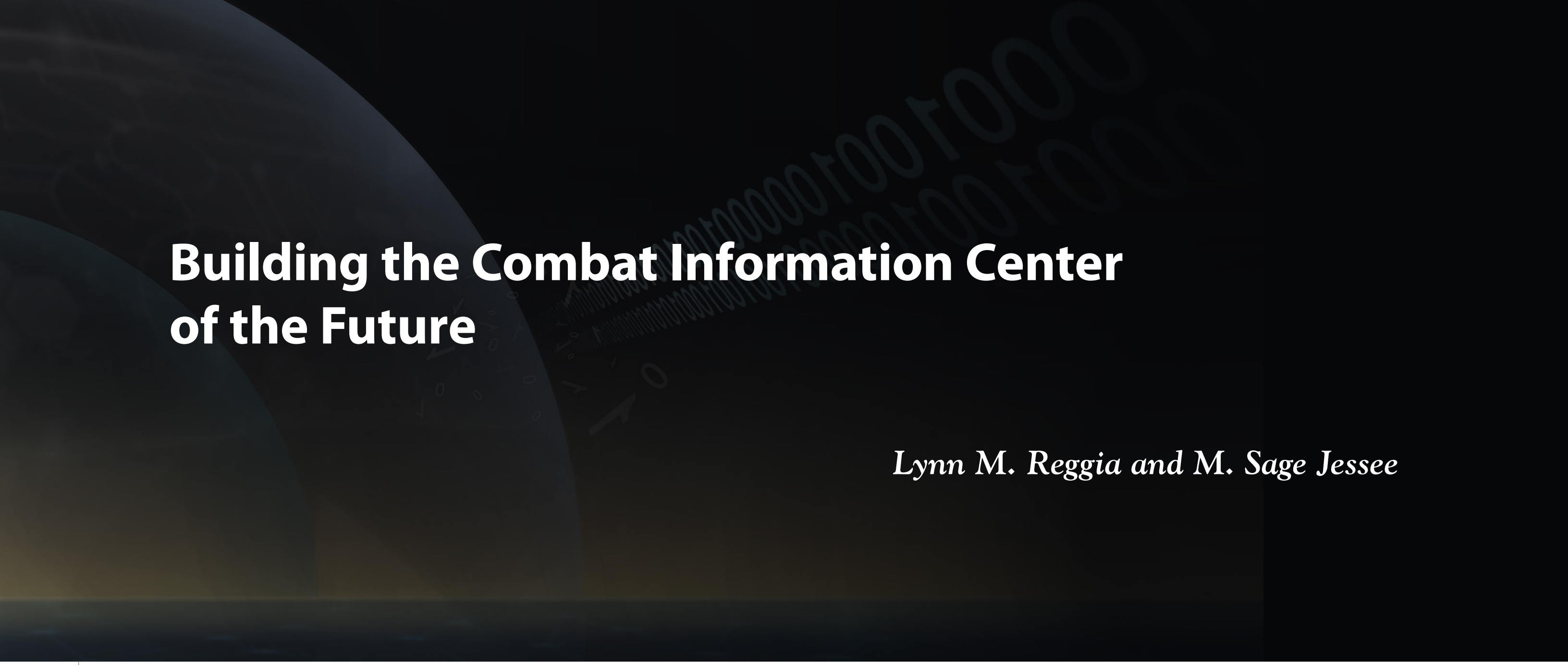

# Building the Combat Information Center of the Future

*Lynn M. Reggia and M. Sage Jessee*

## ABSTRACT

*The Combat Information Center (CIC) is the tactical command center for most US Navy ships. Because of the CIC's dense integration of sailors and complex systems necessary to fulfill the multiple simultaneous missions it supports, adherence to human systems engineering and integration principles is paramount to both its current and future designs. The Johns Hopkins University Applied Physics Laboratory (APL) is undertaking efforts to envision the art of the possible for CIC technology advancements through independent research and development emphasizing collaboration between warfighters and APL engineers. Through forecasting future warfighter needs, skills, and mental models; anticipating future technology trends; and creating flexible, rapid-prototyping environments, APL hopes to bring the Navy CIC into the future and help keep our sailors and country safe.*

## INTRODUCTION

As the busy tactical hub and the center for mission operations of most Navy ships, the Combat Information Center (CIC) is a space that encompasses many complex systems and the sailors who use them. An effective CIC design is driven by the need for a highly integrated human element and requires relentless adherence to human systems engineering (HSE) principles. In this room, lit only by the occasional blue light and glow from console screens, sailors monitor radar and sensor data, defend their ship from threats, and if necessary, take offensive actions. Stakes are high in the CIC because missions of national importance are executed from this command center, and these missions can mean the difference between life and death for our Navy warfighters.

Increasingly, complex systems of today, like the CIC, are enjoying a tighter coupling between end users, stakeholders, designers, and engineers because it is hoped that this coordination will mitigate the ever-present risk of human error. Many no longer consider human systems integration (HSI) a niche field with an uncertain value proposition, but instead think of it as a necessary piece of the systems engineering process with a proven track record. Despite this increased awareness, however, many complex systems continue to exhibit mishaps that have roots in HSI-related shortcomings. Often these mishaps point to significant design failures that trace back to specific gaps in, or worse, the complete lack of, a responsible HSI program.

Throughout the years, many systems, and even more sailors, have cycled through each CIC, prepared to defend their ship, their fleet, and their country. As the threats get more complex and difficult to defeat, and

**Figure 1.** Sailors standing watch in the CIC of USS *Normandy* (CG 60). (US Navy photo by Mass Communication Specialist 3rd Class Justin R. DiNiro/Released.)

as sailors of the "gaming generation" take the seats behind the consoles, it is necessary to think about not just what the CIC *will* look like for the next build but also what the CIC of the future *should* look like. While researching this area, APL human systems engineers are undertaking efforts to increase fleet inputs by going underway on ships. On preliminary trips, these engineers have asked sailors how they envision the CIC of the future. In response, sailors often referenced movies, the most popular of which was *Minority Report*. Although science fiction movies show intriguing possibilities, HSI principles continue to lead us to more user-centered design approaches to determining solutions that enhance human and system performance. To achieve this, the following question must be addressed: What are the needs of the future warfighter in the CIC, and how do we blend HSI fundamentals with the affordances that may be offered by unpredictable future technology? To address this challenge, we must first understand the basic operational environment to which the systems will be tailored. Second, we must consider the persistent biological, technological, and process-related gaps in this domain and the human–computer relationships that may be shaped by future technology. Lastly, it is important to continuously evaluate technological trends that will impact the human–computer relationship, with a focus on building flexible rapid-prototyping environments to gain user feedback early and often.

## THE CURRENT CIC OPERATIONAL ENVIRONMENT

### CIC Overview

Put simply, the CIC is a secure space containing a plethora of consoles, displays, cables, and communication devices, as well as the sailors operating them, as shown in Figure 1. Space is limited, talking is kept to a minimum, and the room is lit with specific blue lights to prevent sailors from losing their night vision. The latest operator console, currently being fielded, is the Common Display System (CDS). It is configured with three horizontal, immovable touchscreen displays, a trackball, a keyboard, and a chair.

An example CIC layout is provided in Figures 2 and 3; however, the size and organization of the CIC heavily depend on what class of ship it is occupying. Across ship classes, clusters of consoles are primarily organized by warfare area. For example, the sailors supporting surface warfare are close together in physical proximity, as are those involved with other warfare areas (i.e., antiaircraft warfare and electronic warfare). The tactical action officer is in charge of CIC operations when the commanding officer, the captain of the ship, is not present. The tactical action officer is positioned at a table at the front and center of the room. No matter the specific layout, currently watchstanders must sit at assigned locations within the CIC. CDS, because of the commonality of these consoles, will eventually allow CIC sailors to log onto any console within the CIC, providing redundancy if one of its systems is down and the flexibility to customize CIC watchstation organization to each mission.

### Considering Issues within the Current CIC

While investigating future warfighter needs, APL researchers are exploring the issues found in today's CICs. Ship visits that give human systems engineers opportunities to directly observe and interview sailors while underway continue to be a focus of this work. These investigative research efforts help bridge the gap between system design and system use, and the knowledge gained is invaluable. The observed issues found in today's CICs can be categorized into three primary groups: technology, process, and biology (i.e., the human).

From a purely technological standpoint, industry is moving much faster than Navy CIC development. Virtual reality (VR) and alternative computer input technologies are becoming common in many commercial products. Each new generation of sailors is accustomed to the latest technology found in smartphones and modern gaming systems; however, CIC technology is stuck in the past, with decades often passing between replacements. Those systems that are replaced are often incrementally updated, and only rarely will a modern human–computer interface make its way into the CIC—a paradigm very different from that found in consumer industry. This has impacts not only on CIC capability but also on sailor training. Figure 4 illustrates the difference between consumer technology and that found on Navy ships today.

Although it seems that the process of CIC system design is evolving for the better, changes happen gradually. While requirements, functional models, and finally physical implementations are defined and executed, there still is often a large gap between the engineers designing the systems and the sailors who will be using them. End-user feedback is often lost in existing processes; direct exchanges between engineers and sailors are infrequent; and, programmatically, HSI-related efforts are often scoped down or eliminated because of the misconception that they cost more money than they save.

Finally, one of the most complex aspects of the CIC is the biological one—the human. Both the strengths and limitations of the sailors in the CIC must be understood to optimize CIC design. Despite advances in artificial intelligence and machine learning, the human brain is still more adaptive and dynamic compared with computational systems. How-

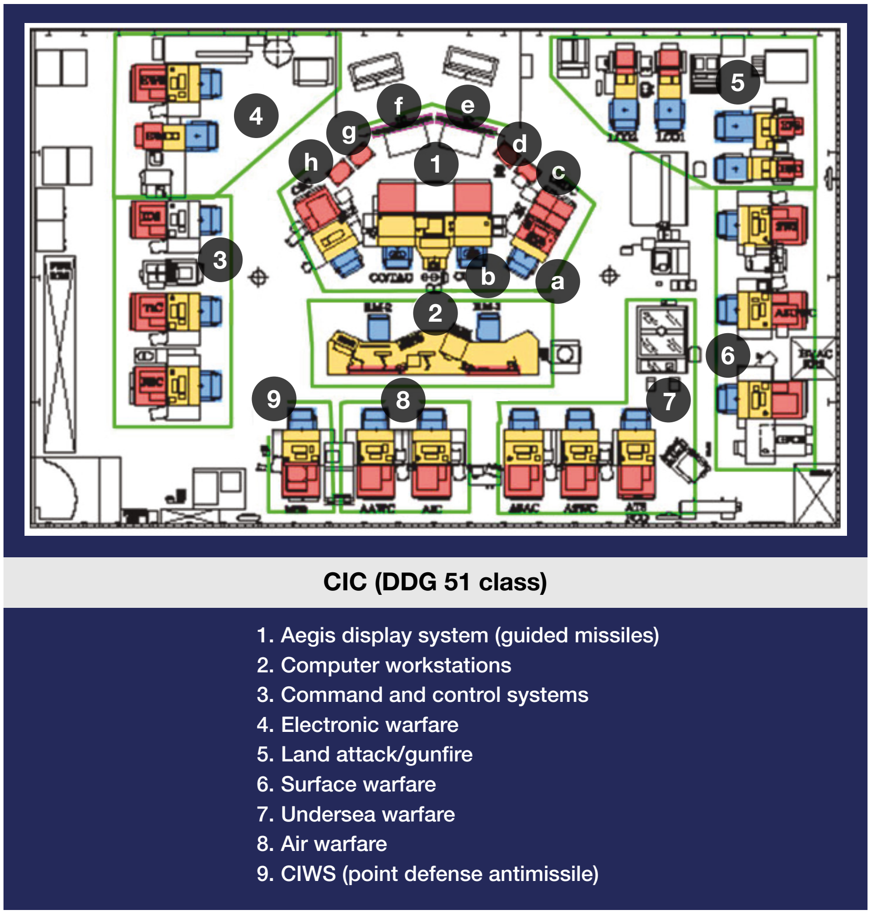

**Figure 2.** Example CIC layout—DDG 51. CWIS, close-in weapon system. (Reproduced with permission from www.projectrho.com/public_html/rocket/spacewartactic.php.)

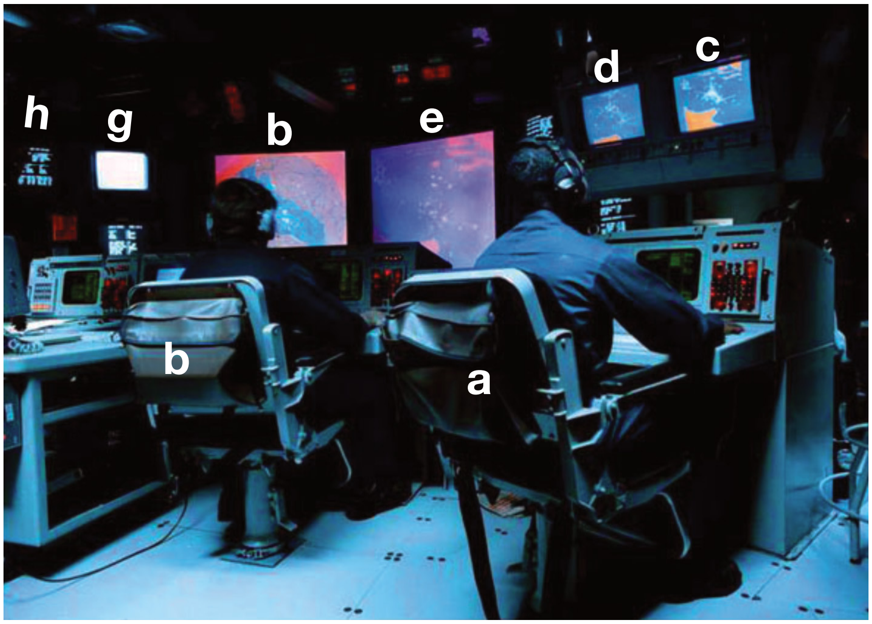

**Figure 3.** Photograph of stations 1a and 1b shown in Figure 2. (Reproduced with permission from www.projectrho.com/public_html/rocket/spacewartactic.php.)

ever, the human brain's information processing capacity and its contribution to reaction time is mostly fixed, whereas computational systems continue to advance in these areas exponentially. Because of these constraints, humans are sometimes removed from the response loop in favor of computational speed. In particular, this tradeoff is becoming increasingly necessary for ship defense decision cycles within the CIC. As these tasks become automated, the sailors' lack of trust in system functionality and output can lead to manual workarounds that increase, rather than decrease, their workloads.

Although only a few examples are listed, it is important to note that many more issues exist. Everything from the desire for accessible cup holders to the need for more efficient and effective communications and training techniques should be addressed in a future CIC. Solving any one of these problems would not be sufficient to produce an optimized system; we must consider all aspects and continually improve the combined technology, process, and human elements of this space to truly meet our future sailors' needs. The next sections discuss some areas we believe are critical to achieving these improvements.

## GAPS IN THE CURRENT HUMAN–COMPUTER PARADIGM

### Addressing the Human Component and the Asymmetrical Human–Computer Relationship

The current human–computer relationship can often be characterized as static and asymmetrical.[1] For example, the user tends to take on an active role while the machine passively performs the functions requested by the user. In this way, most contemporary human–computer interactions (HCI) are defined by a rigid turn-taking structure or serialized action-and-response interactions. Consequently lacking is the continuous dialogue between humans and computers that should more closely resemble an interaction between intelligent adaptive systems. The information flow between humans and computers is also asymmetrical. For example, the user is free to query the operational state of the system (e.g., memory, degradations, and computational processing usage), but the computer remains blind to the internal status and resource capacities of the human. Thus, although many of the systems we create have a plethora of subsystem monitor functions, they lack the ability to inspect the most error-prone component of the overall system—the human. These systems are unable to determine the human's psychological state and cognitive resources, both of which, when degraded, can contribute to human error. As HSI practitioners contribute to the development of advanced, intelligent, and adaptive systems of the future, they must look for opportunities to collect and integrate information about the human as a key component of the overall system.

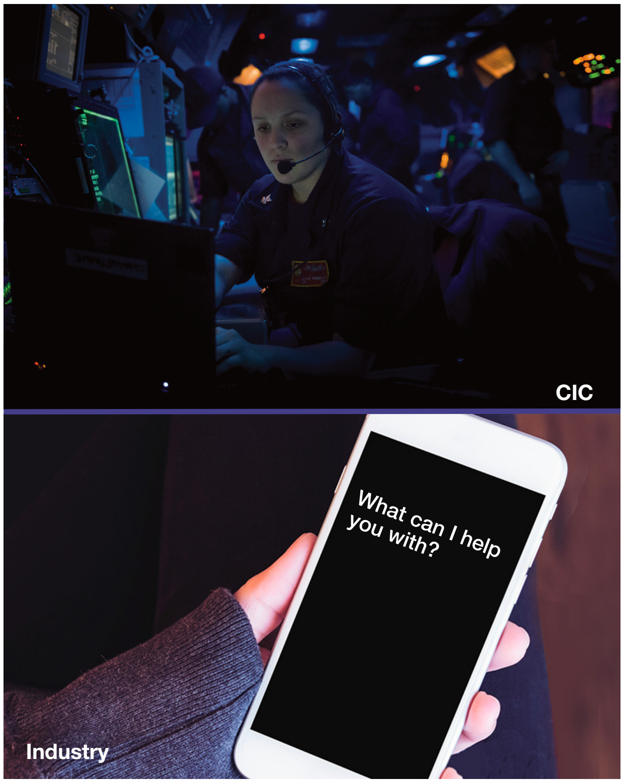

**Figure 4.** Technology in today's CIC versus current technology found in industry. (Top: US Navy photo by Mass Communication Specialist 3rd Class Joshua M. Tolbert/Released.)

An HCI of the future may be represented by a closed-loop dynamic system in which there is persistent parallel interaction between the human and the computer. A closed-loop system is one in which the components engage in a constant dialogue and regulation of each other's states for the purpose of achieving a common goal. For example, the temperature of a room is regulated by the difference between the actual temperature measurement and the desired temperature. This difference, often referred to as the error, is fed back to the system to control the regulation that mediates temperature. Thus, the input-to-output path and the error feedback path create a closed-loop system. In an open-loop system, the input is entirely independent of the output system. For example, a heating element that produces heat as long as the power supply is switched on with no regard for the desired temperature would be an open-loop system. This open-loop control system is more characteristic of the current human–computer relationship. To achieve a closed-loop system between a human and computer, the system must include sensors that disambiguate the human's psychological states and algorithms that fuse these data with task information to apply dynamic mitigations (system regulation) that improve the human–computer dyad's ability to achieve its goal. Approaches to gathering psychophysiological data include electroencephalogram caps, electrocardiogram sensors, and ocular activity measures captured with eye trackers, to name a few.[2] As wearable sensors continue to permeate daily life, so too will cognitive state detection algorithms that serve as a potential component of a closed-loop control system that may be applied to a future CIC. The utility of future closed-loop systems will hinge on the effectiveness of the mitigation strategies used and the reliability of the psychophysiological sensors that enable them.

A mitigation development framework for closed-loop systems has been developed by Fuchs et al.[3] and can be leveraged in the design of a future CIC system. This approach includes identifying key events that contribute to psychological constructs that impact system performance, such as cognitive workload, situational awareness, vigilance, and fatigue. Key events can be defined by leveraging a comprehensive task analysis. For example, the presence of a hostile air track within a protected region would be considered a key event during which the computational system would poll the human's psychological state to ensure that it is attended under manageable cognitive workload constraints. Once key events are defined, the system would identify biomarker signatures that are associated with a positive, or expected, human response and a negative, or unfavorable, human response. For example, available cognitive resource or "managed workload" would be considered a favorable human response, whereas limited cognitive spare capacity would be considered an unfavorable one that requires mitigation. Once the key events and associated biomarkers have been identified, a mitigation management framework can be developed that outlines what to mitigate, when the mitigation should be applied, and how the mitigation should be executed. For example, if the system determined that the human was looking in the wrong place and had not noticed the new hostile track, the system could then provide an alert to direct the human's attention as appropriate. For a more detailed discussion of a mitigation development framework, see Ref. 3.

## TECHNOLOGIES AND PROCESS FOR ENABLING A SYMMETRICAL HUMAN–COMPUTER RELATIONSHIP

In addition to anticipating (and creating) future computing environments, a human systems engineer must consider prospective technology on the basis of its impact on the reduction of human error, improved decision-making, improved situational awareness, cognitive state management (engagement, fatigue, boredom, vigilance, etc.), and optimized cognitive workload. A novel technology's contributions to human factors are not always immediately evident but should be motivated by scientific theories and corroborating research in cognitive psychology and neuroscience. These considerations will ensure that adopted novel HCI technology is implemented in the most useful fashion.

VR/augmented reality (AR) technology serves as one such example of a potentially pervasive future computing platform. As with many revolutionary platforms, this technology was preceded by evolutionary improvements of disparate technologies that reached a tipping point in their readiness to be integrated into a new capability. In the case of VR/AR, the previous improvements in the established mobile industry have impacted display quality and cost, while the computational power of modern graphics processing units has enabled head-mounted displays to alleviate nausea associated with poor display latencies. As a result, VR/AR technology has enjoyed significant quality improvements while achieving significantly reduced unit costs.

Although VR/AR technology is currently geared toward the gaming and entertainment industries, it has many potential military applications. For example, both operator and maintainer training can leverage immersive virtual environments for familiarization training in preparation for qualification on costly live or simulated assets. VR/AR also offers an environment in which physically distributed crews can come together and perform crew coordination tasks in a low-cost environment. Currently, APL is creating a three-dimensional environment (Multi-User Virtual Environment) to facilitate collaborative interaction among distributed participants in a variety of operations centers, such as disaster relief centers.[4] These multiuser virtual command centers could be integrated with VR or AR headsets to further enhance distributed team coordination and collaboration. However, a key remaining challenge for VR/AR technology is the use of appropriate input technology that facilitates naturalistic interactions that match the sense of presence that VR headsets can afford the user.

As novel computing platforms arise, they are almost always accompanied by user input technology designed around the constraints of the new platform. For example, the touch interface did not become widely accepted until underlying operating systems were designed around the constraints of that input. As designers and engineers continue to develop novel computing environments, including VR/AR headsets, the constraints inherent in the input technology must be matched to those environments. A directly relevant example of this challenge occurred when the US Navy spent a large sum to replace AN/UYQ-70-based CIC consoles with the CDS. Unfortunately, the underlying graphical user interface environment was not updated to be optimized for touch input. The size of and distance between icons were designed for a trackball-controlled cursor, and attempts to perform a minimal migration to the CDS touch input led to an unreliable and error-prone user experience. As a result, several programs opted to turn the touch technology off for some of the screens and revert back to the previously used trackball input device for which the graphical user interface was designed.

The design and development of input technology for VR/AR is particularly challenging. In fact, the current HCI paradigm, as a whole, lacks natural user interface (NUI) technology that allows humans to interact with a virtual representation as they would with the real world. For example, a computer mouse is used as a pointing and action surrogate that allows us to interact with two-dimensional computer screens. A more naturalistic interaction would include reaching out and grasping objects of interest directly, using forms of gesture-based input. VR/AR computing environments produce experiences that imply the need for this type of interaction. Furthermore, natural language processing offers the ability to speak directly to computational systems as a form of input that mimics human-to-human communication. These interfaces have become commonplace (although limited) across major platforms and include technologies such as Google Now, Apple's Siri, and Microsoft's Cortana. Eye tracking technology can also facilitate NUI by providing information about how users allocate their visual attention. Although the design language needed to produce naturalistic "eye-enabled" applications is still in development, low-cost trackers have recently become accessible to broader development audiences, and this may lead to common tools and practices for this input technology for VR/AR environments. Other NUI components such as advanced haptic feedback and brain–computer interfaces have received significant attention, but technological breakthroughs are still needed to operationalize a brain–computer interface.

Given the underlying developments that have enabled VR/AR and NUI technology, there is an opportunity to both leverage technological trends as well as augment new capabilities in ways that address warfighter needs. For example, because many physiological sensors that may advance novel HCI require contact with the user, there is an opportunity to transparently integrate these sensors into other technologies that must be worn, such as VR/AR headsets. This provides a clear opportunity to address the broader asymmetrical human–computer relationship gap by integrating technology that was originally developed for a seemingly dissimilar purpose—that is, the sense of presence afforded by VR headsets. As previously mentioned, the success of this type of system will hinge on the mitigation strategies applied by using psychophysiological sensor data and the data's impact on overall system performance. To properly design these mitigation strategies afforded by new technology, established HSE fundamentals should continue to be leveraged. Specifically, HSE practitioners should travel to ships and interface directly with warfighters, looking for opportunities to collect and integrate information about the human as a key component of the overall system.

Currently, no established standard for input exists for VR/AR headsets, but it is highly likely that solutions will be borrowed from the previously mentioned NUI technologies. As VR/AR technology continues to mature and become more pervasive, so too will new interaction paradigms and associated mental models about how to interact in those environments. The forward-thinking designer of complex systems should anticipate those mental models in considering how the users of tomorrow may interact with computers in their daily lives. If these considerations are not addressed, training can be hampered by systems that require the user to learn the "mental models of yesterday" to operate proficiently. An impeccably organized HSI program can be followed for long development cycles and still fail to succeed at its goal because of unforeseeable technological changes and the broader impact that these changes have on targeted user populations. Given the rapid pace of technology improvements, anticipating these variables is a significant challenge. To mitigate this issue, it is important to integrate a flexible rapid-prototyping environment within the system development cycles to evaluate novel computing environments that could increase the effectiveness of the future warfighter.

## CONCLUSION

As novel HCI environments emerge and associated input technology advances, there is an opportunity to anticipate and apply technology in ways that are both familiar and novel to the future warfighter in the CIC. To achieve this kind of application, we must consider the following areas:

- Anticipate the future computational environment—what will be the commonly employed user interfaces throughout the projected system deployment cycle?
- Anticipate the future mental models—how would collaborative artificial intelligence shape the way sailors interact and access information from increasingly autonomous systems?
- Anticipate future skill sets—how will evolving information retrieval and data analysis tools shape the problem-solving approach of tomorrow's sailors?

Creating a new complex capability within the CIC must be considered an anticipatory as well as inventive process because of the scope of the problems that must be addressed. It is impossible, of course, to perfectly predict the minuscule details of tomorrow's broadly used technology along with all of its impacts. However, we encourage complex system designers and developers to monitor technological trends that show potential to have broad implications for the general population as well as for specific warfighter needs.

Finally, as we move forward, we must maintain a holistic view of the biology, technology, and processes found in the CIC to truly optimize its performance. Although it might be exciting to imagine a CIC design similar to Hollywood's futuristic portrayals found in science fiction movies, it is imperative to not lose sight of the true driver that must be behind all design decisions—the needs of the sailors of the future. By bridging the gap between engineers and warfighters, APL is striving to help the US Navy develop a CIC that will advance the Navy into the future and help keep our sailors and country safe.

## REFERENCES

[1] S. H. Fairclough, "A closed-loop perspective on symbiotic human-computer interaction," in *Symbiotic Interaction*, B. Blankertz, G. Jacucci, L. Gamberini, A. Spagnolli, and J. Freeman, Eds., Lecture Notes in Computer Science (LNCS), Vol. 9359, Springer International Publishing, pp. 57–67, 2015.

[2] A. F. Kramer, "Physiological metrics of mental workload: A review of recent progress," in *Multiple-Task Performance*, D. L. Damos, Ed. London: Taylor & Francis, pp. 279–328, 1991.

[3] S. Fuchs, K. S. Hale, C. Berka, and J. Juhnke, "Enhancing situation awareness with an augmented cognition system," in *Augmented Cognition: A Practitioner's Guide*, K. M. Stanney and D. Schmorrow, Eds. Santa Monica, CA: HFES, pp. 112–143, 2008.

[4] S. D. Simpkins, P. D. Allen, J. W. Turner, and S. E. Wright, "Cyber virtual environments final report," APL, Laurel, MD, Rep. AOS-14-0092, 2014.

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