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Human Systems Integration (HSI) Requirements for First Responders

ABSTRACT

In catastrophic events (e.g., the collective impact of a severe earthquake, devastating tsunami, and nuclear fuel damage as occurred in Northern Japan), the role of the First Responder is critical and the demands on the First Responder are onerous. As First Responders perform various mission critical tasks (i.e., search and rescue, provide medical attention, transport victims, recover remains, fight fires, and monitor radiation) they have needs for a wide variety of technology and support systems. Addressing the human performance issues associated with various technology and systems is critical to ensuring mission success. The Human Systems Research and Engineering (HSRE) Program within the Human Factors and Behavioral Sciences Division of the Department of Homeland Security (DHS) Science and Technology (S&T) Directorate is responsible for developing Human Systems Integration (HSI) processes and best practices to improve the design of technologies for First Responder performance and safety, specifically in the areas of technology usability, reliability, supportability, safety, acceptability, and affordability. HSRE is also developing standards specifically for homeland security technology and systems, including an HSI design standard, in partnership with the National Institute of Standards and Technology (NIST), and a design safety standard for the patient compartment of ambulances, in partnership with BMT Designers and Planners (D&P), the National Institute for Occupational Safety and Health (NIOSH) and NIST. This paper will describe the application of HSI methods and metrics to technology and systems for First Responders.

INTRODUCTION

The Department of Homeland Security (DHS) is committed to helping First Responders nationwide by ensuring that emergency response professionals are prepared, equipped and trained for any situation and by bringing together information and resources to prepare for and respond to a terrorist attack, natural disaster or other large-scale emergency. To achieve this objective, the DHS provides technology, training, standards, guidelines, and grants for First Responder assistance programs. The DHS also provides research and development resources to address the role of human performance as a critical element in the success of First Responder technology and systems. The Human Systems Research and Engineering (HSRE) Program within the Human Factors/Behavioral Science Division of DHS Science and Technology (S&T) is responsible for conducting and managing research to understand human performance considerations associated with current and future DHS missions. The purpose of this research is to examine fundamental human performance processes that serve as a basis for performance enhancement, sustainment, and knowledge and skill acquisition for individuals and teams to support the design of user interfaces. The Program is also developing, demonstrating, and evaluating a standardized process for implementing human systems integration (HSI). Its focus is on defining human performance requirements in the development of systems

and technology, and on evaluating human performance requirements for existing technology. This effort will lead to a greater understanding of the needs of the various Department end-user communities, and development of tools, methods and data for enhanced system design, safety, efficiency, and operational performance. The HSRE Program is described in more detail in Wilson D. P. et al (2009).

As applied to first response, the thrust of the HSI effort is to enhance the capability of the Responder in an emergency situation, and to ensure the First Responder's health and safety is maintained in an extremely hazardous working environment.

The efforts being conducted in the HSRE Program will directly impact efforts to enable and protect First Responders in emergency situations. These efforts include design of emergency information handling systems to enhance performance, design of personal protective equipment (PPE) to safeguard the First Responder, and design of the patient compartment of an ambulance to protect the First Responder and the patient as well as to enhance the ability of First Responders to perform their mission.

HSI IN EMERGENCY INFORMATION HANDLING

The National Institute for Standards and Technology (NIST) asserts that commanders at the World Trade Center on 9/11 did not have adequate information and that interagency information sharing was ineffective. For example, on September 11, 2001 people in the New York City Police Department (NYPD) emergency call center told callers from the World Trade Center to remain in place and wait for instruction from firefighters and police officers. This was the plan for managing a fire incident in the building and the call center staff were following the plan. This was partly countered by public safety workers going floor-by-floor and telling people to evacuate. In the Final Report of the National Commission on Terrorist Attacks upon the United States (2004), the 9-11 Commission, suggests that both the NYPD call center and New York City Fire Department (FDNY) dispatch would benefit from better situation awareness. The Commission described the call centers as not "fully integrated" with line personnel at the World Trade Center. The report suggests the call center and FDNY dispatch were overrun by call volume. Adding to the confusion, radio coverage problems, radio traffic blocking, and building system problems occurred inside the burning towers. The facts as reported in the 9-11 Commission show that much of the equipment worked as designed and users made the best of what was available to them. The major problem, related to HSI, was a lack of situation awareness. Vital pieces of information were not available to communications personnel or to decision makers, for a variety of reasons. A long period of time passed before Call Center personnel even knew which floors had been impacted in either tower. After the South tower collapsed, many First Responders in the North tower were not told of that event and, when the evacuation order came, did not respond with the urgency that they might have displayed knowing of the collapse of the other tower and the likely imminent collapse of their own tower.

Ensuring that critical information is available to First Responders, and that communication of such information is usable, accurate and timely, is an HSI issue. Ensuring that voice communications are intelligible and able to be transmitted in a standard format, are also HSI concerns. The application of the human performance requirements analysis (HPRA), developed by the HSRE Program as part of its standard HSI process, would address these particular issues.

The HPRA addresses human performance requirements, such as information handling, in the context of scenarios selected to be challenging to human performance. The analysis entails 1) the identification of

system functions, 2) the identification of high driver functions by examining lessons learned from legacy systems, and 3) the allocation of functions to human or machine performance, or a combination of both.

The HPRA then proceeds to a development of concepts to support human performance, including approaches to user interfaces, personnel skills and training, personal survivability, and health and safety considerations. The concepts are further developed through the application of modeling and simulation, including human-in-the-loop simulation, and they are assessed in terms of their inherent risk and affordability. Tasks and task performance requirements are developed and assessed in the modeling and simulation exercises. The final result of the HPRA is a definition of requirements, concepts and criteria for human performance in the system. The HPRA is depicted in Figure 1.

In addition to the HPRA, user-centered design of user interfaces, human performance risk assessment, and user-centered test and evaluation are also elements of the HSRE HSI process which are of direct relevance to enhancing the capability of First Responders in an emergency situation.

The HSRE HSI risk assessment process addresses determination of the risks to human performance, including potential for human error, inability to perform, and health and safety hazards associated with user tasks and task sequences for selected scenarios. This HSI risk assessment approach is critical to determining the human performance and safety risks for First Responders in emergency scenarios. The HSI risk assessment and mitigation process was reported by Malone et al (2010). The process is depicted in Figure 2.

The HSRE Program is also addressing the design of First Responder systems and technology from an HSI perspective through the development of numerous HSI best practices concerned with the designing of user interfaces, reducing human performance risk, conducting user-centered test and evaluation, human performance metrics, and identifying personnel and training requirements In addition, the HSRE Program is working with NIST to develop an HSI standard for DHS system user interfaces that would include guidance relevant to First Responder system design. This standard would modeled after MIL STD 1472 Department of Defense Design Criteria Standard, Human Engineering, but directed at the end users of DHS technology and systems.

HSI IN PERSONAL PROTECTIVE EQUIPMENT (PPE)

A total of 2,973 died on 9/11. Of these, 418 were First Responders. Additionally, over 2,000 First Responders were injured as a result of the attack. Since the initial attack, a total of 916 First Responders have died due to health impacts of the 9/11 environment. This fact speaks to deficiencies in the use or design of the PPE used by First Responders that day, and succeeding days at Ground Zero. The major issues with PPE include its effectiveness against specific toxins or contaminants, the capability to be effectively donned and doffed (put on and taken off in a quick and safe manner to ensure integrity of the ensemble), and the capability and comfort of the First Responder to perform tasks while wearing the PPE. The first issue is an engineering problem and not normally within the responsibility of HSI. The ability of First Responders to don and doff the PPE and the impact of wearing the PPE on First Responder performance, are HSI issues. The ability to don and doff PPE as well as the degradation of First Responder capabilities while wearing the PPE, were addressed in a study funded by NIOSH and RAND (Jackson et al, 2002). This report cited problems with respirator life, eye protection, fatigue and heat stress due to continued wearing of PPE in a hot

environment; impaired capabilities to perform tasks wearing the PPE; and discomfort associated with wearing the PPE. There were also cited difficulties with PPE procedures and training.

One of the first efforts to identify HSI requirements for PPE was conducted by Unconventional Concepts Inc. for the U.S. Army's Natick Soldier Center (Christian and Malone, 2005). These authors cite the HSI method of crew resource management as an effective technique of team training for aircrews, which is based on the finding that 80% of accidents are human related, and that poor communication among crew members is often a contributing if not a causal factor. This method could be applied to fire service operations (Christen and Malone, 2005).

Moore-Merrell et al (2008) examined 3,450 injury cases involving firefighters and cited the dominant contributing factors to line-of-duty injuries as: lack of situational awareness (37%), lack of wellness/fitness (28%), and human error (11%). It is interesting to note that these authors define human error as a mistake made by a firefighter rather than caused by a poorly designed process or malfunctioning of equipment. These three contributory factors (all within the aegis of HSI), account for 76% of firefighter injuries.

In a comprehensive human factors assessment of human performance while wearing PPE, Battelle (2004) evaluated sizing and fit, gross body mobility, psychomotor performance (including donning and doffing), speech intelligibility, and visual performance of personnel wearing state-of-the-art PPE ensembles. While the PPE involved in this study was designed for explosive ordnance disposal (EOD) and will differ in some respects from First Responder PPE, the test protocol employed has direct relevance to the First Responder PPE human performance evaluation.

HSRE activities in the assessment of PPE include support to the University of Louisville in a DHS-sponsored study to assess physiological and psychological effects of respiratory protection use among healthcare personnel during routine work activities in a medical intensive care unit.

HSRE prepared a plan to address human performance and safety concerns in the evaluation of the use of the N-95 respirator by healthcare personnel conducting routine work activities in a medical intensive care unit. The HSI process describes HSI application to technology in terms of six interrelated objectives, which include improvements to technology:

1. usability - enhance the ease of use of technology by ensuring that its user interfaces are designed in compliance with human factors engineering criteria;
2. reliability - reduce the incidence of human error in the use of the technology that will impact the availability of the technology to the user, and the safety of the user and other personnel;
3. safety - reduce safety and health hazards associated with technology use;
4. supportability - reduce the time and effort to keep the technology in working order through ease of preventive maintenance, fault isolation, access to supplies, and enhanced training;
5. affordability - reduce costs associated with requiring high entry-level skills of users, and reduce costs associated with training and recovery from human error.
6. acceptability - enhance the level of user satisfaction, and level of comfort, convenience, and user support in the use of the technology.

The University of Louisville study plan describes a simulation exercise in which healthcare personnel (i.e., registered nurses with experience in using respirators and respiratory protection for illnesses capable of transmission via airborne, droplet and contact routes) will wear designated pieces of respiratory protection during the routine performance of their job responsibilities.

HSI IN AMBULANCE DESIGN

A third area of HSRE activity to enhance the performance and safety of First Responders is an effort to develop guidelines for the design of the ambulance patient compartment. The primary mission of Emergency Medical Services (EMS) personnel is to stabilize patients at the site of the emergency and then transport them to medical facilities. A key concern during the transport phase of the EMS mission is the safety of EMTs, as well as patients, riding in the patient compartment. While there are restraints and procedures in place to try to minimize injury risk in the moving ambulance, all too often the EMT must care for the patient during transport, unrestrained, leading to increased risk due to normal vehicle maneuvers, sudden avoidance maneuvers, and accidents.

Green et al (2008) reported that:

- 2002 Bureau of Labor Statistics data estimate that U.S. EMS personnel have an annual fatality rate of 12.7 per 100,000 workers, which is more than three times the national occupational injury rate of 4 per 100,000 workers.
- National Highway Traffic Safety Administration (NHTSA) data indicate that between 1991 and 2000, ambulances were involved in 300 fatal crashes resulting in the deaths of 82 ambulance occupants and 275 occupants of other vehicles or pedestrians. EMS workers accounted for 27 of the fatalities. In addition to the 82 fatalities, 521 ambulance occupants suffered non-fatal injuries of varying severity, including 131 incapacitating, 222 non-incapacitating, and 168 identified as injured with severity unspecified. Riding in the patient compartment was associated with greater injury severity compared to riding in the front seat of the ambulance.
- NIOSH and NHTSA crash investigations show that non-use of occupant restraints resulting in secondary collisions between unrestrained occupants and bulkheads, fixtures, and cabinets is the primary patient compartment injury risk.

As these data illustrate, the risk of injury to both patients and EMTs riding in the back of an ambulance is high. This risk includes a number of factors including (a) crashworthiness of the patient compartment as well as the equipment in the patient compartment such as cabinets; (b) how the patient and EMTs are protected from injury during transport and accidents through restraint systems and airbags; and (c) how well the design and layout of the patient compartment supports EMT mission and task performance while reducing injury risks. Currently here are no HSI or human factors engineering design standards that apply to the design of ambulances to improve the safety of EMTs and patients, and to enhance the performance of EMTs in caring for patients. MIL STD 1472 Department of Defense Design Criteria Standard, Human Engineering and its derivatives do not address the specific and unique challenges posed by the patient compartment of an ambulance. The existing standards that do address ambulance design include GSA's KKK-A-1822F United States federal government guidelines for the proper construction of an ambulance, Ambulance Manufacturers Division (AMD) standards, ASTM F2020 Standard Practice for Design, Construction, and Procurement of Emergency Medical Services Systems (EMSS) Ambulances, and the National Fire Protection Association (NFPA) standard 1917, Standard for Automotive Ambulances do not address human performance or EMT and patient safety. The results of the DHS S&T led effort will be standards and guidelines developed from human performance requirements analysis and laboratory testing, and will be included in the next version of NFPA 1917. The objectives of the HSRE research project are to:

- Develop an understanding of EMT users, their tasks, and the context within which they perform their tasks;
- Perform the appropriate analyses to understand human performance and safety risks associated with EMT task performance as well as current and emerging technologies that support the EMT mission;
- Define human factors, safety and ergonomic requirements for patient compartment design;
- Develop and test design concepts for patient compartments as well as coordinate those concepts with other efforts such as the NIOSH crashworthiness research;
- Develop a preliminary draft of human factors and safety design guidelines for ambulance patient compartments.

CONCLUSIONS

HSI is a critical determiner of First Responder performance and well being by virtue of its emphasis on human performance requirements, user interface design and evaluation, personnel skills and training, and survivability, health, and safety. The HSI processes, best practices, standards and data under development by the HSRE Program in the Human Factors/ Behavioral Sciences Division in the DHS S&T are having a direct impact on First Responder capability and safety. The results of HSI application to First Responder systems, equipment, technology, and training systems include the following:

- Workloads that are acceptable;
- Manning that is optimal;
- Utilization that is efficient;
- Error and accident rates that are minimal;
- Performance that is effective and teams that are productive;
- Working environments that are safe and facilities that are habitable;
- Information and knowledge that is readily shared and understood;
- Communications that are intelligible and meaningful;
- Interfaces that are usable;
- Training that is responsive to requirements and is effective;
- Procedures that are consistent;
- Jobs that are enriching;
- Duty cycles that are satisfying;
- Systems that are affordable.

The application of HSI principles and best practices addresses a critical gap in the domain area of Emergency/First Response. Previously there has been no systematic approach that addresses human performance and safety issues for this particular community as a whole. The efforts described provide a good first step in this direction. Our First Responders are a vital asset and we must ensure that they are able to successfully perform the tasks that are essential for mission success.

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AUTHORS BIOS

Darren P. Wilson currently serves as a Program Manager within the Department of Homeland Security (DHS) Science and Technology Directorate's Human Factors / Behavioral Sciences Division. The focus of the research and engineering efforts Mr. Wilson is currently managing are aimed at ensuring human systems integration analysis, design and test activities are incorporated into DHS research, acquisitions and technology development. He received both his B.S. and M.S. in Human Factors and Systems from Embry-Riddle Aeronautical University and is a Board Certified Human Factors Engineering Professional (CHFEP).

Janae Lockett-Reynolds, Ph.D., is a Program Manager for the Human Systems Research & Engineering Program in the Department of Homeland Security, Science and Technology Directorate. Her efforts have resulted in the development of a standardized HSI process that is currently being implemented on various DHS S&T Projects and Acquisition Programs, as well as the development of DHS Acquisition Policy that addresses HSI across the system lifecycle. Dr. Lockett-Reynolds has also worked as an Engineering Psychologist for NSWC Dahlgren and the Human Performance Center NAVSEA Detachment.

Thomas B. Malone, PhD is President of Carlow International Incorporated and has 48 years experience in the development and application of HSI to complex systems. He is Past President of the Human Factors and Ergonomics Society of which he is a Fellow, as well as being a Fellow of the Washington Academy of Sciences.

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Larry W. Avery is Principal Human Factors Analyst at BMT Designers and Planners. He has extensive experience in applying human factors engineering technology and methods to complex systems. He is currently leading a project to develop human performance and safety standards for the design of ambulance patient compartments.

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The findings and conclusions in this paper are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health (NIOSH).

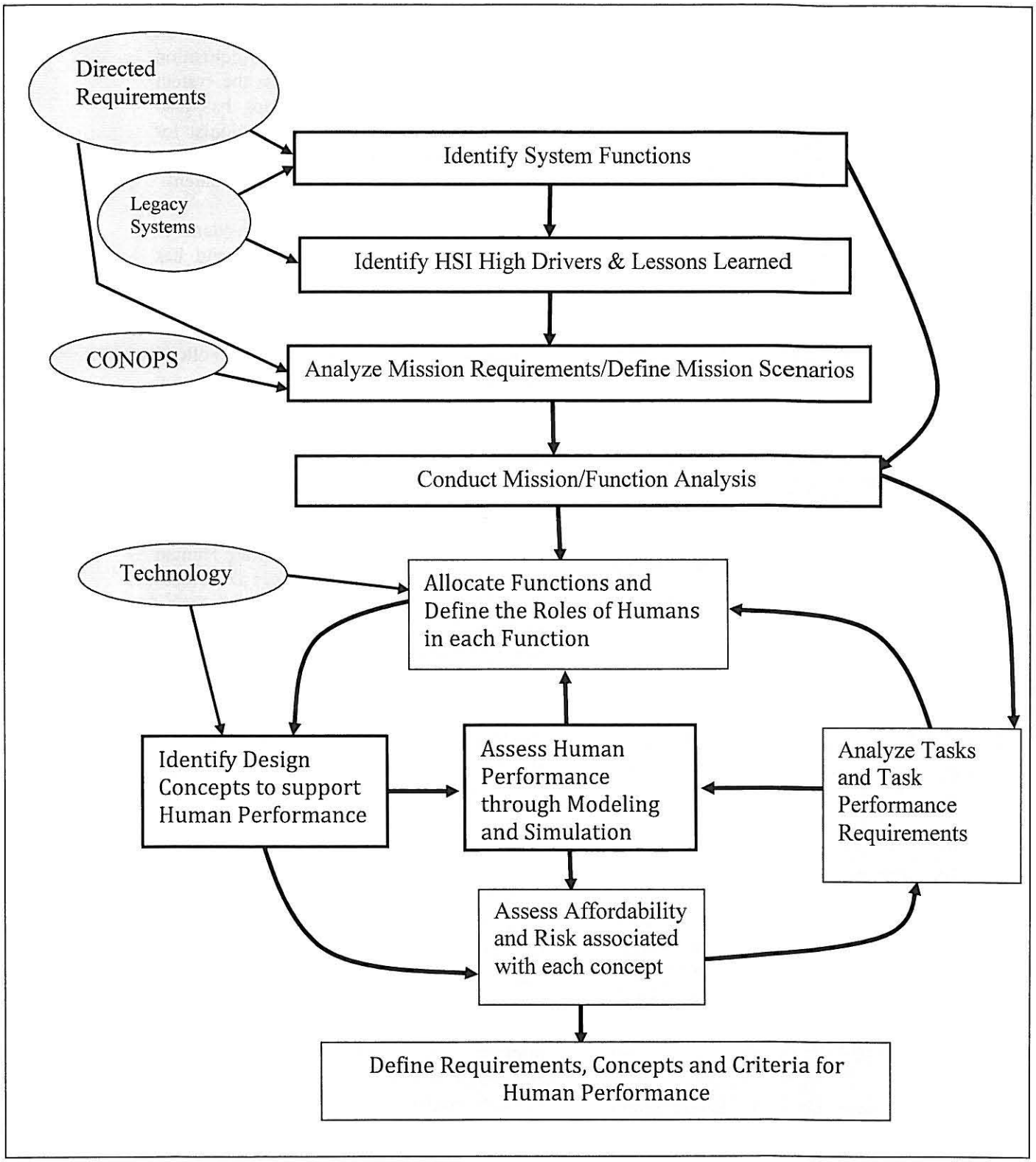

Figure 1 The HSRE HSI Human Performance Requirements Analysis Process

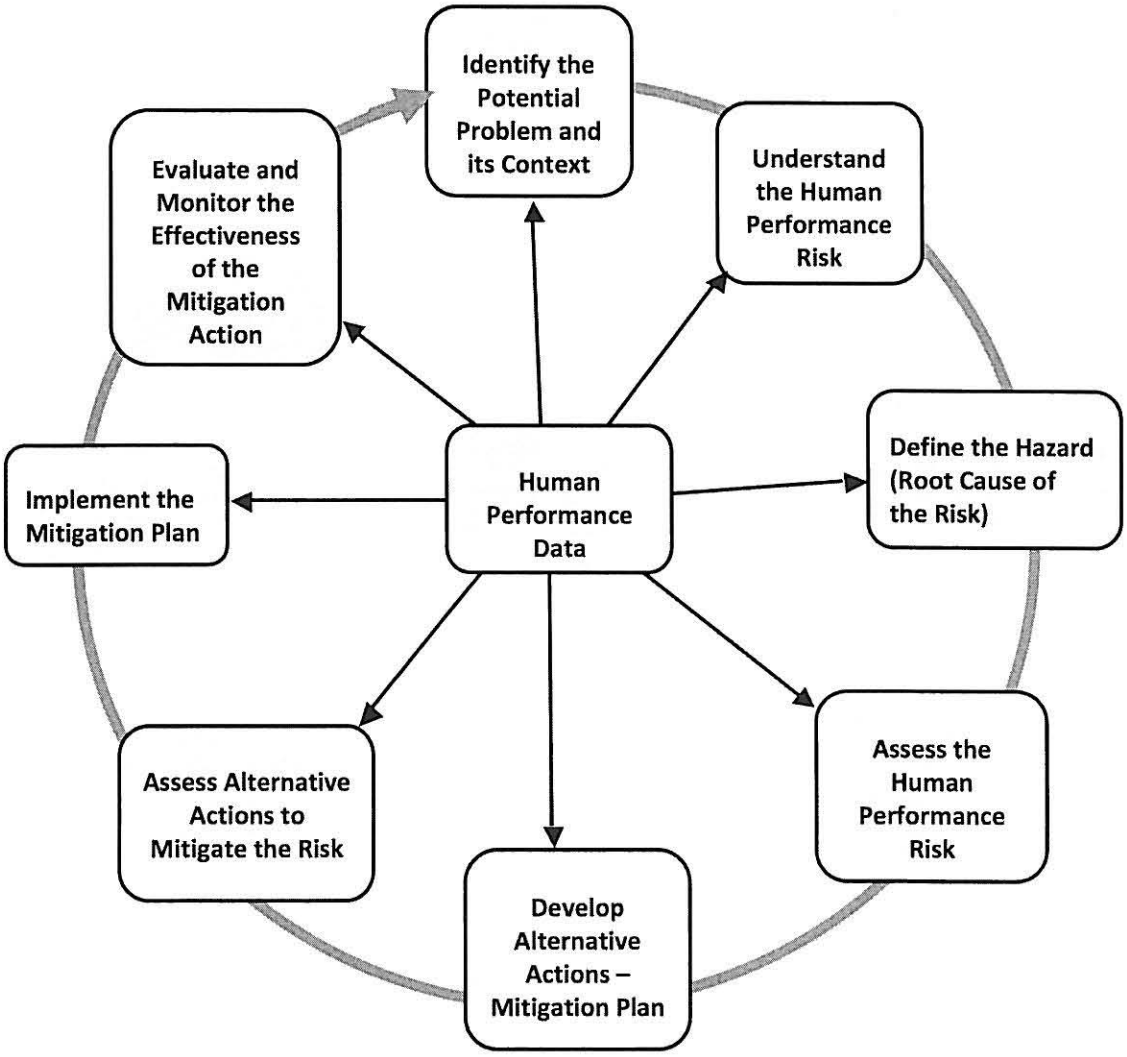

Figure 2. The HSRE HSI Risk Assessment and Mitigation Process