rapidly move patients to higher levels of care

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14. ABSTRACT

Future Expeditionary Medical Treatment Facilities (EMTF) are expected to achieve the same effectiveness as current facilities while facing predictions of fewer personnel, personnel with lower initial qualifications, and growing sophistication of equipment. The present research aims to develop tools to improve the design of such facilities and equipment by providing Human Systems Integration (HSI) principles and design requirements. Specific aims are to identify the highest priority HSI technical challenges in next-generation facilities, assess the tradeoffs among the HSI technical domains related to the design of these facilities, evaluate candidate technologies that address the HSI issues, and develop HSI guidance. Our approach takes the following steps: We started with an assessment of the state of the art in EMTF design, emerging technologies and important trends. This assessment was guided by an advisory panel consisting of medical personnel experienced with remote consultation and diagnostics, and service personnel with experience in EMTFs. We collected data from the research literature on reported HSI issues in EMTFs, supplemented by data collection through interviews and site visits. We also identified and analyzed emerging technologies that may impact EMTFs in areas linked to HSI in the near future. From these sources we have identified high-priority HSI issues and developed plans for an open, scalable, and flexible facility design to support HSI experimentation, with automated data collection capability. Future work will make use of the mockup and prototype design facility to investigate high priority HSI issues in EMTFs, analyze results, and develop actionable guidelines for future EMTF design with detailed descriptions and supporting data.

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as rapidly as possible when necessary. At each level, doctors, nurses, technicians, and other personnel provide care to patients in a variety of types of facilities and using various types of medical equipment appropriate for the level of care expected at each facility. Other US military services operate healthcare systems as well. Although there are areas of overlap, the services coordinate the development of capabilities to avoid unnecessary duplication of effort. Each service develops and operates facilities that are appropriate to the range of operations and deployments that each service is expected to conduct. One area of particular interest to the Air Force is expeditionary medicine. The Air Force is capable of quickly setting up medical treatment facilities and of commencing treatment of trauma patients within a few hours of arrival. Modular design allows a facility to become fully functional and offer a wide range of medical services within 24 hours.

Human Systems Integration (HSI) is the interdisciplinary technical and management process for integrating human considerations within and across all system elements. In this respect HSI enables systems engineering to properly consider human-related technical concerns during system planning, design, development, evaluation, and implementation. By taking into account the interests of the operators, maintainers, and other support personnel, HSI can help optimize system performance and minimize ownership costs. Human-related technical concerns are often overlooked in the early stages of system design. HSI provides a structured process for identifying and addressing those concerns during the design process. From a program management standpoint, HSI ensures that human-related concerns are properly considered and coordinated by all the technical disciplines that are concerned with each issue. From a technical standpoint, HSI ensures that human performance issues are identified early and addressed effectively in the program.

The range of issues addressed by HSI spans multiple technical domains. These technical domains are human factors engineering, manpower, personnel, training, safety and occupational health, survivability, habitability, and environment. Many of these issues have different implications for different domains, and thus for some issues tradeoffs must be made across domains. For example, pressure to reduce manpower leads to the need for personnel with higher qualifications and/or more extensive training. Similarly, attempts to reduce human error can be addressed by some combination of improved human factors engineering of user interfaces and modified training.

HSI can contribute to improving the design of future EMTFs in a number of ways. Simpler system design allows crews to perform their tasks effectively and without the inefficiency and frustration of overly complex systems, thereby leading to more efficient use of available manpower. For example, if a mobile unit can be assembled more quickly and with fewer tools, or if the site can be maintained with fewer labor hours, then a reduced staff may be sufficient to operate the facility. Standardizing user interfaces can help reduce training requirements and lead to lower probability of user errors, especially if user interfaces in EMTFs are consistent with user interfaces of functionally similar equipment used in permanent facilities (which may be the previous and/or next duty assignment of personnel in an expeditionary facility.)

The objectives of the present research are to identify HSI issues in the next generation of EMTFs and to develop tools to help address those issues in facility planning, design, and operation. Issues were identified from three primary sources: reports and interviews conducted with military medical personnel experienced in current facilities; published reports of issues in comparable systems; and issues associated with emerging technologies expected to be deployed in the next generation of facilities. Overall, this project is focused on the design of future facilities rather than remediation of problems in current facilities. Some of the solutions developed in the present research, however, may be applicable to current systems.

HSI ISSUES IN EXPEDITIONARY MEDICINE

Over 100 potential HSI issues were identified based on our review of the literature, interviews and discussions with experts familiar with current systems, published lessons learned from other military medical facilities and mobile non-military medical facilities, and an analysis of emerging technologies that are strong candidates for implementation in future expeditionary facilities. These issues were categorized by the HSI technical domains. Many HSI issues were identified that involve two or more HSI domains.

Major themes that emerged from the literature include reduction of human error, improved training, impact of pressure to reduce manpower, and shift of certain responsibilities to less-qualified personnel. Human error is a particularly sensitive topic across all sectors of health care, but the time pressure and environmental austerity often found in expeditionary medicine make error reduction a high priority issue. Factors that may lead to higher probabilities of error include poorly-designed user interfaces, environmental conditions, inadequate training, fatigue, poor communications among team members, and stress. Thus, attempts to reduce human error require contributions across all the domains of HSI.

Principles of human factors engineering directly address many of the issues that are discussed in the literature. Lai (2007) discussed the importance of human factors engineering in the designing of medical equipment and technology. Lai suggests that applying existing national and international human factors and healthcare quality guidelines to the design of new facilities and equipment will help ensure that new devices are functional, natural to use, embraced by users, and safe. Johannigman (2008) discussed some of the current problems faced in critical care transport, noting some fundamental human factors problems such as poor lighting, alarms that aren't detectable in a noisy environment, display screens that are too small and hard to read at a distance or in the dark, and clumsy user interfaces.

Human factors engineering alone, however, is not sufficient to address the range of issues faced by future EMTFs. Design of the overall facility and of the equipment and devices in the facility must be coordinated with development of the concept of operations for the facility, planning for staffing the facility, and training and equipping the staff. Reiling (2001) described the design of a hospital that emphasized patient safety. Important features included standardization of procedures, control of the environment (especially noise), use of automation where possible, and setting work schedules to minimize fatigue.

Reports from deployed personnel about problems they experience highlight issues associated with personnel qualifications and training. Ross, Smith, Smith, Ryan, and Humphreys (2008) analyzed deployed nurses' after-action reports, many of which were related to HSI issues, including negative comments about frequent turnover of personnel, being assigned to jobs they have not been trained for, leaders being unable to make decisions, doctors allowing people do things beyond their scope-of-practice, and poor morale. Similarly, Brewer and Ryan-Wenger (2009) interviewed nurses about their deployed experience on critical care transport teams and noted recurring themes of problems associated with personnel readiness, leadership, and challenges related to physical and emotional stress and sleep deprivation. Whitcomb and Newell (2008) recommended that team composition in expeditionary medical facilities be planned to make sure that appropriate technical expertise and deployment experience is spread across teams, in particular to avoid having a team with a lack of experienced personnel. For example, they suggested that one nurse who had emergency experience and one nurse who had intensive care experience be assigned to each team. Such issues as these cannot be addressed by one HSI domain alone – they require coordinated action from human factors engineering, personnel, manpower, and training.

The need for coordination of facility and equipment design with personnel selection and training is highlighted by the pressure to use lesser-qualified personnel in lieu of physicians for many activities. Cost is

usually a driver of these decisions, but the limited availability of physicians (even if cost is not a constraint) and the demand for physician time across a wide variety of activities also drives the need to shift some tasks to other personnel. Levy, Goldstein, Erez, and Levite (2007) specifically addressed using physicians versus paramedics during ground forces operations. Although many of the tasks that need to be performed promptly for trauma care during ground combat operations can be performed by paramedics, physicians are typically able to treat a wider variety of medical conditions and have a broader knowledge base. Paramedics, in contrast, may be more accustomed to performing life-saving procedures in field settings, have higher levels of physical fitness, and often have other combat skills and experience that physicians don't have. Thus, simply substituting paramedics for physicians on a medical team impacts much more than saving money or freeing up physicians for other tasks: it impacts overall need for specialized training, design of equipment, provisions for medical evacuation, and command and control of medical activities.

The need for team training, and for technologies to support team training, also illustrates the need for coordination across the HSI domains. Team training is seen as a means for reducing human error in medical teams (Alonso, Baker, Holtzman, Day, King, & Toomey, 2006) and for improving team performance in the face of reduced team size and modified composition (Baker, Gustafson, Beaubien, Salas, & Barach, 2005). Baker, et al. (2005) discuss both simulator-based and classroom-based medical team training programs. They specifically recommended that future team training programs address all three components of comprehensive team training: awareness, skills practice and feedback, and recurrence.

Johannigman, (2005) captured many of the cross-domain HSI issues in his discussion of preparedness for combat conditions and other disasters. He noted that the majority of military medical facilities are focused on maintaining the healthcare delivery system for the active duty and retired components of their service members, and thus do not (and cannot afford to) focus on the delivery of trauma care. This prompted the development of collaborative military/civilian training platforms, which allow military medical personnel to gain trauma experience in level I trauma centers. These training programs provide pre-deployment refresher and sustainment training for a significant number of physicians, nurses, corpsmen, and medics. Such training, however, does not replicate the unique combat setting, but instead reflects domestic (typically urban) trauma care rendered with predictable transport time to definitive care and without the threats to survivability found in combat conditions. Thus, military medical personnel deploy for duty in EMTFs having the bulk of their experience in traditional facilities that primarily provide routine care, with training for trauma care conducted in conditions quite different than conditions they face in theatre. Moreover, their experience is with different equipment than is found in the EMTF and they must perform as a member of a team with which they have little training in trauma care.

In the section below, each HSI domain is introduced, and issues associated with each domain and with multiple domains are listed. Full details of the literature review and assessments appear in Folds, Fain, and Kelly (2009).

Human Factors Engineering

The human factors engineering domain of HSI involves the process by which human abilities and limitations are considered throughout the design process to ensure that the overall system performance is optimized. This domain, more than the others, is how user interface elements and other system properties are designed so that the potential for error is minimized and the desired efficiency is achieved.

The USAF definition of this domain follows:

“The technical consideration and application of the integration of design criteria, psychological principles, human behavior, capabilities and limitations as they relate to the design, development, test,

and evaluation of systems. The goal is to maximize the ability of users to perform at required levels through the elimination of design-induced errors, and to ensure that system operation, maintenance, and support are compatible with the total capabilities and limitations of users operating or maintaining those systems.”

The following issues are associated with the domain of human factors engineering in expeditionary medical facilities:

- 1) Equipment or gear may not be suitable for operation in austere environments
- 2) Medical equipment may not be suitable for use in loud or noise prone environments
- 3) Medical equipment may not interface or be compatible with other equipment or gear

Manpower

The manpower domain of HSI involves determination of total numbers of humans required for a system to support full operational capabilities to support operation, maintenance, and sustainment of a system. The USAF definition of this domain follows:

“The consideration of the net effect of systems on overall human resource requirements and authorizations (spaces) to ensure that each system is affordable from the standpoint of manpower. It includes analysis of the number of people (military, civilian and contractor) needed to operate, maintain, repair, and support each system being acquired.”

The following issues are associated with the domain of manpower in expeditionary medical facilities:

- 1) There may not be enough people to execute the mission
- 2) The available manpower may not be correctly utilized

Personnel

The personnel domain of HSI involves determination of total human characteristics (both cognitive and physical) and skill requirements for a system to support full operational capabilities necessary to operate, maintain, and support a system.

The USAF definition of this domain follows:

“The consideration of human aptitudes (i.e., cognitive, physical, and sensory capabilities), knowledge, skills, abilities, and experience levels that are needed to properly perform job tasks across the military, civilian and contractor work force to operate, maintain, and support a system in peacetime and war. Personnel factors are used to develop the DoD Component personnel system classifications and civilian job series of system operators, maintainers, trainers, and support personnel.”

The following issues are associated with the domain of personnel in expeditionary medical facilities:

- 1) Personnel may be medically unfit for duty
- 2) Personnel may not have sufficient personal resilience to perform
- 3) Team affect is important
- 4) There may be a need for unique non-medical skills that are not present in the team

Training

The training domain of HSI involves the use of analyses, methods, and tools to ensure systems training requirements are fully addressed and documented by systems designers and developers to achieve a level of individual and team proficiency that is required to successfully accomplish tasks and missions. The USAF definition of this domain follows:

“Training is the learning process by which personnel individually or collectively acquire or enhance predetermined job-relevant knowledge, skills, and abilities by developing their cognitive, physical, sensory, and team-dynamic abilities. Training, as a related HSI domain, is the use of analyses, methods and tools to ensure systems training requirements are fully addressed and documented by systems designers and developers to achieve a level of individual and team proficiency that is required to successfully accomplish tasks and missions. Training systems must ensure that the training objectives are met through the delivery of instructional methods, media, personnel, and system support through the life cycle.”

The following issues are associated with the domain of training in expeditionary medical facilities:

- 1) Continuous training may not be possible due to lack of facilities or resources after deployment
- 2) The operational tempo may not be sufficient to maintain skill level
- 3) Feedback may be insufficient to provide for efficient training
- 4) Errors may be made because triage and care practices in non-combat and combat medical facilities are not equivalent

Safety and Occupational Health

The safety and occupational health domain of HSI involves consideration and application of system design characteristics that serve to (1) minimize the potential for mishaps that may cause death or injury to operators or maintainers and (2) reduce factors that may threaten the operation of the system. Occupational Health refers to those system design features that (1) minimize the risk of injury, acute or chronic illness, or disability; and/or (2) decrease the likelihood of reduced job performance of personnel who operate, maintain, or support the system. (In some contexts these are treated as two domains.) The USAF definition of this domain follows:

“The development of system design characteristics and procedures to minimize the risk of accidents, and mishaps that cause death or injury to operators, maintainers, or support personnel; threatens the operation of the system; or causes cascading failures in other systems. Safety analyses and lessons learned are used to aid in development of design features that prevent safety hazards to the greatest extent possible and manage safety hazards that cannot be avoided. Occupational health focuses on system design features and procedures that serve to minimize the risk of injury, acute or chronic illness, disability, and enhance job performance of personnel who operate, maintain, or support the system. Occupational health analyses and lessons learned are used to aid in development of design features that prevent health hazards where possible, and provide recommendations on personal protective equipment, protective enclosures, or mitigation measures where health hazards cannot be avoided.”

The following issues are associated with the HSI domain of Safety and Occupational Health in expeditionary medical facilities:

- 1) Medical errors may not be addressed because of lack of reporting

- 2) Staff (and equipment) may be at risk for secondary exposure to chemical or biological agents

Survivability

The survivability domain of HSI involves consideration and application of system design features (e.g., life support, body armor, helmets, plating, egress/ejection equipment, etc.) that reduce the risk of fratricide, reduce the probability of detection, reduce the risk of attack if detected, and minimize damage if attacked.

The USAF definition of this domain follows:

“The consideration of the characteristics of a system (e.g., life support, body armor, helmets, plating, egress/ejection equipment, air bags, seat belts, electronic shielding, etc.) that reduce susceptibility of the total system to mission degradation or termination. The goal is to reduce detectability of the warfighter, prevent attack if detected, prevent damage if attacked, minimize medical injury if wounded or otherwise injured, and reduce physical and mental fatigue. These issues must be considered in the context of the full spectrum of anticipated operations and operational environments and for all personnel who will interact with the system (e.g., users/customers, operators, maintainers, or other support personnel). Adequate protection and escape systems must provide for personnel and total system survivability when they are threatened with harm.”

The following issues are associated with the domain of survivability in expeditionary medical facilities:

- 1) The facility may be vulnerable to some types of attacks at certain phases of operation

Habitability

The habitability domain of HSI involves consideration of system related working conditions and accommodations that are necessary to sustain the morale, safety, health, and comfort of all personnel. The USAF definition of this domain follows:

“Consideration of the characteristics of systems focused on satisfying personnel needs which are dependent upon physical environment. Habitability analyzes factors of working conditions and accommodations that are necessary to sustain the morale, safety, health, and comfort of the user population that contribute directly to personnel effectiveness and mission accomplishment.”

The following issues are associated with the domain of habitability in expeditionary medical facilities:

- 1) Personnel may experience problems with morale and burnout due to poor living conditions
- 2) Personnel may experience sleep disorders due to shift work

Environment

The environment domain of HSI involves consideration of concepts of operation and the requirements necessary to protect systems from the operational environment (e.g., shock, vibration, extreme temperatures) and the environment (i.e., water, land, air, space, and cyberspace) from the systems operations, sustainment and disposal. The USAF definition of this domain follows:

“The consideration of Environment is important in that it affects concepts of operation and the requirements to protect systems from the operational environment (i.e. shock, vibration, extreme temperatures, etc.) and the environment (i.e. water, land, and air, space and cyberspace) from the systems operations, sustainment and disposal.”

The following issues are associated with the domain of environment in expeditionary medical facilities:

- 1) Excessive light and noise may adversely impact medical personnel or patients

HSI ISSUES ASSOCIATED WITH MULTIPLE DOMAINS

In addition to the issues identified below, there are many issues that span multiple HSI domains. In the paragraphs below, issues that span two or more domains are listed. Details of the source of reports of these issues are found in Folds, et al. (2009).

Human Factors Engineering and Manpower

The following issues are associated with the HSI domains of human factors engineering and manpower in expeditionary medical facilities:

- 1) There may be too few people to operate equipment and gear
- 2) There may be too many people required for simple tasks
- 3) Situation awareness may not be preserved between shift changes
- 4) There may not be enough room for critical personnel to fully access the patient area

Human Factors Engineering and Personnel

The following issues are associated with the HSI domains of human factors engineering and personnel in expeditionary medical facilities:

- 1) The design of medical equipment and gear may be too complex for available medical personnel
- 2) Medical personnel may experience negative transfer due to differences between civilian and military equipment and gear
- 3) The design of medical equipment and gear may exclude certain operators (e.g., color blind, height / reach requirements)
- 4) The design of medical equipment and gear may make certain tasks more difficult for certain operators (e.g., language barriers, technical language, mental demands)
- 5) The design may rely too heavily on the short term memories of medical personnel

Human Factors Engineering and Training

The following issues are associated with the HSI domains of human factors engineering and training in expeditionary medical facilities:

- 1) Given the time available for training, the material that needs to be covered may not be adequately addressed
- 2) Infrequent tasks may be difficult to remember (poor retention)
- 3) The availability of medical equipment and gear may limit the ability for training on actual devices/equipment that will be used in theater
- 4) There may be an overreliance on training to attempt to overcome device complexity

- 5) Complex training systems may impede skill and knowledge acquisition
- 6) Training may not transfer from virtual or simulator technologies to real world situations

Human Factors Engineering and Safety / Occupational Health

The following issues are associated with the HSI domains of human factors engineering and safety / occupational health in expeditionary medical facilities:

- 1) The design of medical equipment and gear may make it difficult to recover from errors
- 2) Self protection systems or electronic weapons may interfere with medical equipment and gear operation
- 3) The design of medical equipment and gear may make it difficult to detect when errors occur
- 4) User interface elements and supplies that are similar may be easily miss-identified
- 5) Alarms and alerts from multiple devices may be confused or obscured
- 6) Equipment and gear may not easily located when needed due to inadequate storage or poor organization
- 7) Procedural tasks may not be trained as a checklist and checklists may not be provided
- 8) Medical equipment and gear may not operate properly in austere environments
- 9) The design may require unsafe handling of dangerous materials
- 10) The design may result in an unsafe exposure to dangerous materials

Human Factors Engineering and Survivability

The following issues are associated with the HSI domains of human factors engineering and survivability in expeditionary medical facilities:

- 1) The design may result in unnecessary exposure to hostilities
- 2) Protective features or equipment may interfere with ability to provide medical care
- 3) Medical equipment and gear may not be usable under conditions of light or noise discipline

Human Factors Engineering and Habitability

The following issues are associated with the HSI domains of human factors engineering and habitability in expeditionary medical facilities:

- 1) Medical equipment and gear may take up too much space
- 2) Medical equipment and gear may subject personnel to uncomfortable temperatures, noises, or odors

Human Factors Engineering and Environment

The following issues are associated with the HSI domains of human factors engineering and environment in expeditionary medical facilities:

- 1) Medical equipment or gear may not be suitable for use in direct sunlight
- 2) Added weight from protective gear may hinder the mission

Manpower and Personnel

The following issues are associated with the HSI domains of manpower and personnel in expeditionary medical facilities:

- 1) Leadership style may not be compatible with a given team
- 2) Personnel may be overqualified for a given job
- 3) Too many senior people may result in role confusion
- 4) A sufficient number of people with the required skills may not be available
- 5) The mixture of personnel may not be appropriate for the mission or operational tempo
- 6) There may be a need for people to perform multiple roles, due to a limited number of staff

Manpower and Training

The following issues are associated with the HSI domains of manpower and training in expeditionary medical facilities:

- 1) The training pace may not be able to keep up with manpower demands
- 2) Teams may not be able to train as a team prior to deployment
- 3) High turnover may reduce the effectiveness of team training

Manpower and Safety / Occupational Health

The following issues are associated with the HSI domains of manpower and safety / occupational health in expeditionary medical facilities:

- 1) Required number of people may not be available to ensure safe operation
- 2) There may be an insufficient quantity of protective gear
- 3) Personnel may not be aware of their own abilities to continue to provide care in the presence of stressors
- 4) The work schedule may induce people to take performance enhancing drugs that result in behavioral or cognitive changes
- 5) Shifts may be too long because sufficient staff is not available
- 6) Time zone changes may result in caregiver fatigue during patient transport if sufficient staff is not available
- 7) High workload can lead to errors

Manpower and Survivability

The following issue is associated with the HSI domains of manpower and survivability in expeditionary medical facilities:

- 1) Protection may not be afforded for everyone required to operate the system

Manpower and Habitability

The following issues are associated with the HSI domains of manpower and habitability in expeditionary medical facilities:

- 1) The facility may be overcrowded resulting in diminished living conditions
- 2) High workload can cause fatigue and reduce morale

Manpower and Environment

The following issue is associated with the HSI domains of manpower and environment in expeditionary medical facilities:

- 1) Large groups of personnel may have a negative impact on the environment

Personnel and Training

The following issues are associated with the HSI domains of personnel and training in expeditionary medical facilities:

- 1) The training system may be too difficult/complex for available personnel
- 2) Procedural steps may not be captured and trained as a checklist
- 3) The training system may not reflect deployed conditions
- 4) The training system may not overcome negative transfer
- 5) The training system may not adequately cover teamwork or leadership skills
- 6) Training may not be maintained to criterion after deployment
- 7) There may be an insufficient mix of experienced and novice staff to promote knowledge transfer after deployment
- 8) There may be a learning curve when transitioning from peacetime care to combat casualty care

Personnel and Safety / Occupational Health

The following issues are associated with the HSI domains of personnel and safety / occupational health in expeditionary medical facilities:

- 1) Personnel may be required to perform tasks that are not part of their normal responsibilities and outside of their training
- 2) Personnel may not comprehend the risk associated with a specific action
- 3) The operational tempo may be too high for some people
- 4) Errors may result from poor teamwork or communication
- 5) Non-technical interpersonal skills may be missing or lacking in key personnel
- 6) Teamwork may be degraded under conditions of high stress

Personnel and Survivability

The following issues are associated with the HSI domains of personnel and survivability in expeditionary medical facilities:

- 1) Personnel may not be sufficiently familiar with emergency procedures or equipment

Personnel and Habitability

The following issues are associated with the HSI domains of Personnel and Habitability in expeditionary medical facilities:

- 1) Personnel may not be compatible
- 2) Insufficient habitability may negatively impact morale, performance, and retention

Personnel and Environment

The following issues are associated with the HSI domains of personnel and environment in expeditionary medical facilities:

- 1) Environmental noise may impact medical personnel performance
- 2) Poor lighting may impact medical personnel performance
- 3) The operational environment may impact medical personnel performance

Training and Safety / Occupational Health

The following issues are associated with the HSI domains of training and safety / occupational health in expeditionary medical facilities:

- 1) The training may be inadequate to ensure safety
- 2) There may be an over-reliance on training to address safety problems
- 3) Training may expose personnel to dangerous situations or substances prior to receiving adequate information about handling dangerous substances or avoiding dangerous situations

Training and Survivability

The following issues are associated with the HSI domains of training and survivability in expeditionary medical facilities:

- 1) Training may not include lessons on how to integrate survivability skills with providing critical medical care

Training and Habitability

The following issue is associated with the HSI domains of training and habitability in expeditionary medical facilities:

- 1) Training may not represent the actual conditions where the knowledge is used or the skill is expected to be performed

Training and Environment

The following issues are associated with the HSI domains of training and environment in expeditionary medical facilities:

- 1) Training environment may not reflect deployed environment
- 2) Training may not adequately address risks present in the environment

Safety / Occupational Health and Survivability

The following issues are associated with the HSI domains of safety / occupational health and survivability in expeditionary medical facilities:

- 1) Protective gear may interfere with the safe operation of equipment
- 2) Critical gear may be inaccessible or difficult to access due to safety concerns

Safety / Occupational Health and Habitability

The following issues are associated with the HSI domains of safety / occupational health and habitability in expeditionary medical facilities:

- 1) Unsanitary conditions due to improper cleaning may lead to long term health concerns
- 2) Low morale may lead to a failure to observe safety protocols
- 3) Protective gear may be so cumbersome that it impacts compliance
- 4) Fatigue, stress, and high workload may contribute to medical errors

Safety / Occupational Health and Environment

The following issues are associated with the HSI domains of safety / occupational health and environment in expeditionary medical facilities:

- 1) Low lighting levels may lead to errors
- 2) High noise levels may contribute to errors

Survivability and Habitability

The following issues are associated with the HSI domains of survivability and habitability in expeditionary medical facilities:

- 1) Equipment and gear necessary for survivability may be uncomfortable
- 2) Long durations in shelters designed to provide extra protection during an attack may not provide adequate space

Survivability and Environment

The following issue is associated with the HSI domains of survivability and environment in expeditionary medical facilities:

- 1) Local combat may impact the ability to provide healthcare

Habitability and Environment

The following issue is associated with the HSI domains of habitability and environment in expeditionary medical facilities:

- 1) The environment may influence living conditions for personnel

Human Factors Engineering, Training, and Safety

The following issues are associated with the HSI domains of human factors engineering, training, and safety in expeditionary medical facilities:

- 1) Safety features may be too easily ignored
- 2) Safety procedures may be too difficult to remember

Human Factors Engineering, Personnel, and Training

The following issues are associated with the HSI domains human factors engineering, personnel, and training in expeditionary medical facilities:

- 1) Training devices may not be realistic or of a high-enough fidelity to ensure adequate transfer of knowledge for some people
- 2) There may be a lack of shared mental models and situation awareness

Human Factors Engineering, Personnel, and Safety / Occupational Health

The following issue is associated with the HSI domains human factors engineering, personnel, and safety / occupational health in expeditionary medical facilities:

- 1) The design of medical equipment and gear may require personnel to assume uncomfortable postures

Human Factors Engineering, Personnel, and Environment

The following issues are associated with the HSI domains human Factors engineering, personnel, and environment in expeditionary medical facilities:

- 1) Poor arrangement of medical equipment and gear may impact the performance of some medical personnel
- 2) The physical layout of the medical facility may hamper teamwork

Human Factors Engineering, Training, and Survivability

The following issue is associated with the HSI domains human factors engineering, training, and survivability in expeditionary medical facilities:

- 1) Training on how to provide care while wearing protective gear may be inadequate

Personnel, Training, and Safety / Occupational Health

The following issues are associated with the HSI domains personnel, training, and safety / occupational health in expeditionary medical facilities:

- 1) Medical personnel may be distracted by the severity of the wounds
- 2) Team training on adaptability may be inadequate

EMERGING TECHNOLOGIES

Advances in technology used directly in patient care, and to support medical operations, will impact how expeditionary medical treatment facilities of the future are configured and how they will operate. The present research is focused on future facilities, and thus it is prudent to attempt to identify emerging technologies that have the potential to impact future facilities. Primary sources of information about emerging technologies were (1) technologies already in the pipeline of development, test, and evaluation for inclusion in Air Force medical treatment facilities; (2) technologies that are beginning to appear in advanced medical facilities in the non-military sector; (3) technologies described in the open literature with the stated context of application in medical facilities; and (4) technologies displayed or described at research conferences and trade shows for the medical profession. Many of these technologies may never mature to the point of being candidates for inclusion in future Air Force medical treatment facilities, and of the ones that so, not all will have significant HSI issues associated with them. The following subsections describe the emerging technologies that were identified as having HSI issues worthy of consideration before incorporating them into future EMTFs.

Patient Transfer Systems

The philosophy of the modern expeditionary medical system is one of hierarchical care. Patients are diagnosed, treated, and stabilized to the extent required to move them up to the next level of care. A number of HSI issues surround patient transfer. Manual transfer may require an awkward lift that risks injury to medical personnel due to the weight of the patient and the position of lifters. The gear and apparatus needed by the patient en route may be cumbersome especially when in transit, and the gurney or litter used in transit may not be designed to accommodate the gear attached to it. A modular system that is ergonomically designed to facilitate patient transfer and containment of necessary medical equipment would reduce the manpower required to transfer patients while simultaneously increasing the safety of both the caregivers and the patients. Robotic technologies will soon be available that will enable transport of patients over a variety of terrains. A modular litter system that expands to accommodate needed medical equipment and interfaces with a robotic gurney will be feasible in the near future.

Baseline Datasets

Military personnel in the future may have large volumes of baseline data collected about them shortly after induction and perhaps updated periodically as warranted. For example, future inductees may have complete CT scans of the head and upper torso performed, and this data may be used in the event that reconstructive surgery is needed after trauma. Baseline data on performance of certain psychomotor tasks may be collected to aid in diagnosis of traumatic brain injury after blast exposure. Optical whole-body scans may be performed to aid in fitting protective gear. Such data sets will be available in some form to medical personnel in the field in the course of providing medical treatment. HSI issues include how those data will be presented to surgeons or other care-givers so they can be used effectively, how errors in identifying or transmitting those data can be reduced, and how medical personnel will be trained to interpret those data.

Ubiquitous Data Networks

The availability, reliability, and bandwidth of data networks in deployed environments are expanding rapidly. Data collected from medical technicians at the sight of the injury could arrive at an expeditionary medical

facility prior to the patient's arrival. Medical personnel could use the information to pre-triage the patient as well as to prepare a treatment plan prior to arrival. HSI issues include how the data will be presented to medical personnel, how to avoid biasing the decisions made by medical personnel (because of selective availability of data prior to the patient's arrival), and training people in the EMTF and those providing transit on use and interpretation of such data. This technology offers an opportunity to reduce certain errors and speed the delivery of appropriate care, but also introduces opportunities for new errors and need for new types of team training.

Plasma Based Decontamination

Current technologies for decontamination involve heavy use of consumables or sterilization technologies that require relatively long periods of time to become effective. New technologies for decontamination using protein ion discharge or cold plasma may allow personnel to safely and rapidly disinfect soldiers and equipment without needing to rely on disposable supplies. An EMTF deployed with the ability to generate cold plasma would reduce the amount of time needed to sterilize equipment, increase the effectiveness of current sterilization techniques, and reduce the number of supplies needed to insure adequate sterilization. This could significantly reduce the labor required for decontamination and for inventorying and handling the consumable supplies currently required by decontamination. It will also create opportunities for new types of errors and the need for new training.

Simulation and Augmented Reality

There are a number of technologies that are in development that may transform how medical procedures are executed and/or how medical personnel train. For example, the capability to mix virtual imagery into or onto a patient's body either through glasses worn by medical personnel or by optical systems that project the image provides the opportunity to more accurately translate imagery (such as from a CT scan or MRI) collected previously for use in real time during an examination or procedure (such as biopsy or surgery). Predictive computational models may be used to help guide surgical procedures by cueing the surgeon to the location of objects to be removed. These visualization techniques could also be used to keep parametric data about the patient's condition or history within the field of view of the physician during an exam or procedure.

Portable patient simulators that can be programmed to exhibit certain symptoms and respond to medical interventions may be taken to theatre and used for individual and team training. Patient simulators can also be programmed to participate in verbal interactions with medical personnel. These devices, perhaps combined with augmented reality, could greatly increase the capability to train in theatre and could help provide training for new procedures. Surgical workstations that can allow the surgeon to plan and practice complex surgeries, perhaps in conjunction with patient simulators and/or augmented reality, may improve overall team performance during surgery by reducing surgery time and reducing errors. Prosthetic wounds can be placed on non-injured personnel who are playing the role of patient during team training. These devices can be programmed to simulate a wide variety of wounds and help improve the robustness of trauma care training, even in theatre. Such technologies create opportunities to improve performance, but also introduce the possibility of new types of errors and create the need for new types of individual and team training. HSI issues for simulation and augmented reality technologies include the potential for new types of errors, the possibility of negative transfer of training, and the need for new personnel skills and training to support these technologies.

Robotic Surgery

Laparoscopic surgeries require less rehabilitation time and can be safer to the patient. The disadvantage is that the surgeries are more difficult to perform and can take longer than standard surgeries. The instruments used in laparoscopic surgeries may be difficult to control and master. Robotic surgical systems may reduce the skills required for complex laparoscopic surgeries. These technologies may allow for greater precision of movement than manually controlled systems. If controlled from a workstation, the same user interface used for surgical rehearsal could be used to control the robots used in the actual surgery. Remote surgeons could monitor the procedure and intervene when necessary. A major HSI issue is whether these systems will be used to perform surgery in the absence of an on-site surgeon, and if so, what on-site person should oversee the surgery and under what conditions should they intervene, and, obviously, what type of training is required.

Handheld Brain Diagnostics

Brain hematomas are a common head trauma injury and may be difficult to detect without a CT scan. Trauma victims may not exhibit symptoms until the underlying medical condition has become critical. A number of technologies are in development that may help detect and diagnose various brain injuries. Some are dependent on the existence of a baseline dataset for the injured patient. Introduction of these technologies could help with patient care but also creates the need for good user interface design and training.

HSI TOOLS FOR FUTURE EMTFS

The sections above present and summarize a large number of HSI issues that have been reported in the literature or identified in interviews with personnel, as well as potential issues that may arise from the introduction of new technologies into future EMTFs. Technical solutions for many of these issues are known, and simply need to be shared with the planners, designers, and operators of future facilities. Simply raising awareness of the issue (and its known solution) is sometimes an effective way to get the issues addressed. Other solutions may be known generically, but need focused research to develop specific solutions for specific problems. For example, the generic solution for a system design that requires users to assume unsafe postures is to redesign the system so it doesn't require the unsafe posture. Information about principles of design that promote good posture, and examples of designs that support good posture, may be all that a designer needs to redesign the system. In some cases, though, it is not apparent how to redesign the system to eliminate the problem. In these cases a focused study on a particular point design problem may be needed to produce a solution.

The tools that are needed to provide HSI guidance to the planning and design of future EMTFs will, therefore, be a combination of assimilated existing guidance gleaned from decades of research and existing authoritative sources, properly focused and explained in terms of EMTF design, and new data generated in studies conducted as part of the present research. These new data will be targeted at high-priority HSI issues for which the existing guidance is incomplete. Guidance on materiel vs. non-materiel solutions is important, and for issues that span multiple domains the best solution may include elements of both.

The present research includes the development of a research facility that can be used to conduct studies to produce HSI guidance for issues in future EMTFs. The facility, currently in development, will include capabilities to support human factors evaluations of user interface design and workstation layout, assess the effectiveness of team training and advanced technologies to support that training, and to examine the impact of networked medical technologies and data. A series of evaluations is planned to address high-priority HSI issues in future facilities that are not adequately covered by existing guidelines and standards.

Although we have not completed prioritizing the issues and certainly have not designed the HSI tools to be developed in the present research, we envision that the tool set will reflect the following considerations:

- Existing guidelines and standards from other fields will be brought together, linked, and annotated in the context of specific EMTF-related issues
- The professional and scientific literature supporting or otherwise discussing the guidelines or other issues will be explicitly identified, with appropriate links or extracts embedded in the tools
- Methods for evaluating system or component design against the guidelines will be identified and explained
- Examples to emulate and pitfalls to avoid will be presented, illustrated, and discussed.

CONCLUSIONS

Future EMTFs face a wide variety of HSI issues, some found in current facilities, and some with roots in the emerging technologies for future facilities. HSI, as a systems engineering process, offers the opportunity to address these issues in a systematic way, thereby avoiding fielding systems with problems that could have been identified and avoided. Many of the issues are relatively straightforward human factors issues that can be addressed by applying known principles to design problems in future facilities. Many of the issues, though, go beyond the human factors domain, and will require combined contributions from multiple HSI domains in order to be addressed effectively. In particular, coordination among human factors (for facility and equipment design), manpower (for determining staffing levels), personnel (for skill qualifications), and training (individual and team) is sorely needed to address many of these issues.

Such coordination will not happen without the right guidance from policymakers, but even if so guided, will not be effective without good technical tools that help find satisfactory answers. The present research is an attempt to address HSI issues facing future EMTFs in a comprehensive manner, and will produce tools that can be used by planners, designers, and operators of future facilities to avoid problems before they appear in the field.

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