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DEFENSE ANALYSIS CAPSTONE REPORT

ROBOTIC AUTONOMOUS SYSTEMS:
MANNED / UNMANNED TEAMING (RAS-MUM-T)

by

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13. ABSTRACT (maximum 200 words)

Rapidly changing technology and near-peer adversaries in the Great Power Competition are dramatically changing the battlefield of the future with artificial intelligence and autonomous systems emerging as major components in small unit maneuvers. The Hyper-Enabled Operator System (HEO) is designed to allow operators to interface with autonomous systems without increasing users' cognitive load in order to achieve successful manned-unmanned interactions that increase survivability and lethality of operators. For HEO to succeed, however, it is essential that all technical components coalesce around a strong human machine interface (HMI) and that architecture for sensors, weapons, computing, and radio systems are designed for human operators in actual use cases. The goal of this capstone project is to emphasize the importance of HMI-centered design as a key pillar of the HEO system and to caution against implementing technology without thoroughly considering how it will be used by operators in actual war-fighting situations. Too much focus on developing HEO technology without sufficient attention to how such innovative technology will be adopted by the end-user creates a gap in technical capacity and human capabilities that can lead to cognitive overload for users and wasted development and procurement resources.

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ABSTRACT

Rapidly changing technology and near-peer adversaries in the Great Power Competition are dramatically changing the battlefield of the future with artificial intelligence and autonomous systems emerging as major components in small unit maneuvers. The Hyper-Enabled Operator System (HEO) is designed to allow operators to interface with autonomous systems without increasing users' cognitive load in order to achieve successful manned-unmanned interactions that increase survivability and lethality of operators. For HEO to succeed, however, it is essential that all technical components coalesce around a strong human machine interface (HMI) and that architecture for sensors, weapons, computing, and radio systems are designed for human operators in actual use cases. The goal of this capstone project is to emphasize the importance of HMI-centered design as a key pillar of the HEO system and to caution against implementing technology without thoroughly considering how it will be used by operators in actual war-fighting situations. Too much focus on developing HEO technology without sufficient attention to how such innovative technology will be adopted by the end-user creates a gap in technical capacity and human capabilities that can lead to cognitive overload for users and wasted development and procurement resources.

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LIST OF ACRONYMS AND ABBREVIATIONS

AFSOC	Air Force Special Operations Command
AI	Artificial Intelligence
AISUM	Artificial Intelligence for Small Unit Maneuver
ARSENL	Advanced Robotic Systems Engineering Laboratory
ATAK	Android Tactical Assault Kit
ATM	Automated Teller Machine
C2	Command & Control
CBAM	Concerns-Based Adoption Model
CCS	Common Control Station
CE	Civil Engineering
CL	Cognitive Load
COP	Common Operating Picture
COTS	Commercial Off-The-Shelf
DOD	Department of Defense
EAST	Event Analysis of Systemic Teamwork
EEG	Electroencephalography
ECL	Extraneous Cognitive Load
EMS	Electromagnetic Spectrum
FOL	Forward Operating Location
FRAM	Functional Resonance Method
GAO	Government Accountability Office
GCL	Germane Cognitive Load
GDTA	Goal Directed Task Analysis
GPS	Global Positioning System
GUI	Graphical User Interface
HASO	Human-Autonomy System Oversight
HCI	Human Computer Interaction
HEO	Hyper Enabled Operator
HF/E	Human Factors/Ergonomics
HMI	Human Machine Interface
HSI	Human Systems Integration
HUD	Heads-Up Display
ICL	Intrinsic Cognitive Load
IED	Improvised Explosive Device
IoT	Internet of Things
ISR	Intelligence Surveillance Reconnaissance
JSOC	Joint Special Operations Command
JVAB	Joint Vulnerability Assessment Branch
NPS	Naval Postgraduate School
NSW	Naval Special Warfare
NSS	National Security Strategy
PAB	Piezo-acoustic Backscatter

PDMS	Polydimethylsiloxane
PET	Polyethylene Terephthalate
MEMS	Microelectromechanical Systems
ML	Machine Learning
MUM-T	Man and Unmanned Machine Teaming
NSIB	National Security Innovation Base
OODA	Observe-Orient-Decide-Act
OT&E	Operational Test & Evaluation
PAAS	Protection As A Service
PC	Polycarbonate
POI	Point of Interest
RAS	Robotic Autonomous System
RRTO	Rapid Response Technology Office
RTB	Return To Base
SAR	Search and Rescue
SATLAS	Semi-Autonomous Threat Learning Alert System
SIGCHI	Special Interest Group on Computer–Human Interaction
SME	Subject Matter Expert
SOCOM	Special Operations Command
SOF	Special Operations Forces
STS	Sociotechnical System
SUM	Small Unit Maneuver
sUAV	small Unmanned Aerial Vehicle
TACPS	Joint Terminal Area Controller
TRL	Tactical Reediness Level
UAM	Urban Air Mobility
UAS	Unmanned Aerial System
UCAS	Unmanned Combat Air System
USAF	United States Air Force
USMC	United States Marine Corps
USSOCOM	United States Special Operations Command
UX/UI	User Experience/User Interface
UxV	Unmanned Air/Sea/Land Vehicle
WiSAR	Wilderness Search and Rescue

I. THE BATTLEFIELD OF THE FUTURE

The operator's role on the battlefield of the future will be profoundly different than it is today. Rapidly changing, powerful technology means more unmanned systems under operator control will be the first through a breach, and sensors will translate radio traffic into 3D audio headphone feeds to provide precise positional data.[1] Near-peer adversaries in the Great Power Competition will also have similar technologies and the training to leverage them effectively. The U.S. military advantage will rely on its doctrinal and organizational integration of Artificial Intelligence and automated systems technology into the wider conventional and allied forces and across multiple domains to capitalize on the vast networks of collected information.[2] To prevent cognitive overload from burdening the end user, the military must ensure that the data is understandable, visible and most importantly linked in a reliable and intuitive human machine interface (HMI). Adopting early integration with artificial intelligence and autonomous systems, tailoring user interface design, and conducting appropriate training will build operators' trust in the salience of information the systems provide.[3]

A. THE HYPER-ENABLED OPERATOR

The Hyper-Enabled Operator (HEO) system is designed to allow operators to interface with autonomous systems without increasing the user's cognitive load in order to achieve successful manned-unmanned interactions to increase survivability and lethality of operators.[4] The goal of the HEO is to ensure the right information is given to the right

[1] Ala Al-Fuqaha, Mohsen Guizani, Mehdi Mohammadi, Mohammed Aledhari, and Moussa Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Communications Surveys & Tutorials* 17, no. 4 (2015): 2347–2376.

[2] Scott Flanick, Andrew Davidson, Ashley Yoo, John David Mote, and Vikram Mittal, "Expanding the Hyper-Enabled Operator Technology across the Special Forces Enterprise," *Industrial and Systems Engineering Review* 7, no. 1 (May 2019): 2–8.

[3] Alvin Toffler, *Future Shock* (New York: Bantam Books, 1971),181.

[4] Flanick et al., "Expanding the Hyper-Enabled Operator," 2–8.

person at the right time in order to ensure they can be more effective.[5] The HEO concept evolved from the now discontinued Tactical Assault Light Operator Suit (TALOS) project—a powered-armored exoskeleton suit that uses augmented reality situational awareness for the operator.[6] HEO abandoned the exoskeleton concept and instead integrated robust sensing, processing, and augmented reality technology that empowers operators across an array of mission types from counter-terrorism to mobility operations.[7]

B. PROJECT GOAL

The goal of this capstone is to highlight the importance of Human Machine Interface-centered design as a key pillar of the HEO system and to ensure organizational changes allow for operators proper training to build trust and proficiency with artificial intelligence (AI) and unmanned autonomous systems (UASs). For the hyper-enabled operator concept to succeed, it is essential that all technical components coalesce around a strong human machine interface (HMI) architecture which links all sensor inputs, weapons, and radio systems with seamless computing to provide the human operator maximum situational awareness while reducing their cognitive overload. Additionally, identifying cognitive overload through performance and neuro-physiological data to raise the operators' cognitive advantage, and then individually adjusting training, is the beginning to creating organizational changes which will optimize the individual's impact on the battlefield.

C. PROBLEM STATEMENT

The HEO systems are not properly designed to consider the human cognitive limitations and the optimal design features to optimize the human's tasks and decision-making abilities.[8] This creates a gap in technical capacity and human capabilities that can

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[5] Flanick et al., 2–8.

[6] Flanick et al., 2–8.

[7] Flanick et al., 2–8.

[8] Julie Adams, "Cognitive Task Analysis for Unmanned Aerial System Design," *Handbook of Unmanned Aerial Vehicles*, edited by Kimon P. Valavanis and George J. Vachtsevanos, 2425–41. Dordrecht: Springer Netherlands, 2015.

lead to cognitive overload for users and wasted development and procurement resources. This N aims to fill this gap by focusing on the unique needs of Artificial Intelligence for Small Unit Maneuvers (AISUM) and the challenges of innovation adoption.

D. AREAS OF RESEARCH

This report examines the importance of Human Machine Interface-centered design through six critical lenses:

- The major elements that define **HEO**
- The specific needs of **AISUM**
- The nature of Cognitive Load in Neuroscience
- The crucial elements of good User Experience and User Interface (UX/UI)
- The analysis of human behavior and interaction through **Sociotechnical Systems (STS)**
- The challenges and opportunities of **Innovation Adoption**

Figure 1. Project Visualization

E. KEY TAKEAWAYS

HEO leverages HMI to provide operators with actionable intelligence and precise information by integrating sensing technology, algorithm and processing technology, communications technology, and system level technology.[9] These technical requirements in turn drive enabling technologies—applied innovations that foster rapid and radical change in user capabilities.[10]

As AI SUM conducts more robust tasking, the human's ability to control the machines must become increasingly more reliant on robust autonomy and artificial intelligence to reduce the cognitive burden and the team size required to operate the machines.[11]

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9 Al-Fuqaha et al., "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," 2347–2376.

10 Mick Ryan, *Man-machine Teaming for Future Ground Forces* (Washington, DC: Center for Strategic and Budgetary Assessments, 2018), 26.

11 Adams, "Cognitive Task Analysis for Unmanned Aerial System Design," 2426.

Managing cognitive load through proper training with artificial intelligence-enabled automated systems will help operators gain trust in their systems. Additionally, cognitive measurement tools should be used during training to identify and then remedy situations which cognitively overload an individual. Training to each specific situation should be individualized based on the operator's strengths and weaknesses identified during this advanced method of instruction. For example, the importance of the data provided to the operator can be adjusted through auditory, visual, tactile, and kinesthetic methods to prevent cognitively overloading the individual. And finally, improving the Human Machine Interface design through tailored systems based on individual cognitive assessments will help each individual perceive and receive information scaled to their innate strengths and weaknesses.[12]

UX/UI Design is a crucial lynchpin in a Human-Machine Team; cumbersome user interface removes the operator from the battlefield while reducing the drone swarm utility. To improve innovation adoption, user interface/user experience must be highlighted and emphasized throughout development.

Sociotechnical System Thinking finds that effective jobs and workflows are those that consider this interaction of technical and human needs by balancing the operator's intrinsic needs with the operation's need for technical efficiency.[13]

Innovation adoption involves independent variables on the individual and collective levels, including the characteristics of leaders in the organization, characteristics of the internal structure, and external characteristics of the organization.[14] The size and complexity of the DOD's mission and systems creates friction and latency into decision-

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[12] JJ Walcutt, Cort Horton, Dhiraj Jeyanandarajan, Walt Yates. "Neuro-Optimization for Accelerated Learning Pace and Elevated Comprehension: Military Applications," 2020, 14.

[13] Richard Daft, *Organization Theory and Design,*12th ed. (Boston: Cengage Learning, 2016), 462.

[14] Ismail Sahin, "Detailed Review of Rogers' Diffusion of Innovations Theory and Educational Technology-Related Studies Based on Rogers' Theory," *Turkish Online Journal of Educational Technology-TOJET* 5, no. 2 (2006): 14–23

making, adding additional layers of required coordination, rules, regulations and other mechanisms that inherently hinder the pace innovation.[15]

F. CONCLUSIONS AND RECOMMENDATIONS

- USSOCOM's concept of the HEO and NSW's AISUM must optimize the UX/UI in order to mitigate cognitive and information overload.
- This requires not just developing the technology to completion but ensuring SOCOM and its subordinate commands implement the right innovation adoption and sociotechnical approach in order to successfully realize the concept of the HEO.
- Failure to account for human user in major weapon systems programs leads to serious issues impacting operator survivability not to mention unnecessary redesigns, delays, and additional financial cost.
- The Special Operations Forces Community must prioritize early training with Artificial Intelligence and automated systems to build the operators' trust in the salience of information provided so the operators can decrease the cognitive effort required to monitor the unmanned systems.[16]
- The military should invest in neuro-physiologic measuring devices which can identify and quantify real-time cognitive overload in a dynamic, Full Mission Profile (FMP) scenario to mitigate the detrimental effects of cognitive overload on operators in combat.
- Refocus the Preservation of the Force and Families (POTFF) to emphasize the importance of wearable technology to achieve individual Neural

[15] U.S. House Armed Services Committee on U.S. Pacific Command Posture, 115th Cong. (2017) (Statement of Dr. Eric Schmidt), 1.

[16] Mica R. Endsley, "From Here to Autonomy: Lessons Learned From Human–Automation Research," *Human Factors: The Journal of the Human Factors and Ergonomics Society* 59, no. 1 (February 2017): 8, https://doi.org/10.1177/0018720816681350.

Fitness—or the balance of cognitive, emotional, and physical fitness.[17] As the Preservation of the Force and Families initiative in the military continues, continuous physical and mental health monitoring using data collected from emerging wearable devices should be invested in and become a daily part of the individual health and neural fitness.

[17] Andrew Huberman and Sam Golden, “Biomechanical Acoustic Devices and Measuring Biologic Signals,” (Zoom lecture, Stanford University, CA and Northwestern University, MI, August 5, 2020).

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APPENDIX A. HYPER ENABLED OPERATOR

> Ten years from now, if the first thing going through the door after a breach is not an unmanned system, then shame on us. And if there are not more unmanned systems than U.S. Army and Marine Corps ground units, shame on us.
>
> —Robert Work, U.S. Deputy Secretary of Defense

A. BACKGROUND

The 2017 National Security Strategy (NSS) clearly states that a primary task for the military is to seek new capabilities that create clear advantages for our service members. This includes eliminating bureaucratic impediments to innovation while embracing less expensive and time-sensitive commercial off-the-shelf solutions to field enhanced capabilities that can be easily upgraded as new technologies come online.[18] Throughout the current battlefield Naval Special Warfare (NSW) has successfully utilized unmanned aircraft systems (UAS) to conduct intelligence, surveillance, and reconnaissance (ISR) in support of combat operations. In support of the guidance put forth by the president NSW has made it a top priority to develop and improve AI-enabled robotics in support of Small Unit Maneuver (SUM) in order to enhance combat effectiveness and situational awareness.

In 2010, the Department of Defense restated autonomy as the single greatest theme for today's unmanned systems. Barry Scott defines autonomous warfare as, "an operational concept that exploits the advantages of unmanned, autonomous, and robotic systems to increase autonomy and freedom for the human warfighter." [19] Paul Scharre reiterates this point in his article, "Robotics on the Battlefield Part II: The Coming Swarm," when he explains that emerging robotic technologies such as uninhabited systems will enable future special operators to fight as a swarm, with increased combat power, highly coordinated

[18] White House, *National Security Strategy* (Washington, DC: White House, 2017), https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf, 28.

[19] Barry S. Scott, "Strategy in the Robotic Age: A Case for Autonomous Warfare" (master's thesis, Naval Postgraduate School, 2014), 3.

networking, and the ability to speed up the decision making loop on the battlefield.[20] The introduction of this swarm technology is the first step in the human-machine teaming that will change the way wars are fought in the future.

As of 2015, the Naval Postgraduate School (NPS) was leading autonomous drone swarm technology implementation. NPS's Advanced Robotic Systems Engineering Laboratory (ARSENL) set a record by flying 50 commercial off-the-shelf (COTS) autonomous drones simultaneously.[21] In 2000, John Arquilla and David Ronfeldt co-wrote a revolutionary publication, *Swarming & the Future of Conflict*, which originated the concept of swarming in the 21st century. The underlying theme of this publication identifies the fourth basic form of warfare, "swarming."[22] Scharre describes swarming as a network of uninhabited vehicles that autonomously coordinated their actions to accomplish a task under some degree of mission-level human direction.[23] There has never been a better time for institutions like NPS and war colleges across the country to take the lead on research and development of emerging technology in the field of Robotic Autonomous Systems (RAS).

The application of this style of warfare requires, as noted by Arquilla and Ronfeldt, "building a fully integrated surveillance and communication system in support of swarm forces, a highly sophisticated command-and-control structure, and doctrinal innovation." [24] The concept of Artificial Intelligence for Small Unit Maneuver (AISUM) is Naval Special Warfare's vision for the future of tactical maneuver elements teamed with intelligent adaptive systems. In the future multi-domain environment, the adversary will attempt to contest all domains through cutting off key communications and navigation

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20 Paul Scharre, *Robotics on the Battlefield Part II: The Coming Swarm* (Washington, DC: Center for a New American Security, 2014), https://www.jstor.org/stable/resrep06405.

21 Timothy H. Chung et al., "Live-Fly, Large-Scale Field Experimentation for Large Numbers of Fixed-Wing UAVs," in *2016 IEEE International Conference on Robotics and Automation (ICRA)* (Washington, DC: IEEE, 2016), 1255–62, https://doi.org/10.1109/ICRA.2016.7487257.

22 John Arquilla and David F. Ronfeldt, *Swarming & the Future of Conflict* (Santa Monica, CA: RAND, 2000).

23 Scharre, *Robotics on the Battlefield*, 11–12.

24 Arquilla and Ronfeldt, "Swarming & the Future," 46.

bands of the electromagnetic spectrum (EMS). The adversary's ability to leverage complex and congested terrain will lead to a decrease in joint force capabilities and reduce effectiveness of SOF maneuver elements. It is essential that Naval Special Warfare leverage the advancements in Artificial Intelligence (AI) and Machine Learning (ML) to revolutionize human-machine teaming. The continued experimentation and research in theory and technology that supports robotic autonomous systems (RAS), miniaturized sensors, and secure autonomous communications networks will decrease the cognitive load on the operators and will prove to be a force multiplier in small unit maneuver warfare; however, if we don't begin to foster a culture of innovation within the SOF organization while teaming up with private industry we will quickly fall behind our adversaries in this era of Great Power Competition.

In 2019, a capstone team from the Naval Postgraduate School recognized the DOD's inability to innovate was related to a lack of education and identified the need for a curriculum that can bring together stakeholders, students, and private industry to create innovative solutions. This became the driving force behind 697's Applied Design for Innovation. The goal of the 697 curriculum is to provide solutions to real world problems and deliver leaders with a comprehensive understanding of the innovation process back to the force.[25]

This appendix will highlight how hands-on work with stakeholders, cross-campus collaboration, external partnership, and deliverable products are the four pillars in which future capstone teams will use to advance their lines of effort. Fostering relationships with private industry to advance capabilities and integrate Robotic Autonomous System's will prove vital to developing the AISUM concept and moving one step closer to the hyper-enabled operator.

[25] Leo Blanken, "Solving Wicked Problems: 697 Applied Design for Innovation." (Class lecture, Naval Postgraduate School, April 14, 2020)

B. HYPER-ENABLED OPERATOR SYSTEM

Human-machine interaction (HMI) is an interdisciplinary design science that combines knowledge and methods from professional fields including psychology, sociology, computer science, instruction and graphic design, human factors and ergonomics.[26] HMI is at the heart of our experiences with the technology that facilitates routine processes that range from checking our account balance to operating heavy machinery, providing decision support in everything from professional fields to driving directions, delivering education and training, and providing a platform and content structure for leisure, culture, and community interaction. The goal of HMI is to improve the quality of life for users on both the individual and community level, and to this end its central concern is usability.

The U.S. Military Standard for Human Engineering Design Criteria defines four high level goals for usability that relate to HMI:

1. Achieve required performance by operator, control and maintenance.
2. Minimize skill and personnel requirements and training time.
3. Achieve required reliability of personnel-equipment combinations.
4. Foster design standardization within and among systems.[27]

Each goal is predicated on limiting cognitive load for operators, load which has always been the limiting factor in such interactions and remains the North Star for designing autonomous systems for defense capabilities.

The hyper-enabled operator system, or HEO, is, at a high level, a system designed to allow operators to interface with autonomous systems without increasing the user's cognitive load in order to achieve successful manned-unmanned interactions to increase

[26] Ben Shneiderman, Catherine Plaisant, Maxine Cohen, Steven Jacobs, Niklas Elmqvist, and Nicholas Diakopoulos, *Designing the User Interface: Strategies for Effective Human-Computer Interaction,* 6th ed. (London: Pearson Education Limited, 2016), 37–38.

[27] *Human Engineering Design Criteria for Military Systems, Equipment and Facilities*, Document MIL-STD-1472D, Notice 3 (Washington, DC: United States Department of Defense, 1989), 11.

survivability and lethality of operators.[28] Originally designed to protect operators who are the first through a door in a rescue mission or hostage situation, the scale and expense of the system requires it to be expanded to support a range of missions across United States Special Operations Command (USSOCOM) ranging from transport to combat to medical. In essence, the goal of the HEO is to ensure the right information is given to the right person at the right time in order to ensure they can be more effective.[29] By managing task load across units, the HEO manages cognitive load for each individual. To achieve this, the HEO leverages HMI to provide operators with actionable intelligence and precise information by integrating sensing technology, algorithm and processing technology, communications technology, and system level technology. These technical requirements in turn drive enabling technologies –applied innovations that foster rapid and radical change in user capabilities.[30]

C. HUMAN MACHINE INTERFACES (HMI)

The interfaces operators engage with to receive information and mission critical support must be intuitive in that they deliver data in a way humans naturally receive and process it; they must also be highly flexible such that they can be modified in accordance to evolving human needs and contexts. The presentation of information to users must not interfere with their critical perceptual tasks or battlefield operations.[31]

The quality and usability of human machine interfaces is a key pillar in the HEO system and the operator's ability to interact and control smart autonomous systems in the HEO context.[32] Innovative technology and design principles are being applied to make

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[28] Flanick et al., "Expanding the Hyper-Enabled Operator," 2–8.

[29] Ryan, "Man-machine Teaming for Future Ground Forces," 21.

[30] Ala Al-Fuqaha, Mohsen Guizani, Mehdi Mohammadi, Mohammed Aledhari, and Moussa Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Communications Surveys & Tutorials* 17, no. 4 (2015): 2347–2376.

[31] Alex MacCalman et al., "The Hyper-Enabled Operator | Small Wars Journal," Small Wars Journal, June 6, 2019, https://smallwarsjournal.com/jrnl/art/hyper-enabled-operator, 7.

[32] Walcutt et al., "Neuro-Optimization for Accelerated Learning Pace and Elevated Comprehension: Military Applications," 2020, 14.

interfaces more natural and usable. These include using 3D audio systems rather than traditional non-directional headphone audio so that different actors and radio traffic elements can be delivered from identifiable positions in a 3D landscape; haptic feedback can be used to deliver spatially significant alerts and data, reducing cognitive load while maintaining situational awareness.[33]

Control mechanisms are also evolving beyond the typical tactile, button or pixel-based interface with voice and gesture control taking a more prominent role that allows operators to keep hands free for other tasks. Augmented reality enables maps and data feeds to be arbitrarily displayed in the operator's field of view whether in a headset or spatial projection; intelligence, surveillance, and reconnaissance feeds can be displayed in ways that are customizable and can be activated and deactivate on demand with voice and gesture controls.[34]

Human-Machine Interface is nested within the HEO System Boundary which further categorizes the system features into necessary and enabling elements, such as foundational infrastructure like data management and analytics, and related capability areas, such as biotechnologies like human performance optimization (Figure 2).[35]

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33 Walcutt et al., "Neuro-Optimization for Accelerated Learning Pace and Elevated Comprehension: Military Applications,"14.

34 Walcutt et al., 14.

35 Al-Fuqaha et al., "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," 2347–2376.

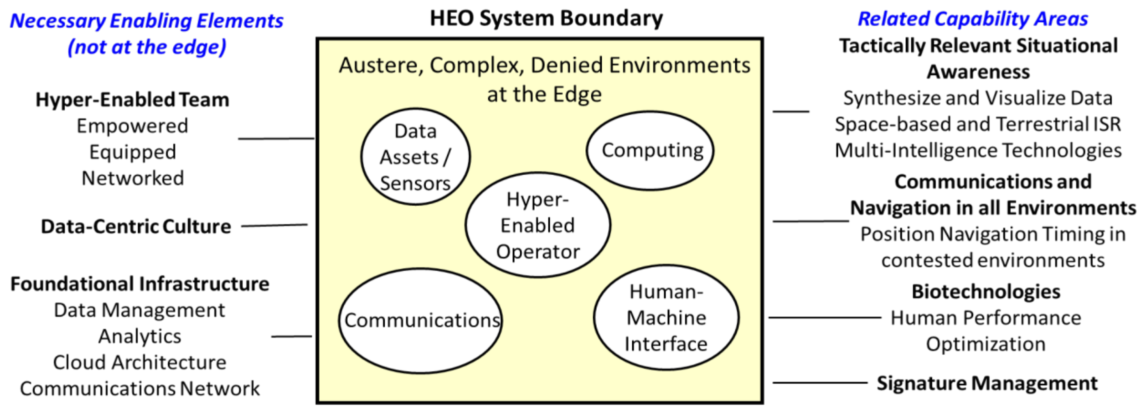

Figure 2. HEO System Boundary

D. SENSORS

Sensing technologies focus on collecting threat information using sensory data processing tools such cameras for both visible and non-visible spectrum imaging, microphones, antennae, and cyber signature detection. Sensing leverages a range of enabling technologies, including MEMS, distributed sensing, adaptive / flexible sensors, and underwater sensors.

Microelectromechanical Systems, or MEMS, combine electrical and mechanical components on an integrated microchip in order to perform a broad range of sensory tasks such as motion detection and sound detection using gyroscopes, accelerometers, and other technology.[36] MEMS technology is a fundamental part of military navigation, communication, and optical systems, integrating with other core technologies like Lidar.[37] MEMS bio-sensing capabilities expand into water toxicity testing[6] and other novel field applications.

Distributed sensing is a network-centric approach to sensory processing and situation assessment that leverages a hierarchy of capabilities, information, and control

[36] Paul B Ruffin and Sherrie J. Burgett, "Recent Progress in MEMS Technology Development for Military Applications," Proc. SPIE 4334 In *Smart Structures and Materials 2001: Smart Electronics and MEMS*: (August 2001), 1–2.

[37] Xiaobao Lee, Chunhui Wang, Zhaoxu Luo, and Shengqing Li, "Optical Design of A New Folding Scanning System in MEMS-Based Lidar." *Optics & Laser Technology* 125 (2020): 106013, 1.

nodes.[38] Distributed sensing can collect higher quality information by combining different spatial perspectives, different sensing modalities, and higher density deployment to create a fuller picture of the available data.

Flexible sensors are lightweight, wearable, and often designed for biological integration, or so-called electronic skin; constructed of deformable substrates like polycarbonate (PC) or polyethylene terephthalate (PET), polydimethylsiloxane (PDMS) or silicone rubbers, they are designed for pliancy, stretchability, and transparency.[39] These sensors use electrical properties such as triboelectricity, capacitance, or piezoelectricity of solid nanomaterials or metallic liquids to detect pressure, temperature, torsion, strain, humidity and other physical data.[40]

Using the lowest power wireless communication and networking capability available, piezo-acoustic backscatter (PAB) technology allows for battery-free or extremely low power underwater sensing of data such as temperature, acidity, or toxicity.[41] Similarly, by leveraging the piezoelectric electric effect, underwater sensors detect the vibrations of waves and reflect signals back to receivers in a binary system alternating between wave and no wave to transmit data and harvest energy.[42]

E. ENABLING TECHNOLOGIES

The HEO system uses a blend of enabling technologies to collect and analyze data in order to generate actionable intelligence. Artificial intelligence is leveraged to increase system autonomy and situational awareness and reduce operator requirements, while

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[38] Henry Leung, Sandeep Chandana, and Shuang Wei, "Distributed Sensing Based on Intelligent Sensor Networks," *IEEE Circuits and Systems Magazine* 8, no. 2 (2008): 38–52.

[39] Joo Chuan Yeo and Chwee Teck Lim, "Emerging Flexible and Wearable Physical Sensing Platforms for Healthcare and Biomedical Applications." *Microsystems & Nanoengineering* 2, no. 1 (2016): 1–19.

[40] Leung et al., "Distributed Sensing," 38–52.

[41] Junsu Jang and Fadel Adib, "Underwater Backscatter Networking," In *Proceedings of the ACM Special Interest Group on Data Communication*, (2019): 187–199.

[42] Rob Matheson, "A Battery-Free Sensor for Underwater Exploration," *MIT News*, Massachusetts Institute of Technology, accessed September 7, 2020, https://news.mit.edu/2019/battery-free-sensor-underwater-exploration-0820.

machine learning allows the system to communicate equipment or navigational issues or errors for operator action. Computer vision applies artificial intelligence and deep learning technology for image identification and classification, with applications for threat assessment and situational awareness that enhances decision making, removes blind spots, and provides navigational guidance.

Computational processing technology serves to reduce the Observe-Orient-Decide-Act (OODA) loop timing interval by leveraging distributing processing and edge computing so that data and computation functions are as close to the decision point as possible, saving bandwidth and improving response times.[43] The flow and integrity of information between stages in the OODA loop is essential, and the system incorporates non-standard encryption technology and novel frequencies.[44] This paradigm extends to the overall communication system that incorporates adaptive/resilient networks focused on expanded autonomous networking in order to transform static networks into dynamic ones.[45]

On a procedural level, the HEO uses algorithms for key functions that include change detection, behavioral modeling, tracking, 3D mapping, GPS-denied navigation, biometrics, and image fusion.[46] On a system level, HEO technologies provide tactical weaponry for air, naval, and land and protection with lightweight armor and signature management.

F. APPLICATIONS

HMI allows for new display and visualization paradigms such as augmented reality, transparent displays to provide useful data that improves situational awareness while

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[43] Mahadev Satyanarayanan, "The Emergence of Edge Computing." *Computer* 50, no. 1 (2017): 30–39.

[44] Kennedy Harrison, Josh White, Paul Rivera, Tyler Giovinco, Jaritzel Jurado, and Vikram Mittal, "Aligning Needs, Technologies, and Resources for Special Operations," In *The Proceedings of the Annual General Donald R. Keith Memorial Conference*, (Department of Systems Engineering United States Military Academy, 2019), 113–118.

[45] Matheson, "A Battery-Free Sensor for Underwater Exploration."

[46] Flanick et al., "Expanding the Hyper-Enabled Operator," 2–8.

reducing cognitive load.[47] HMI also enables new automation and operating concepts that can be realized with the HEO, such as swarm optimization with the operator controlling self-organizing robot swarms and remotely controlled fully autonomous robot platforms in conflict situations.[48] Medics can use the technology to combine bio sensing with augmented reality for proximally contextualized guidance and remote communications for telemedicine support from surgical experts.[49] Air controllers can leverage transparent and augmented reality displays to manage information such as proximity of supporting resources that are currently only tracked by radio communication; this would significantly reduce cognitive loads and improve operator lethality.[50]

G. CONCLUSION

Successful HMI centers on translating human goals into explicit instructions computers can follow while translating the machine's decision space into a context the operator can understand and control through visual, aural and tactile feedback.[51] As a system, the HEO needs to increase operator survivability and lethality across a variety of functions and roles, including joint terminal air controllers, intelligence officers, vehicle drivers and mission sets as diverse as counterterrorism, foreign internal defense, covert operations, and direct action. Solving the HMI challenge while serving all stakeholders, requires clear conceptual planning, innovative thinking, and partnering with private industry to develop cutting edge technology. The Autonodyne project has focused on establishing a process which can serve as a model for future capstone endeavors and a foundation for further research towards the actualization of AISUM in an HEO system.

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[47] Flanick et al., 2–8

[48] Ryan, "Man-machine Teaming for Future Ground Forces."

[49] Flanick et al., "Expanding the Hyper-Enabled Operator," 2–8

[50] Flanick et al., 2–8

[51] Andrew Ilachinski, "AI, Robots, and Swarms: Issues, Questions, and Recommended Studies," CNA Corporation, (2017), 106.

H. AUTONODYNE SUMMARY REPORT

1. Purpose

There is a need for RAS's C2 and HMT Interface to allow a single operator or a team of operators to control multiple dissimilar platforms without Cognitive Overload. NSW currently operates a multitude of unmanned systems that all have completely different ground control stations, operating functions, displays and User Interfaces (UI). Non-intuitive and complex user interfaces are a common problem when incorporating new systems. This adds additional complexity for operators who must be trained on multiple systems but may not be a subject matter expert in unmanned systems. This adds training requirements and learning time for operators that is already limited.

2. Key Stakeholders

- Air Force Special Operations Command (AFSOC) has performed its own experimentation and development work integrating the DJI Mavic and linking ATAK with the Autonodyne CCS. **AFSOC has supplied the endorsement Memorandum of Understanding (MOU) supporting this Phase II SBIR.**

- Separately, Naval Special Warfare (NSW) has partnered with Autonodyne since FY18 to develop a Common Control Station (CSS) for small Unmanned Vehicles (UxV), sponsored by DOD's Rapid Reaction Technology Office (RRTO).

- Naval Postgraduate School in coordination with NSW. SOCOM EOTACS is currently evaluating for sUAS Program of Record

3. Autonodyne LLC

Autonodyne is a 2014 spinoff from commercial avionics company Avidyne, a provider of full-suite aviation technology. The initial efforts involved adapting Avidyne's manned avionics systems and software for high-performance DOD unmanned combat aerial systems (UCAS), and optionally piloted (OPV) civil aircraft. The Autonodyne

CEO/Co-founder had been leading the engineering efforts at Avidyne and was able to leverage his experience and contacts as an Air Force attack/test pilot to optimize the technology for DOD use cases.

Autonomy is at the core of all systems developed with the mindset of utilizing multiple Robotic Autonomous Systems (RAS) to accomplish missions in a complex and contested environment. In the current Period of Performance (PoP) the company is leveraging and enhancing existing capabilities to allow for full-mission swarming. Autonodyne makes it a priority to use open-system architecture which allows for modularity. The use of open standards for data ingest, storage as well as for training, and transfer of AI models such as neural networks is a key component to working with the Department of Defense (DOD).

4. History

By 2017, Autonodyne began optimizing this technology suite for sUAS platforms, emphasizing the synergy between advanced human-machine interfaces (HMI) and autonomy behaviors and applying that to multi-vehicle, multi-domain operations with the goal of using on-board semantic reasoning to develop contextual awareness so the group of UxS platforms serve as a human force multiplier.

In 2018 and 2019, Autonodyne was able to secure a range of customers/partners to help fund development of this technology to include state and federal law enforcement, state and federal emergency response organizations, and DOD with focus on drone package delivery, humanitarian assistance and disaster relief (HADR) and intelligence, surveillance, and reconnaissance (ISR) applications.

DOD’s Rapid Reaction Technology Office (RRTO) and JSOC-X funded 9 months of development in late 2018 and first half of 2019 that resulted in a baseline sUAS control application capable of simultaneously controlling up to 9 UxS devices and became the basis of the current development efforts.

An AFWERX Phase I SBIR with a period of performance (PoP) from Dec 2019 to Mar 2020 served as a transition from the 2019 RRTO/NSW baseline CCS to the current

Phase II PoP running July 2020 to July 2021. The principal deliverables in the Phase II include 8 additional autonomy behaviors, adding support for 4 SOCOM-directed UxS, and studying secure communications methodologies as they can be applied to these platforms and C2 systems.

5. Human-Machine Interface and Autonomy

On the HMI side of development, Autonodyne has created a Common Control Station (CCS) application that intentionally does not require adding any hardware or software to the UxS platform. Instead, the company creates "software wrappers" that act as behind-the-scenes translators and command/control interfaces to the existing UxS platforms. One powerful legacy of both Avidyne and now Autonodyne is significant effort and success in designing highly intuitive interfaces designed to reduce operator cognitive burdens/workload while at the same time increasing functionality.

On the autonomy side of development, Autonodyne has been executing a strategy of creating a library of autonomy behavior building blocks. Behaviors such as "Fly Over That," "Hold Over There," autonomous detection and avoidance of static and dynamic 2D/3D obstacles/threats interwoven into autonomous path planning algorithms, were part of the baseline system by 2019 and actively used in programs and applications spanning the sUAS space to UCAS.

6. Why a Common Control Station (CCS)?

First and foremost, what this project is driving at is communicating the need for high levels of integration between components taking part in future battlefields. One must envision planes talking to ground forces who are talking to robot enablers both on the ground and in the air. All of this vertically integrated sharing C2, information streams, back calls, forward and backwards communications.

As RAS's begin to become established in the formations the CCS is the forward-edge of the C2 infrastructure. The Joint Force CCS is required to capitalize on the employment of RAS and small unit maneuvering. As a force we need to educate ourselves as to what a CCS looks like NOW, so we can create and plan new Tactics, Techniques and

Procedures (TTPs) with these new systems. Cognitive overload can lead to confusion when working with the systems resulting in risk to performance and may ultimately hinder the development of future concepts like AISUM and the HEO.

Finally, the Joint Force will need to streamline the C4ISR for these concepts to *really* work. There needs to be a robust, defensible, highly integrated intelligent system of autonomy instead of the heterogeneous systems of handsets and C2 currently on the shelves. The system will need to be fully integrated both vertically and horizontally across the battlefield and across component commands in order to maneuver the RAS's across multiple domains in a way that takes full advantage of the emerging technology. This is not just Autonomy Within Systems, but also Computer Vision (CV) and Artificial Intelligence (AI).

7. WHAT: RCU-1000 Common Control Station Application/Software

a. Common Control Station Approach

- Autonodyne is utilizing human centered design to meet requirements by teaming with Subject Matter Experts (SMEs) from the Military and the private sector.
- **Multi-Input**: Supports multi-touch (e.g., pinch zoom), traditional keyboard/mouse, commercial gaming controls (e.g. Xbox), and voice/gesture inputs from augmented reality devices (e.g. Meta2, Pison).
- **Hardware Agnostic**: CS runs on most Windows 7 or later devices (PCs, laptops, tablets) as well as iOS and Linux and Android. Runs on Block 30 F-16 center display unit & one of the 12 cores of F-35 mission computers
- **Link Agnostic**: 8 links implemented, 5+ in work, working on cyber-resiliency
- **Advanced Natural User Interface**: Use advanced NUI designs running on mobile devices including use of augmented reality and UI elements from first-person shooter gaming system.

- **RCU-1000 app**: Designed to be a common user interface (UI) Common Control Station to allow a single operator to control and interact with several different UAS types and quantities.

Figure 3. Dissimilar Platforms (sUAS) controlled by RCU-1000

- RCU-1000 app is primarily a task-based control mechanism but also provides full manual control of an unmanned platform

Figure 4. RCU-1000 CCS on Android End User Device

I. PRE-AIR FORCE SMALL BUSINESS INNOVATION RESEARCH (SBIR) PHASE II *(CURRENT AS OF 14JUL2020)*

1. Baseline Functionality

a. Multi-vehicle, multi-domain demonstration at the November JIFX event. The vehicles above were controlled simultaneously via a single RCU-1000 app.

(1) Up to 8 simultaneous platforms demonstrated

(2) Fixed wing, VTOL, Ground Rover

b. Several high-level tasks/autonomous behaviors ("additive autonomy")

(1) Fly over that

(2) Loiter

(3) Hover

c. 7 Datalinks supported

(1) MPU 3/4/5,

(2) Link 16

(3) 9XX MHz DDLs

(4) WiFi

(5) 4/5G LTE

a. TTNT

b. Iridium SATCOM

d. ***ATAK and CoT Integration w/ up to 18 makes/models***

e. ***API exists for 3rd party use (e.g., add new vehicles or payloads)***

J. AIR FORCE SBIR PHASE II

1. (1st 4 months) NPS Collaboration with Autonodyne

a. ***Autonomous behaviors requirements***

(1) Capstone Team coordinated with JSOC-X, AFSOC, and Autonodyne to down-select from 25 candidate autonomy behaviors to the final 8 (Inspect, Observe, Follow Me, Stack, Surveil, Track, Impact, Morphing Swarm)

b. ***Autonomous behavior storyboards***

(1) Capstone Team collaborated with Autonodyne to ensure Operational requirements were met when developing Storyboards.

c. ***NPS Capstone Team has secured three loaner SRR platforms to support the CCS integration.***

d. ***Autonodyne has prototyped initial secure comm techniques (e.g. "Go Dark") and is actively flight testing the capability.***

2. (2nd 6 months) Future Capstone Team

a. ***NPS Capstone Team and JSOC-X operator feedback on the first four autonomy behaviors in an operationally representative environment followed by iterative updates as required.***

b. ***Collaborate with NSW sponsored NPS Professor on Effectiveness of Human-Machine Teams in UAV operations Experiment to find the optimal operator to platform ratio.***

c. ***Completing functional prototypes of next four autonomy behaviors.***

d. ***Integrating with SRR and other customer selected UxS platforms and demonstrating that integration in lab and field environments.***

e. ***MESH network integration and continued development and study in the area of secure communications.***

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APPENDIX B. AUTONOMOUS SYSTEMS / USER INTERFACE / TRUST IN SYSTEMS

As the Hyper Enabled Operator concept continues to evolve and humans become increasingly more reliant on autonomous systems to maintain battlefield supremacy, the human's ability to control them while minimizing cognitive burden will be increasingly more important.[52] Autonomous systems and Artificial Intelligence has the potential to improve the military's effectiveness by providing timely and accurate intelligence to decision makers and operators on the ground. However, Neuroscientists widely agree that in order to prevent cognitive overload when controlling human-centered automated machines, the functionality and the interface must be prioritized.[53] Individuals must be provided with the appropriate methods and time to train with the automation and artificial intelligence to ensure they trust the autonomous systems in order to decrease the cognitive effort required to monitor the unmanned systems.[54]

When designing a human-centered automated machine, neuroscientists widely agree that the two main components which should be considered are the functionality and the interface.[55] An effective automation interface design will directly improve the automated system's situational awareness and also improve and calibrate the human's trust in that automated system.[56] The user interface and system functionality must provide a clear mapping for the operator so that the individual can create an interface which is compatible with their goals and mental models.[57] To improve human interaction with

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[52] Adams, "Cognitive Task Analysis for Unmanned Aerial System Design," 2426.

[53] Raja Parasuraman, Thomas B. Sheridan, and Christopher D. Wickens, "Situation Awareness, Mental Workload, and Trust in Automation: Viable, Empirically Supported Cognitive Engineering Constructs," *Journal of Cognitive Engineering and Decision Making* 2, no. 2 (June 2008): 154, https://doi.org/10.1518/155534308X284417.

[54] Endsley, "From Here to Autonomy," 8.

[55] Parasuraman, Sheridan, and Wickens, "Situation Awareness, Mental Workload, and Trust in Automation," 154.

[56] Endsley, "From Here to Autonomy," 10.

[57] Endsley, 11.

autonomous systems, design interventions include human–automation interface features and central automation interaction paradigms comprising levels of automation, adaptive automation, and granularity of control approaches.

Computer Science professor from Vanderbilt University, Dr. Julie Adams, PhD, writes in *Handbook of Unmanned Aerial Vehicles,* in her chapter "Cognitive Task Analysis for Unmanned Aerial System Design," that humans are factored into the unmanned systems platform and payload design after the systems have been built. She expounds that, "such system design approaches do not properly consider the human cognitive limitations and do not design the system to support the human's tasks and decision-making."[58] With military Special Operations Forces and others operating in dynamic environments, the integration of the humans cognitive ability to control the systems to minimize overload and maximize effectiveness must be considered in the initial design phase.

Prioritizing training with Artificial Intelligence and automated systems to build the operators' trust in the salience of information the systems provide will decrease the cognitive effort required to monitor the unmanned systems.[59] In 1983, cognitive psychologist Lisanne Bainbridge wrote a research paper titled, "Ironies of Automation," in which she states that, "when workload is the highest, it is often of the least assistance."[60] Sporadic implementation of future technology in training will prevent the individual from valuing the timely information being provided.

In his 2017 journal article, *From Here to Autonomy*, Mica Endsley highlights that, while automation is designed to relieve complexity, a lack of trust in the system may have the opposite effect if the operator must maintain situational awareness and inject corrections to ensure that it is performing correctly.[61] Endsley points out that "increasing automation *reliability* and *robustness* will act to decrease *attention allocation* to

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[58] Adams, "Cognitive Task Analysis for Unmanned Aerial System Design," 2425.

[59] Endsley, "From Here to Autonomy," 8.

[60] Endsley, 12.

[61] Endsley, 9.

automation performance, as moderated through *operator trust*." Endsley highlights that when dealing with humans and machines, the complexity to the situational awareness, the monitoring of autonomous systems, and building trust in the systems is called the Human-Autonomy System Oversight (HASO). Endsley suggests that in order to gain the trust of the systems, thorough training and drilling with the systems will reduce cognitive burden. As is outlined in the Department of Defense (DOD) Data Strategy, if the data is not trustworthy and operators lack confidence in the systems, then this may impede the decision maker's judgment and prevent the optimal choice from being made.[62]

The data management and presentation of unmanned systems information to the operator are the most vital aspects of an effective user interface and user experience. In the DOD's 2020 Data Strategy, Deputy Secretary of Defense David Norquist highlights that data is a strategic asset that can significantly improve the military's effectiveness by providing timely and accurate intelligence to decision makers and operators on the ground. Maintaining the strategic, operational, and tactical advantage will require coordinating the combined collection of a variety of data sources to provide accurate situational awareness to the decision maker in a usable manner.[63] Under the DOD Data Strategy, the DOD identifies seven Goals to become a data-centric DOD. These seven principles apply not only to the leaders in Joint Operations Centers to make strategic decisions but also to the tactical leader or individual soldier as they reduce military footprint but increase available information. Alvin Toffler in his 1970 book *Future Shock* writes that, "Overstimulation can occur on at least three different levels: the sensory, the cognitive, and the decisional."[64] As it relates to the user interface and information flow of data, making the data understandable, visible and most importantly linked are of critical significance to the success of the end user.

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[62] Department of Defense, Executive Summary: DOD Data Strategy - Unleashing Data to Advance the National Defense Strategy (Washington, DC: DOD, 2020), 8.

[63] Department of Defense, 1, 7.

[64] Toffler, *Future Shock*, 348.

As the UAS systems gain autonomy to conduct more robust tasking, the human's ability to control the machines must become increasingly more reliant on robust autonomy and artificial intelligence to reduce the cognitive burden and the team size required to operate the machines.[65] The Man and Unmanned Machine Teaming (MUM-T) interaction is directly proportional to the expectations humans place on systems. Due to the complexity of full automation, Endsley states that, "the development of autonomous systems that can support (man and unmanned teaming), should be based on a detailed foundation of research on human automation interaction."[66] As a result of the complexity of automated systems, the combination of what Endsley states is "cognitive complexity, display complexity, and task complexity of the system created by the automation interface," the interaction between the human and machine teaming will be increasingly important as more systems become semi-autonomous.

Situational awareness for disaggregated teams in a dynamic environment creates an inherently complex position. In their book, *Designing for Situation Awareness, An Approach to User-Centered Design*, Endsley, Bolte and Jones discuss the Goal Directed Task Analysis (GDTA) as a type of cognitive task analysis which emphasizes situational awareness in a dynamic environment.[67] Taking Endsley's work into an even more military appropriate domain, Humphrey and Adams expound upon the GDTA principle in a journal article titled, "Analysis of Complex Team-Based Systems," in which they linked basic goals and decision questions that the individual operating the drones must complete in order to integrate properly with the UAS.[68] Adams then applied her studies on GDTA to an existing project which uses UASs for wilderness search and rescue called WiSAR. The results of the integration between the GDTA and the WiSAR was that it highlighted to the

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65 Adams, "Cognitive Task Analysis for Unmanned Aerial System Design," 2426.

66 Endsley, "From Here to Autonomy," 6, 8.

67 Mica R. Endsley, Betty Bolté, and Debra G. Jones, *Designing for Situation Awareness: An Approach to User-Centered Design* (New York: Taylor & Francis, 2003), 10.

68 Curtis Humphrey and Julie Adams, "Analysis of Complex Team-Based Systems: Augmentations to Goal0-Directed Task Analysis and Cognitive Work Analysis," *Theoretical Issues in Ergonomics Science* 12, 2001, no. 2 (June 15, 2010): 149.

Search and Rescue (SAR) leadership what situational awareness information the UAS can collect to help the searches on the ground. It additionally identified cognitive tasks that burdened the drone operator, helped to find better searching methods, and improve overall communications between element leaders.[69]

12/4/2020 3:47:00 PMIn Alvin Toffler's 1970 book *Future Shock* he states, "communications systems designer Sol Cornberg, a radical prophet in the field of library technology, declared that reading would soon cease to be a primary form of information intake."[70] Toffler's intent with this statement is to symbolize the rapid expansion of information available to each individual and the many methods which they can perceive and process that information. He breaks down the reception of information into uncoded and coded messages. Uncoded signals are how someone perceives what they hear, see, or feel through their sensory apparatus and in what way they form a mental image of that sensory signal referred to as a message. Humans also receive coded messages, or messages conveyed by means of a language, dance step, pictograph or other arrangement. While both coded and uncoded forms of communication are relevant to the military operator, "more of our imagery derives from man-made messages than from personal observations of raw, "uncoded" events."

With the improvement of technology and the artfully crafted and carefully spread messages from mass media by communications experts, humans receive and read massive quantities of meticulously crafted messages daily. As a result, Toffler states that the information perceived is "highly purposive, preprocessed to eliminate unnecessary repetition, consciously designed to maximize information content. It is, as communications theorists say, 'information-rich.'"[71] In 1970, Toffler reported that the average American is exposed to an average of 560 advertising messages per day – of which they only notice 76 in order to "preserve their attention for other matters." To ensure that their advertisement

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69 Adams, "Cognitive Task Analysis for Unmanned Aerial System Design," 2428.

70 Alvin Toffler, *Future Shock*, A Bantam Book (New York Toronto London: Bantam Books, 1990), 161–65.

71 Toffler, 165, 167.

will be one of the 76 memorable ones, Toffler states that advertisers will use symbolic art techniques combined with "verbal and visual to accelerate image-flow… to communicate maximum imagery in minimum time."[72] In a similar way as advertisers capture the individual's attention, options should be provided to the individual in the battlefield to capture their attention when required to highlight imminent threats, but also be able to provide access to less important information at the individuals inquiries rather than flooding them with information.

A. COGNITIVE TASK ANALYSIS

To identify the optimal human centric system, the focus can be narrowed down to three specific functions – cognitive task analysis, cognitive work analysis, and information flow analysis.[73] From a cognitive capabilities perspective, Dr. Adams states that "Cognitive task analysis seeks to understand the cognition required by the human user to complete tasks and how to turn that understanding into tools that assist the human."[74] The methods which people receive and transmit information varies widely based on their backgrounds, genetics and physical human performance. As a result, Dr. Adam's states that machine systems which will be controlled should provide adjustable control modalities to match the cognitive demands of the operator based on their specific learning requirements and adjust them to meet the increased stress caused in a dynamic environment.

Cognitive task analysis is the focus on the individual's cognitive requirements to conduct a task, how to train the human to control the system, and ultimately to design a system so that it best serves the human. When controlling a UAS, Dr. Adam's shows that the individual is responsible for supervising the automated system, commanding it to conduct the task required, and also must interact with the UAS through a control station.[75]

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[72] Toffler, *Future Shock*, 1990, 167.

[73] Adams, "Cognitive Task Analysis for Unmanned Aerial System Design," 2426.

[74] Adams, 2427.

[75] Adams, 2427.

The burden of each requirement is significant and is compounded when the requirement is to operate in a dynamic environment and to then react to changes by notifying other personnel in the group of imminent threats, calling in an air strike on the target, or maneuvering troops against the enemy. In these scenarios, it will become increasing important for the Ground Force Commander to maintain situational awareness while managing unmanned assets.

Another critical component when designing the Common Control Station for controlling multiple UASs is the cognitive work analysis.[76] Dr. Adams describes that the work analysis aspect measures the human's workload on a specific device, separate from the individual operator's capabilities. More directly, she supports that the work analysis attempts to find different ways that the tasks can be completed, such as optimizing the social and technical factors, to improve the overall operating function of the systems. Adams refines the definition of the work analysis by writing that its function is "to better integrate cognitive analysis and the design and development of revolutionary systems."[77] In the end, the cognitive work analysis function is designed to identify the problem the system is attempting to monitor or fix, and to optimize how that information is present to the operator. This function leads in well to the last function, which is the information analysis.

The cognitive information flow analysis intent is to highlight methods to improve the flow of information, identify when too much information is overloading the human user, and then to sort out where that information should go so that it is presented to the right people at the right time.[78] In a writing Adams did with Humphrey in 2010 titled, "Cognitive information flow analysis," in Cognition, Technology, and Work, they merge together the cognitive tasks with cognitive work analysis to understand the optimal flow

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[76] Adams, "Cognitive Task Analysis for Unmanned Aerial System Design," 2430.

[77] Endsley, Bolté, and Jones, *Designing for Situation Awareness*, 2431.

[78] Adams, 2433.

and analysis of information.[79] The flow analysis method helps the designers to understand the method which the information is being created, processed, and then disseminated into the system, and who is using and benefiting from that information.[80] The information production is all of the data that is input into the system whether by sensors, humans or artificial intelligence. The consumption of information is when the systems or the human uses it to complete a function. And the transformation is when the consumption of the information by a process results in new information.[81]

In the end, the combination of cognitive task analysis, cognitive work analysis, and information flow analysis can provide a very valuable method to design the UAS controlling and information dissemination systems. While there is no definitive method to conduct this in a dynamic environment where contingency management is the most critical aspect, the combination of the man and machine can be optimized to relieve workload whenever possible to allow the human operator the mental bandwidth to make decisions when the computer becomes overwhelmed.

In their writing, *Situation Awareness, Mental Workload, and Trust in Automation: Viable, Empirically Supported Cognitive Engineering Constructs*, authors Parasuraman, Sheridan and Wickens conclude that, "Situational awareness, mental workload, and trust are viable constructs that are valuable in understanding and predicting human-system performance in complex systems."[82] The basis behind their research states that Human Factors/ Ergonomics (HF/E) must have a human performance baseline from which to design complex human-machine systems. Automated systems can alleviate workload and enhance operator situational awareness. They can also provide opportunities for operators to build too much trust in the system, which, when it ultimately breaks down, can increase

[79] Curtis M. Humphrey and Julie A. Adams, "Cognitive Information Flow Analysis," *Cognition, Technology & Work* 15, no. 2 (May 1, 2013): 133, https://doi.org/10.1007/s10111-011-0198-z.

[80] Adams, "Cognitive Task Analysis for Unmanned Aerial System Design," 2433.

[81] Adams, 2433.

[82] Parasuraman, Sheridan, and Wickens, "Situation Awareness, Mental Workload, and Trust in Automation," 140.

the cognitive burden on the individual. Ultimately, trust in the systems is paramount to creating a successful socio-technical system.

B. RECOMMENDATIONS / CONCLUSION

When designing autonomous systems using artificial intelligence, the functionality and the user interface must be a priority for technology designers to alleviate cognitive load on the military operator.[83] Significant amounts of data and information can be available to the operators which, under optimal conditions and with the proper training, can provide them with significantly more battlefield situational awareness than is available today. The Special Operations Forces Community must prioritize early, and consistent training with Artificial Intelligence and automated systems to build the operators' trust in the salience of information provided so the operators can decrease the cognitive effort required to monitor the unmanned systems.[84] Trust in the autonomy systems and Artificial Intelligence is critical to creating a successful socio-technical system in which the human operator trusts the autonomous systems which surround them.

[83] Adams, "Cognitive Task Analysis for Unmanned Aerial System Design," 2426.

[84] Endsley, "From Here to Autonomy," February 2017, 8.

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APPENDIX C. COGNITIVE LOAD

The overstimulated soldier in combat finds themselves flooded with uncertainty and ambiguity, or as 19th century Prussian military philosopher Carl von Clausewitz termed it, the fog of war.[85] The British coined this overstimulation Long Range Penetration Strain, described as when a soldier became, "incapable of doing the simplest thing for himself and seemed to have the mind of a child."[86] Regardless of the terminology, psychologists unanimously agree on two cognitive load principles: first, that humans have a limited cognitive capacity; and second, that cognitively overloading one's system leads to a significant decrease in performance.[87] These experiences significantly degrade the human's ability to receive information and causes their minds to be more closely related to a schizophrenic mind than a normally functioning individual.[88] Identifying cognitive overload in stressful situations, and then adjusting individual training to mitigate its impacts on the operator, is the beginning to creating organizational changes which will optimize the individual's impact on the battlefield. It will become increasingly important for Special Forces organizations to train and drill with existing and innovative technology which can identify and remedy individual's cognitive overload, and to adapt the technology so those operators can comprehend greater information in order to prevent decision paralysis. New advances in wearable technology, and algorithms to identify physiological changes to identify cognitive load, are being developed that will improve the ability to identify, and then theoretically reduce, cognitive load.[89]

Cognitively overloading the mind with excess data has been shown to create the fog of war in soldiers, culture shock in travelers, or disaster shock in victims of traumatic

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[85] Carl von Clausewitz, Michael Eliot Howard, and Peter Paret, *On War*, First paperback printing (Princeton, NJ: Princeton University Press, 1989), 1.

[86] Toffler, *Future Shock*, 1990, 345.

[87] Toffler, 352.

[88] Toffler, 353.

[89] Huberman and Golden, "Biomechanical Acoustic Devices and Measuring Biologic Signals."

experiences. The psychological effects of overstimulation in combat has nearly identical cognitive and physiological symptoms as culture shock and disaster shock. Alvin Toffler, prominent futurist and best-selling author on technologic impacts on humans, states that the person who experiences a disaster will often show "confusion, anxiety, irritability and withdrawal into apathy."[90] He continues in his book Future Shock that the traveler who immerses themselves into a foreign culture, albeit devoid of war or chaos and in a benign and peaceful environment, can become overwhelmed by the enormity of the novel experiences which prevents them from grasping and cognitively processing the new objects, sights, sounds and events. A common symptom of culture shock on the traveler is, as psychologist Sven Lundstedt describes it, a "feeling of loss, and a sense of isolation and loneliness," such that he or she becomes "anxious, confused and often appears apathetic."[91] According to Toffler, the linkage between combat stress, disaster and culture shock all share three basic similarities: confusion and disorientation, fatigue and extreme irritability, and a point of no return upon which apathy and emotional withdrawal set in.

Information studies psychologist Dr. James Miller, former director of the Mental Health Research Institute at the University of Michigan, also found that very similar performance characteristics were identified between those of cognitively overloaded individuals and people with mental illness – specifically schizophrenics.[92] According to Dr. Miller, one of the main features of a schizophrenic is that their minds produce words and phrases in an "incorrect associative response," or they categorize words or situations in "arbitrary or highly personalized categories." For example, when presented with a series of similar physical objects such as Legos or marbles, the healthy person will categorize them in geometric shapes. According to Dr. Miller, a schizophrenic, on the other hand, may categorize them subjectively or as a group of feelings. To describe his findings more specifically, in his book Disorders of Communication, Miller tested two groups of mentally healthy individuals. One group was provided with words or concepts and was allowed to

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90 Toffler, *Future Shock*, 1990, 346–47.

91 Toffler, *Future Shock*, 1990, 347.

92 Toffler, *Future Shock*, 1990, 351–54.

work at their own pace, while the other group was provided the same information but under a time constraint. The results showed that those under the conditions of greater time constraints and higher information input generated responses with "errors more like those of schizophrenics than of self-paced normals." Or to put it more directly, normal humans under excessive cognitive load produce similar results as schizophrenics under normal conditions.

A significant number of scientific studies show that humans have a very narrow limit of working memory, and the Cognitive Load Theory supports that the design of education must respect those limitations.[93] Psychologist George A. Miller of Rockefeller University states that, "there are severe limitations on the amount of information that we are able to receive, process, and remember."[94] While the military operator must consider a wide spectrum of problems in their pursuit of preventing cognitive overload, the requirement is also a heuristic one which will employ a practical solution to a problem that may not be optimal, but is sufficient for achieving the tactical or operational solution. Improving cognitive load capability to prevent decision paralysis can be thought of similarly to training for a physical sporting event. There is a cost-risk-benefit analysis for cognitive loading when considering what information is presented to the individual and how that information is disseminated.

Identical to the human body succumbing to overstimulation when being immersed into a disaster scenario, the cognitive decision making processes behave unpredictably when overloaded.[95] While the limits to cognitive learning are yet unknown, the energy demand placed on learning is significant, and it opens the environment for a potentially disastrous social situation – or as Alvin Toffler calls it, "Future shock."[96] Toffler finds that at the neurological level, there are limits on the speed and quantity of images that any

[93] Jimmie Leppink, "Cognitive Load Theory: Practical Implications and an Important Challenge," *Journal of Taibah University Medical Sciences* 12, no. 5 (October 2017): 386, https://doi.org/10.1016/j.jtumed.2017.05.003.

[94] Toffler, *Future Shock*, 1990, 351.

[95] Toffler, 343.

[96] Toffler, 181.

individual is capable of processing. In a similar vein, placing significant amounts of technology on an individual in a dynamic and novel situation greatly increases the risk for information overload, and relieving that cognitive burden through trustworthy artificial intelligence, appropriate training, and tailored design will create better decision makers.

When an individual is immersed into a new, rapidly changing and dynamic situation, Toffler highlights that, "predictive accuracy plummets… (and they) can no longer make the reasonably correct assessments on which rational behavior is dependent."[97] He goes on to suggest that for an individual to react "normally" and make effective, rational decisions, they must be able to process more information than ever before, at an extremely high rate of speed. In combat, the Special Operations Forces operators will experience dynamic and changing environments. To prevent information overload from mentally paralyzing the individual, they must be able to think faster and process higher volumes of information. Identifying the existing technology to help provide the training, drills, and mental stimulation to help individuals process greater information loads will create better leaders by preventing decision paralysis.

A. TRAINING TO REDUCE COGNITIVE LOAD

A variety of training, drilling, and readiness measures can alleviate cognitive load and prepare the individual for complex situations. Maintaining the optimum physical performance directly relates to the mind's ability to cognitively process information, drilling correctly to build trust in the equipment, and data management. Although some human reactions to novel and dynamic experiences result in involuntary responses by the individual, most human reactions are preceded by conscious thought, a reaction that is a result of the individual's ability to absorb information, process, react and retain information.[98] According to Toffler, every individual's ability to handle sensory input is a result of their physiological makeup. He goes on to explain that the individual's physical organs and how quickly their body sends impulses throughout its neural system creates

[97] Toffler, 351.

[98] Toffler, *Future Shock*, 1990, 349–50.

biological limitations to the speed and amount of data that can be transmitted. This highlights the importance of selecting future Special Operations Forces who are cognitively capable, and can train to and rapidly process scenarios, which should inherently decrease the overstimulation in combat and improve their performance under stress.

In his short story “Superiority,” Arthur C. Clarke laments on the cause of the failure of a militaries far superior forces to defeat the enemy – defeated “by the inferior science of our enemies. I repeat – by the *inferior* science of our enemies.”[99] Despite the initial advantage of technologically advanced weaponry, and the military calls to improve their existing weapon, he points out that the “existing weapons have practically reached finality… that there has been no basic change in armaments for over a century.”[100] With many similarities, while the tactics, techniques, and procedures, and the technology which the United States has used to conduct warfare since World War II has advanced in many ways, the method which the United States trains has adapted very incrementally.

Cognitively burdening individuals has proven to lead to reduced information intake and increased stress with negative outcomes. Relieving the mind of problem-solving during training scenarios will speed up the learning processes. Limiting problem solving techniques to selection and assessment scenarios or select testing situations where the goal is to identify individual strengths and weaknesses will enhance learning with degrading the long-term objective – better operators. Neuroscience experts from Qneuro, a leading neuro-optimization for an accelerated learning company, projects that, “personalized learning informed by both performance and neuro-physiological data” can now be used to “not only optimize the way the military designs training but also raise the cognitive advantage across the force.”[101] To measure cognitive load, nascent wearable technology is becoming available which will allow operators in a dynamic environment to be measured in real time to assess the cognitive burdens they are operating under. The other key aspect which

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99 Arthur C. Clarke, “Superiority,” *The Magazine of Fantasy & Science Fiction,* August, 1951, http://nob.cs.ucdavis.edu/classes/ecs153-2019-04/readings/superiority.pdf, 1.

100 Clarke, “Superiority.”

101 Walcutt et al., “Neuro-Optimization for Accelerated Learning Pace and Elevated Comprehension: Military Applications,” 1.

remains in its infancy, however, is the real time data processing to analyze the information as it is being collected to build algorithms to quickly assess the readings.[102]

To help identify when an individual is being overloaded, scientists can measure cognitive load (CL) through the Electroencephalography (EEG) to provide real-time analysis.[103] While there are more complex methods to measure CL and a few which are less burdensome, the EEG and new wearable technology is emerging and becoming more accessible for scientists and engineers to study and analyze the individuals collected data, according to Dr. Walcutt. With real time neuromonitoring, professionals can provide personalized content for enhanced learning, or provide immediate feedback on the user's mental capacity. While at the end of the year 2020 the wearable devices and the human studies are still prototypes which require engineers to conduct data analysis on each experiment, algorithm generation is ongoing and within a couple of years, the algorithm creation should rapidly decrease the cost, time and effort of identifying physiological signs of cognitive overload.[104]

Technology is currently available in a static environment which can measure physiological symptoms such as eye tracking software, heart rate, breathing, pupil size, and a variety of other factors to identify performance parameters while conducting realistic operations in Augmented Reality headsets.[105] In a laboratory setting, this data is then analyzed by data engineers and electronic gamers to identify immediate action, goal directed behaviors to identify time-lock actions to know when people are performing better or worse. For a more dynamic environment, Northwestern University has partnered with a company called Neurolux to develop a wearable Bio-Mechanical Acoustic Device (BMAD) the size of a human thumb which can monitor up to 30 different dynamic responses to identify immediate human responses to situations. While the technology to

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[102] Huberman and Golden, "Biomechanical Acoustic Devices and Measuring Biologic Signals."

[103] Walcutt et al., "Neuro-Optimization for Accelerated Learning Pace and Elevated Comprehension: Military Applications," 6.

[104] Huberman and Golden, "Biomechanical Acoustic Devices and Measuring Biologic Signals."

[105] Huberman and Golden.

collect the raw data is currently available, it can only be done in a static environment and requires data engineers to process and analyze the information.

According to Andrew Huberman, neuroscientist and professor from Stanford University, the key to optimal performance is optimizing nervous system function – or neural fitness.[106] He describes Neural fitness as the balance between physical, emotional and cognitive fitness. Just as physical conditioning revolves around endurance, strength, mobility and flexibility, emotional fitness revolves around positive feelings and reflections. Likewise, cognitive fitness is described as maintaining creativity, memory, focus and task switching. Further research into the physical and mental health has been done by Naval Postgraduate School (NPS) student, Major Scott Cook, and can be found in the NPS thesis library for further reading.

Dr. Jimmie Leppink, psychologist and senior lecturer in medical education, has identified through corroborating research three guidelines for the design of educational instruction and assessment. To optimize learning in the cognitive load theory requires, as he states, the "development and automation of cognitive schemas," under three types of cognitive load: intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL).[107] According to Leppink, intrinsic cognitive load is when an individual is confronted with information that is about to be learned and the mind has not yet created schemas for this information – or it is not yet mentally automated in their way of thinking. Extraneous cognitive load is a result of cognitive processes that exist but do not contribute to cognitive learning. And finally, germane cognitive load is the cognitive load that is directly related to and beneficial to learning, to include asking appropriate questions about the topic, being able to accurately explain it to others and following up the learning with more education.

Two simple models exist to explain the improvement of learning – one which seeks to minimize ECL, or cognitive learning that does not contribute to learning, and one with

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[106] Huberman and Golden, "Biomechanical Acoustic Devices and Measuring Biologic Signals."

[107] Leppink, "Cognitive Load Theory," 386.

a direct relationship between ICL and GCL.[108] Leppink explains that first method to reduce the ECL and point new learners in the right direction is to provide them with an example of successfully completed problem first to help them identify a successful method to complete the task. The learner should attempt to eliminate distractions from learning such as emotions from previous mistakes, confusing instructions from peers or instructors, or extreme complexities beyond the student's capacity. Leppink explains that the second method to improving ICL and reducing ECL is to have specific and realistic goals for what the objective is that they students are trying to learn.[109] For example, a military operator who has never faced realistic challenges may focus on the wrong details of a contingency in an operation which would increase their ECL (cognitive distractions) and decrease their ICL (cognitive learning abilities). The conclusion for the ICL/GCL (stimulate learning/ create long-term schema) relationship while minimizing the ECL (mental distractions) is to set realistic goals for the learning objectives which do not over complicate the learners' capabilities. Leppink explains that the instruction should be presented simply and clearly, attempts should be made to reduce external student complications and provide realistic examples which clearly show what the expectations are for the exercise.

In his 1988 journal article titled "Cognitive Load during Problem Solving: Effects on Learning," John Sweller describes how domain specific knowledge, known as schemas, are the primary aspect which delineates novices from experts in problem-solving.[110] Sweller describes a schema as the mind's ability to recognize that a problem exists in a particular category, and then to apply the particular moves to solve that problem from existing experiences. He postulates that problem solving in the means-ends method is an ineffective learning device because the cognitive process required to problem solve does not overlap the cognitive processes of learning. Additionally, the problem solving requires

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[108] Leppink, "Cognitive Load Theory," 386, 387.

[109] Leppink, 387.

[110] John Sweller, "Cognitive Load During Problem Solving: Effects on Learning," *Cognitive Science* 12, no. 2 (April 1, 1988): 257, https://doi.org/10.1207/s15516709cog1202_4.

such a large cognitive workload that the mind is then unavailable to create schemas.[111] One example Sweller uses is a chess master versus a novice chess player. A master chess player, he explains, will have multiple schemas planned from the start, whereas a novice player will begin with the end goal and apply a series of means to achieve that goal – not choosing a known or very likely solution to their problem. Applying this theory to the military, ground force commanders and their artificial intelligence systems can work together to help achieve the expert level despite having less experience than an expert.

According to Dr. Sweller, conventional problem solving is not an effective learning method.[112] During a complex problem-solving scenario, Sweller teaches that the cognitive load imposed during a means-ends analysis may significantly degrade the learning during problem solving, and "leads to problem-solution, not to schema acquisition." While it would be assumed that to build more schemas, or patterns to solve problems, would be to practice on a large number of problems to build problem-solving skills, Sweller concludes through many years of studies that this method is ineffective. As a result, regardless of the outcome, a very little amount of long-term memory creation has actually taken place.

Excessive reliance on these actions, without preformed schema, may lead to excessive cognitive load.[113] Furthermore, while large cognitive load during problem solving hinders learning, scientists assume three things: 1) that each human has a fixed cognitive capacity; 2) that both problem solving and learning will take up that cognitive capacity; and 3) that problem solving and learning are different cognitive functions.[114] The resulting outcome, according to Sweller, is that any increased mental bandwidth absorbed by the mind during problem solving will have a direct decrease on the minds ability to learn. The importance here for the military can be directly applied to not only the common, "crawl, walk, run," method of instruction, but also the importance of Artificial Intelligence

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111 Sweller, "Cognitive Load During Problem Solving: Effects on Learning," 257.

112 Sweller, 260, 283.

113 Sweller, 265.

114 Sweller, 275.

to apply historic lessons learned into future military technology to absorb the added strain of problem solving on future operators.

In *Information, Power, and Grand Strategy: In Athena's Camp*, Dr. John Arquilla and David Ronfeldt highlight the increasing importance in the relationship between information and power, proposing that the trends between them may provide implications on the "theory and practice of warfare and for grand strategy in times ahead."[115] *In Athena's Camp* breaks down information into three different views: 1) Information as the inherent message; 2) information as the medium of production, storage, transmission, and reception; and 3) information as a physical property.[116] While much is written on the theory of power, *Athena's Camp* breaks power into three areas: 1) material; 2) organizational (or systemic), and 3) immaterial in nature. Arquilla and Ronfeldt apply these powers across the political, military and economic fields.[117] The merging of the two theories of information and power are inversely related. The traditional view will propose that information is historically important and valuable and will continue to become more important. Arquilla and Ronfeldt, however, argue "a new Athena-like view" that states information is a much larger, more complex problem than originally postulated and should be viewed "as a basic, underlying and overarching dynamic of all theory and practice about warfare in the information-age."[118]

In the view of Athena, the Greek goddess of warrior wisdom, the future merging of information and power happens where information becomes physical and power becomes immaterial.[119] In a step into the future, and a concept which is in line with the historic war theorist Carl von Clausewitz's theories, the Athenan future warfare concept minimizes internal disorganization and maximizes disruption against the enemy. The optimal

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[115] John Arquilla and David Ronfeldt, "Information, Power, and Grand Strategy: In Athena's Camp - Section 1," n.d., 1.

[116] Arquilla and Ronfeldt, 145.

[117] Arquilla and Ronfeldt, 150.

[118] Arquilla and Ronfeldt, 154.

[119] Arquilla and Ronfeldt, 156.

information and power merging will be a system which can provide data and systems information in a model that maintains robust power and resistance from disruption. *Athena's Camp* says that maximum information matter must be processed and provided to the individual, organization, or nation which it is serving in a manner that it can be used to achieve victory. The data processing and transmission of that information to the individual in the information-age will be increasingly difficult in communications denied environment, but also increasingly important as the information processing requirements grow and the mind's ability to process it remains mostly static.

B. CONCLUSION/ RECOMMENDATIONS

1. Recommendation A

To mitigate the detrimental effects of cognitive overload on operators, the military must first invest in technology to identify and quantify real-time cognitive overload in a dynamic, Full Mission Profile (FMP) scenario. Using the Virtual and Augment Reality headsets, human systems integration and tests should be conducted using the Ground Force Commander simulation trainers to measure an operator's physiological symptoms to identify cognitive load. The available systems use off-the-shelf eye tracking software, heart rate monitoring, breathing rates, pupil size and a variety of other factors, and once analyzed by data engineers, instructors can identify areas of learning improvement.[120] As the Bio-Mechanical Acoustic Device wearable technology becomes more mainstream, and the data algorithms have been robustly developed, military operators and leaders can use these devices to monitor the cognitive load on their forces. The neuro-physiologic measuring devices can be used during training to identify specific weaknesses and build individualized training plans. They can also during combat operations to highlight combat stress and to improve the military team's effectiveness.

2. Recommendation B

Refocus the Preservation of the Force and Families (POTFF) to emphasize the importance of wearable technology to achieve individual Neural Fitness – or the balance of

[120] Huberman and Golden, "Biomechanical Acoustic Devices and Measuring Biologic Signals."

cognitive, emotional, and physical fitness.[121] As the Preservation of the Force and Families initiative in the military continues, continuous physical and mental health monitoring using data collected from emerging wearable devices should be invested in and become a daily part of the individual health and neural fitness. These impacts may reach beyond military training and have an impact on post-traumatic stress disorders and suicide prevention, by identifying individual cognitive load.

3. Recommendation C

Operators should take cognitive assessments on their ability to perceive and receive information, then have professionals assist them with setting up the information they receive toward their strengths and weaknesses. For example, if someone is an auditory learner, more important information may be provided audibly. If they perceive information more efficiently visually, then more can be placed in an Augmented Reality heads up display.

Identifying cognitive overload in stressful situations, and then adjusting individual training to mitigate its impacts on the operator, is the beginning to creating organizational changes which will optimize the individual's impact on the battlefield. It will become increasingly important for Special Forces organizations to train and drill with existing and innovative technology which can identify and remedy individual's cognitive overload, and to adapt the technology so those operators can comprehend greater information in order to prevent decision paralysis.

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121 Huberman and Golden, "Biomechanical Acoustic Devices and Measuring Biologic Signals.."

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APPENDIX D. USER EXPERIENCE AND USER INTERFACE DESIGN

How will wars be fought in the next 10, 20, or 50 years? Rapidly improving technology, has the potential to leave the human behind and overwhelmed without thoughtful development of user experience/user interface (UX/UI) to ensure true "human-machine teaming." This appendix will not only show the importance of user design but establish a common framework and terminology, and then illustrate how industry design practices in the technology field can be incorporated into AISUM. Interface design is the linchpin between the technology and the end user, it is the bridge between AI and SU, in AISUM. For the program to be successful not only does the technology have to work, but the end user needs to adopt, incorporate, and embrace the capability. Unfortunately, the United States military has countless examples of failure to focus on the end users at the beginning and during the entire acquisition process. At its core this capstone's goal is to ensure innovation adoption at the tactical level, by not just focusing on the technology, but instead, the user. When we look closer at User Experience (UX) and User Interface (UI) specifically related to Artificial Intelligence for Small Unit Maneuver (AISUM) and the common control station (CCS) that Autonodyne is creating for SOCOM, it is clear there is a critical need for purposeful UX/UI design influenced by operational subject matter experts (SME) to ensure true human-machine teaming. As technology improves and drones become more prevalent and necessary on the battlefield, human operators must still be able to maintain situational awareness in the context of human-machine teaming without being overtasked or cognitively overloaded.

In order to examine specific details of UI and UX systems, we must first establish a taxonomy of fundamental principles and definitions since terms vary among differing industries, academia, and within the Department of Defense (DOD) itself. We use SAE International's definition of Human Systems Integration (HSI) as "the management and technical discipline of planning, enabling, coordinating, and optimizing all human-related considerations during system design, development, test, production, use and disposal of systems, subsystems, equipment, and facilities."[122] The key part of the definition is the optimization of human-related considerations throughout the life cycle of a product. Failing to consider the human element leads to constant redesigns resulting in delays and additional costs.

HSI originated with the DOD as part of the total systems approach to acquisitions directed by DOD 5000.02 with the goal of "optimizing total system performance among hardware, software, and human assets, operational effectiveness, suitability, survivability, safety, and affordability."[123] This emphasis on optimizing the total system and specifically including human resources is an important principle that considers the context in which hardware and software are intended to be used. Accepting that system performance requires maximizing human capabilities, it becomes apparent that the principles of HSI need to be incorporated throughout the DOD's acquisition process (illustrated below).

[122] G-45 Human Systems Integration, *Standard Practice for Human Systems Integration* (United States: SAE International, 2019), 45, https://www.sae.org/content/sae6906.

[123] Department of Defense, *Operation of the Defense Acquisition System*, DOD Instruction 5000.02 (Washington, DC: Department of Defense, 2017), 52.

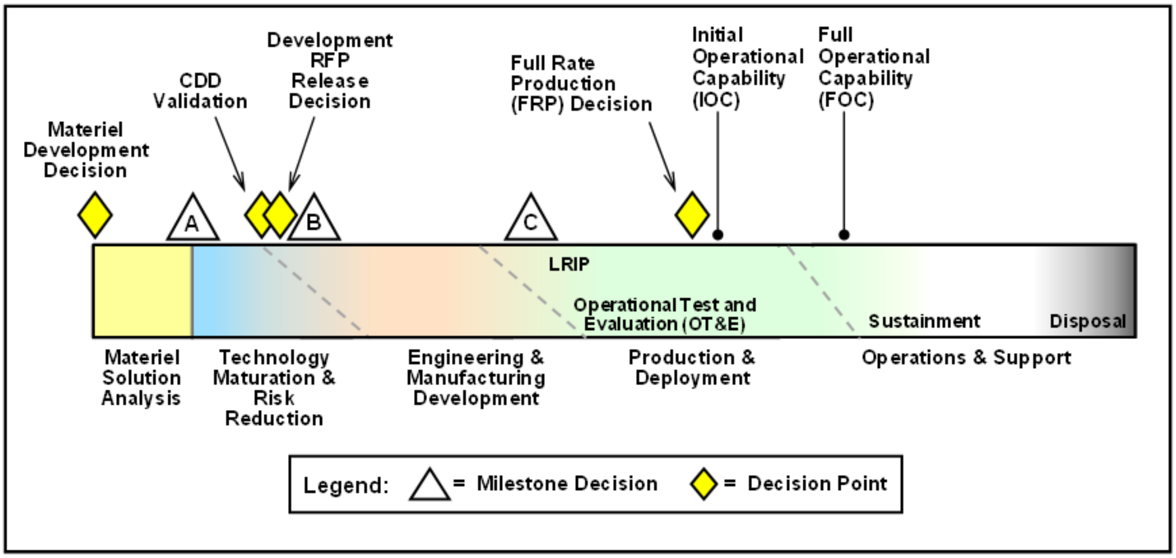

Figure 5. Model 1: Hardware Intensive Program[124]

The DOD's acquisition process is phase-based with each phase culminating in a milestone at which point it is determined if the process should proceed to the next phase (indicated by the A, B, and C above). Milestone approval is contingent on the fulfillment of certain criteria that is defined in relation to the project's goals. HSI, specifically with operational SME's involvement, cannot begin during Operational Test & Evaluation (OT&E) at which point the product has already been designed, engineered, and manufactured and when addressing problems requires redesign that delays final operational capability and delivery of an often-critical product to the warfighter. This is why DOD Instruction 5000.02 specifically requires Program Managers to take steps through "contract deliverables, government and contractor integrated product teams, and other mechanisms to ensure ergonomics, human factors engineering, and cognitive engineering is employed throughout the systems engineering process and over the life of the program in order to ensure effective human-machine interfaces and fulfillment of all HSI requirements."[125] Instruction 5000.02 goes on to specify, "system designs will minimize or eliminate system characteristics that require excessive cognitive, physical, or sensory skills; entail extensive

[124]Source: Department of Defense, 8.

[125] Department of Defense, 79.

training or workload-intensive tasks; result in mission-critical errors; or produce safety or health hazards."[126] Unfortunately, this is not always the case, and every member of this capstone team has experienced, during the course of their career, HSI not being properly considered during the development of a product or device intended for the warfighter to utilize in combat.

A simple example that illustrates this occurred during OT&E of the AC-130J. A particular piece of equipment was installed across all C-130Js that Air Force Special Operations Command (AFSOC) had in its inventory. To make the installation simple, it was decided at the program level to install the new equipment in the same place on each variant of C-130J. However, on the AC-130J there was a piece of communications equipment in the way of the new install, which engineers moved to accommodate the new device. It was not until a flyer saw the modification already completed that anyone realized a big problem. The operator did not need to directly interact with the new piece of equipment that had been installed in a location that is ergonomically and proximally optimal for operators to reach. The communications equipment that was previously in that location, however, is used by operators on every flight and must be physically touched to function. To accommodate the new install, the communications device was moved to the top of the aircraft making it unreachable during flight. The failure to understand what was being moved and how it was utilized by operators led to serious issues that had to be resolved. There are a lot of factors that play into where to install something in an aircraft, such as weight, access to power, heat, utility, and size; however, in this instance there was a failure in HSI. This happened because the human element was not taken into consideration, resulting in unnecessary redesigns, delays, and additional cost. The effects of these deficiencies in execution have been costly and time-consuming, ballooning program budgets and delaying timelines. A 2005 U.S. Government Accountability Office (GAO) report concluded that "major weapon systems programs experience early cost increases by an average of 42% over original estimates and schedule slips by an average of almost 20%; of the identified overrun causes." GAO analysts determined that "most

[126] Department of Defense, 79.

were the result of problems that could have been discovered early in the design process."[127] By properly applying HSI earlier in the process these issues can be identified prior to design and manufacturing, thus saving time and money.

As previously mentioned, terminology can get confusing since, according to the DOD, HSI is required to be implemented with the goal "to optimize total system performance and total ownership costs, while ensuring that the system is designed, operated, and maintained to effectively provide the user with the ability to complete their mission."[128] The instruction, however, does not spell out a specific definition for HSI. The HSI Requirements Pocket Guide refers to Air Force Instruction 63–1201—"Life Cycle Systems Engineering," which defines "Human Systems Integration as a disciplined, unified, and interactive systems engineering approach to integrate human considerations into system development, design, and life cycle management to improve total system performance and reduce costs of ownership."[129]

HSI can be broken down into nine domains illustrated below in Figure 6.

[127] GAO, *Assessments of Selected Major Weapon Programs* (Washington, D.C.: U.S. Government Accountability Office, 2005), www.gao.gov/cgi-bin/getrpt?GAO-05-301.

[128] Department of Defense, *Operation of the Defense Acquisition System*, 79.

[129] Bridget Simpkiss, *Human Systems Integration Requirements Pocket Guide*, AFHSIO-001 (Air Force Human Systems Integration Office, 2009), 4, https://ww3.safaq.hq.af.mil/LinkClick.aspx?fileticket=a-SJ8pDnkSE%3d&portalid=63.

Figure 6. HSI Domains[130]

This project focuses on the domain of Human Factors (HF) as the central concern of the team's work with Autonodyne on their CCS for multiple Small Unmanned Aerial Vehicles (sUAV). According to the *INCOSE Handbook*, the Human Factors domain addresses how to incorporate human characteristics and limitations into systems design for optimal usability. Hardman spells out how the HF domain is commonly divided into four sections:

- Cognitive— e.g., response times, level of autonomy, cognitive workload limitations
- Physical—e.g., ergonomic control design, anthropomorphic accommodation, workload limitations

[130] Source: Nicholas S. Hardman, "An Empirical Methodology for Engineering Human Systems Integration" (PhD diss., Air Force Institute of Technology, 2009), 176, https://scholar.afit.edu/etd/2102/.

- Sensory— e.g., perceptual capabilities, such as sight, hearing or touch
- Team dynamic—e.g., communication and delegation, task sharing, crew resource management[131]

Overall, HF is centered around the creation of effective human/machine interactions. The four sections classify how the human user relates to, and is able to effectively utilize, the machine. Considering technological developments in artificial intelligence (AI) and machine learning that are core to sUAV, as well as improved automation and ever-increasing payload capabilities, it is critical to recognize the immense significance of the interaction of operators and sUAV. According to Hardman in his doctoral dissertation, "formal study of this has matured and expanded in perspective over the last three decades, and is now generally referred to as human-computer interaction (HCI)."[132] Hardman goes on to offer a functional definition of HCI as "a field of study that seeks to improve the relations between users and computers by making computers more usable, intuitive, and accommodating of human capabilities and limitations."[133] Properly accounting for the limitations and capabilities of a single operator, specifically at the tactical level where that individual is in a dynamic, foreign, and dangerous environment will reduce cognitive overload and, perhaps more importantly, improve adaptation and acceptance of the technology. Hardman asserts that the central emphasis of HCI is the "design of effective user interfaces (UIs); that is, the multi-modal exchanges between a human being and hardware; these interfaces facilitate interaction between human cognition and software logic."[134] Figure 7 is a pictorial depiction of human factors, HCI, and UI design and how they relate and build upon each other.

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[131] Hardman, 177.

[132] Hardman, 206.

[133] Hardman, 206.

[134] Hardman, 207.

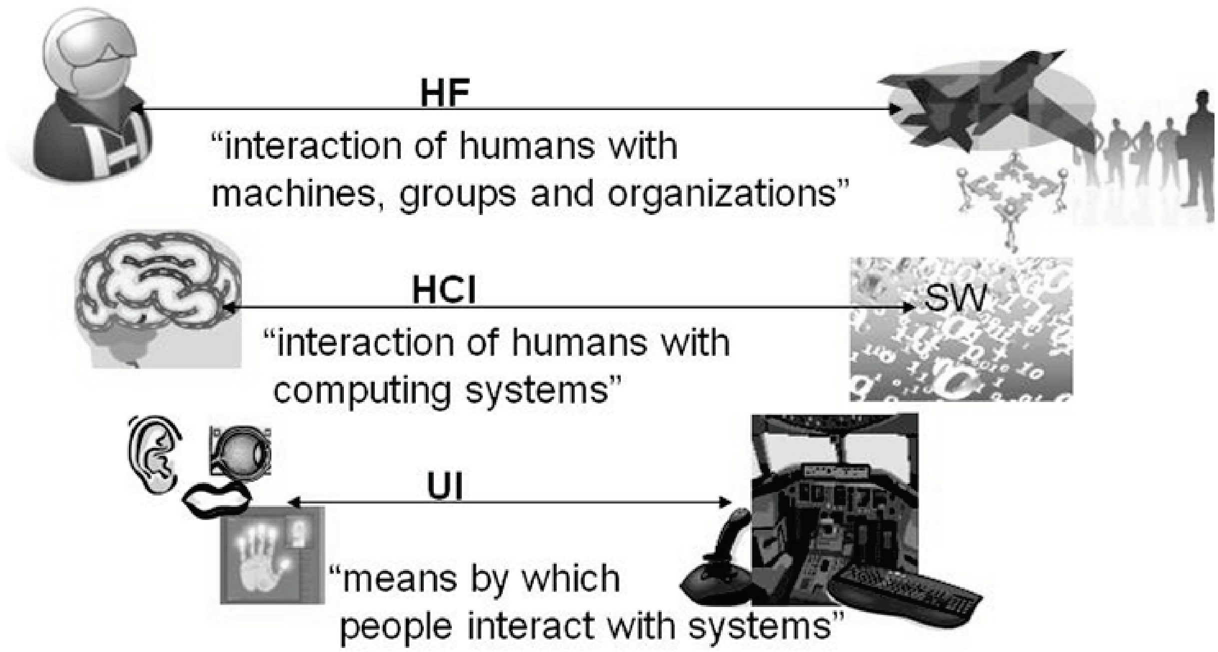

Figure 7. Human Factors Domain Components[135]

To understand the importance of HCI, consider for argument's sake that an operator can easily manage four sUAV in a static environment or even out on a mission that is relatively benign. What happens, however, when things become more dynamic from either a troops-in-contact situation, the deployment of an improvised explosive device (IED), or any number of potential dangers troops face during combat? If the operator cannot maintain situational awareness regarding the unfolding situation, simultaneously manage the sUAV, and becomes cognitively overloaded, a critical point is reached when training kicks in and tasks are prioritized in order of danger and/or criticalness. In aviation, the phrase used is "aviate – navigate – communicate." This means when things start to go wrong an operator must focus on keeping the aircraft in the air, avoid flying into a mountain, and start communicating to support channels outside the aircraft. Thus, the operator would have to focus their attention on the task at hand while ignoring the management and control of the sUAV, rendering the devices useless. If an operator can't control, manage, task, and receive critical information from the sUAV in a dynamic environment, then once the fog and

[135]Source: Hardman, 207.

friction of war appear they are no longer in the fight. Therefore, UX and UI design that reduces cognitive load and lets the user maintain situational awareness is absolutely critical in the development of a CCS for sUAV.

Having established principles and operational understanding of HSI, the HF domain, and HCI, we must now consider the specifics of User Experience (UX) and User Interface (UI). Maier argues the importance of both by stating, "The greatest leverage in system architecting is at the interfaces, and the greatest dangers are also at the interfaces."[136] The success of this critical node is often linked to the overall success or failure of the product and/or company, specifically in the private sector. There are lots of examples of this in the internet/technology sector such as BlackBerry failing to adapt to the competition by not developing touchscreen capability, MySpace overestimating user desire for full customization, and even Microsoft and the dreaded Windows 8 debacle of removing the "Start" button. Nicolas Hardman points out that while the impact of such fiascos in the commercial sector are on market share or profits, in the military they impact tactical advantage and could result in the loss of life, and the "Defense Acquisition Guidebook affirms this, identifying interface management, including the user interface, as a critical process that systems engineers must focus on."[137] Previous cost studies conducted by the DOD have concluded that the majority of total life-cycle costs are related to manpower, personnel and training.[138] In *The Importance of Designing Usable Systems*, Susan Dray suggests a direct trade-off between manpower, personnel, and training costs and investment in the user interface; She cites a company project in which an "improved user interface on a large-scale internal application resulted in a 32% overall rate of return

136 Mark W Maier, "Architecting Principles for Systems-of-systems," *Systems Engineering* 1–460 (1998): 32, https://doi.org/10.1002/(SICI)1520-6858(1998)1:4<267::AID-SYS3>3.0.CO;2-D.

137 Hardman, "An Empirical Methodology for Engineering Human Systems Integration," 161.

138 Cecilia Haskins, International Council on Systems Engineering, and Systems Engineering Handbook Working Group, *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities* (San Diego, Calif.: International Council of Systems Engineering, 2011), 45.

stemming from a 35% reduction in training and a 30% reduction in supervisory time."[139] This result dramatically illustrates the profound impact of user interfaces.

The terms UX and UI are often used interchangeably, which can lead to some confusion, so it is important to define each concept independently and describe the manner in which they interact. Don Norman, a cognitive scientist, is credited with coining the term "user experience" in the late 1990s, which he describes as "encompassing all aspects of the end-user's interaction with the company, its services, and its products."[140] UX, on the other hand, is a combination of the complete user experience while UI refers specifically to the actual product's interface – in other words, what the user actually sees when they interact with the product. User Interface, put simply, is the point of human-computer interaction and communication on a device, webpage, app, or, in our specific application, Autonodyne's graphical user interface (GUI) for their common control station. A simple, if crude, analogy would be that UI could be considered a person's Tinder dating profile while the UX would be how the date they have with someone they connect with through the app goes. UI is often centered around functionality, while UX is much more of a psychological idea. For instance, the functionality might be just fine for a product, but if the UX is awful then it will be difficult to get the core users to adopt the product and continually utilize it.

In the journal article *Human–Systems Integration Verification Principles for Commercial Space Transportation*, Guy André Boy states that, "User experience is linked to human factor issues and cognitive functions involved in the use of a system for executing a prescribed task in specific situations and environments."[141] Boy went on to explain that "human factors mainly include training (expertise), trust, risk of confusion, lack of knowledge (ease of forgetting what to do), workload, adhesion, and culture, while

[139] Susan Dray, "The Importance of Designing Usable Systems," *Interactions* 2, no. 1 (January 2, 1995): 18, https://doi.org/10.1145/208143.208152.

[140] Don Norman, Jakob Nielsen, "The Definition of User Experience (UX)," Nielsen Norman Group, accessed September 8, 2020, https://www.nngroup.com/articles/definition-user-experience/.

[141] Guy André Boy et al., "Human–Systems Integration Verification Principles for Commercial Space Transportation," *New Space* 6, no. 1 (March 1, 2018): 53–64, https://doi.org/10.1089/space.2017.0040.

cognitive functions include learning, situation awareness (that involves understanding, short-term memory, and anticipation), decision-making, and action (that involves anticipation and cross-checking)."[142] This illustrates the importance of a holistic and comprehensive approach to user experience from training and documentation to complexity and ease of use for the intended user. For military technology designed to be utilized on the battlefield this means specifically the user experience under those conditions and not, for instance, when casually using the system on a test range.

In the next section we will examine ten guidelines for user interface design and provide examples of how they can be applied specifically to Autonodyne's CCS in a military context. Jakob Nielsen, a renowned web usability consultant, established a list of ten user interface design guidelines in the 1990s; these guidelines are referred to as heuristics because they are broad rules of thumb and not specific usability recommendations.[143]The ten heuristics were first presented by Nielsen at the Special Interest Group on Computer–Human Interaction (SIGCHI) Conference on human factors in 1994. Nielsen's heuristics are listed below and after each heuristic exactly how they can be applied in the context of sUAV are:

- **Visibility of system status**: The system should always keep users informed about what is going on through appropriate feedback within reasonable time.

As drone swarms increase in complexity, system status reports should be limited to addressing only catastrophic failures. Also, multi-modal responses should be explored to enable greater flexibility and prevent the user from having to see a visual of a system status update.

- **Match between system and the real world**: Designers should endeavor to mirror the language and concepts users would find in the real world

142 Boy et al., 55.

143 Jakob Nielsen, "10 Heuristics for User Interface Design," Nielsen Norman Group, accessed September 8, 2020, https://www.nngroup.com/articles/ten-usability-heuristics/.

based on who their target users are. Presenting information in logical order and piggybacking on a user's expectations derived from their real-world experiences will reduce cognitive strain and make systems easier to use.

Maintaining normal military jargon, brevity, and code words can reduce cognitive strain and training. Terms made up by engineers to describe functions are often different than how troops are trained, which can lead to confusion.

- **User control and freedom**: Offer users a digital space where backward steps are possible, including undoing and redoing previous actions.

Mistakes happen, and during the fog and friction of war it is imperative to have an ability to abort a command even if it is not related to a kinetic strike.

- **Consistency and standards**: Interface designers should ensure that both the graphical elements and terminology are maintained across similar platforms. For example, an icon that represents one category or concept should not represent a different concept when used on a different screen.

This is extremely important since the CCS will be able to control several different types of drones from different manufacturers. Icons and commands should be the same, and the software should be intelligent enough to not display commands that a particular drone with its given payload is not capable of executing.

- **Error prevention**: Even better than good error messages, a careful design which prevents a problem from occurring in the first place is tantamount to ease of operation. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.

Intuitive user interface and smart software can help prevent user errors from occurring. In a dynamic environment on the battlefield troubleshooting error messages will be extremely difficult for an operator to manage.

- **Recognition rather than recall:** Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Due to the limitations of short-term memory, designers should ensure users can simply employ recognition instead of recalling information across parts of the dialogue. Recognizing something is always easier than recall because recognition involves perceiving cues that help us reach into our deep memory and retrieve relevant information.

During combat, often the operator will be juggling multiple tasks at once making recognition a critical component to limit cognitive overload. For example, using common military color schemes to indicate friendly or enemy positions and using normal military symbols for different units help with operator recognition.

- **Flexibility and efficiency of use**: With increased use comes the demand for fewer interactions to allow for faster navigation. This can be achieved by using abbreviations, function keys, hidden commands, and macro facilities. Users should be able to customize or tailor the interface to suit their needs so that frequent actions can be achieved through more convenient means.

This can aid in two ways: allowing system setup and display based on user expertise, and providing an ability to scale the complexity of displays when a user starts to become over-tasked. In the future, a responsive UI based on biometric monitoring could make these adjustments automatically based on predetermined biometric data points. For example, as a user becomes more stressed as determined through active biometric monitoring, the UI automatically declutters the heads-up display (HUD) to remove distractions from the operator.

- **Aesthetic and minimalist design**. Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

Combat removes the luxury of the unnecessary. Only the relevant or critical is required.

- **Help users recognize, diagnose, and recover from errors**. Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

Operators will have little time, or ability, to troubleshoot error messages in combat. Therefore, the manner in which error messages are categorized and ultimately displayed to the operator is critical. If an error can't be fixed and degrades the sUAV to the point it has lost its utility, then a simple notification of a loss is sufficient. However, details on what happened are an example of unnecessary communication to the operator.

- **Help and documentation**: Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search for, focused on the user's task, list concrete steps to be carried out, and not be too large.[144]

The majority of the time this will only be used in training or during a static, relatively safe position, however, it should still be simple and easy to reference.

Future program development can benefit from utilizing Jakob Nielsen's ten heuristics for user interfaces. These will ultimately ensure great UI for a dynamic environment and a UX that enables organizational adoption of the technology. The performance of the humans in the system is built on the foundation of human systems integration in system development as portrayed in Figure 8.[145]

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[144] Nielsen.

[145] Hardman, "An Empirical Methodology for Engineering Human Systems Integration," 160.

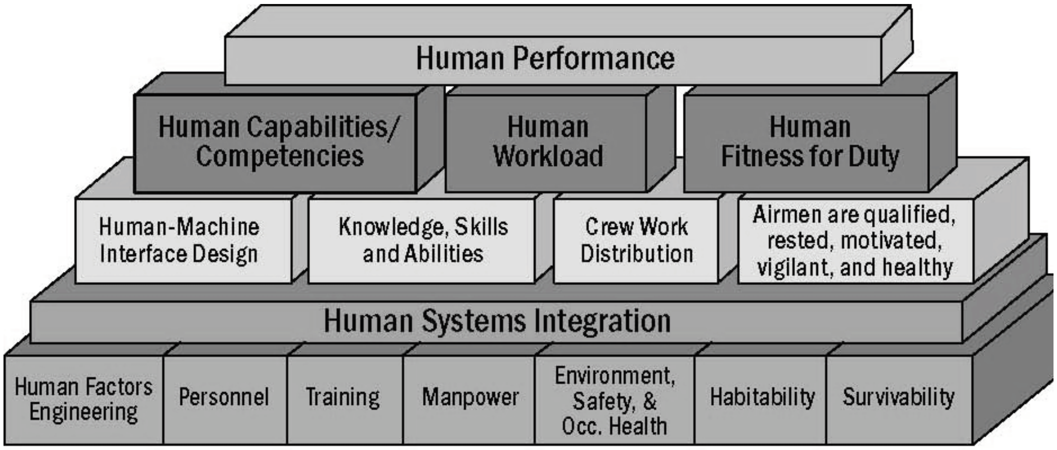

Figure 8. The Domains of Human Systems Integration[146]

As illustrated above the domains of Human Systems Integrations ultimately build the foundation of human performance. All the building blocks of the pyramid are related. For example, the field of human–computer interaction has the potential to increase the trade space for the total system requirements –meaning that increased interface reduces demand on manpower, personnel, and training requirements, while a lower error rate improves efficiency, which reduces task execution times.[147] As this analysis has shown, it is critical that HSI be initiated at the beginning of development and involves subject matter experts (SMEs) throughout the development process in order to realize the maximum benefits to the final product and reduce life cycle cost by avoiding continual refinement due to poor human integration. As the DOD looks to innovate and bring advanced technology to the battlefield, the adoption and incorporation for the warfighter will rely heavily on successful user experience design.

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[146] Hardman, 160.

[147] Hardman, 166.

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APPENDIX E. SOCIOTECHNICAL SYSTEM

Jon R. Lindsay of the Munk School of Global Affairs & Public Policy defines military organizations as systems of interdependent people, practices, and machines.[148] The relation between these elements is dependent on systems and processes that are defined and refined over time in reaction to advancements in technology. From moving troops on horseback to enabling operators to manage autonomous swarms, technical capacity is consistently informing the manner in which people and practices are utilized and empowered. As a fundamental element of the military, it is helpful to examine in detail how the nature of sociotechnical systems impacts the HEO system and USSOCOM's progress toward autonomous systems.

A. INTRODUCTION

When Lord Wilfred Banks Duncan Brown became managing director of London's Glacier Metal Company in 1939, the company was in a precarious financial position. Glacier had been fabricating plain bearings for engines since the turn of century, but in 1938 it was embroiled in a patent infringement lawsuit that nearly put the company out of business, only being granted a brief reprieve during World War II to keep infringing on the patent in the name of national security.[149] Perhaps understanding he had nothing to lose, Brown was emboldened to reshape the company's operational approach based on a theory he described as "the necessity of encouraging everybody to accept the maximum amount of personal responsibility, and allowing them to have a say in every problem in which they can help".[150] In practice, this meant joint consultation between workers and management,

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[148] Jon R Lindsay, "Reinventing the Revolution: Technological Visions, Counterinsurgent Criticism, and the Rise of Special Operations," *Journal of Strategic Studies* 36, no. 3 (June 2013): 422–53, https://doi.org/10.1080/01402390.2012.734252.

[149] Bill Wilson, "Glacier Plain Bearings: A Materials and Production Engineering Success Story," *Industrial Lubrication and Tribology* 48, no. 5 (January 1, 1996): 7–13, https://doi.org/10.1108/00368799610129036.

[150] "Here Comes the Boss Programme 2: Keep Talking: An Experiment in Industrial Democracy in the 1940s and 1950s," BBC Education, accessed September 4, http:/www.bbc.co.uk/education/boss/trans2.html.

bringing employees into the decision-making processes to build trust, and encouraging employee responsibility.[151]

B. RESEARCH ORIGINS

Once the war ended, Parliament commissioned a panel to study the Glacier process, enlisting the Tavistock Institute of Human Relations led by the Canadian psychologist Dr. Elliott Jaques. He went on to publish his findings in a series of books starting with *The Changing Culture of a Factory* in 1951 which examined the workplace as a social system focused on technical functions, leading Jaques to postulate the relation between these elements required a new field of inquiry.[152]

Another landmark study involving coal miners identified how social technical systems find workers who organize into autonomous teams and develop group-based strategies to overcome technical challenges and the differentiation and interdependence of tasks.[153] Over the next 20 years, the Tavistock Institute was at the forefront of research into socio-technical systems, with co-founder Eric Trist establishing the first graduate program in sociotechnical theory at UCLA in 1966.[154] Sociotechnical system theory proposes that people, as the constituent components of an organization, generate products or provide services using technology, with people impacting the function and appropriateness of the technology that is used, and technology influencing the actions and attitudes of the people using it.[155] Sociotechnical theory finds that effective jobs and workflows are those that consider this interaction of technical and human needs by

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151 "How Glacier Broke the Ice on Worker Participation," *Industrial Management* 75, no. 9 (January 1, 1975): 12–14, https://doi.org/10.1108/eb056557.

152 E. L. Trist & K. Bamforth, "Some Social and Psychological Consequences of the Longwall Method of Coal Getting," *Human Relations* (2015): 5.

153 "How Glacier Broke the Ice on Worker Participation," 12–14.

154 E. L. Trist, *The Evolution of Socio-Technical Systems: A Conceptual Framework and an Action Research Program* (Ontario: Ontario Quality of Working Life Centre, 1981), 5.

155 William Pasmore, Carole Francis, Jeffrey Haldeman, and Abraham Shani, "Sociotechnical Systems: A North American Reflection on Empirical Studies of the Seventies," *Human relations* 35, no. 12 (1982): 1179–1204.

balancing the people's intrinsic needs with the organization's need for technical efficiency.[156]

C. TECHNOLOGY AND BEHAVIORS

The design of an organization constrains the social systems functioning within it by defining the types and quality of behaviors needed for the organization to operate; the level of control, challenge, or feedback available to people, for example, results from the ordering and design of the technology.[157] Based on a review of 134 sociotechnical experiments conduct during the 1970s, Pasmore, Francis, Haldeman, and Shani identified four orders of effects technology has upon organizations. Starting with the most direct effects on productivity, place, motions, and behaviors in the center, the model they created (Figure 9)[158] moves outwards towards orders that emerge from the preceding layer with second order effects such as roles and relationships developing in order to coordinate actions and goals related to the direct effects. Adaptability, learning and other growth and sustaining skills emerge in the third order in relation to how people feel they are treated or valued by the organization, and in the final order, the technological patterns that define the organization impact its relationship with other organizations and society at large.[159]

D. EVOLUTION OF SOCIOTECHNICAL SYSTEMS

As human-computer interaction has become a pervasive aspect of work and life, the sociotechnical approach has provided a lens through which to view the intersection of technology and people in information systems and cognitive systems; it also has provided insight into the ways computers shape and define daily life and influence the manner in

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[156] Richard Daft, *Organization Theory and Design,*12th ed. (Boston: Cengage Learning, 2016), 69.

[157] Trist, *The Evolution of Socio-Technical Systems: A Conceptual Framework and an Action Research Program,* 35.

[158] Pasmore et. al., "Sociotechnical Systems," 1179–1204.

[159] Pasmore et. al., 1179–1204.

which computer systems are used.[160] The importance of understanding the human behavior and interaction models with sociotechnical systems spawned ergonomics and human factors research, research which aims to apply this understanding to interaction design in real-world settings.[161]

In considering real-world sociotechnical interactions, there is an effort to establish a taxonomy of these interactions in order to limit unintended consequences and to develop

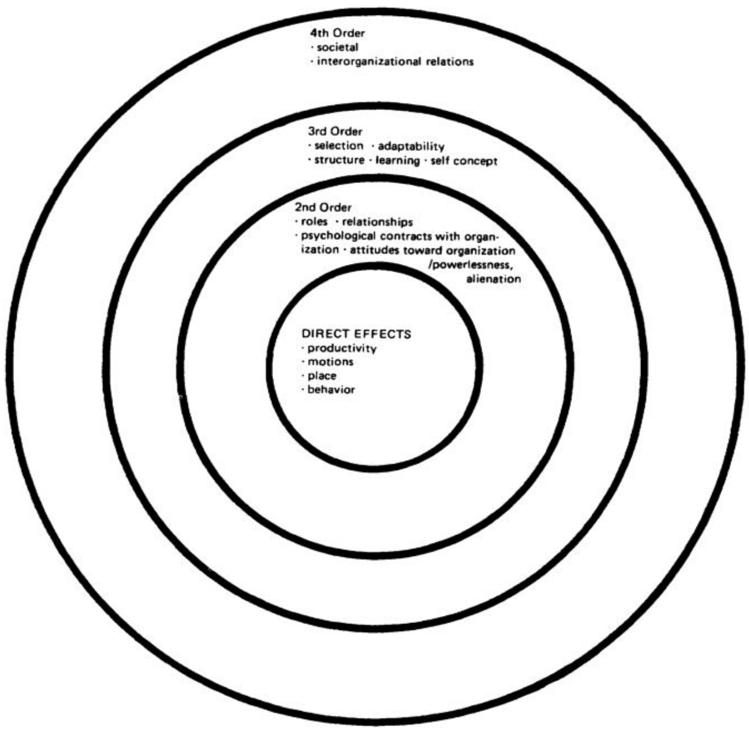

Figure 9. The Impact of Technology on Behavior

new approaches to human and computer interaction in a host of contexts.[162] For instance, applying this approach to a simple interaction with an ATM, we find taxonomic categories

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[160] Gordon Baxter and Ian Sommerville, "Socio-technical Systems: From Design Methods to Systems Engineering," *Interacting with Computers* 23, no. 1 (2011): 4–17.

[161] Pascale Carayon, "Human Factors of Complex Sociotechnical Systems," *Applied Ergonomics* 37, no. 4 (2006): 525–535.

[162] Tarcisio Abreu Saurin and Riccardo Patriarca, "A Taxonomy of Interactions in Socio-technical Systems: A Functional Perspective," *Applied Ergonomics* 82 (2020): 1–12.

like *output nature,* which defines the acceptable precision of the machine reading the card; if the machine fails to read the card the first time it is inserted, it can lead to a state change in the user, such as memory lapses when typing in their PIN, a situation which occurs frequently.[163] Even in this discreet element of a common activity, we can see the direct effects on human behavior and the nature of complexity in sociotechnical systems.

E. SYSTEM PRINCIPLES

The sociotechnical systems approach builds on general systems theory that is common to each scientific discipline, specifically the nature of interdependency and interrelation in cohesive, connected structures. Early on, Trist organized the system into three levels: the primary work system level, whole organization systems level, and macrosocial level.[164] On the primary work level Trist defined seven principles of work design: 1) optimum variety of tasks, 2) meaningful pattern of tasks, 3) optimum length of work cycle, 4) scope for setting quality and quantity standards and feedback of knowledge of results, 5) inclusion of auxiliary and preparatory tasks, 6) inclusion of care, skill, knowledge or effort worthy of respect in the community, and 7) contribution to the utility of the product to the customer.[165] Trist also developed new paradigms for a whole organization system which called for: joint optimization, workers as complimentary to the machine, workers as resources to be developed, optimum task grouping, internal controls, and a flat organization chart that allows for broad participation, collaboration, commitment, and innovation.

Trist set the table for sociotechnical system to evolve into a broader societal context. Observing the rise of computing in business and anticipating its ability to impact society, he formulated a macrosocial approach that recognized systems larger than the single organization and proposed looking at sociotechnical systems on a domain level that

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[163] Tarcisio and Patriarca, 1–12.

[164] Trist, *The Evolution of Socio-Technical Systems: A Conceptual Framework and an Action Research Program,* 51.

[165] Trist, 52.

cut across whole industries.[166] Trist also identified community-based sociotechnical endeavors, such as labor and management working together to reverse economic decline in communities.

F. HISTORY AND USES

From its inception, sociotechnical research has combined methods and subject matter expertise in psychology, sociology, and anthropology with engineering, mathematics, and business. Increasingly, sociotechnical system thinking involves computer science, human factors engineering, user experience design and similar disciplines. This pattern follows its evolution from an initial focus on production and manufacturing, where the goal was to humanize industries like coal, petrochemicals, and textiles, to its peak in the 1970s and 1980s, when it became increasing focused on the integration of computers into industry and business processes.

By the beginning of the 21st century, principles of sociotechnical system theory had permeated design methodologies such as participatory design, design which often places users into system developer roles and empathic and contextual design which has developers adopting the user's perspective.[167]

G. JOINT OPTIMIZATION

In order for work systems to operate effectively, the products or services they provide and the social and psychological impacts on people must generate positive outcomes and effects. When a sociotechnical system reaches this point of output equilibrium, it is said to be jointly optimized. Joint optimization recognizes the essential interrelatedness of the social, technical, and environmental components to the point that they cannot be separated; if these system components are addressed in isolation, each other

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166 Trist and Bamforth, "Some Social and Psychological Consequences of the Longwall Method of Coal Getting." 3–38.

167 Trist and Bamforth, 3–38.

component is affected, leading to potential unforeseen consequences from performance degradation to complete system failure.[168]

Figure 10 conceptualizes this relationship to illustrate that if any of the three components is moved independent of the others, the center zone of the Venn diagram is reduced. The dynamic nature of these relationships makes systemic adjusts complex, so core principles of joint optimization, informed by Trist's principles, should be considered at all times. First, individual stakeholders need to have *responsible autonomy;* second, tasks, schedules, and processes should be *adaptable*, such that they can be adjusted by team members for optimization; third, tasks must be *meaningful* throughout the cycle of operations; and finally, there must be *feedback loops* based on recursive interactions.[169]

H. JOINT OPTIMIZATION TAXONOMY

Rhodes and Ross proposed a five-aspect taxonomy to analyze system performance for optimization and for classification of research: "*structural* related to the form of system components and interrelationships, *behavioral* related to performance, operations, and reactions, *contextual* related to the circumstances the system exists within, *temporal* related to the properties and dimensions of systems over time, *perceptual* related to stakeholder preferences, perceptions, and biases." [170] Structural and behavioral aspects are further clarified as fundamental to the state of research practice, which is widely applied to systems architecture and design and systems engineering. Contextual, temporal, and perceptual aspects are more cutting-edge aspects of optimization that are being applied to new methods for modeling system relations such as epoch modeling and analysis in neural

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[168] Paola Di Maio, "Towards a Metamodel to Support the Joint Optimization of Socio Technical Systems," *Systems* 2, no. 3 (2014): 273–296.

[169] Trist, *The Evolution of Socio-Technical Systems: A Conceptual Framework and an Action Research Program,* 55.

[170] Donna H. Rhodes and Adam M. Ross, "Shaping Socio Technical System Innovation Strategies Using a Five Aspects Taxonomy," Massachusetts Institute of Technology Systems Engineering Advancement Research Institute, (2010): 3–4, http://seari.mit.edu/documents/preprints/RHODES_EUSEC10.pdf

networks, and Deep AI, multi-stakeholder negotiations, and complex data set visualizations.[171]

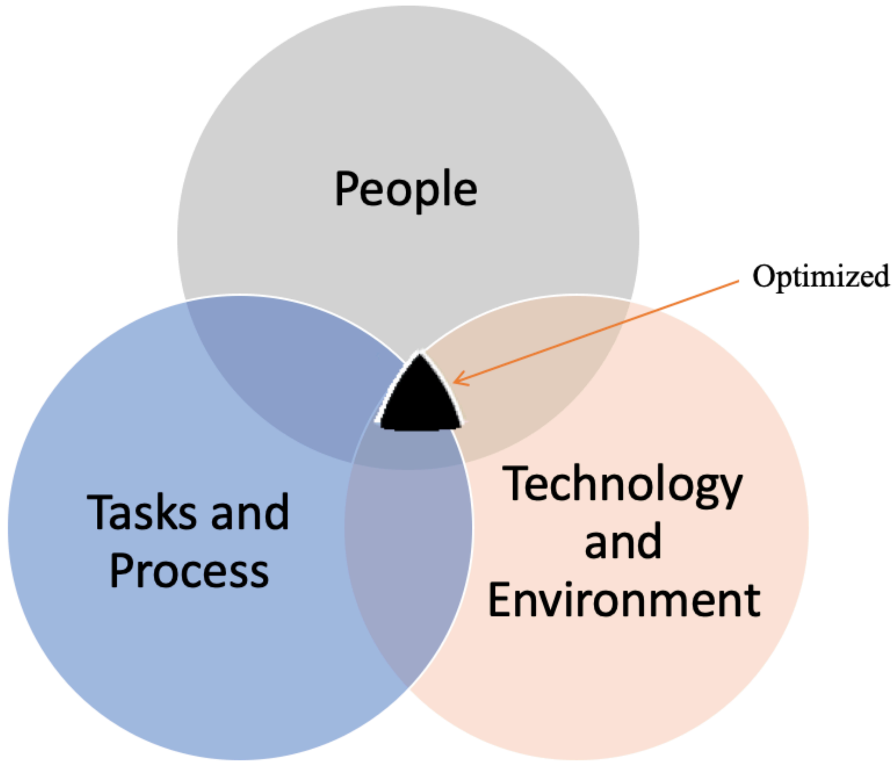

Figure 10. Joint Optimization Diagram

Applying the five aspect taxonomy to the optimization components reveals correspondence in each domain and provides a model for examination of granular aspects of the system for optimization. In the People/Social component, structural aspects are adaptable roles and self-managing teams, behavior aspects include ethics and collaboration, contextual aspects are politics, history, and culture, temporal aspects might be evolution of social norms, while perceptual aspects might be human cognition and biases.[172] In the Technical / Environmental domain, structural aspects include modular design of technical systems and sustainable design practices, behavioral aspects

[171] Di Maio, "Towards a Metamodel to Support the Joint Optimization of Socio Technical Systems," 273–296.

[172] Di Maio, 273–296.

interoperability and sustainable practices, contextual aspects include technical platforms and industry or market paradigms, temporal aspects include requirement changes and resource depletion, and perceptual aspects include cognitive systems.[173]

I. RISK ASSESSMENT

Critical industrial, technical, and public health and safety functions require sociotechnical systems, so evaluating the reliability of such systems is crucial.[174] Problem analysis and risk assessment of sociotechnical systems focuses on human error as related to human-machine interactions as well as interactions between humans; human error is the main cause of accidents, the implications of which can often be catastrophic and lead to system failure.[175] Theories for understanding and evaluating the causes and consequences of accidents have evolved from Heinrich's domino theory, that asserts accidents result from chains of events,[176] and James Reason's Swiss Cheese Model, which posits that barriers in systems intended to prevent errors all have weaknesses or holes.[177] Other systems thinking-based theories assert that accidents are the result of interactions between multiple human and technical elements such as functional resonance method (FRAM) and systems-theoretic accident model and process.[178]

173 Di Maio, 273–296.

174 Erik Hollnagel, *Human Reliability Analysis: Context and Control*, 1st Edition, Computers and People Series (London ; San Diego, CA: Academic Press, 1994).147-202.

175 Andreas Gregoriades, Alistair Sutcliffe, and Jae-Eun Shin, "Assessing the Reliability of Socio-Technical Systems," *Systems Engineering* 6, no. 3 (2003): 210–223.

176 Kiyanoosh Golchin Rad, "Application of Domino Theory to Justify and Prevent Accident Occurrence in Construction Sites." *IOSR J. Mech. Civ. Eng. IOSR-JMCE* 6 (2013): 72–76.

177 Thomas V. Perneger, "The Swiss Cheese Model of Safety Incidents: Are There Holes in the Metaphor?," *BMC Health Services Research* 5, no. 1 (2005): 71.

178 Clare Dallat, Paul M. Salmon, and Natassia Goode, "Identifying Risks and Emergent Risks Across Sociotechnical Systems: the NETworked Hazard Analysis and Risk Management System (NET-HARMS)." *Theoretical Issues in Ergonomics Science* 19, no. 4 (2018): 456–482.

J. BROKEN LINKS APPROACH

More recently, case studies involving the British Royal Navy have tested an approach known as Event Analysis of Systemic Teamwork (EAST) to capture risk throughout the entire system, rather that examine constituent parts.[179] The EAST approach examines systems in relation to social, task, and information networks with sociometric data used to identify key nodes, each of which has complex safety management roles and behaviors; a holistic social-task-information diagram is created and the relations between nodes are described as links.[180] Broken links indicate communication breakdowns and information transfer failures and are used to predict possible risks in sociotechnical systems. Research also indicates that cultural differences, such as conflict avoidance or conflict resolution or collectivist or individualistic cultures, can lead to team errors in sociotechnical systems, especially in high pressure situations.[181]

K. FUTURE TRENDS

The technology-saturated state of the world finds cities transformed into smart urban ecosystems and the Internet of Things powering so much of daily life. These two examples reveal the complexity and reach of sociotechnical systems and reveal new opportunities and challenges that require a sociotechnical design approach. Three fundamental properties must be articulated in the context of these systems: the mutual constitution of people and technologies, the contextual embeddedness of this mutuality, and the importance of collective action.[182]The system must be examined from each of

[179] Neville A. Stanton and Catherine Harvey, "Beyond Human Error Taxonomies in Assessment of Risk in Sociotechnical Systems: A New Paradigm with the EAST 'Broken-Links' Approach," *Ergonomics* 60, no. 2 (2017): 221–233.

[180] Erik Hollnagel, Human Reliability Analysis: Context and Control, 1st Edition.

[181] Barry Strauch, "Can Cultural Differences Lead to Accidents? Team Cultural Differences and Sociotechnical System Operations," *Human Factors* 52, no. 2 (2010): 246–263.

[182] Yilin Huang, Giacomo Poderi, Sanja Šćepanović, Hanna Hasselqvist, Martijn Warnier, and Frances Brazier, "Embedding Internet-of-Things in Large-Scale Socio-Technical Systems: A Community-Oriented Design in Future Smart Grids," *The Internet of Things for Smart Urban Ecosystems* (Cham: Springer, 2019): 125–150.

these perspectives to identify the design problems as well as the roles, responsibilities, and requirements of all stakeholders. Ultimately, a collaborative design process is required that balances the needs of the community and the power of the technology, which is the essence of the sociotechnical system approach.

L. CONCLUSION

As sociotechnical systems, the AISUM concept and HEO can be better implemented by understanding the nature of such systems, the challenges they face, and the opportunities for optimization. By applying the principles of joint optimization that recognize that the social aspects of the operator, the specific powers of the technology, and the interaction with environment and context are intricately linked, we establish a rationale for design that considers how each aspect is affected by changes to the others. By emphasizing the impact of human factors we ensure that technical changes are not made without closely examining how they impact the end users. Sociotechnical system thinking provides logical structure to leverage the advancements in Artificial Intelligence and Machine Learning required for revolutionizing human-machine teaming while ensuring that usability in social context of military operations and individual operational capacities are central to our definition of success.

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APPENDIX F. INNOVATION ADOPTION

In his testimony before the House Armed Services Committee in April, 2017, Defense Innovation Board (DIB) chairman Dr. Eric Schmidt stated, "DOD does not have an innovation problem; it has an innovation adoption problem." [183] Citing the size and complexity of the DOD's mission and systems, Schmidt noted that friction and latency has been built into the Department's decision-making process, adding additional layers of required coordination, rules, regulations and other mechanisms that inherently hinder the pace of change and growth.[184] This resistance to innovation is not unique to the DOD and is it indicative of structural patterns that can be observed throughout culture and commerce. To better understand these challenges in the context of the HEO and AISUM writ large, it is instructive to examine the socio-technical concepts that underpin the adoption of innovation.

A. INTRODUCTION

Popular opinion holds that 19th century American essayist Ralph Waldo Emerson said, "Build a better mousetrap, and the world will beat a path to your door," evincing the notion that innovation improves the quality of life and is rewarded with success. True to form, this very quote appears to be an innovation on what Emerson actually wrote in his journal in 1855, the more verbose statement being, "I trust a good deal to common fame, as we all must. If a man has good corn, or wood, or boards, or pigs, to sell, or can make better chairs or knives, crucibles, or church organs, than anybody else, you will find a broad, hard-beaten road to his house, though it be in the woods."[185] In addition to making it pithier and easier to remember, the innovated version of the Emerson quote actually

[183] U.S. House Armed Services Committee on U.S. Pacific Command Posture, 115th Cong. (2017) (Statement of Dr. Eric Schmidt).

[184] U.S. House Armed Services Committee on U.S. Pacific Command Posture, 115th Cong.

[185] Jack Hope, "A Better Mousetrap," American Heritage, accessed September 6, 2020, https://www.americanheritage.com/better-mousetrap.

mentions a mousetrap, a widely used cliché that captures a common sentiment. The quote is a successful example of innovation adoption.

B. INNOVATION DIFFUSION

In his book *Diffusion of Innovations*, Rogers defines an innovation as “an idea, practice, or project that is perceived as new by an individual or other unit of adoptions” and explains that adoption occurs when full use of the innovation is “the best course of action available;” he goes on to posit that the idea spreads through diffusion, which is “the process in which an innovation is communicated thorough certain channels over time among the members of a social system.”[186]

Diffusion of innovations requires four main components: the innovation, communication channels, time, and a social system. An innovation need not be new, in fact, it can be something that was invented a long time, but if people perceive that it is new, it is innovative to them.[187] The newness might be expressed in knowledge, persuasion, or the user’s decision to adopt the innovation.[188] Communication channels are the means by which a message is transmitted from individual to the next; time has multiple roles in diffusion, but one of the most important is the relative earliness or lateness of adoption with a social system or a set of interrelated units engaged in joint problem solving towards a common goal.[189]

C. LEVELS OF USE

To better understand individual variation in adoption of an innovation, Gene Hall and colleagues defined eight levels of use of an innovation, or distinct states characterized

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[186] Everett M. Rogers, *Diffusion of Innovations*, 5th ed. (New York: Free Press, 2003), 10–31.

[187] Ismail Sahin, “Detailed Review of Rogers’ Diffusion of Innovations Theory and Educational Technology-Related Studies Based on Rogers’ Theory,” *Turkish Online Journal of Educational Technology-TOJET* 5, no. 2 (2006): 14–23.

[188] Sahin, 14–23.

[189] Sahin, 14–23.

by different user behavior, as part of the Concerns-*Based Adoption Model* (CBAM).[190] Hall et al. claimed each level is defined by seven categories of behavior --knowledge, acquiring information, sharing, assessing, planning, status reporting, and performing—that reveal the user's trajectory from having a simple awareness of the innovation to collecting data, disseminating information to others, determining potential use, and performing.[191] The eight levels of innovation use are: non-use, orientation, preparation, mechanical use, routine, refinement, integration, and renewal with a key decision made by the user that triggers progression from one stage to the next.

D. CONCEPTUAL MODELS

A range of models have been developed to better understand technological and process innovation in different sectors including organizational management, consumer goods, and social groups.

E. ORGANIZATIONAL MODELS

Innovativeness within organizations is related to independent variables on the individual and collective levels, including the characteristics of leaders in the organization, characteristics of the internal structure, and external characteristics of the organization[192] In Roger's Diffusion of Innovation model, the leader's attitudes towards change is more significant than in other approaches; internal characteristics of the organization structure factor highly, such as centralization, complexity, formalization, interconnectedness, organizational slack, and size while external characteristics of the organization are expressed in terms of system openness.[193] Roger's model as applied to information

[190] Rogers, Diffusion of Innovations, 10–31.

[191] Gene E. Hall, Susan F. Loucks, William L. Rutherford, and Beulah W. Newlove, "Levels of Use of The Innovation: A Framework for Analyzing Innovation Adoption," *Journal of Teacher Education* 26, no. 1 (1975): 52–56.

[192] Sahin, "Detailed Review of Rogers' Diffusion of Innovations Theory and Educational Technology-Related Studies Based on Rogers' Theory." 14–23.

[193] Fariborz Damanpour and Marguerite Schneider, "Phases of the Adoption of Innovation in Organizations: Effects of Environment, Organization and Top Managers," *British journal of Management* 17, no. 3 (2006): 215–236.

technology adoption has been used to study software acquisition, intranet, website implementation, and e-business. Other models consider the organization's financial health as a key influencer on adoption, with greater financial health positively impacting adoption.[194]

F. CONSUMER MODELS

Consumer adoption of new technology is a major economic driver, with nearly half of all commercialized products failing in the marketplace, and a history of technical superior products losing out to competing ones.[195] Historically, managers have relied on market research of consumer attitudes toward an innovation, and their intention to purchase, but research has found consumer attitudes toward adoption don't correspond to actual adoption; consumers indicate the intention to adopt more complex innovations that better match their needs, however, consumers actually adopt innovations that are less complex but have higher relative advantages.[7]

G. SOCIAL MODELS

Innovation adoption in social and political contexts tends to manifest as campaigns to change public behavior, such as antismoking initiatives or campaigns to stop drunk driving. Some interesting factors determine which social innovations are adopted and which fail. Researchers examined an elementary school program to provide students with a fluoride-based dental rinse in an effort to reduce cavities, but districts, by and large, failed to adopt it. This was not because they had the carefully weighed the pros (reduced cavities) and cons (potential health impacts of fluoride), but because they made no decision at all.[196]

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[194] Vittorio Chiesa and Federico Frattini, "Commercializing Technological Innovation: Learning from Failures in High-Tech Markets," *Journal of Product Innovation Management* 28, no. 4 (2011): 437–454.

[195] Joep Arts, Ruud T. Frambach, and Tammo HA Bijmolt, "Generalizations on Consumer Innovation Adoption: A Meta-Analysis on Drivers of Intention and Behavior," *International Journal of Research in Marketing* 28, no. 2 (2011): 134–144.

[196] Mary Ann Scheirer, "The Life Cycle of an Innovation: Adoption Versus Discontinuation of the Fluoride Mouth Rinse Program in Schools." *Journal of Health and Social Behavior* (1990): 203–215.

H. COGNITION

Another approach to determining the intentions behind user behavior is a cognitive learning model. While behavioral models consider observable behaviors in response to external stimuli, cognitive learning models look at the degree of problem solving a user undertakes in response to stimuli.[197] Cognitive models factor in six internal beliefs that shape user attitudes towards adoption: perceived difficulty, adoptive experiences, perceived commitment, perceived benefits, compatibility, and enhanced value.[198] One example is the Technology Acceptance Model, which holds that computer technology acceptance is informed by perceptions of usefulness and ease of use, as well as individual affects.[199]

I. SOCIAL DIFFUSION

Social cognitive theory is based on an agentic perspective [200] asserting that people are proactive, self-organizing, self-regulating, and self-reflecting and not just reactive parties , and that our self-development and adaptation are rooted in social systems.[201] The Social Cognitive Theory of Mass Communication emphasizes modelling's effects on the adoption of innovation; modelling behaviors use the power of demonstration and description to instruct people on new ways of behaving and thinking.[202] Modelling the benefits of an innovation enhances individual self-efficacy and motivates as it informs,

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[197] Vanessa Ratten and Hamish Ratten, "Social Cognitive Theory in Technological Innovations," *European Journal of Innovation Management* 10, no. 1 (2007): 90–108.

[198] Alan Kai-ming Au and Peter Enderwick, "A Cognitive Model on Attitude Towards Technology Adoption," *Journal of Managerial Psychology* 15, no. 4 (2000). 262–282.

[199] Ruud T Frambach and Niels Schillewaert, "Organizational Innovation Adoption: A Multi-Level Framework of Determinants and Opportunities for Future Research." *Journal of Business Research* 55, no. 2 (2002): 163–176.

[200] Albert Bandura, "Human Agency in Social Cognitive Theory," *American Psychologist* 44, no. 9 (1989): 1175.

[201] Bandura, "Social Cognitive Theory of Mass Communication," *Media Psychology* 3, no. 3 (2001): 265–299.

[202] Katrin Talke and Sven Heidenreich, "How to Overcome Pro-Change Bias: Incorporating Passive and Active Innovation Resistance in Innovation Decision Models," *Journal of Product Innovation Management* 31, no. 5 (2014): 894–907.

accelerating the diffusion of innovation through social channels by weakening the restraints of more cautious potential users once they see the how the innovation benefits early adopters.[203]

Much of the theoretical discussion on adoption models suggests a pro-change bias that makes the assumption that consumers are fundamentally open to change and therefore more interested in adopting new products.[204] Increasingly though, research reveals that consumers often reject innovations out of hand before considering their potential benefits. To overcome this pro-change bias, some theorist differentiate passive resistance to innovation from active resistance to innovation, with the former based on consumers being generally predisposed to resist change or be skeptical of innovative claims, and the latter reflecting a hardening of attitudes in reaction to negative reviews or evaluations of an innovation.[205]

User resistance to change and bias towards the status quo has been found to be the leading barrier to large scale information technology innovation adoption in organizations.[206] Similarly, certain consumers continued to resist using Internet banking well past the point that it became established and a successful innovation; reasons for resistance included security and privacy concerns, but some customers also perceived that online banking had not demonstrated enough advantages over using the ATM which more customers were familiar with.[207]

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[203] Scheirer, “The Life Cycle of an Innovation: Adoption Versus Discontinuation of the Fluoride Mouth Rinse Program in Schools.” 203–215.

[204] Hee-Woong and Atreyi Kankanhalli, “Investigating User Resistance to Information Systems Implementation: A Status Quo Bias Perspective,” *MIS Quarterly* 33, no. 3 (April 2009): 567–582.

[205] Tuire Kuisma, Tommi Laukkanen, and Mika Hiltunen, “Mapping the Reasons for Resistance to Internet Banking: A Means-End Approach,” *International Journal of Information Management* 27, no. 2 (2007): 75–85.

[206] Kai-ming Au and Enderwick, “A Cognitive Model on Attitude Towards Technology Adoption,” 266–282.

[207] Frambach and Schillewaert, “Organizational Innovation Adoption: A Multi-Level Framework of Determinants and Opportunities for Future Research” 163–176.

This begs the question: why is it a problem if some users prefer ATMs over online banking, since there is still a unique need for both? The points of resistance can themselves be drivers of new innovation. For instance, consumers who once resisted online banking using their PC at home might more readily adapt to using a banking app on their mobile phone, perhaps because they perceive it as more secure or simply that it actually demonstrates the appropriate advantages they need from a banking innovation, and they finally found the better mousetrap they were looking for.

In the context of HEO and AISUM, the ability to leverage the technology across the broader USSOCOM enterprise increases value and necessity of adopting the innovation. As Dr. Schmidt points out in his House testimony, "in an organization as large as DOD, good ideas that cannot scale would seem to have limited utility." [208] This echoes Davidson and colleagues' findings that design of the HEO system has been informed by the need to provide logistics, sustainment, and transportation support missions sets ranging from counter-terrorism, covert operations, and direct action to hostage rescue, high-value target hunting, intelligence operations, and unconventional warfare across the entire combatant command.[209] This versatility also presents new opportunities for support from leaders in a variety of competencies, and in keeping with Roger's model, strong leadership around an innovation can drive adoption. It is the goal of this capstone project to provide the data and applied findings that leaders in USSOCOM can use to champion HEO system development while emphasizing strong human machine interfaces and robust operator support in order to achieve broad adoption.

[208] U.S. House Armed Services Committee on U.S. Pacific Command Posture, 115th Congress, 2.

[209] Flanick et al., "Expanding the Hyper-Enabled Operator Technology across the Special Forces Enterprise." 2–8.

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