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QUANTIFYING HUMAN SYSTEMS INTEGRATION CONSIDERATIONS FOR NOVEL HELMET MOUNTED DISPLAY (HMD) DEPLOYMENT

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ABSTRACT

As U.S. Army leadership continues to invest in novel technological systems to give warfighters a decisive edge for mounted and dismounted operations, the Integrated Visual Augmentation System (IVAS) and other similar systems are in the spotlight. Continuing to put capable systems that integrate fighting, rehearsing, and training operations into the hands of warfighters will be a key delineator for the future force to achieve and maintain overmatch in an all-domain operational environment populated by near-peer threats. The utility and effectiveness of these new systems will depend on the degree to which the capabilities and limitations of humans are considered in context during development and testing. This manuscript will survey how formal and informal Human Systems Integration planning can positively impact system development and will describe a Helmet Mounted Display (HMD) case study.

1. INTRODUCTION

For hundreds of years, militaries have recognized that battlefields expose humans to environmental extremes. While history is replete with interesting and somewhat isolated examples of special considerations for humans on the battlefield (such as the Prussian *Potsdamer Riesengarde* ("Potsdam Giants") of the 1600s, which required special acommodations due to their unusual size), it was not until the 1800s that scientific rigor (although preliminary) began to take shape around quantifying the needs and capabilities of people for specific battlefield contexts [1]. Military interest in this topic began in earnest during the American Civil War and has continued to evolve and mature to this day.

Unfortuntely, despite the fields of Human Factors Engineering (HFE) and Human Systems Integration (HSI) being well established, frequently the human element is not considered early or often enough throughout military acquisition [2]. This remains true despite a general sense that failure to consider performance characteristics of human operators throughout a development process leads to inefficiencies, catastrophic system failures, and loss of human life.

There remains a pressing need for integrating an understanding of the needs and capabilities of humans into the development process across the Department of Defense (DoD). While an HSI Plan might be mandated for certain programs [3], it is important that these plans are not simply checkboxes, but rather deliberate processes that ensure that all human-related technical concerns are properly addressed across analysis activities, planning, design, development, and testing. Doing so is a key way to control total ownership costs on a program and manage manpower costs, which are among the highest cost drivers in the DoD.

Many HSI practitioners extoll the virtues of applying sound human-centered practices for ongoing development efforts across the DoD, but often this is done without a clear presentation of the "how," leaving program managers and developers guessing at how to oversee proper implementation.

Although everyone on a development program may acknowledge and understand that HSI considerations are important, if they lack a concrete understanding of how to do it well (if at all), new interventions are necessary to assist them. This manuscript will provide an overview of HSI program planning in the context of emerging Helmet Mounted Display (HMD) technologies that will be increasingly critical to the American warfighter, and will describe a case study where, in the absence of a formal HSI Plan, human-centered considerations are being adressed by a team that has already begun program development.

2. HSI DOMAINS

HSI should first and foremost be understood as a Systems Engineering process. Its purpose is to ensure that all human-related concerns are addressed adequately during system analysis, planning, design, development, and testing. HSI should always be understood as a management strategy as much as a technical one, the goal of which is to reduce total ownership costs. Therefore, implicit in any HSI effort is the consideration of processes that deliver value in terms of manpower costs (direct and indirect), opportunity costs, risk, and long-term costs (that is, those associated with attrition and morale).

HSI (particularly in military contexts) is considered across various domains. Each domain of HSI is a subset of a larger technical area. HSI domains are interconnected and interdependent, and therefore HSI as a strategy facilitates tradeoffs across the domains. For this reason, it is critical that analysts avoid looking at any one domain in isolation.

While opinions vary as to how many domains of HSI there are, the authors will consider for this manuscript eight domains: Human Factors Engineering, Manpower, Personnel, Training, Safety, Occupational Health/Environment, Survivability, and Habitability. Each is expounded upon in the following subsections in the context of HMD development, using domain definitions sourced from Georgia Institute of Technology curriculum.

2.1. Human Factors Engineering

The Human Factors Engineering (HFE) domain integrates considerations related to human capabilities and limitations into system analysis, definition, development, and evaluation to influence human-machine design for optimal total system performance.

The primary question that program managers and development teams should consider around the HFE domain is how decisions specifically influence design. HFE is about the realization of design criteria, and is therefore narrowly construed to appraise design aspects such as colors, controls, displays, and their intersection with human needs and limitations in a given context. A large portion (but not all) of HSI activities fall into the HFE domain.

In the context of HMDs, the HFE considerations are numerous and include basic interface design characteristics, such as color, text, and control selection, to ensure legibility and usability. Higher-level design features, such as layout, customizability, and automation, that can reduce or mitigate errors and facilitate effective and efficient use of the system, are also within the purview of the HFE domain.

2.2. Manpower

The Manpower domain pertains to the assessment of human capital requirements in terms of the number of personnel by category who are required, authorized, and potentially available to train, operate, maintain, and support a fielded system.

The primary question that program managers and development teams should consider around the Manpower domain is “do I have the right number of people?” This includes the often-neglected system maintainer.

In the context of HMDs, the Manpower domain is concerned with how many people are needed to perform required tasks. This number may be impacted by HMD-specific capabilities or limitations, which could enable operation with fewer people than traditional interfaces or could require additional people because of inefficiencies of HMD interaction. Manpower issues may also cross over with the HFE and Training domains; for example, how to ensure teams of users work together effectively when they are in the inherently isolating HMD environment.

2.3. Personnel

The Personnel domain addresses the comprehensive assessment of human attributes (knowledge, skills, abilities, and cognitive and physical capabilities) required to operate, maintain, and support a system, versus the availability of those attributes in the actual and potential personnel pool.

The primary question that program managers and development teams should consider around the Personnel domain is “do I have the right people?”

The Personnel domain is deeply concerned with human attributes expressed as Knowledge, Skills, and Abilities (KSAs). What KSAs are required to operate and maintain HMDs? What new KSAs are required for command and control of unmanned vehicles using an HMD as compared to traditional interfaces? Once the required KSAs are identified, analysis will reveal which Military Occupational Specialties (MOSs) most closely align with the required KSAs, what KSA gaps exist, and how best to close those gaps (e.g., by defining an Additional Skill Identifier (ASI) or by creating a new MOS).

2.4. Training

The Training domain considers the design and development of the instructional content, material resources, and support required to provide operators, maintainers, and support personnel with the requisite knowledge, skills, and abilities to properly operate, maintain, and support fielded systems.

With regard to the Training domain, program managers and development teams should be concerned with how well training maps to personnel needs. In this way, Training as a domain is about more than just the instructional content itself.

When considering HMDs, the Training domain can inform the types of training required for HMDs, both to use and maintain the HMD itself and to use the HMD to execute missions. The Training domain also considers the instructional strategies that will best impart the required KSAs to trainees.

Furthermore, the Training domain can identify opportunities for using HMDs for future force training and mission rehearsal in augmented or virtual reality, in keeping with the Army vision for fighting with the same system with which soldiers train.

2.5. Safety

The Safety domain considers the development and assessment of system characteristics and associated procedures that minimize the potential for mishaps causing death or injury to operators, maintainers, and support personnel or threaten the operation of a fielded system.

Implicit to the Safety domain of HSI is a consideration of mishaps or accidents, which distinguishes it from the Occupational Health/Environment domain that considers longer-term hazards.

For HMDs, the Safety domain can assess the potential for mishaps related to soldier attention focused inside the HMD, resulting in a loss of Situational Awareness (SA) of the surrounding environment, particularly in a dismounted use case.

2.6. Occupational Health/Environment

The Occupational Health/Environment domain pertains to the development and assessment of system design features and work assignment schedules that serve to minimize the (often) longer-term exposure to workplace hazards which contribute to the risk of injury, acute or chronic illness, or disability; and/or enhance job performance of personnel who operate, maintain, or support a fielded system.

This domain is primarily concerned with long-term exposure to potentially adverse conditions. This is a particularly important domain for DoD programs since there is a strong interest in reducing financial and performance costs associated with working conditions.

For HMDs, the Occupational Health/Environment domain can evaluate the long-term health effects of wearing an HMD for extended periods of time, including chronic neck injuries due to improperly balanced or improperly fitted HMDs and vision issues associated with up-close viewing of displays in the future.

2.7. Survivability

The Survability domain involves the comprehensive consideration of system design features and characteristics in order to reduce the likelihood of death or severe injury in the presence of life-threatening conditions such as enemy attack, fire, or collision.

This domain is about more than just mitigating fratricide, as its comprehensive consideration should impact system features that enhance warfighter and system survivability.

In the context of HMDs, the Survivability domain may consider approaches for ensuring the safety of the HMD operator while maintaining operational capabilities; that is, what steps can be taken to protect the HMD operator while his attention is focused on remote activities? The Survivability domain could also consider ways to guard against friendly fire/fratricide due to incomplete SA and a limited view of the remote environment.

2.8. Habitability

The Habitability domain integrates considerations about characteristics of systems, facilities, social interactions, and living conditions to promote high levels of personnel morale, quality of life, safety, health, and comfort adequate to sustain maximum personnel effectiveness, support mission performance, and avoid personnel recruitment and retention problems.

This domain is primarily concerned with living conditions, as opposed to the Occupational Health /Environment domain that focuses on working conditions.

For HMDs, the Habitability domain could consider motion sickness due to visual-vestibular mismatch in extended HMD use, including temperature and ventilation considerations that can mitigate or exacerbate motion sickness. The Habitability domain could also assess bright and/or noisy working conditions, which may degrade HMD functionality and reduce operator effectiveness.

Figure 1. An SA-62 HMD system in a laboratory at the Georgia Tech Research Institute (GTRI).

3. IMPACT CASE STUDY: THE HMD GUIDEBOOK

Idealy, every program would have a complete HSI program (as defined in DODI 5000.95) in place early in the acquisition process. This HSI program is intended to ensure that human considerations are integrated into the overall Systems Engineering process in order to optimize total system performance, minimize total ownership costs, and ensure that the system accommodates the characteristics of the user population that will operate, maintain, and support it. Ongoing and future HMD programs are no exception.

For various practical reasons (e.g., lack of funding, no explicit requirement, short timeline), programs may omit or shortchange the HSI program. However, it is still critical for these programs to consider HSI issues so that they can reap the benefits provided by a human-centered design approach. In the absence of a comprehensive HSI Plan, even for programs that are already underway, one way to bridge the gap is to leverage an HSI Guidebook as an informal method to incorporate HSI thinking.

Intended to compliment Playbooks (which define tactics, techniques, and procedures) and Menubooks (which define user interface details), Guidebooks are reference documents created by HSI practitioners that distill critical HSI direction from MIL-STDs, other government and industry standards documents, current research, and HSI best practices, tailored specifically for a particular acquisition program. An HSI Guidebook helps designers, developers, and program managers identify and address the major HSI considerations that impact their program. The Guidebook approach avoids blanket “comply with MIL-STD-1472” directives, which can be overwhelming, by giving tailored and focused guidance to designers and developers. Guidebooks can also bring valuable insights from non-DoD sources (such as the FAA or NASA), which may evolve more rapidly than DoD standards, into the acquisition process.

This paper describes the initial release of an HSI Guidebook for a program investigating the use of HMDs for command and control of remotely-operated vehicles as a catalyst for the development of an informal HSI planning concept.

The first step in the development of the HMD Guidebook was to become familiar with the goals and characteristics of the HMD program. HSI practitioners reviewed CONOPS and other program materials to identify the human’s role in the system, the components and interfaces the human will interact with, the tasks the humans will perform, the environments in which the human will operate, and other factors. This information was assessed in the context of each of the HSI domains to identify potential

HSI pitfalls, which were then written as a series of problem statements or “considerations.” Applicable standards, guidelines, and research papers were reviewed to extract actionable guidance that could be applied to mitigate or avoid each of these pitfalls.

Each consideration in the HMD Guidebook is a brief (two to four pages), self-contained document that begins by defining the details of the consideration and describing the consequences if it is not properly addressed. Then one or more “applications,” which are approaches for designers and developers to apply to avoid or mitigate those consequences, are presented. Finally, a short list of references is provided; the references include specific guidelines or sections from standards documents that are relevant to the consideration, online tools, and links to longer-form research that provides a deeper dive into the topic.

Figure 2. Pages from the initial release of the GTRI-produced HMD Guidebook.

For the initial release of the HMD Guidebook, twenty-two considerations focused primarily on the HFE domain (with some forays into other domains) were grouped into the following topic areas, which were organized from broad and widely-applicable to domain-specific:

- *User Interface:* ensuring that the fundamentals of the interface (color contrast, text characteristics, control size and layout) result in an interface that is usable for the intended task in the expected environment.
- *Operator Environnment:* identifying ways in which the operating environment may degrade operator or system performance.
- *Display Device:* issues associated with the HMD hardware and its effect on the operator (such as the potential for Occupational Health issues due to extended use).
- *Controls and Input Methods:* guidance for how users should interact with the system, given the assortment of non-traditional interaction methods supported by an HMD system in this context.
- *Alerting:* how best to ensure that the operator’s attention is focused where it is required without distracting or overwhelming the operator.
- *Mobility:* unique isssues associated with operating a vehicle remotely and with limited sensory feedback.
- *Payload Operation:* optimizing controls and displays for sensor and weapon systems to enhance operator performance.
- *Coordination and Collaboration:* ensuring effective communication and coordination within and between teams of operators.
- *C2 of Multiple Assets:* enabling operators to safely and effectively monitor and control multiple assets simultaneously.

The topic areas of the HMD Guidebook relate to areas of concern that might hold programs back from effectively meeting the objectives of the U.S. Army’s Robotic and Autonomous Systems Strategy (RAS). Of notable interest are the objectives addressing SA and lightening soldiers’ physical and cognitive workloads. Further, the topic areas are well-suited to help program managers, designers, and software developers understand how to meet long-standing multitasking challenges with Human Robot Interfaces (HRIs). These include SA-oriented design needs such as support for visually demanding tasks, understanding robot localization and situatedness, user interfaces for higher level SA, and systematic assessments of contextualized information needs [4].

As autonomous agents on the battlefield increase in number and capabilitity, the amount of perishable and highly dyamic combat data presented to warfighters will continue to exponentially increase. In this way, the human-machine team's effectiveness deteriorates under the finite cognitive processing capabilities of humans. A future where the tyranny of warfighter multitasking is addressed will be the product of programs where HSI is kept at the forefront.

Many programs operate without a formal HSI Plan. The desire for speed and the common reality of budget limitations only compound this challenge. But that does not mean that programs that are seeking to compress their development cycle cannot benefit from the technical and management strategies that HSI planning represents. The HMD Guidebook was conceived to address this challenge and illustrates the HSI Guidebook concept, which the authors consider a part of what they call "informal HSI planning."

This idea could be applied to any number of other programs and could be particularly impactful in the areas of user interface design that are extensible to the command and control of cross-platform teams of unmanned systems on the battlefield, converged battlespace management solutions, intel applications, or even real-time visualizations of the electromagnetic spectrum. Future HSI Guidebooks could also extend beyond user interface applications and could be applied as a quick reference solution to other HSI domains such as Manpower, Personnel, Training, or Environment for a program.

Another highly relevant research area for the DoD is addressing the "unobtrusive requirement"[5] for future soldier wearable sensors and systems. Effectively stewarding warfighters into a future that truly embraces the benefits of fighting, rehearsing, and training with the same system will require program managers to be intentional around the intersection of ubiquitous computing and human systems considerations.

4. CONCLUSION

Future systems (such as HMDs) that represent novel approaches to making the future force more effective can be flawless in vision but doomed to failure in execution if the needs and limitations of warfighters in context are not considered and if lifecycle costs are not tempered by HSI-centric thinking. A successful future where HMDs are integrated into regular warfighting operations wherein warfighters fight, rehearse, and train with a common platform can only be realized if HSI considerations are placed at the forefront as a programmatic priority impacting everything comprehensively from mission design to test and evaluation.

The development of HSI Guidebooks is one way to help ensure that visions of the future are realized by enabling designers, developers, program managers, and test and evaluation practitioners to quickly and easily consider critical human-related design criteria in the absence of a comprehensive HSI program.

5. REFERENCES

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