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HOW CAN THE CENTER FOR NAVY SECURITY FORCES LEVERAGE IMMERSIVE TECHNOLOGIES TO ENHANCE ITS CURRENT TRAINING DELIVERY?

December 2018

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This research answers the following research questions:

•How are public safety and security forces using augmented and mixed reality technologies to support training?

•What have been the outcomes of such technology use reported in academic and trade literature?

•What gaps and opportunities exist in current training/delivery?

•How could augmented/mixed reality technologies best address these gaps?

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AAR	After Action Review
AR	Augmented Reality
CAVE	Cave Automatic Virtual Environment
CBA	Capabilities Based Assessment
CENSECFOR	U.S. Navy Center for Security Forces
CONOP	Concept of Operation
COTS	Commercial Off the Shelf
CQB	Close Quarters Battle
CTTL	Course Training Task List
DHS	Department of Homeland Security
DoD	Department of Defense
DoN	Department of the Navy
DOT	Director of Training
EVO	Emergency Vehicle Operators
EW	Electronic Warfare
FATS	Fire Arms Training Simulator
FPSS	Force Protection Ship Simulator
HCI	Human–Computer Interaction
HMD	Head Mounted Display
JCS	Joint Chiefs of Staff
LE	Law Enforcement
LSO	Landing Signal Officers
MR	Mixed Reality
R&D	Research and Development
SRF	Navy Security Reaction Forces
TCCD	Training Course Control Document
VE	Virtual Environment
VR	Virtual Reality

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I. INTRODUCTION

In a period in which the Navy is experiencing ever-growing budget deficits combined with the effects of years of sequestration, the Navy requires effective and cost-efficient techniques for preparing its forces for conflict. Augmented reality (AR) and virtual reality (VR) are technologies the Navy may be able to leverage to effectively and efficiently provide realistic training without the high costs of mobilizing a unit for combat training. This study surveys currently available AR and VR system technologies and explores current training applications in the military, law enforcement, and public safety sectors to assess their potential utility for the U.S. Navy Center for Security Forces (CENSECFOR) training.

A. PURPOSE OF RESEARCH

The purpose of this research project is to support the CENSECFOR in its delivery of ready and relevant training to its students by providing information on CENSECFOR's training delivery. CENSECFOR is headquartered in Little Creek, VA, and consists of five detachments and eight learning sites/training locations (CENSECFOR, 2017a). Its mission is "to develop and deliver Anti-terrorism, Navy Security Force fundamentals, Code of Conduct, and Expeditionary Warfare training to achieve maritime interdiction and irregular warfare superiority" (CENSECFOR, 2017a). CENSECFOR delivers 42 courses in support of this mission (CENSECFOR, 2017a).

We focused our assessment of technology applications on CENSECFOR's training for Navy Security Reaction Forces (SRF). This training is vital to the security of the Navy's personnel and equipment. As stated in Antiterrorism/Force Protection (Department of the Navy [DoN], 2006),

> Reaction forces, afloat and ashore, provide a response capability during a terrorist incident or threat and provide the capability to immediately augment duty security forces or deck watchstanders armed, trained, and equipped personnel in response to an incident or increased threat. Leaders and personnel must receive in-depth training to effectively support AT/FP [antiterrorism/force protection] watchstanders and security personnel. (p. 8–1)

SRF training consists of a 15-day SRF-Basic (SRF-B) course and a 10-day SRF-Advanced (SRF-A) course designed to train sailors on multiple operational security tasks while on-shore and at sea. These tasks include reinforcing sentry posts, responding to armed intruders, responding to hostage situations, and responding to any violation of an established perimeter (DoN, 2006).

B. RESEARCH QUESTIONS

To guide our research, we developed four research questions. The answers to these questions will assist CENSECFOR in deciding what, if any, AR and/or VR technologies may enhance their current training delivery. The questions are as follows:

1. How are public safety and security forces using AR and/or VR reality technologies?
2. What outcomes of such technology use have been reported in academic and trade literature?
3. What gaps and opportunities exist in CENSECFOR's current training delivery?
4. How could AR/VR technologies best address these gaps?

This professional report is organized as follows. Chapter II describes the research approach and methods. Chapter III provides the results of the literature review, answering the first two questions: How are public safety and security forces currently utilizing AR and/or VR technologies, and what are the outcomes of this use? Chapter IV presents gaps and opportunities in CENSECFOR's current training delivery. Chapter V outlines how AR and/or VR technologies may address these gaps, answering questions three and four. Additionally, Chapter V discusses implications and practical recommendations for further study.

II. RESEARCH METHODS

This study is an assessment of the potential of AR and VR technologies based on a systematic review of trade reports and academic literature and a needs analysis. We assessed the potential of AR and VR technologies for meeting CENSECFOR's needs using a Quick Turn Capabilities Based Assessment (CBA; Joint Chiefs of Staff J-8 [JCS J-8], 2009). A CBA (JCS J-8, 2009, p. 9)

- synthesizes existing guidance and specifies the problem to study,
- assesses how well we currently address the problem,
- recommends needs to address the problem, and
- makes a general recommendation for solutions to needs.

A Quick Turn CBA is normally done in less than two months and requires several modifications to the standard CBA process (JCS J-8, 2009, p. 68). Figure 1 outlines the fundamental process of a standard CBA in its simplest form.

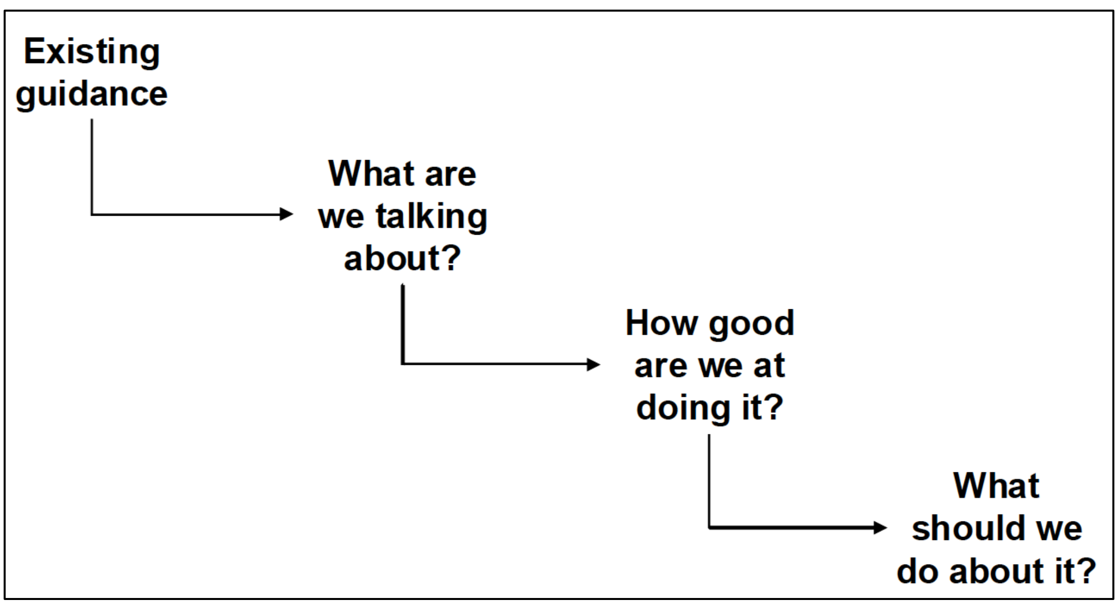

Figure 1. Basic Elements of a CBA. Source: JCS J-8 (2009, p. 10).

We structured our research according to these guiding questions. Existing guidance in our research is our analysis of the CENSECFOR training documents and the four research questions in Chapter I. Our literature review in Chapter III of AR and VR along with current training applications in the military and law enforcement arenas answers the question: What are we talking about? In Chapter IV, we assess the current CENSECFOR SRF-A training program to determine how good the Navy is at doing it. Finally, in Chapter V, we assess the spectrum of immersive technologies to determine what, if anything, the Navy could do to enhance SRF-A training. In the following paragraphs, we explain in greater detail the steps we conducted to complete this Quick Turn CBA.

A. DATA SOURCES

We initiated the study with an in-depth review of the history and development of VR and AR. We searched the Naval Postgraduate School library's database using the terms AR, VR, AR/VR history, technology behind AR/VR, AR/VR system components, AR/VR Tracking technology, haptic devices, commercial uses of AR/VR, AR/VR in education, and AR/VR in industrial training applications. This resulted in 46 initial documents. We narrowed this initial search result down to 24 documents. We then used the sources in this search to lead us to additional resources, resulting in a total of 75 documents (42 research/conference papers, portions from six books, 25 magazine/news articles, one thesis, and one class lecture), totaling 763 pages.

In July 2018, our research team conducted a site survey of the CENSECFOR training program at Detachment San Diego. During this visit, we were able to observe actual training of the SRF-A course. At the time, CENSECFOR had multiple classes in session in varying phases of the SRF-A course. This allowed our team to observe all phases of the SRF-A course. We took detailed notes, documenting our observations of the available training resources, training environment, current use of technology in support of the training, and any training gaps or limitations.

This site survey provided our research team a better understanding of the CENSECFOR program of instruction, current training delivery methods, and observed constraints and limitations of the training tools and facilities at the Detachment San Diego location. Additionally, CENSECFOR provided 19 documents on its training programs totaling 1,175 pages/slides. These documents, with a brief description of each, are listed in Table 1.

Table 1. CENSECFOR SRF-A Training Documents with Brief Descriptions

Document name	Description
Lesson 1.1: Introduction to SRF-A	PowerPoint presentation providing an introduction to the SRF-A course, the mission of an SRF, and general course requirements
Lesson 1.2: Tactical Communications	PowerPoint presentation covering basic SRF communications procedures
Lesson 1.4: Search Procedures	PowerPoint presentation covering the basics of personnel and area searches
Lesson 1.5: Employment of Force	PowerPoint presentation covering the types of force and conditions for employment of force
Lesson 1.6: Tactical Team Movement	PowerPoint presentation introducing SRF team movement techniques as well as team member and team leader responsibilities
Lesson 2.1: Tactical Team Management	PowerPoint presentation reviewing the requirements of an SRF team leader to include sustainment training, mission planning, and tactical communication
SRF-A Knowledge Test Administrator’s Guide (Revision-B, Change 2) (February 8, 2018)	Provides the SRF-A tests as well as guidelines for administration of tests
SRF-A Performance Test Administrator’s Guide for Force Protection Internal Scenarios (Revision-B, Change 2) (February 8, 2018)	Provides the guidance for the execution and evaluation of the internal practical exercises.
SRF-A Performance Test Administrator’s Guide for Force Protection External Scenarios (Revision-B, Change 2) (February 8, 2018)	Provides the guidance for the execution and evaluation of the external practical exercises
CENSECFOR Instruction 1540.1A: Training Policy and Guidance Instruction (October 6, 2011)	Provides CENSECFOR training management policy covering the SRF-A course

Document name	Description
CENSECFOR Instruction 3591.1A: Small Arms Weapons Qualification and Instructor Sustainment (March 7, 2016)	Provides CENSECFOR guidance for weapons qualification and instructor weapons performance demonstration
SRF-A Course Training Task List (CTTL) (Revision-B, Change 2)	Lists the 23 tasks trained at the SRF-A course
SRF-A Lesson Plan (Revision-B, Change 2)	Provides a detailed outline for the SRF-A instructors for each block of instruction to include the learning objectives, required training materials, and instructor guidance
SRF-A Master Test Bank (Revision-B, Change 2)	Provides the answers for all SRF-A knowledge tests
Naval Education and Training Command (NETC) Instruction 1500.5B: Instructor Qualification, Certification, and Sustainment Program (August 22, 2013)	Provides the guidelines for qualification and certification of SRF-A instructors
Training Course Control Document (TCCD) for SRF-A (Revision-B, Change 2)	Provides the approved standards for the SRF-A training curriculum to include requirements for attendance, course conduct, and required training objectives; implements Revision-B, Change 2
Testing Plan for SRF-A (Revision-B, Change 2) (February 8, 2018)	Establishes procedures for evaluation of SRF-A trainee's mastery of the course learning objectives
Trainee Guide for SRF-A (Revision-B, Change 2)	Provided to trainees at the beginning of the SRF-A course and serves as a complete guide to each lesson and study guide. Provides a reference resource for the trainees after completing the course.
Training Project Plan for SRF-A (Revision-B) (September 2012)	Provides the overarching plan for the SRF-A course to include course revisions, safety concerns, curriculum development method, and resource requirements

We then conducted an extensive review of academic and trade literature, vendor websites, and press releases to identify current practices and innovative uses of VR and AR technology in the realms of military, law enforcement, and public safety. We conducted our research utilizing primarily internet searches of the following keywords in varying combinations: virtual training, augmented training, mixed reality, military, law

enforcement, security forces, future training enhancements, immersive training environments, military uses of AR, military uses of VR, and synthetic training.
When reviewing the literature and resources from our search results, we narrowed down our literature review based on the perceived relevance to CENSECFOR training requirements derived from our site survey and our review of CENSECFOR training materials.

As they did before, these searches provided us with a foundation and allowed us to trace the sources of these searches to additional sources. These searches resulted in approximately 74 sources for a total of approximately 706 pages. Table 2 summarizes the final output of this search.

Table 2. Sources for Military, Law Enforcement, Public Safety Research

Type	**Quantity**	**Pages**
Newspaper/Magazine Articles	9 articles	31
Conference Proceedings	12 articles	166
Professional Journals	4 articles	39
Book chapters	2 chapters	45
Patents	1 patent	8
Military trade journal	19 articles	73
Professional research papers	21 papers	235
Thesis	1 thesis	11
Department of Defense Manual	1 manual	97
Official Military Memorandum	1 memo	1
Websites	3 sites	

The literature review served as a form of market research to assess the availability and features of potential technologies. We first divided our research efforts into a military-focused team and a law enforcement-focused team to present our findings thematically. The military and law enforcement categories were further broken down into categories by purpose of the technology (e.g., type of training or supported warfighting function) to logically present our data in Chapter III.

B. QUICK TURN CBA OUTLINE

Figure 2 represents a typical Quick Turn CBA task flow. The gray boxes highlight the critical outputs of the process: specify conditions, derive tasks, and develop standards. As is common with a Quick Turn CBA, much of this information was available to us at the start of our research allowing for this expedited assessment.

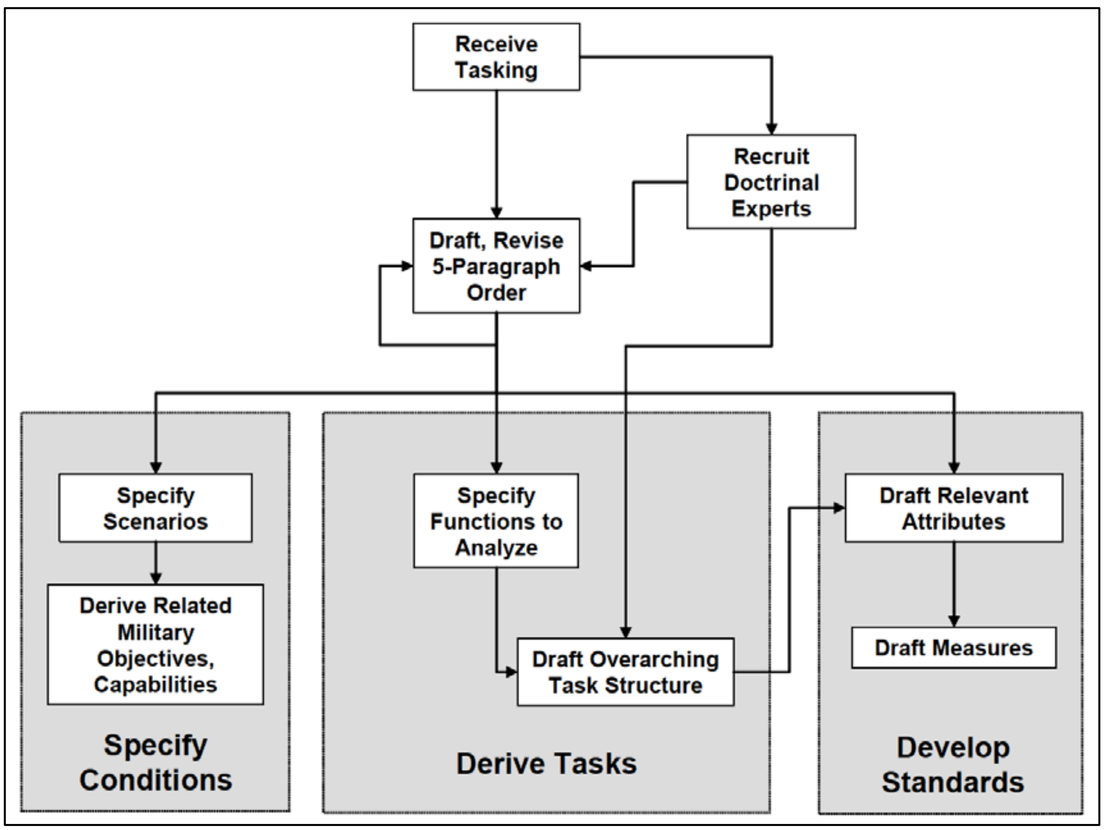

Figure 2. Example Quick Turn CBA Study Definition Task Flow. Source: JCS J-8 (2009, p. 73).

The conditions for our Quick Turn CBA of the CENSECFOR SRF-A training are specified by the internal and external training scenarios by which the SRF trainees are trained and evaluated. The tasks are explicitly stated in the SRF-A Course Training Task

List. With the conditions and tasks defined, this left our research team with the requirement to draft the relevant attributes to develop the standards necessary for a needs assessment. Our standards development process is documented in Chapter IV through our analysis of best practices of existing immersive technology applications and the SRF-A training requirements. The standards we developed were then used in the needs assessment in Chapter V to evaluate the potential value of technology applications across the spectrum of immersive technology. Figure 3 is a diagram from the JCS J-8 (2009) CBA user's guide representing the needs assessment process following the development of tasks, conditions, and standards shown in Figure 2.

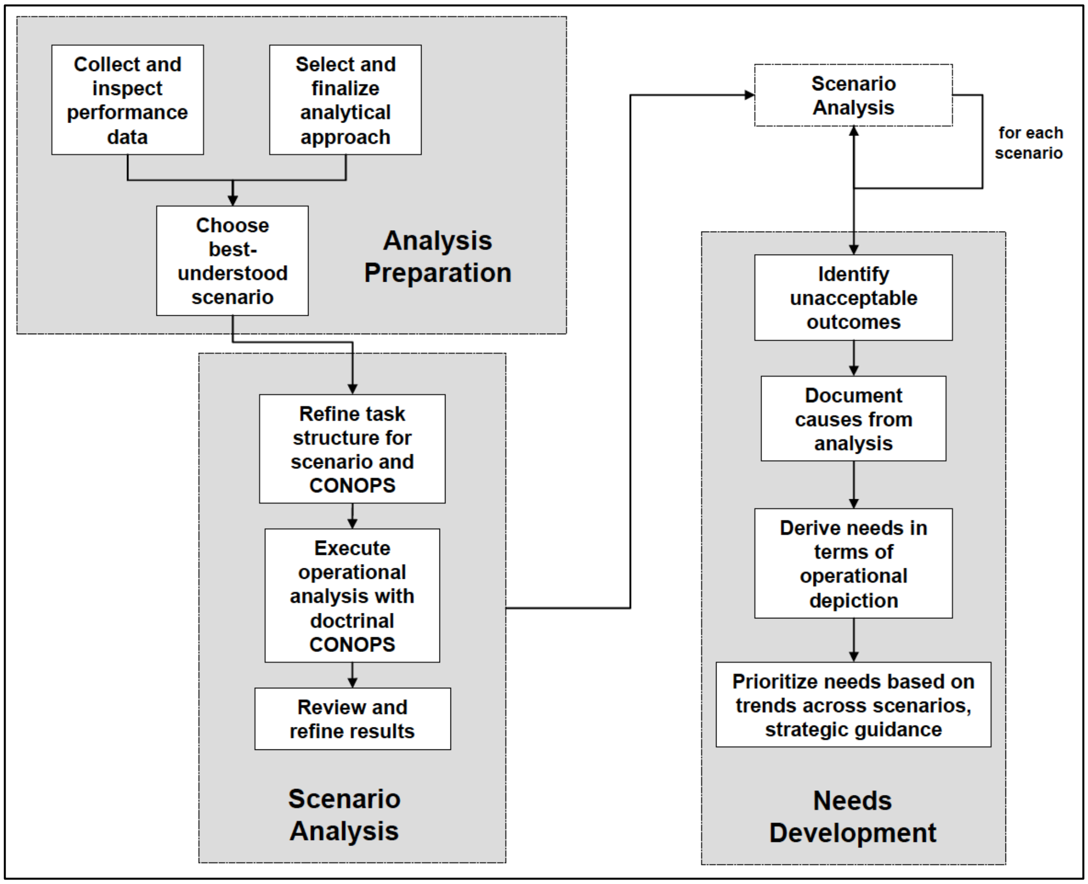

Figure 3. Example Quick Turn CBA Needs Assessment Process. Source: JCS J-8 (2009, p. 74).

This task flow represents the use of standards to evaluate multiple scenarios in order to develop needs assessment gaps. In the scenario analysis phase, we did not execute the operational analysis against a doctrinal concept of operations (CONOPS) as we are evaluating the potential application of immersive technologies to enhance training and do not need to consider doctrinal enemy forces. During the scenario analysis phase, we looked at technologies across the spectrum to evaluate their application in the SRF-A training environment.

This leads us to the final phase of solution analysis in Chapter V. Because we conducted a Quick Turn CBA, this process was simplified accordingly. The needs assessment gaps identified in Chapter IV led into the alternatives generation step. Due to the nature of our research and the request of CENSECFOR, we were specifically looking at materiel alternatives in the form of AR and VR technologies and their potential to enhance SRF-A training. We considered transformational capabilities; however, they possess significant technical risk at this time. Due to time and the scope of our research, we did not consider affordability in our analysis, but we address affordability studies in Chapter V. Figure 4 is a diagram from the JCS J-8 for the standard CBA solution phase task flow. The red outlines in the figure represent the steps utilized in our Quick Turn CBA approach based on our situation.

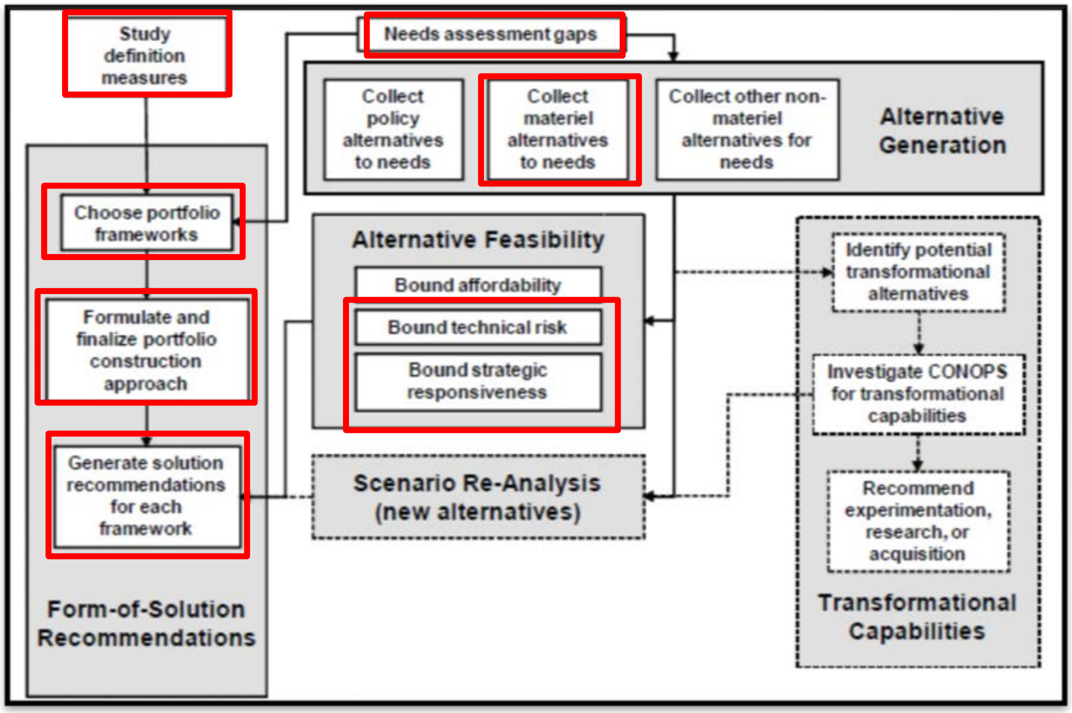

Figure 4. Solution Phase Task Flow. Source: JCS J-8 (2009, p. 65).

Due to the significant number of different AR and VR materiel alternatives currently on the market, we had to create a way to categorize them for evaluation. We decided to develop portfolios or categories of technologies based on the guidance in the JCS J-8 (2009) CBA guide that portfolios are sets of options that "are mutually supporting sets of recommendations that are related by a common theme" (p. 61). This portfolio generation allowed us to establish a limited number of categories along the AR and VR spectrum for evaluation against our developed standards from Chapter IV.

To conduct our analysis of these portfolios of technologies, we decided to use a group methodology approach and expert judgement techniques due to time constraints. The JCS J-8 (2009) CBA guide states that "expert judgement techniques, typified by a variety of group voting and weighting methods … fall into the category of mathematical methods, because they are evaluative" (p. 50). See Figure 5 for the spectrum of analysis approaches. Additionally, as the guide states, "If you need to examine a large number of alternatives, then you will need abstraction (and analytical expertise)" (JCS J-8, 2009, p.

49); this is in line with a mathematical model or group methodology as we considered a large number of technology alternatives.

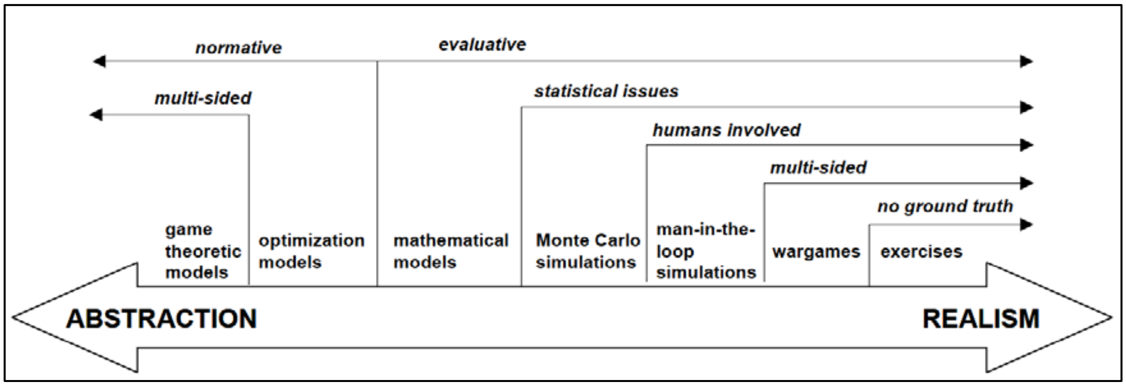

Figure 5. A Classification Scheme for Analysis Approaches. Source: JCS J-8 (2009, p. 49).

In Chapter V, we conduct our group analysis. To do this, we first generated a spreadsheet with which to assess the portfolios of technology against the standards developed in Chapter IV. Prior to our analysis, we recorded agreed-upon definitions for the standards, the individual technology portfolios, and the scoring criteria onto a single document for our reference during the evaluation. For our evaluation, we divided the current CENSECFOR SRF-A training program into a crawl, walk, and run phase. The overall objective of the SRF-A course is to train Navy personnel to serve as team members or team leaders of an SRF (CENSECFOR, 2018a, p. 1). This training must reflect the asymmetrical environment an SRF may encounter on board a ship, from the pier, or in a garrison environment (CENSECFOR, p. 1, 2018a). However, each phase of training has specific training objectives and utilizes different resources. Our team agreed on the following definitions and parameters for each SRF-A training phase for evaluation.

- **Crawl:** Classroom training was conducted during week one of training; primarily Lessons 1.1–1.5 topics (e.g., tactical communications, restraint equipment, personnel and area search procedures, employment of force decisions); training venues are primarily classroom instruction with some usage of the FATS and/or outdoor stationary drills (e.g., how to employ OC spray, personnel search techniques).

- **Walk:** During the walk phase of training, the trainees begin to transition to more team work and tactical drills and less classroom instruction. This transition occurs at the end of week one and the beginning of week two with Lesson 1.6 (Tactical Team Movement). In this phase of training, the trainees begin to integrate all of the individual skills they have learned in the crawl phase to work as a team. There may be live role players for certain exercises. The primary venues for this phase of training are in the interior and exterior areas of the Force Protection Ship Simulator (FPSS).

- **Run:** The run phase of training is conducted primarily in the interior and exterior areas of the FPSS. In this phase of training, the trainees are executing the scenarios as teams at full speed with simunition rounds and live role players. This is the phase in which the trainees are evaluated by the instructors for their performance as team members and team leaders.

After completing our analysis, we recorded the results into a table for each phase indicating the level of perceived enhancement against current training using "-" for negative perceived enhancement, "o" for no perceived enhancement/NA, "+" for some perceived enhancement, or "++" for considerable perceived enhancement. With this data, we developed a set of recommendations in Chapter V in the form of courses of action and future research efforts. We make no specific technology recommendations but do suggest areas in which we see potential for technology to enhance the current SRF-A training. As the JCS J-8 (2009) CBA guide states, researchers must "do enough work to defend your recommendations for forms of solutions, but not their particular characteristics … but you do need to guide the solutions communities" (p. 58).

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III. AR AND VR BACKGROUND AND CURRENT USES IN MILITARY AND LAW ENFORCEMENT TRAINING

The purpose of the background discussion for AR and VR in the following sections is to provide the reader with a baseline understanding of the basic concepts and technology involved with the development of a training system. We do not delve deeply into the technical requirements or design specifications of these systems. Our research into these technologies is focused on an acquisition and training outcome perspective.

A. AUGMENTED REALITY

In this section, we define and discuss AR. We discuss the technology behind AR, current uses, and AR's benefits and issues. In later chapters, we discuss the specific applications for military and law enforcement training, focusing on marksmanship and security training applications.

1. Augmented Reality Defined

First, we consider the definition of AR. In the most basic terms, AR is overlaying or combining computer-generated images with real environments or objects. A simple example of this would be overlaying computer-generated pictures of internal organs on a human body to demonstrate the location of those organs.

The technical definition we follow originates from the research of Ronald Azuma (1997). He described AR as a "variation of the virtual environments (VE)" (p. 355), differentiating between the two by stating that in the virtual environment, the user is unable to see his or her surroundings, while with AR, the user can view the real world with the computer-generated objects overlaid on the existing environment (Azuma, 1997). In more recent research, Azuma and his team identified three properties of an AR system: (a) it combines real and virtual objects, (b) it happens in real time, and (c) it registers or aligns the images in 3D (Azuma et al., 2001).

2. Technology behind Augmented Reality

In this section, we explore the technology and components required for an AR system. The most well-represented technologies in research revolve around handheld devices such as smartphones and tablets. We further limit our focus on technologies that offer opportunities for use in conducting realistic training for military security forces.

There are six components required for AR: (a) processing unit (computer or mobile device), (b) display (hand-held or head-mounted), (c) camera, (d) tracking system (location and orientation), (e) method to identify a location for virtually displayed information (marker system or marker-less system), and (f) AR software. These components work together to performs the tasks necessary to enable the AR system to function as intended (Schmalstieg & Hollerer, 2016).

Mobile AR systems work by capturing the real environment and augmenting that environment with the desired information or graphics. This can be accomplished using a head-mounted display with a built-in video camera. To determine what object or information is to be augmented into the field of view and at what orientation, the system needs to be able to identify the scene. Scene identification is possible through either a marker-based system or a non-marker–based system. Marker-based systems use 2D shapes that contain a barcode or a pattern that provides location, identification, and image information so that the appropriate image is displayed, in the correct position, and aligned in the proper direction. Marker-based systems can use a variety of marker types; the most popular are the square or circular marker. The most common non-marker systems we found in our research use image recognition (visual), geo-positioning (GPS), or a combination of both (hybrid) to determine the location, identification, and image information (Lopez, Navarro, & Relano, 2012). Visual tracking systems require that the system recognizes features or objects captured by the built-in camera and places the computer-generated object into the field of view based on the type of object identified. GPS tracking systems receive GPS signals from satellites through a built-in GPS antenna to determine user location. The system uses the location data and user orientation to determine where to place the computer-generated objects. A hybrid tracking system can use any combination of tracking technologies in support of each other to provide location and orientation data to determine where to place computer-generated objects (Lopez et al., 2012; Schmalstieg & Hollerer, 2016). Marker-based systems are the most accurate of the two methods. The next task for an AR system is scene processing. Scene processing is a method of combining the “real world” environment with the augmented information or images that system designers desire the user to see. Scene processing enables the final step in the process, which is a visualization of the enriched scene by the user through the head-mounted display (Lopez et al., 2012).

3. Commercial Applications of Augmented Reality

Several firms are offering lightweight, wearable mobile AR systems designed to improve business processes and facilitate learning. Currently available systems include the DAQRI Worksense, Microsoft HoloLens, MetaVision Meta 2, and MagicLeap One. Some of the current uses for these systems are engineering and construction projects, industrial environments, manufacturing and production processes, engineering and medical training, maintenance and technical support, and logistics.

AR offers many benefits to the field of engineering for both students and engineers. AR glasses and goggles are being used in the education of students by providing capabilities not traditionally available in the classroom. When students wear the glasses, they can better visualize the 2D design translation. For instance, in a study from La Laguna University in Spain, the research showed an improvement in student learning when using AR technology in the study of graphics engineering (Gutierrez & Meneses Fernandez, 2014). The researchers divided the groups into a control group consisting of 22 engineering students and compared them to 25 first-year mechanical engineering students. The testing and survey results demonstrated a significant improvement in motivation and academic development among the students using AR technology (Gutierrez & Meneses Fernandez, 2014).

For practicing engineers and project managers working on construction projects, the use of AR can also provide the ability to view design details on an actual project site. For example, the ability to translate computer-aided design (CAD) files and overlay them inside a structure allows engineers and project managers to ensure everything will fit into the area without conflicting with other objects. This translation reduces the chances for costly design changes and rework. Research on the application of AR technology in the construction process highlighted several processes that could benefit from such technology, including efficiency, effectiveness, and the overall outcome. Project managers realized they could improve cost, schedule, and performance through the use of smart glasses, which allowed them to manage the project data electronically and transmit it between the lenses and the server. Some of the potential process improvements include the following: (a) Design information being available in the glasses reduces the need to print the CAD designs; (b) data-sharing between on-site personnel and those back at the management office reduces wasted time traveling between locations to work out design issues; and (c) having the 3D CAD files overlaid through the glasses allows on-site personnel to identify and correct problems while updating the design changes onto the server that is accessible to management (Moon, Kwon, Bock, & Ko, 2015).

Industrial firms are also exploring the benefits of using AR to improve their operations. Industrial areas identified for potential applications of AR technology include the production process, where the use of AR may enhance the speed and learning curve involved with assembling products; quality control, where quality assurance/quality control (QA/QC) personnel can compare the actual outputs to the specifications and standards; maintenance operations, where technicians can use AR devices to display troubleshooting or maintenance procedures instead of using paper manuals; and training of new employees or new tasks. Additionally, using AR to train personnel as they are working on the production line has the potential to improve the overall learning process (Aromaa, Aaltonen, Kaasinen, Elo, & Parkkinen, 2016; Pierdicca, Frontoni, Pollini, Trani, & Verdini, 2017).

Researchers in a 2017 case study investigated the potential application of AR technology for on-the-job training of industrial personnel (Pierdicca et al., 2017). The researchers used a head-mounted display to show step-by-step instructions in the assembly process. The researchers found that the use of AR to provide personnel instructions for assembling parts resulted in faster task completion. They also identified the potential to realize cost savings by reducing or eliminating the need for expensive training programs through the use of on-the-job training using AR with the head-mounted display (Pierdicca et al., 2017).

The automotive and industrial sectors are additional areas that benefit from AR. In the automotive industry, AR is helping to improve maintenance processes. For example, Porsche announced that it would launch an AR system for the servicing of its vehicles in 2018 (Porsche, 2017). The system, Tech Live Look, uses AR glasses to allow service technicians at dealership service centers to reach back to the technical support center in Atlanta for assistance. The lenses provide technicians with information such as technical specifications while also allowing the higher level support team to see the same view as the repair technician. Porsche estimates this technology will save 40% in repair time based on the test run at eight locations in 2017 (Porsche, 2017). In a study of the use of AR for maintenance in industrial environments, researchers evaluated the usefulness of AR in the servicing of a crane (Aromaa et al., 2016). The study involved the use of three devices used together for knowledge-sharing: AR glasses, a smartwatch, and a smartphone. The users found these devices useful in performing their work. However, they stated there was a limited benefit from having three devices because they felt the devices became cumbersome and no longer aided in completing tasks (Aromaa et al., 2016).

In addition to commercial sectors, the medical field is also making great strides in the application of AR technology. Medical professionals and educators are beginning to embrace it for the benefits it can bring to medical education, patient interaction, and surgical outcomes (Gardner, 2016). For example, AR offers the ability to create a realistic and interactive training program to educate medical students. Students can use mobile devices or AR glasses to view and interact with realistic wounds by viewing organs overlaid on books, peers, or patient care manikins. Using manikins, the students can perform common medical procedures and gain valuable experience before delivering the techniques on patients (Gardner, 2016). One study compared the differences between a textbook and an AR technology, mARble, on forensic medicine education. Students using mARble showed a significantly higher level of knowledge improvement over the students using a textbook. Additionally, the students using mARble rated their learning experience higher than those using the textbook (Albrecht, Folta-Schoofs, & Behrends, 2013).

Surgeons are also using AR to improve surgical outcomes. AR has enhanced surgical planning by allowing surgeons to use patients' actual 3D medical imaging and virtual images to identify best methods for conducting surgery (Gardner, 2016). AR also supports the "telementoring" of surgeons. For instance, the University of Alabama developed technology that uses a combination of Google Glass and Virtual Interactive Presences and AR (VIPAAR) during surgery, allowing surgeons to get support if needed (Gardner, 2016). The surgeon's Google Glass provides the mentor with the same view as the surgeon and allows the mentor to provide feedback, including overlaying the mentor's hands on the patient to guide the surgeon. Additional surgical applications, such as MedicAR and Computer Assisted Medical Diagnosis and Surgery System (CAMDASS), are also being developed. MedicAR allows surgeons to superimpose patient diagnostic data, surgical guides, and other imagery onto the patient's skin. CAMDASS is being tested by the European Space Agency to enhance astronauts' ability to perform medical procedures while in orbit. The system will use a head-mounted display to provide necessary information even while out of communication range of the earth (Gardner, 2016).

AR is also helping improve patient interactions and experiences. Doctors at Beth Israel Deaconess Medical Center in Boston are testing Google Glass for use in patient care. As doctors approach a room, a QR marker outside the room triggers the glass to access patient records. Google Glass then displays the medical records, enabling the physicians to keep their hands free while they treat their patients. Finally, hospitals are also using AR to improve patients' experience during diagnosis and treatment. Using AR to educate patients on the human body—displaying their specific health issues and showing them how surgeons perform procedures—helps to alleviate patients' fear or anxiety surrounding surgery (Mueller, 2017; Gardner, 2016).

The use of AR technology in logistics shows potential for promising improvements in efficiency and accuracy. A 2014 pilot program conducted by the shipping company DHL to assess potential performance improvements of its warehouse personnel, compared pickers using hand scanners with those using AR glasses (Kückelhaus, 2015). Over three-weeks, DHL compared the speed and accuracy of the two groups to determine whether it could improve the efficiency and speed of its pickers, which DHL estimates accounts for two-thirds of its warehouse costs. The results of the program were that the AR-enabled pickers showed a 25% performance improvement and significant time savings. The personnel using AR provided positive feedback on the usability of the hands-free system. DHL has identified 11 tasks in its supply chain where AR solutions could improve its operations (Kückelhaus, 2015).

The rapid advancement in commercial applications of mobile AR, highlighted in the previous examples, provides tremendous opportunities for use by the military and other government organizations. The military could tailor commercial AR technologies used in areas like healthcare, systems acquisition, training and education, and equipment maintenance for use in military applications. Piggybacking on the research and development (R&D) efforts of these educational institutes and industry leaders offers an opportunity for the Department of Defense (DoD) to cost-effectively acquire and customize AR technologies for similar uses to improve DoD efficiency and effectiveness in providing for the defense of the nation.

4. Issues with Augmented Reality

In spite of all of the recent advances in AR, universal acceptance and widespread use of AR systems still face challenges. Besides the high costs associated with using AR—Microsoft's HoloLens costs between $3,000–$5,000 without software—concerns have also been raised in several other areas. Researchers have expressed the potential for issues with human–computer interaction (HCI), technology limitations, and security/privacy concerns.

Research has identified several concerns related to the interaction between the user and AR systems (Bhutta, Umm-e-Hani, & Tariq, 2015). First, there is the potential that users of AR systems will experience information overload. The availability of so much information constantly available on AR glasses while the user is performing tasks has the potential to overwhelm users, resulting in them rejecting the technology. There is also the potential for physical challenges for the users such as eye fatigue, discomfort resulting from wearing the hardware, motion sickness, and issues with depth perception (Bhutta et al., 2015).

Current limitations in technology have also slowed the acceptance of AR. The limited capabilities of visual displays impact the realism of the experience. Issues with image contrast, resolution, brightness, and limited field of view reduce the realism of virtual imagery. Tracking also poses a challenge to realism. When marker systems are not used, mobile AR must rely on the limited processing capabilities of the CPU to use the visual, GPS, or hybrid tracking systems discussed earlier in Chapter III (Bhutta et al., 2015; Lopez et al., 2012). Additionally, mobile AR technology must balance size and capacity. Mobile AR must be small, and currently providing the capabilities of a stationary AR system in a mobile platform is prohibitively costly for most users. Therefore, most extant mobile systems lack the capability to process information in real time. This mobile system also suffers from issues with low battery life, poor resolution in less-than-optimal environmental conditions, and delays in the processing of data (Bhutta et al., 2015).

Finally, security and privacy are significant issues with AR systems. Bhutta and colleagues (2015) note a growing concern, especially with recent events, with compromised security and privacy. For instance, AR and facial recognition software might allow unauthorized users access to sensitive information through a combination of social media sites and online information services. The continuous recording of a user's field of view through the AR glasses threatens the privacy and security of those in the line of sight. Also, because AR uses location data and WiFi networks to operate properly, AR user's information might be compromised. Nefarious groups might be able to hack AR systems, placing malicious software that can provide them with access to AR user's personal information, a company's intellectual property, or a military unit's location (Bhutta et al., 2015).

B. VIRTUAL REALITY

In this section, we define and discuss virtual reality (VR). We provide a brief history, the technology behind VR, current VR uses, and VR's benefits and issues. In later chapters, we discuss the potential applications for military training, focusing on marksmanship and security training applications. The scope of our VR research is focused on providing a general understanding in order to assess VR's potential application in an AR or VR training system.

1. Virtual Reality Defined

Unlike AR, in which the computer-generated images are placed over the real environment, VR involves placing the user into a computer-generated environment while providing feedback to the user's senses. Perhaps the most common example of VR use is video games, in which the user wears a headset to completely remove the real environment and replace it with a 3D simulated environment that the user interacts with using some type of controller and haptic device.

The term *virtual reality* is not only commonly used to describe the technology or the system itself, but it is also used interchangeably with the term *virtual environment* to describe the computer-generated world used in the display. When we refer to VR, it is to describe the technology to include the components necessary to create the virtual environment. For our purposes, we use the definition provided by Matjaz Mihelj, Domen Novak, and Samo Begus (2014). They define VR as an "interactive computer simulation, which senses the user's state and operation and replaces or augments sensory feedback information to one or more senses in a way that the user gets a sense of being immersed in the simulation" (Mihelj et al., 2014, p. 1).

2. Technology behind Virtual Reality

This section explores the technology and components of a VR System. We focus our research on the technologies that provide the ability to conduct realistic training for military security forces.

VR Systems are categorized by the level of user immersion: immersive, semi-immersive, and non-immersive (Bamodu & Ye, 2013; see Figure 6). VR systems become increasingly more complex and costly as they become more immersive. The level of immersion describes how strong the user connection is to the computer-simulated environment. In an immersive system, the user is highly connected to the computer-simulated environment through the use of a head mounted display (HMD), which completely replaces the real environment with a virtual environment, a haptic device(s) that provides feedback to the senses, and an input device(s) that allows the user to seamlessly interact with the virtual environment (Bamodu & Ye, 2013). In this type of system, the user feels as though he or she is part of the virtual environment.

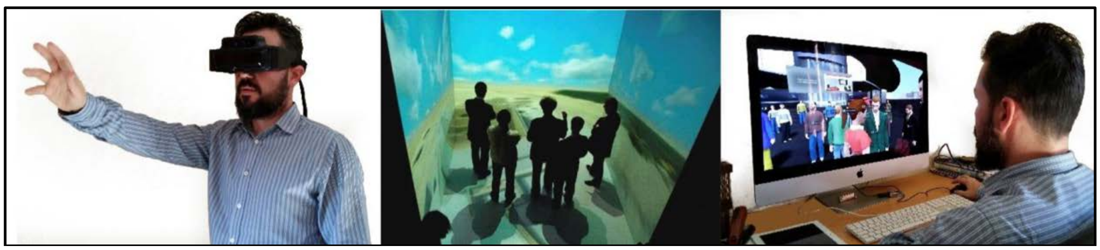

Figure 6. Degree of Immersion within Virtual Reality Systems.
Source: Martín-Gutiérrez, Mora, Anorbe, & González-Marrero (2017).

In a semi-immersive system, the user's senses are not completely immersed in the computer-generated environment, resulting in a less realistic experience. Semi-immersive systems commonly use projectors or multiple screens surrounding the user, such as a cave automatic virtual environment (CAVE) or cockpit, for the display and may or may not use haptic or input devices. Examples of this type of system are flight/driving simulators, which may engage the senses through the display, motion, and/or vibrations, or a system that surrounds the user similar to the CAVE training systems designed for the military (Bamodu & Ye, 2013; see Figure 7).

Figure 7. CAVE Training System. Source: MetaVR Inc. (2017).

Non-immersive VR systems stimulate the user's senses the least, require minimal computer processing capability, and are generally the least expensive category of VR systems. Non-immersive systems allow the user to remain aware of the surrounding environment by only displaying the virtual environment on a portion of his or her field of view. The RehabGame, a VR motor function rehabilitation system, which uses a Microsoft Kinect motion sensor, a gesture control arm band, and a flat screen display to guide users through rehabilitative motions, is an example of a non-immersive system (Esfahlani, Thompson, Parsa, Brown, & Cirstea, 2018).

Regardless of the type of VR system employed, in addition to the user, the system requires three basic hardware components: input device, output device, and processor. Depending on the level of realism desired, the system may employ several input and output devices. Some common input devices are the data glove, joystick, motion tracker, microphone, virtual sphere, or other motion platform (Reality Technologies, n.d.).

Output devices provide feedback to the user's senses. Three basic types of output devices exist: visual feedback devices, audio feedback devices, and haptic feedback devices (Burdea, Richard, & Coiffet, 1996). Visual feedback is provided through the display, such as a head-mounted display (HMD) or CAVE-type display. The audio feedback can be provided through a headset or other system speakers. The haptic feedback device provides stimulation to the touch through tactile or force feedback. A few examples of haptic feedback devices are joysticks that vibrate; vests that allow the wearer to feel impacts; gloves that allow the user to feel the response to his or her actions, such as the pressure or sharpness of a surgical device during a surgical training simulation; or training weapons that simulate recoil using compressed air (Burdea et al., 1996; Parkin, 2016; Delazio et al., 2018). These input and output devices can be configured in a variety of combinations to create an immersive virtual experience for the user.

The final hardware component required in a VR system is the computer system consisting of the computer processing unit (CPU), video card/graphics processing unit (GPU), memory (RAM), and data storage (hard drives) (Bamodu & Ye, 2013; Heltzel, 2018; Puget Systems, 2018). The CPU and the GPU power have the biggest impact on the level of immersion (realism) achievable with the VR system. The GPU affects the quality of the displayed graphics, while the CPU controls the interface between the user and the input/output devices and runs the required software (Heltzel, 2018; Bamodu & Ye, 2013).

3. Commercial Applications of Virtual Reality

VR systems are currently used in a variety of applications such as education, medical training, military training, flight/driver training, entertainment, product/ technology development, therapy, and many other applications. Rapid technology advances have led to an increase in companies developing VR systems and solutions, making the technology more affordable and accessible for organizations and individuals.

Educators in numerous fields of study are seeking creative ways to improve the learning outcomes of their students through the use of VR. One such example is the University of Maryland. There, the Institute for Advanced Computer Studies and the Center for the Advanced Study of Languages have teamed up to develop a VR language training program that allows users to experience Russian cultural and language immersion without the need to travel to a foreign country. This reduces costs and, in some cases, also increases safety (Tare, Golonka, & Clark, 2017). In another study, Alhalabi (2016) compared the learning outcomes for engineering students using one of three VR systems to using no VR. This study found that the use of VR in the education of engineering students resulted in a significant improvement in scores over the students without VR (Alhalabi, 2016).

VR systems are proving effective in training medical professions as well. Similar to AR, VR is used across a variety of tasks, from patient interaction and treatment to complex surgical procedures. Both civilian and military medical professionals are employing these systems because of the limited number of trained professionals available for treating patients and training students. These systems are proving effective in the initial training of medical personnel, as well as helping personnel to reacquire skills that may have atrophied due to lack of use over time (Gasbakk, Snarby, & Lindseth, 2017; Geake et al., 2015; Siu, Best, Kim, Oleynikov, & Ritter, 2016).

VR has proven extremely useful for operator training in both flight and driver training programs. Organizations are using CAVE/cockpit style simulators as well as HMDs to provide these immersive training solutions. For instance, UPS is using VR to improve training of their drivers (UPS, 2017). The company is replacing a touch screen–based training system with a VR system to improve the training experience of their parcel delivery drivers. The company has also begun to use VR headsets to train their drivers in the identification of road hazards (UPS, 2017). Civilian and military pilots have been using flight simulators for years. Boeing uses flight simulators to train its customers' pilots to operate its Dreamliners (Airline Industry Information [M2], 2013). The military has recognized the importance of using flight simulation since the 1960s and continues to assess the training capabilities of VR flight training systems. Finally, in a study that began in January 2018, the Air Force is studying the impacts of the flight training system on the learning rates of three test groups of pilots. Each group varies in their flight experience levels. It is using this research to prove whether VR training can improve the effectiveness and efficiency of training. If successful, the Air Force could apply VR training across a broad spectrum of training tasks (Holcomb, 2018).

4. Issues with Virtual Reality

Although the technological advances in VR have reduced many of the cost and technology maturity concerns, they have not addressed the increase in health concerns of users. There have been several concerns about the use of VR and the potential short-term and long-term health effects. Although there is plenty of literature discussing various health concerns, the scientific evidence supporting them is limited (Viire, 1997). Common concerns include the effects on muscles and joints from wearing the device and the effects of being completely immersed in the virtual environment. The concerns dealing with immersion are safety and health related. Safety issues arise when the user is not spacially aware of his or her surroundings, resulting in trips, falls, or collision with objects in the immediate area. Health issues are due to the display itself and result in motion sickness, siezures, eye strain, or even possible pyschological effects from prolonged exposure to the virtual environment (Mon-Williams, 2017; Gasbakk et al., 2017; Viire, 1997).

C. MIXED REALITY

In the background section, our discussion focused on two immersive technologies, VR and AR. However, these are just two of the possible display technologies along what is known as the Reality-Virtuality Continuum (Milgram & Kishino, 1994). We briefly explain the concept of mixed reality to provide an understanding of how the various technologies along the continuum can provide varying levels of immersion. This allows us to include systems that are not exclusively VR or AR for comparison in our analysis of alternatives in meeting the military's training needs.

The Reality-Virtuality Continuum encompasses the various states of reality from the real environment to the virtual environment (see Figure 8). Mixed reality, as defined by Milgram and Kishino (1994), is the merging of the real world and a virtual environment. The spectrum for mixed reality encompasses everything in the Reality-Virtuality Continuum except the real environment and completely immersive VR (Milgram & Kishino, 1994). When we discuss mixed reality, we focus on the display combinations that fall between AR and VR. Because each of the systems are capable of incorporating similar input/output devices such as haptic feedback devices, we differentiate based on the degree to which the real and virtual environments are combined.

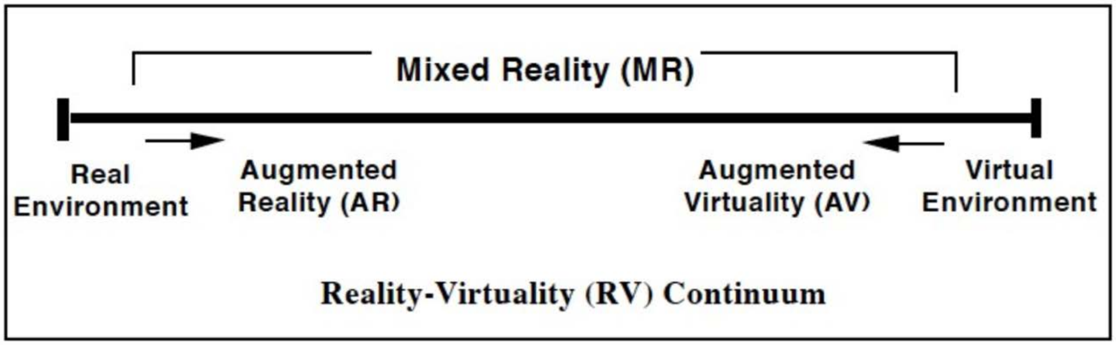

Figure 8. Reality-Virtuality Continuum. Source: Milgram & Kishino (1994).

D. MARKET SURVEY OF MILITARY AND LAW ENFORCEMENT IMMERSIVE REALITY TRAINING SYSTEMS

Military and law enforcement agencies use immersive-based systems today to enhance their live, virtual, and constructive training. This section provides the history of military and law enforcement (LE) use of immersive systems for enhancing training, the benefits achieved by using the technologies, known issues with immersive technologies in military training, and design requirements to build future systems.

1. History of Military Use of Immersive Technologies to Enhance Training

The military understands that today's youth have grown up in the gamer generation and have a broad understanding of the role of games in the learning environment (Harper, 2017; Emond et al., 2016). The gamer generation intuitively understands the input methods and the output response required in games, and it knows how games present images and graphics and the interactions needed by a player's gaming avatar to complete knowledge transfer of a task the game expects as the outcome (Emond et al., 2016). The gamer generation creates a situation in which students are more motivated to learn through playing games versus traditional instructional methods (Kirkley, Tomblin, & Kirkley, 2005). Gamers have a desire to "win" at games, which means they are more willing to practice, receive feedback from their mistakes, and repeat the scenario until they are successful (Kirkley et al., 2005). As with any other task, the more a trainee practices a skill, the greater the likelihood of successful knowledge transfer (Emond et al., 2016).

During the last three decades, military operations have become diverse, and traditional training cannot provide opportunities to cover the complete gamut of military training requirements (Livingston et al., 2011). The military initially focused on warfighting tasks; however, during the last 20 years, there has been a shift in training requirements that requires additional tasks that are difficult to teach using standard training methods (Loftin, Scerbo, Mckenzie, & Catanzao, 2004). For example, the manning of military checkpoints during the war in Iraq exposed troops to the threat of suicide bombers. There was no way to replicate the training realism using traditional live training because it is difficult to represent in the real world (Loftin et al., 2004; Yang & Kim 2002). Because of the training gap and threat, the military identified the need for new training methodologies to overcome the training gap and incorporated VR and AR systems into its training regimen to provide realistic training to the force (Livingston et al., 2011). The military approached Defense Advanced Research Projects Agency (DARPA) to develop a solution to their training gap, and DARPA created the Simnet project to promote individual and crew training environments and, based on its success, encouraged the military to invest heavily in immersive virtual and augmented training environments (Moshell, 1993).

Since Simnet, the military continued to look towards virtual and AR environments to develop cost-effective training that includes aspects of the real world while saving money on live training (Macedonia, 2002). The military conducted a significant level of R&D to develop immersive environments that meet its extensive training requirements (Macedonia, 2002). One key aspect of developing immersive environments is that developers must understand the tasks that the trainees are expected to perform, and developers must account for the rapid rate of change in tasks and the cognitive skills required to transfer the knowledge to the trainee (Sikorski, Palla, & Brent, 2017). The resultant VR system can transfer knowledge for training that is skill-based, rule-based, and knowledge-based (Sikorski et al., 2017). To develop such a system, designers must have a detailed understanding of the cognitive tasks required to perform each overarching task and the expertise required to complete overarching and sub-tasks (Sikorski et al., 2017). The development team needs to create the appropriate responses expected for each task response against the trainee's skill level (Sikorski et al. 2017). The key to knowledge transfer, however, remains in repetitive practice (Emond et al., 2016) because as the learner practices the skill, individual performance tends to improve (Emond et al., 2016).

The Army and Marine Corps are committed to using immersive technologies in training at the highest levels. Chief of Staff of the U.S. Army General Mark Milley said, "It's through iteration and intense, realistic training that … our soldiers will prevail and survive on the battlefield" (Harper, 2017, p. 40), and "we just need at our level to focus our resources and provide them the opportunity" (Harper, 2017, p. 40). The Army leadership's approach to a new paradigm of training includes modernization of existing synthetic training environments (STEs; Harper, 2017). Current simulated environments are built on 1980s technology and must be modernized to account for Army leadership's intent to create a robust, distributed training environment that provides live, virtual, constructive, and repeatable training that is used to build soldier skills (Harper, 2017). The issues with the current paradigm are that live training is costly to perform and is not easily extensible. If leadership wants to change a training variable, it takes considerable time to reset the scenario, and live training is also expensive and logistically challenging. In an STE environment, training variables can be changed to increase the complexity of the script to build soldier and leadership skills (Harper, 2017). Specifically, the Army plans to create an STE that provides a battlefield common operating picture. However, the Army intends to develop the STE where it cannot currently train (e.g., within a current mega-city). The Army plans to train units ranging from individual soldier through team up to the corps level and can include geographically separate elements such as deployed forces and coalition partners (Harper, 2017).

The Army is looking for a plug-and-play architecture that allows extensibility and the ability to modernize the STE throughout its life cycle (Harper, 2017). The Army proceeded to the acquisition process with industry days and requests for information that would inform its acquisition strategy. Due to the rapid pace of gaming technology improvements, Army leadership received interest from 80 vendors; it expects teaming between the established defense contractors and new Silicon Valley industry partners (Harper, 2017).

The Marine Corps development approach for a live, virtual, and constructive training environment is supported by General James Mattis' objective to improve the decision-making of officers and Marines at the company level (Ebbutt, 2010a). The Marine Corps approach creates three immersive training environments. It starts with the Squad Immersive Training Environment (SITE) that conducts constructive and iterative training at the small unit level and allows the unit to progress through the military "crawl, walk, run" building block approach to training (Ebbutt, 2010a).

2. Benefits of Immersive Training

The benefits of immersive training in the military are that VR and AR enhance and complement the traditional cognitive process by providing scalable information to trainees and users (Neumann & Majoros, 1998). AR can improve the skills and abilities required in military training and operations by eliminating wasteful time searching for information (Neumann & Majoros, 1998). During their study of manufacturing and maintenance tasks, he found that up to 50% of time used in repetitive tasks was spent looking up information and 50% was spent executing the task (Neumann & Majoros, 1998). When individuals had the information presented to them while completing a job, they could become information experts more quickly (Neumann & Majoros, 1998). His subjects were able to recall task steps and derive meaning when the system provided the information to them without the subjects having to look up the steps and conduct the task methodically by a checklist (Neumann & Majoros, 1998). The spatially-defined entities of AR systems present the information so users can develop an understanding of the physical layout and develop a cognitive map of the entity that helps users derive a context and clarity (Neumann & Majoros, 1998). When the information available to a trainee is scalable to the task and the role of the user, it prevents the user from being overwhelmed with too much information and allows him or her to transfer knowledge more efficiently (Neumann & Majoros, 1998). This can be achieved by providing realism, fidelity, immersion, and presence, and through motivating learning.

a. Realism

Realism is an essential aspect for immersive military training environments. Realism in training ensures that training meets the underlying intent of providing a situation that the trainees will encounter when they perform a task in the real world. (Winston, Schreiber, Portrey, & Bell, 2017). For the sense of realism, the environment is not as crucial to learning as the "cognitive realism" development of the actual task (Herrington, Reeves, & Oliver, 2007). A trainee's ability to interact with the scenario and reflect on the problem using traditional problem-solving methodology is more critical than the creation of the immersive world (Herrington et al., 2007). Therefore, developers need to focus on integrating technologies that stimulate cognitive processes used to solve complex issues; this will shift responsibility for learning back toward the learner versus the automated environment (Herrington et al., 2007). To meet the realism expectation, military immersive training systems must be representative of real-world training using 3D displays or live scenes; they must also provide feedback to users using haptic devices that allow trainees to interact with the environment and sensors that provide trainees' location and body positions and can also include sound and smells for complete immersion (Bowman & McMahan, 2007). The system must meet realism expectations that cannot be replicated through traditional classroom instruction, usability, fidelity, and immersion, and must provide for a sense of presence (Bowman & McMahan, 2007). But most of all, the system must be affordable enough for the military to justify the expense of immersive training environment implementation (Bowman & McMahan, 2007).

b. Fidelity

Fidelity demonstrates the linkage of training to system design, especially as the paradigm shifts to automated training (Winston et al., 2017). The system must also be realistic to provide the fidelity linkage to the task that ensures effective knowledge transfer during training (Bowman & McMahan, 2007). Despite the low fidelity of training, the relatively low cost and training effectiveness are seen as advantages of the immersive and non-immersive training systems when compared with traditional live and constructive training costs (Moshell, 1993).

c. Immersion and Presence

The system must provide immersion and presence to ensure realism and fidelity in an immersive training environment (Bowman & McMahan, 2007). Yang and Kim (2002) describe *presence* as leaving the trainee with the feeling that the training was real, which increases the chance of learning. The preference in most immersive training systems is for full immersion because it places the trainee in an immersive environment that he or she can manipulate (Robertson, Card, & Mackinlay, 1993). Non-immersive virtual and AR environments do not provide for full immersion but do provide training value (Robertson et al., 1993). Immersive and non-immersive environments can be expanded to include multiplayer scenarios with multirole actions, allowing interaction between players in the same training scenario (Robertson et al., 1993).

Proprioception is an important aspect that leads to the sense of presence in immersive environments. Mine, Brooks, and Sequin (1997) describe proprioception as an individual's sensing of his or her position and location within the individual's context and the manipulation of his or her environment through three forms of interaction (Mine et al., 1997). Direct manipulation is how the individual senses his or her environment to manipulate items, physical mnemonics are how the individual uses information that relates to his or her body, and gestural actions are how the individual issues commands to his or her body to control his or her actions (Mine et al., 1997). These three actions determine the level of interaction and their ability to manipulate virtual objects in a three-dimensional environment. The key to interaction is haptic feedback that allows users to interact intuitively without having to relearn spatial reasoning (Mine et al., 1997).

d. Learning Motivation

Learning motivation plays a crucial role in training environments (Kirkley, S., Tomblin, & Kirkley, J 2005; Neumann & Majoros, 1998). Learning motivation and memory recall are the primary factors that influence the rate of learning and successful knowledge transfer (Winston et al., 2017). The system must entice the learner to engage the scenario by creating a fun, meaningful, and interactive environment that effectively facilitates the knowledge transfer of the desired task. Immersive environments present that opportunity to transfer knowledge for procedural tasks involved in maintenance and manufacturing because the options used to engage the trainee are nearly limitless (Neumann & Majoros, 1998). Immersive systems also reduce the risk of the potential for error by allowing trainees to become experts in the training tasks through repetition and limited performance variability within the task and by providing the trainee with information to support task execution (Neumann & Majoros, 1998). Another aspect to learner motivation that is key to any system is gaining buy-in and adoption by the expected user community. There are challenges and skeptics regarding the shift to immersive training, but the new generation tends to buy in faster (Cressey, 2011). Expectations are higher today in training environments, and if the scenario does not seem as real as today's video games, the targeted users lose interest (Cressey, 2011). When the system has a "Call of Duty"–like environment, though, there is much more buy-in (Cressey, 2011).

3. Known Issues and Limitations of Immersive Training Environments

As with any system, there are substantial investments required to develop, maintain, and support the system throughout the system's life cycle. To date, the DoD has invested more than $5 billion into R&D of simulations and equipment to support simulation-based training (Kirkley et al., 2005). The DoD began by investing $35 million annually in the Institute of Creative Technologies (ICT; Kushner, 2017) to develop a training simulation; however, because of budget uncertainty, the ICT experienced budget cuts and decreasing dollars throughout development, which has created risk for the program (Kushner, 2017). Likewise, the Virtual Battle Space program was a video game–

based learning environment used to identify improvised explosive devices, and the software licenses cost between $500 and $30,000 per system (Kushner, 2017).

Additionally, the Army is investing in a $27 million venture with an additional $490 per system to field a system of hardware and software distributed simulations (Kushner, 2017). The key to system design is determining the correct level of immersion on the immersion continuum that is required to assist in the knowledge transfer for the desired task (Bowman & McMahan, 2007). The proper immersion level prevents investing in costly investments that might not be the correct training approach, as the trend is towards lower cost systems (Bowman & McMahan, 2007).

There is the potential that users of augmented reality systems will experience an information overload (Bhutta et al., 2015). The availability of so much information while the user is performing tasks has the potential to overwhelm users, resulting in them rejecting the technology (Bhutta et al., 2015). There is the potential for physical challenges for users such as eye fatigue, discomfort from wearing the hardware, motion sickness, and issues with depth perception (Bhutta et al., 2015). Information overload occurs when an AR system presents all the information it contains about the environment, permanently cluttering the display with information (Julier, Baillot, Lanzagorta, Brown, & Rosenblum, 2001). One way to address information clutter is to develop the ability to filter the information a user needs, which can be based on individual role or by the task the user is performing (Julier et al., 2001).

Another issue of training using virtual environments is a side effect referred to as cybersickness (Stanney, Hale, Nahmens, & Kennedy, 2003). Cybersickness is a term that describes the accompanying conditions of nausea, dizziness, headaches, drowsiness, and fatigue that result from exposure to virtual environments (Stanney et al., 2003). Two theories try to explain why cybersickness exists (Stanney et al., 2003). The first states there is likely a conflict between stimuli and the brain’s interpretation of the environment (Stanney et al., 2003). The battle leads the body to display motion sickness–like symptoms as a defense mechanism to the conflicting stimuli. The other theory is that postural instability in the situation is the cause of the motion sickness (Stanney et al., 2003). Stanney and her research team examined individual aspects to determine if an underlying relationship such as gender, body mass index, health, or previous experience existed that could provide predictive information on who might be prone to cybersickness (Stanney et al., 2003). They found the most significant indicator of cybersickness was determined to be previous motion sickness (Stanney et al., 2003). They suggested that virtual environment developers consider the cybersickness effects and exposure when developing systems and warn users who are prone to motion sickness before use (Stanney et al., 2003).

The display methods limit training options within immersive systems because they do not allow for natural movement and interaction with the environment (Fernandes, Raja, & Eyre, 2003). The lack of normal movement presents a significant challenge for the military to adopt immersive training solutions. A few developers have created options to overcome the limited actions from the tethered visual display. One alternative to overcome the limited mobility in VR was the development of a unicycle that the user sits upon and pedals to simulate movement within the environment (Fernandes et al., 2003). A unicycle is not an ideal solution for military training because it limits movement to walking, and military training requires numerous body positions and movement techniques (Fernandes et al., 2003). The University of Warwick in the United Kingdom developed the Cybersphere, which allows multiple options for movement by creating a multi-sphere system. In the multi-sphere, users enter the sphere and can walk, crawl, and run in any direction; the sensors in the outer sphere detect the movement of the user in the inner sphere and update his or her position and project the change in the landscape by the user’s action (Fernandes et al., 2003).

4. Design Requirements for Immersive Training Systems

A thorough and systematic approach to the requirements process is required to develop a system that achieves the desired results for performance and readiness (Fournier, Lapointe, Munteanu, Emond, & Kondratove, 2011). Requirements must be understood up front to create a system that contains an engaging environment and to ensure that the system supports the task development and provides coaching to provide knowledge transfer to the respective trainee (Emond et al., 2016). In addition to requirements, system development constraints must address high development and sustainment costs and inefficiency in extensibility of training systems to include multiple environments, the lack of realism, and safety concerns within the scenarios (Fournier et al., 2011). The following is a list of development requirements consistent across military training and system development literature:

1. The system should be intuitive both in viewing and manipulation of their environment (Mine et al., 1997). Systems should mitigate system latency (how fast the system responds to user input and reduces the lag [Robertson et al., 1993]) as well as strive for the best resolution (Mine et al., 1997).

2. The system must introduce a sense of realism where the trainee can detect, obtain, assimilate, and discern patterns of information from the stimuli that allow the trainee to understand and engage the environment (Neumann & Majoros, 1998). Realism is also provided by haptic feedback that allows the trainee to interact with and manipulate the virtual or augmented environment (Mine et al., 1997).

3. The system should address the motivation of learners (Kirkley et al., 2005).

4. They immersive system should look to incorporate the emotional aspects of games (Kirkley et al., 2005). The training should engage trainees in a manner similar to the approach for gaming design, in which Malone and Lepper (1987) suggested that learning environments must contain clear and defined objectives. They must also have varying difficulty levels that adjust to the trainee’s experience level and clear structures for scoring and feedback to the trainees. The scenario should also contain random elements of surprise and should appeal to the trainee metaphorically or through fantasy.

5. The system should account for the typical tasks conducted within an immersive training environment, which include locomotion, manipulation, choice, and reaction time tasks (Stanney et al., 2003).

6. The system should consider immersive training environments that include distributed systems that are extensible with the number of users and scenarios and must ensure the system maps training tasks and undergoes a fidelity analysis to provide training that is commensurate with system design goals (Winston et al., 2017).

5. Survey of Current Military Immersive Systems Usage

The following sections discuss current military, law enforcement, and public safety usage across the spectrum of immersive technologies to augment live and constructive training.

a. Immersive Technology Used to Provide Situational Awareness

In one study, Brandao and Pinho explored ways that militaries could introduce AR systems to provide situational awareness to support operations (Brandao & Pinho, 2017). They describe situational awareness as being able to sense, perceive, and interpret factors of the environment that help an individual make decisions based on his or her understanding of what occurs in the environment (Brandao & Pinho, 2017). The authors begin examining what augmented systems could provide operators to help ensure the contextual information they need to help make decisions (Brandao & Pinho, 2017). They believe 2D maps would help operators navigate the scenario and provide various ways they could be displayed or hidden. This is analogous to the current gaming industry map trends that provide a contextual position of self, friendly teammates, and enemy forces relative to known points on the map (Brandhou & Pinho, 2017). They offer options for navigation consisting of an overlaid “path” to direct movement (Brandao & Pinho, 2017). They recommend beacons as another mechanism to provide situational awareness (Brandao & Pinho, 2017). The beacons can be visible or hidden based on operator preference and used for locations or specific intelligence that could help operators

(Brandao & Pinho, 2017). Then they provide four additional AR capabilities. The capabilities include reformatted non-verbal communication signals that assist in message transference and the use of wireframe devices that can project or display building blueprints or waypoints for navigation (Brandao & Pinho, 2017). The capabilities also include a crosshair display that allows expedited aiming of individual weapons to engage enemy forces quickly, target designation, and intel report development that acts similarly to the crosshair designator for firearms that assist in pointing to targets or intelligence reports creation based on the crosshair (Brandao & Pinho, 2017). The authors conclude that there are numerous ways to increase situational awareness with dismounted operators, but additional work is required to develop the capabilities (Brandao & Pinho, 2017).

Shukran et al. (2014) explore AR options for the Malaysian military. The authors theorize that based on cost, Android devices present a platform that could serve as a Malaysian Blue Force Tracker equivalent. They speculate that, based on the price of the platform for either cellular phone or tablet, the ease of use and familiarity with the Android platform, and device extensibility with battery life and physical memory storage provide an already ruggedized option that should be acceptable for the Malaysian military (Shukran et al., 2014). Shukran et al. (2014) propose using the cellular device to send and receive location services (Quantum GIS) and an onboard camera to locate targets/enemy forces to create an AR-based platform soldiers can use to identify friendly/enemy/target forces.

b. Immersive Technology Used to Train Pilots and Flight Crews

The military aircraft training sector can be broken down into three distinct categories that each support a different type of aircraft: combat aircraft, rotary wing aircraft, and transport aircraft (News Reporter Staff, 2015). The flight simulation capabilities include representative elements that simulate flight aircraft, a simulation of the flight environment, and a cueing simulator that requires the pilot to make decisions (News Reporter Staff, 2015). According to the article, flight simulators provide a means to train pilots that is 5%–20% cheaper than traditional flight hours and provides a safer method for training (News Reporter Staff, 2015). Today, approximately 30% of military flight training is conducted using flight simulators (News Reporter Staff, 2015

QuantaDyn created an accredited system that provides a fully immersive Joint Terminal Attach Controller training for squadron-level qualification training and mission rehearsals (Staff Author, 2018b; Staff Author, 2018c). The system is extensible and can be modified to host a range of other training uses, including Close Air Support and Call for Fire interfaces for artillery units and pilot in-the-loop training as well as integrated air defense and electronic warfare training (Staff Author, 2018b; Staff Author, 2018c). The system uses two different-sized domes that allow for varying height restrictions and has surround sound that provides immersion into the environment, as well as infrared functionality for night-vision training (Staff Author, 2018b). It can place both computer-generated forces and semi-autonomous actors into the training scenario (Staff Author, 2018b).

c. Immersion Use in Military Intelligence

The authors explored complete immersive environments, speculating that military intelligence operators must be wholly immersed to completely understand, process, and make sound decisions of intelligence, surveillance and reconnaissance, and surveillance sensor placement in urban settings (Roll, Vendor, Atkins, Lamps, & MtCastle, 2015). Due to the nature of the urban terrain, sensor placement is critical because overcoming the sudden changes in elevation is critical to successful ISR operations (Roll et al., 2015). Roll et al. (2015) concluded that the Xbox controller provided a tactile response that proved a more straightforward use for navigation and manipulation tasks. The authors did not rule out the tablet as a future option because the tablet is extensible to include sensor controls (Roll et al., 2015). However, redesign of the user navigation and manipulation interface might be required for this form factor to be useful. Air Force Research Labs is also conducting follow-on investigations into immersive environments because there was no distinction between the successful tasks in fully immersive to limited immersive environments (Roll et al., 2015).

Warfighters must be able to make a timely decision in densely populated, mega city–type environments, where the population breakdown includes friendly, hostile, and neutral host nation parties (Case, Roy, Bowman, & Patton, 2015). Case et al. (2015) believe non-intrusive devices, like Google Glass, with small form factor computers present an option to push intelligence towards the edge of the battlefield and put it in the hands of decision-makers who need it the most. Google Glass presents information such as mission objective, time, location, or information on soldiers' sensed or observed activities and provides alerts for facial recognition or behavior that seems out of place (Case et al., 2015). This research team conducted a case analysis in two environments to determine the effectiveness of the alerting mechanism. One set was the control, which was at Army Research Lab's (ARL's) Cognitive Assessment and Simulations and Engineering Laboratory (CASEL) in an immersive cognitive readiness simulator (ICS; Case et al., 2015). The second environment was a typical field condition. The researchers conducted two scenarios as a proof of concept. One scenario introduced a high-value target (HVT) into a crowded situation to determine whether the soldier observing the crowd was alerted to the HVT presence (Case et al., 2015). The second scenario introduced Document Exploitation (DOCEX) to determine whether translation and analysis of sensitive documents are possible in a limited bandwidth environment (Case et al., 2015).

The authors concluded there was ample evidence to suggest that actionable intelligence would be an enabler at the edge (Case et al., 2015). They believe with proper bandwidth, a similar system that provides visualization of the environment and computing architecture could offer seamless bi-directional intelligence information exchange and can enable soldier decision-making at the edge by giving soldiers relevant and timely information (Case et al., 2015). The soldier subject identified some limitations with the technology associated with constant wear (Case et al., 2015). Battery life was a significant issue, as were the soldier's sighting and the firing of the soldier's weapon because Google Glass obstructed the view (Case et al., 2015). The authors conclude that wearable technologies could be further explored to provide relevant, real-time information and to alert soldiers at the edge (Case et al., 2015).

A Staff Author (2018f) reviewed ELT's electronic warfare training system designed to develop electronic warfare (EW) skills that counter enemy EW capabilities in an immersive environment. The skills help to develop self-sufficiency in electronic intelligence (both operational and technical), signal intelligence, communications intelligence, electronic attack, and support (Staff Author, 2018f). The system was initially designed as a long-term program to be collocated with the electronic warfare training and simulation center (Staff Author, 2018f). It is a multirole platform that allows EW soldiers to gather information, analyze this information, provide operational crew EW capabilities, and perform maintenance of the EW system (Staff Author, 2018f).

d. Current Naval Uses of Immersive Technologies

One area of interest for naval training involves commercial off-the-shelf (COTS) equipment that can be used to improve training that landing signal officers (LSOs) receive to help land aircraft aboard vessels underway (Greenie, 2016). Navy LSOs get instruction on a fixed site virtual training system while conducting their entry training as LSOs (Greenie, 2016). LSO officers note that there are gaps in the effectiveness in practice due to limited opportunities to use the simulators (Greenie, 2016).

Greenie (2016) developed a prototype system made of COTS devices to use as a training device, which is deployable to any location to augment LSO schoolhouse training. One military application of the prototype system is the use of VR software to create an environment for practical training that assists in the acquisition of the desired skill (Greenie, 2016). Scenario richness, length of exposure in the virtual environment, and virtual resources are crucial, and that judgment of distance is instrumental in the successful execution of LSO tasks (Greenie, 2016). Cybersickness, associated with extended durations in immersive environments, is the most significant drawback of this type of system (Greenie, 2016). To minimize the effects of cybersickness, developers should investigate systems that use higher system refresh frame rates, which are essential to limit cybersickness (Greenie, 2016).

This specific prototype uses a laptop computer and has the flexibility to use multiple input devices (Xbox controller, keyboard, or Leap Motion Controller, which is the most precise input controller), speech recognition software that interprets context and voice inflection, and a head-tracking system such as the Oculus DK2 googles (Greenie, 2016). During a system demonstration of the prototype, the developer received positive feedback from the LSO demonstration participants, and the author concluded that with small changes, the LSO community would benefit from mobile COTS training suites pushed out to the fleet level (Greenie, 2016).

The British Navy has a submarine training environment modeled using game technology (Cressey, 2011). The intent of the simulation was for submariners to learn the location of safety equipment such as fire extinguishers and breathing aids (Cressey, 2011). The results demonstrated significant improvements in being able to locate the safety equipment during times of stress for the submariners who participated in the immersive training versus those who did not (Cressey, 2011). He also noted that the British military expects to decrease its naval fleet, which reduces the opportunity for submariners to practice on live vehicles (Cressey, 2011).

The Navy is also using virtual environments to train its shipboard firefighting teams (Tate et al., 1997). Tate et al. (1997) discuss the impact of shipboard fires as the most hazardous threat to naval operations. Maritime firefighting teams are required to quickly navigate to the location of the fire because every second is crucial to containing the spread of the fire (Tate et al., 1997). The firefighting team must, therefore, know the ship and ensure they do not make wrong turns while navigating, and virtual environments provide a means to learn to navigate a ship and execute the task of fighting fires (Tate et al., 1997). The Navy replicated the USS *Shadwell* as the basis for its virtual environment to determine whether a virtual environment could replicate firefighting training (Tate et al., 1997). It divided the training into two phases, a navigations phase and a firefighting phase (Tate et al., 1997). One team conducted preparations in a virtual environment in which the teams maneuvered to the location of the fire and assessed the situation and the location of necessary firefighting equipment to perform phase two training (Tate et al., 1997). Phase two required the team to navigate the real-world USS *Shadwell* and extinguish a live fire (Tate et al., 1997). The research team determined that the training allowed the firefighting teams the opportunity to learn unfamiliar parts of the ship and practice firefighting skills in a controlled manner that prevented property loss (Tate et al., 1997). The teams responded 30 seconds faster on a two-minute maneuver when compared to groups that did not train using the virtual environment system (Rosenblum et al., 1996).

e. Immersive Technology Use for Engagement Skills Training and Boat Crew Gunnery Skills

Cubic Global Defense created a small arms training system comprised of an indoor live firing or laser-based range that allows up to four qualification lanes (Staff Author, 2018e). The live fire range allows the user to utilize his or her weapon to fire live rounds in an immersive environment, adding realism to the training (Staff Author, 2018e). The system detects live rounds, scores a hit or miss, and records it towards qualification requirements (Staff Author, 2018e). The laser-based qualification system utilizes modified weapons systems that provide haptic feedback similar to real weapons systems and uses sensors to detect shot accuracy (Staff Author, 2018e). The system is programmed to support multiple languages (Arabic, French, Spanish, Turkish, and Vietnamese; Staff Author, 2018e). The training system is extensible to support up to five multi-screen environments that allow users to maneuver and peer around corners (Staff Author, 2018e). The system also provides a shoot-back functionality option using a .68 caliber nylon round in either single, multi, or fully automatic modes to create a more realistic training solution (Staff Author, 2018e).

Meggitt Training Systems created its Remote Desktop Trainer to improve Stryker gunnery skills (Staff Author, 2018d). The trainees act as part of a vehicular crew that contains a vehicular commander and driver station in a three-dimensional environment that allows teams to conduct the basic skills required for gunnery such as driving and manipulating gun controls (Staff Author, 2018d). The system is extensible to provide multiple terrain and environmental conditions and a variety of scenario actors such as friendly forces, civilians, and enemy forces (Staff Author, 2018d). The system has options for a variety of weapons typically found on a Stryker vehicle, such as the M249, M240, MK19, and M2 (Staff Author, 2018d). It replicates the Stryker sensors to provide situational awareness of the environment and a touchscreen interface and display (Staff Author, 2018d).

Cubic Global Defense created an immersive marksmanship trainer configured for either 5-, 10-, or 15-lane projector-based firing lanes that support both tethered and untethered weapons that shoot virtual rounds and provide haptic feedback to give a realistic firing experience (Staff Author, 2018a). The system can qualify small arms weapons, automatic grenade launchers, and light antiarmor weapons (Staff Author, 2018a). The weapons provide haptic feedback using compressed air to simulate the feel of firing the gun and re-aiming between shots (Staff Author, 2018a). The system uses high-resolution projectors and includes a full field of view and wraparound screens for a more immersive feel for the trainees (Staff Author, 2018a). The system is extensible to provide squad-level tactical training and rules of engagement training with shoot/don't-shoot scenarios that test users' judgment (Staff Author, 2018a). Scenario editing allows the users to slightly modify situations, providing differing vehicular movements, different actors, and increased training participants to prevent staleness of the script during training (Staff Author, 2018a). The system determines hits by sensing lasers, and the scenario actors react realistically when hit (Staff Author, 2018a). The Warrior Skills Training system option adds vehicle-born weapons to the dismounted environment to conduct overwatch tactics for dismounted patrols (Staff Author, 2018a). It comes complete with High Mobility Multipurpose Wheeled Vehicle (HMMWV) replicas with mounted crew-served guns used in convoy operations training (Staff Author, 2018a).

f. Use of Immersive Technologies to Control Robots

Turunen, Roening, Ahola, & Pyssysalo (2000) provide an account of early exploration into AR-controlled intelligent robots. They introduce a new concept (new to 2000) of teleoperation, which includes a smart robot, an operator, and a wearable computer with communication means (cellular or wi-fi, depending on the environment), which the authors dub a "cyphone" (Turunen et al., 2000). Sensors help the robot learn and provide a means of information to the operator; there is a head-mounted display (HMD) so the operator can be immersed in the robot's environment and control the robot's actions and a control mechanism where an operator can control the robot (Turunen et al., 2000).

This team's design is to create a COTS system that can be extensible with additional peripherals to make it scalable (Turunen et al., 2000). The design goals were to develop a wearable computer that could perform multiple applications, and the system had to have relatively small size and power consumption requirements. This research team understood the trade-offs required between adding peripherals and having an integrated system. An integrated system needs less power; however, it is less extensible and therefore decreases scalability. Turunen et al. (2000) explain that teleoperation is essential in environments where a human cannot travel, such as an extremely hot or dangerous/hazardous environment. They conclude that their scalable design approach is the best option moving forward (Turunen et al., 2000).

g. Use of Immersive Environments for Small Unit Tactics Training

Intelligent Decisions created its Quantum3 product line that was initially designed and developed in support of the Army Dismounted Soldier Training System (DSTS) product line (Staff Author, 2018g). ExpeditionDI provides an immersive training environment for infantry squads to practice as individuals and collective dismounted teams (up to 16 simultaneous users; Staff Author, 2018g). Each squad member can view other squad members in the virtual world as avatars, but the central master console controls the scenario (Staff Author, 2018g). The system consists of the head-mounted display and eye protection goggles and contains body sensors to determine body position, an untethered individual weapon, and a hand grip controller that coordinates/controls movement throughout the virtual environment (Staff Author, 2018g). The drawback to the system is that each participant must carry his or her computer in a backpack while conducting squad drills. Intelligent Decisions is examining ways to eliminate the pack to reduce soldier burden in future design iterations (Staff Author, 2018g).

Cubic Defense created a scalable training environment composed of up to 12 inflatable soldier environments that can be linked together wirelessly (Ebbutt, 2012). Cubic Defense's system tracks individual movements with five infra-red cameras, and the cameras detect IR reflective tape placed on the trainees' limbs during training (Ebbutt, 2012). This set-up allows trainees to interact with their environment by representing the trainees' actions in an avatar projected on the 360-degree screen (Ebbutt, 2012). Cubic Defense also created a Joint Tactical Air Controller (JTAC) trainer that presents F-16 and A-10 aircraft and allows trainees to call for air support; however, the DoD has not expressed interest in this system yet (Ebbutt, 2012).

The Marine Corps approach creates three immersive training environments. It starts with the Squad Immersive Training Environment (SITE) that conducts constructive and iterative training at the small unit level and allows the unit to progress through the military "crawl, walk, run" building block approach to training (Ebbutt, 2010b). As the small unit completes tasks in the crawl phase, the scenario variable can be changed to increase the challenge level until the environment provides a near-realistic example of what the unit will see when it deploys (Ebbutt, 2010b). Currently, SITE can provide the following types of training: live combined-arms ranges, military operations in urban terrain (MOUT) with role players, combat convoy simulator, individual marksmanship trainer (ISMT), and deployable virtual training environment (DVTE; Ebbutt, 2010b).

The Infantry Immersive Trainer (IIT) provides the building blocks for SITE (Ebbutt, 2010b). It was developed at Camp Pendleton, CA, and replicated both Iraqi and Afghanistani villages so deploying Marines could conduct training to prepare for their deployments (Ebbutt, 2010b). The success of this training environment caused the Marine Corps to invest in similar training environments at each Marine Expeditionary Force (MEF) location (Ebbutt, 2010b). The Marine Corps plans to take this SITE immersive environment and expand the capabilities to the company level in a system called Small Unit Integrated Training Environment (SuITE; Ebbutt, 2010). The Marine Corps also looked to extend the SuITE capabilities from the company level to the Marine Air-Ground Task Force (MAGTF) staff level to provide a holistic environment to train all elements of its force simultaneously (Ebbutt, 2010b).

The Marines expect to conduct this acquisition development in two spirals (Ebbutt, 2010a). Spiral one looks at the capabilities and equipment used to monitor Marines within the environment, and spiral two aims to complete the squad level SITE capabilities (Ebbutt, 2010b). The Marines hosted a Joint Capability Technology Demonstration to develop the Future Immersive Training Environment (FITE; Ebbutt, 2010b). The Marines also teamed with the Army to conduct a Joint Technical Assessment, which will provide knowledge points for each service to develop its service-specific immersive training environment (Ebbutt, 2010b).

h. Survey of Equipment that Supports Immersive Training

The University of Central Florida, in collaboration with the Army Research Institute for the Behavioral and Social Sciences (ARI), developed a fully immersive team trainer tracking harness that allows teams of up to four members to conduct team rescue, counter-terrorism, and building search training (Staff Author, 2010). The system uses MotionStar sensors to track soldier location, body position, gesturing, aiming, and operation of equipment to include firing weapons across the virtual environment (Staff Author, 2010). The developers used an HMD, a backpack frame, and a multi-point tracking harness to detect soldier motions (ankle, head, forearm, and a “flying mouse” for haptic soldier input) as the inputs for the system (Staff Author, 2010).

A team developed a training vest specifically designed to track soldier performance in immersive training environments (Bodenhamer, Dagli, Corns, & Guardiola, 2012). The design looked to recreate an individual garment that provided wireless connectivity and messaging; had onboard haptic sensors to provide real-time, non-intrusive feedback and hand and arm sensors to provide gesture tracking; and the capability to track up to 13 training participants’ locations and biotelemetry data simultaneously (Bodenhamer et al., 2012). The developers looked to create an indoor training environment that offered multiple scenarios ranging from 120 to 12,000 square feet in size (Bodenhamer et al., 2012). The developers are master’s engineering students, and they had not finished the project upon participation in the IEEE conference but provided continued development suggestions for future development work (Bodenhamer et al., 2012).

6. Survey of Law Enforcement and Public Safety Applications of Immersive Technologies

In our research, we found numerous examples of law enforcement (LE) and public safety applications of VR and AR. LE and other public safety offices generally differ from the military in the number of personnel and size of the budget. Having much smaller department sizes, often being geographically separated, and having limited financial and training resources, police and public safety offices have training limitations that must be overcome. Several departments have successfully incorporated VR and AR into their training programs to counter these constraints. We searched out the most innovative and effective examples relevant to CENSECFOR's training program.

For the purposes of our research, we decided to exclude any applications that we felt were not relevant to CENSECFOR's training program based on our review of its provided training documents and observed training during our site survey. For example, there are numerous instances of LE and public safety agencies that utilize VR and AR, such as the Utah Department of Public Safety (UDPS), which uses VR and AR to enhance its department's emergency vehicle operators (EVOs) driver training (Turpin & Welles, 2006). While driver training does not align closely with CENSECFOR's mission set and we do not list examples such as these, we did seek to obtain certain relevant data from these applications as to the effectiveness and lessons learned in the application of VR and AR to a training program. To illustrate, the UDPS analysis found a 67% reduction in critical driving errors from the trainees in the new program incorporating VR (Turpin & Welles, 2006). This provides a data point for the potential of simulated and virtual training.

We did incorporate examples or concepts for applications that are not intended for training, but rather for enhancing LE or public safety operations, as a force multiplier. These applications are included for reference and potential future application to CENSECFOR in training or operations. The training examples are primarily centered on weapons training, which is appropriate considering many critical LE decisions involve the use of weapons. Weapons training includes initial marksmanship training, weapon qualification, remedial training, decision-making (e.g., "shoot/don't shoot"), situational awareness, and weapon transfer training from a primary to a secondary weapon simulating an extended engagement or weapon malfunction.

The next section contains summaries of actual applications of VR and AR in the LE and public safety realm as well as previous research conducted in this realm. These examples provide insight into the current state of simulations and their potential applications to CENSECFOR's mission set, as discussed in Chapter IV.

a. Enhanced Dynamic Geo-Social Environment (EDGE)

The Department of Homeland Security (DHS) Science and Technology (S&T) directorate partnered with the U.S. Army Research Laboratory (ARL) for the development of an emergency scenario training simulator named Enhanced Dynamic Geo-Social Environment (EDGE;) (DHS, 2017a). EDGE is an online, non-immersive, multiplayer, virtual training tool available for free to all first responder agencies and school officials. It is designed to train for and rehearse the complex tasks involved with a coordinated response of first responders (LE, fire, and emergency medical) during various emergency scenarios in a public space such as a hotel or a school (see Figures 9 and 10).

Figure 9. EDGE School Scenario Screenshot. Source: DHS (2017a).

Figure 10. EDGE Hotel Scenario Screenshot. Source: DHS (2017b).

The goal of EDGE is to "improve coordination and communication before an active shooter or other catastrophic event happens in order to mitigate injuries and loss of lives during a live response" (DHS, 2017a, paragraph 5). The EDGE virtual environment is scalable so that a single agency can rehearse alone, or it can incorporate multiple agencies, jurisdictions, and disciplines in a large-scale exercise without the requirement for all parties to be co-located (DHS, 2017a).

EDGE allows the users to experience the roles of any personnel in the scenarios (including the shooter) in order to gain varying perspectives on the situation. Additionally, the software utilizes the user's decisions to guide the scenarios, thus enhancing the realism of the situation while also providing flexibility to the department to create different scenarios (DHS, 2017b). The EDGE software includes after-action review capabilities for replaying scenarios as necessary to critique reactions (DHS, 2017b).

b. Multimodal Interactive Trainer-Police Department (MINT-PD)

Multimodal Interactive Trainer–Police Department (MINT-PD) is an immersive simulator system for course of fire (COF) training developed by the National Research Council (NRC) of Canada (Fournier, Lapointe, Kondratova, Emond, & Munteanu, 2012). The intent of MINT-PD was to develop a COF training tool focused on remedial training for LE personnel based off the original MINT system that was designed for urban operations, threat assessment, and room clearing procedures (Fournier et al., 2012, pp. 4, 8). The authors believed that to be effective, MINT-PD had to overcome challenges of the conventional COF training (see Figure 11). It listed the primary conventional training limitations as the high cost of non-reusable materials, inefficiency of physical training space layouts that are not easily reconfigurable, lack of realism and predictability, and safety concerns with live rounds (Fournier et al., 2012, p. 4).

Figure 11. MINT-PD Trainer Control Interface. Source: Fournier et al. (2012).

The resulting MINT-PD product is a system that is lightweight, portable, and scalable, and allows for customizable scenarios. During development, the MINT-PD team received feedback from the COF instructors that they wanted the ability to manipulate the training environment, conditions, target distance, and movement (Fournier et al., 2012, p. 8). As shown in Figure 11, MINT-PD incorporated a trainer control interface, allowing the instructor to manipulate the scenario in real time to increase the flexibility and reality of the training environment. MINT-PD allows for varying scenarios such as altering lighting conditions down to darkness, which would require the trainee to utilize a flashlight to identify targets. Additionally, the system includes a speech user interface to allow the trainee to communicate to the virtual subjects (Fournier et al., 2012, p. 6).

The authors of the MINT-PD project identified a few areas requiring further refinement and development to increase the realism and effectiveness of this immersive training tool. Their recommendations were to focus on speech recognition under stressful conditions, usability of trainer controls, and human factors (Fournier et al., 2012, p. 9).

c. Royal Canadian Mounted Police Laser-Based Synthetic Training Environment

A paper documenting an experiment utilizing the Royal Canadian Mounted Police (RCMP) found cadets who were trained in a laser-based synthetic environment indicated that it is possible to achieve the same training outcome of live-fire training for LE officers utilizing a synthetic training environment (Kratzig, Parker, & Hyde, 2011). The experiment changed the pistol training program of 124 RCMP cadets from the existing program of entirely live-fire training on a range to an entirely synthetic environment (Kratzig et al., 2011, p. 4).

d. Austrian Federal Ministry of Defense and Sports VR Training Study

A 2017 study sponsored by the Austrian Federal Ministry of Defense and Sports (BMLVS) and the Red Cross Innsbruck, Austria, examined existing VR training capabilities for feasibility of providing training to first responders for a chemical, biological, radioactive, or nuclear (CBRN) disaster (Mossel, Peer, Göllner, & Kaufmann, 2017, p. 3). The authors believe that initial training for disaster response should be in a controlled, realistic environment. Their research found that while there are numerous examples of desktop-based VR training, they lack the visual, 3D immersion as well as the ability of the user to walk around or move naturally, which diminishes the realism of the training (Mossel et al., 2017, p. 2). As the authors state, "Natural walking is essential to simulate stress and physical excitement, which is of particular interest to create a realistic training for on-site squad leaders and rescue teams" (Mossel et al., 2017, p. 2). Through their stakeholder analysis, the authors derived the following requirements for a VR training system to meet their stakeholder's needs: full immersion, the ability for 3D object interaction, natural walking for navigation, and multi-user support for collaborative training (Mossel et al., 2017, p. 18).

The first system mentioned in the Austrian study is the Advanced Network Trainer (ANTares) system utilized by the German Armed Forces. This system consists of modular cubes (shipping container size) that are customizable (see Figure 12). The advantages of the ANTares system are its compatibility with common VR and AR hardware devices such as HMDs. The configurable and customizable nature of this system allows for a more immersive, multi-user training experience with complex scenarios (Mossel et al., 2017, pp. 8–9). Natural walking, however, is limited in this cube design.

Figure 12. Modular Cubes of ANTares System. Source: Mossel et al.(2017).

VirtSim is another system covered in the Austrian study. This system is a multi-user, fully immersive system that provides LE and military tactics training up to the squad level (Mossel et al., 2017, p. 10). A VirtSim system requires an open, indoor space of approximately 20x20 meters and allows the users to walk around within the designated perimeter. Numerous tracking cameras and sensors are required to track the users' movements and location. The technology requirements for this system increase the complexity of setup as well as the associated cost (Mossel et al., 2017, p. 10). The system has the ability to edit numerous environments and scenarios for training. For LE applications, VirtSim has pre-defined scenarios to train necessary skills such as "weapon discipline, making deadly force decisions, covering danger areas, team clearing techniques, use of cover and concealment, and communications among team members" (Mossel et al., 2017, p. 10).

An important feature of this system is its ability to record all users' movements and shots, which can then be played back from any angle or user perspective (Mossel et al., 2017, p. 10). This provides a critical training tool for collaborative training.

e. Virtual Police (ViPOL) Virtual Training Environment Study Utilizing German Police Personnel

In 2014, a team conducted a field study of the effectiveness of virtual training utilizing German police personnel as part of a larger project looking to incorporate a virtual training environment (VTE) in their police force (Bertram, Moskaliuk, & Cress, 2014). The team found that the personnel receiving the virtual training perceived the standard training as better; however, when the study measured actual learning transfer in a "real and complex situation," the authors found the virtual training as effective as the standard training (Bertram et al., 2014, p. 284).

The team did an extensive literature review on what is required to deliver training effectively for complex, collaborative tasks for teams. They found that transfer of training models have three main factors: individual (a positive attitude toward the training), intervention (feedback during and after the training), and environmental (the possibility to apply learned skills on the job; Bertram et al., 2014, p. 286).

To test these conditions, the authors conducted a study utilizing German police officers in a complex scenario requiring ground forces to coordinate with a helicopter crew in a crisis scenario using the VTE known as Virtual Police (ViPOL) (Bertram et al., 2014, pp. 285, 291). What they found was that a VTE can outperform live training in a real situation when the VTE is realistic (Bertram et al., 2014, p. 291). They stressed the importance of realism and the ability to evoke an emotional state in the trainees that they may experience in a real-life scenario, as this directly impacts decision-making. Additionally, a first-person perspective enhances virtual learning and, when combined with real-life experiences, enables the development of context-dependent knowledge (Bertram et al., 2014, p. 286). As the authors concluded, “The VTE ViPOL can be used to prepare police officers for operations that can hardly be trained for in reality” (Bertram et al., 2014, p. 291).

E. SUMMARY

While AR and VR have the potential to create opportunities for previously unachievable levels of productivity and performance, developers must overcome several areas of concern before industry and the general public accepts these technologies for everyday use. These areas include usability, security, and cost.

Companies specializing in the development of AR applications and hardware will need to focus R&D efforts toward improving the usability of mobile AR systems. They will need to provide seamless integration of the augmented information with the real-world environments regardless of the environmental conditions or network accessibility. Mobile AR developers will also have to work with internet security firms to develop security measures and software that will allow users and nonusers to feel secure with the use of AR technology.

Because the level of immersion is tied to cost, the components required for AR and VR systems should be selected based on the desired outcome. Organizations seeking to develop an immersive virtual experience will need to invest in more powerful (and higher cost) components, including high speed processors, multiple input/output devices, and a light weight package.

Although AR and VR have been around since the 1960s, the technology was not advanced enough to gain widespread acceptance. However, recent developments in technology have led to increased popularity of immersive technologies, fueled largely in part by the entertainment and gaming industries. This renewed interest has driven many organizations to seek new and innovative training solutions using immersive technologies. This interest could provide additional opportunities for the military to partner with industry to develop more immersive training applications designed to improve learning outcomes and provide realistic training experiences that can replicate the high stress situations which previously could not be replicated safely.

The DoD and LE agencies continue to invest in simulation-based learning and immersive environments to augment live training. As seen previously, industry and academia have developed prototypes and systems that cover the many types of military and LE training. However, developmental issues remain as the technology continues to advance.

Technology systems for training purposes should be produced with the requirements that the systems allow for a positive attitude toward training, provide opportunities for after action review (AAR) during and after training, and allow for the application of learned skills in a realistic environment (Bertram et al., 2014; Mossel et al., 2017). A VTE can perform as well as or better than a live training environment if it is realistic (Bertram et al., 2014; Kratzig et al., 2011). Incorporating these concepts into the acquisition of a VR or AR technology will help to ensure the investment produces the desired learning objectives and provides value for the customer.

In Chapter IV, we utilize this information in the framework of a Quick Turn CBA to develop a set of standards necessary to identify training gaps and opportunities in CENSECFOR’s current training delivery.

IV. QUICK TURN CBA: STUDY DEFINITION PHASE AND NEEDS ASSESSMENT PHASE

In this chapter, we conduct the first two phases of a Quick Turn CBA: the study definition phase and the needs assessment phase. The output of these phases is the documentation of a set of needs that could enhance the current SRF-A training program. These needs are utilized in the solutions recommendation phase of the Quick Turn CBA in Chapter V.

We begin by reviewing the objectives of this study. We then provide our observations of the CENSECFOR training program and facilities that we observed at Detachment San Diego. Next, we outline our analysis of the provided training documents from CENSECFOR. Finally, we identify training needs and opportunities for immersive technology applications utilizing the Quick Turn CBA framework.

A. STUDY OBJECTIVES

CENSECFOR requested research support from the Naval Postgraduate School in applying AR systems to their mission. The CENSEC mission is focused on combat augmentation in the security realm:

> The CENSECFOR mission is to produce disciplined, motivated, physically fit, and tactically proficient Sailors who embody Navy Core Values and who are fully prepared to augment combat security forces around the world, and to perform other functions and tasks as assigned by higher authority. (Boorujy, 2011)

In support of this mission, CENSECFOR tasked our team with evaluating currently available immersive technologies that are utilized for training by security and public safety organizations and their potential application in the CENSECFOR training curriculum. CENSECFOR's interest in these technologies is to enhance their existing training program to ensure they continue to deliver relevant training to their security forces in the most efficient manner possible. To provide an answer to CENSECFOR, our team developed four research questions:

1. How are public safety and security forces using AR and VR technologies to support training?

2. What have been the outcomes of such technology use reported in academic and trade literature?

3. What gaps and opportunities exist in current training delivery?

4. How could AR or VR technologies best address these gaps?

By answering these questions, we provide CENSECFOR with some ideas and strategies for how they may implement immersive technologies in the future to enhance their current training delivery. While we will not provide recommendations for a specific technology, we will provide an overview of possibilities, a discussion of best practices, and a list of considerations for the application of immersive technologies in a training environment.

B. WHAT WE OBSERVED AT CENSECFOR

During our site survey to CENSECFOR Detachment San Diego on August 29–30, 2018, we observed multiple training classes in different phases of the Security Reaction Force–Advanced (SRF-A). The first phase of SRF-A involved basic close quarters combat drills utilizing batons and Oleoresin Capsicum spray. We were informed by the instructors on site that this is really refresher training from the Security Reaction Force–Basic (SRF-B) course that all of the students complete as a prerequisite for attending the SRF-A course.

Following completion of the refresher phase, the students then move into the Force Protection Ship Simulator (FPSS) also known as the “ship in a box.” Detachment San Diego has two FPSSs located adjacent to each other, allowing for training multiple groups simultaneously. The FPSSs are constructed of shipping containers stacked three levels high in such a manner as to simulate a portion of a ship (see Figure 13). Additionally, the immediate surrounding area of the FPSS consists of props and materials to resemble a pier or ship deck area. This set up allows for scenarios involving boarding a ship and accessing the interior of a ship, the pier, or the ship deck. Additionally, we observed that the instructors were able to conduct multiple scenarios at once on one FPSS. One team could conduct a scenario on the ground adjacent to the ship or on the lower levels while another team practiced entering a ship or working on the upper levels of the FPSS.

Figure 13. Trainees Entering the FPSS at Detachment San Diego

Critical elements we observed during the training include the ability to move between the three levels of the FPSS, working in confined conditions representative of an actual ship, and working in low light conditions inside the FPSS (see Figure 14). The trainers are able to reconfigure the furniture and some of the walls within the FPSS to train different tactics and techniques and keep the training fresh. The exterior of the FPSS also had a hook and climb capability to allow for training on Visit Board Search &

Seizure (VBSS) scenarios. All of these elements provided increased realism to the FPSS training.

Figure 14. FPSS Interior

For weapons, the trainees at the FPSS are provided modified M4 Rifles and M9 pistols that fire simulation paint rounds (also commonly referred to as *simunitions*). While these rounds do not have the range or velocity of actual ammunition, they do provide visible feedback through paint markings upon impact as well as tactile feedback from the impact of the round when shot and from the recoil of the weapon when shooting. The potential for a real, noticeable impact from the simulation round improves the realism and reactions of the trainees. For example, trainees are more likely to seriously consider their movements and protected positions if they know they can actually be shot by the simulation round. In addition, the trainees' stress levels are increased by the heightened realism. This was considered an important part of live scenario training.

The use of simulation rounds in the FPSS training adds a requirement that the trainees wear protective gear in addition to their normal SRF uniform. This protective gear consists of a protective mask for the face, ears, and throat as well as a groin protector. The trainers at the site wear the same protective gear as well as brightly colored vests (similar to traffic safety vests) to symbolize that they are out-of-play for the scenario. During our observation of the scenarios we wore the same safety equipment as the trainees (see Figure 15). The protective face mask and throat protector proved to be the most burdensome in our experience. We were advised by the FPSS staff upon donning the protective gear to lift the mask up slightly at the bottom to improve airflow when the eye lens began to fog up. A couple of us experienced fogging while we observed training. It was also noted that a small portion of people experience claustrophobia while wearing the mask.

Figure 15. FPSS Required Safety Equipment and Observer Vest

We saw that each group of trainees had multiple trainers observing each scenario, and they would often be staged in a room or hallway before the SRF team entered in order to observe the team's entry technique for AAR purposes. While this does provide multiple perspectives from different angles to provide the SRF team feedback, it did introduce an artificial element to the training as the students have to contend with out-of-play personnel in the scenario and pretend they do not exist.

The FPSS trainers at Detachment San Diego primarily use trainees or student role players to serve as the opposition force (OPFOR) during the scenarios. The site lead during our visit explained that this method is reliant on the instructors selecting the correct students for the job based on personalities and keeping a "short-leash" on the student role players. The instructors also had the ability to serve as the OPFOR or role players as necessary. During one scenario we observed, the instructors had hidden a small, female trainee underneath a box to evaluate the SRF team's search procedures when clearing a room. Another scenario involved the SRF team handling multiple detainees simultaneously while the SRF team leader sent the appropriate reports to his higher headquarters. The higher headquarters in this instance was simulated by one of the instructors who was standing next to the SRF team leader.

The FPSS facility lacks any form of camera system for observation or recording capabilities. The site lead informed our team that they previously used a camera system to observe and record training, which they found to be beneficial for AARs. However, this camera system became inoperable and obsolete over time due to a lack of funding for system sustainment. We are unsure if any of the other five SRF-A training locations have a recording capability.

We observed several limitations of the FPSS in providing realistic training. First, the size of the FPSS is not as large as an actual ship, which limits the scenario complexity achievable for training. Second, many of the trainees at the SRF-A course are junior personnel that often arrive at the SRF-A course lacking the critical marksmanship skills necessary to perform on the SRF team. From our observations, we also learned that SRF is treated as an additional duty for sailors and not their primary mission. Finally, the trainees at the SRF-A course do not attend with their fellow assigned SRF-A team members from their assigned ship. Therefore, a cohesive SRF team is not developed at the SRF-A course, but only certifies individuals for the duty. According to the instructors, a well-organized SRF team requires multiple personnel to attend the course and conduct extensive team practice on-board their assigned ship.

On the second day of our site visit, we observed the Fire Arms Training Simulator (FATS) (see Figures 16 and 17). This is a VR system used for weapons familiarization, weapon transition training (e.g., switching from a rifle to a handgun during an engagement), shoot–don't shoot scenarios, and weapons qualification training. Detachment San Diego had two rooms with separate FATS systems adjacent to each other with the ability to run two distinct classes at a time. During our visit, we observed one class working weapon transition drills simulating a malfunction of their rifle, necessitating a transition to their hand gun. We were also provided the opportunity to experience the Navy's weapon qualification procedures on the FATS and several shoot–don't shoot scenarios. These consisted of both shipboard and land-based scenarios. The FATS site lead stated that they have a limited ability to create, add, and modify scenarios for the trainees.

Figure 16. FATS Training Room Detachment San Diego

Figure 17. An Author Demonstrating FATS

During our observation of the FATS system, we experienced multiple system malfunctions requiring a system or scenario restart. The FATS system weapons are modified M4 rifles and M9 pistols which provide physical and audible feedback to the operator through the use of compressed air cartridges that fit into the magazine well of the weapons. While the FATS system provides some enhancement to their training program, it is a legacy VR system with limitations. System weapons failed and there is no voice recognition capability for interaction with the trainee.

C. REVIEW OF CENSECFOR PROVIDED SRF-A TRAINING DOCUMENTS

Following our site survey at Detachment San Diego, we were provided 19 documents from CENSECFOR for our reference (K. Littel, personal communication, September 21, 2018). These documents include the following:

1. Classroom presentation for Lesson 1.1: Introduction to SRF-A

2. Classroom presentation for Lesson 1.2: Tactical Communications

3. Classroom presentation for Lesson 1.4: Search Procedures

4. Classroom presentation for Lesson 1.5: Employment of Force

5. Classroom presentation for Lesson 1.6: Tactical Team Movement

6. Classroom presentation for Lesson 2.1: Tactical Team Management

7. SRF-A Knowledge Test Administrator’s Guide (Revision-B, Change 2) (February 8, 2018)

8. SRF-A Performance Test Administrator’s Guide for Force Protection External Scenarios (Revision-B, Change 2) (February 8, 2018)

9. SRF-A Performance Test Administrator’s Guide for Force Protection Internal Scenarios (Revision-B, Change 2) (February 8, 2018)

10. CENSECFOR Instruction 1540.1A: Training Policy and Guidance Instruction (October 6, 2011)

11. CENSECFOR Instruction 3591.1A: Small Arms Weapons Qualification and Instructor Sustainment (March 7, 2016)

12. SRF-A Course Training Task List (CTTL) (Revision-B, Change 2)

13. SRF-A Lesson Plan (Revision-B, Change 2)

14. SRF-A Master Test Bank (Revision-B, Change 2)

15. Naval Education and Training Command (NETC) Instruction 1500.5B: Instructor Qualification, Certification, and Sustainment Program (August 22, 2013)

16. Training Course Control Document (TCCD) for SRF-A (Revision-B, Change 2)

17. Testing Plan for SRF-A (Revision-B, Change 2) (February 8, 2018)

18. Trainee Guide for SRF-A (Revision-B, Change 2)

19. Training Project Plan for SRF-A (Revision-B) (September 2012)

The Course Training Task List (CTTL) for SRF-A provides all of the required tasks that trainees must perform as part of the course and traces those tasks back to the respective source document (K. Littel, personal communication, September 21, 2018). Additionally, the CTTL describes the purpose of the course as follows:

> The Security Reaction Force–Advanced course is designed to provide personnel assigned to a Reaction Force the training and education for the prevention of threats, whether from the pier, small boat, or any other means from penetrating a unit in accordance with current naval directives under normal and emergency conditions. This course, while training Reaction Force members, also enables individuals to perform as a Reaction Force Leader, to include managing a 2, 4 and 6 member Reaction Force. Members receive necessary training on coordinating team responses in an asymmetrical environment, to include, offensive/defensive perimeters in a lighted, low-light and no light situations. Members conduct briefs and debriefs for team and chain of command in accordance with current naval directives. (K. Littel, personal communication, September 21, 2018)

The SRF-A course is open to U.S. Navy personnel as well as DoD civilians (GS-5 and higher) and CENSECFOR contract personnel. SRF-A is designated a high-risk course requiring a medical screening prior to enrollment. Trainees must be physically fit with no limiting medical conditions. Trainees must hold current weapons qualifications for both the rifle and category-II pistol and must have successfully completed either the Armed Sentry/Security Reaction Force-Basic course or the Navy Security Forces Sentry and Security Reaction Force Team Member-Basic course. Additionally, the Master at Arms “A” course post-September 2006 is a valid prerequisite for enrollment into SRF-A (CENSECFOR, 2012, p. 8). The SRF-A course is offered in six locations: Detachment Chesapeake, Detachment Pearl Harbor, Detachment San Diego, Learning Site Bangor, Learning Site Mayport, and Learning Site Yokosuka (CENSECFOR, 2012, p. 11). These sites utilize the FPSS for training while other Navy facilities are instructed to designate a facility “conducive to a Close Quarters Battle (CQB) training environment” (CENSECFOR, 2012, p. 17).

The overall design of the SRF-A training program can be described as a typical crawl, walk, run format in which participants must learn to crawl before they run. In this approach, the trainees are first introduced to the purpose and concepts of the training course (crawl phase), then necessary individual skills are gradually taught (walk), and finally all the skills are brought together in team-level exercises (run). The trainees are provided a very detailed 197-page *Trainee Guide for Security Reaction Force-Advanced* at the start of training that serves as a guide and reference for each block of instruction. SRF-A is broken down into two units of instruction over a two-week (10 day) period consisting of 16 class hours and 64 lab hours (CENSECFOR DOT, 2018a; CENSECFOR, 2012, p. 11). The course emphasizes the use of concurrent training to reduce training bottlenecks and provide as efficient instruction as possible. There are two terminal learning objectives for the SRF-A course: perform as a reaction force member and perform as a reaction force leader (CENSECFOR, 2017b, p. 10).

D. DESCRIPTION OF UNIT ONE TRAINING (LEARNING THE BASICS—CRAWL AND WALK)

Unit one is the crawl and walk phase and consists of four class periods that provide instruction on the roles and responsibilities for performing as a reaction force team member. The trainees are evaluated with written tests during this phase and must attain a score of at least 80% on all written tests to pass (CENSECFOR DOT, 2018a).

The lessons taught in unit one include tactical communications, use of personnel restraint equipment, search procedures, employment of force, and tactical team movement. Week one is a mixture of classroom instruction and lab exercises and culminates with knowledge test #1 on the final day of week one (CENSECFOR, 2017b, p. 12). Following are brief summaries of the classroom lessons taught in unit one.

Lesson 1.1 is an introductory lesson to the SRF-A course. As such, it provides a lot of administrative details for the conduct of the course as well as the basics of what it means to be a member of an SRF team. The trainees are informed that SRF team members must become tactical decision makers, maintain situational awareness while constantly assessing the evolving threat, and communicate with and direct fellow security force personnel and other first responders (CENSECFOR DOT, 2018a, slide 6). From the first day of the course, there is an emphasis on the importance of decision making as a member of an SRF team.

Lesson 1.2 provides the basics of tactical communications and covers the standard communications plan (COMPLAN) to include radio monitoring, the phonetic alphabet, call signs, acknowledgement, and confirmation (CENSECFOR DOT, 2018b, slide 6). Trainees are taught the standard radio status reports to include the SALUTE (size, activity observed, location, unit, time, equipment) report utilized while conducting observation, the HUTS (hostages, unknowns, terrorists, shooters) report for reporting the objective, and the SAALT (size, activity, arms, location, time) report for providing updates while on the move (CENSECFOR DOT, 2018b, slides 3–5).

Our team was not provided the actual presentation for Lesson 1.3: Use of Personnel Restraint Equipment, but found the content in the *Trainee Guide for Security Reaction Force-Advanced* on pages 24–74. The topics covered in this block of instruction include various mechanical advantage control holds (MACH) performed as an individual and a team, the utilization of nonlethal weapons to include the expandable baton and Oleoresin Capsicum (OC) spray, and use of personnel restraint devices (CENSECFOR, 2017b, p. 25).

Lesson 1.4 covers the standard procedures for personnel and area searches. The trainees are taught personnel searches to include opposite gender, searching with a known bomb threat, external area searches, interior area searches, and actions upon discovering an explosive device (CENSECFOR DOT, 2018c).

Employment of force is covered in Lesson 1.5 and covers judgement, less than deadly force, use of deadly force, and conditions for employment of force (CENSECFOR DOT, 2018d, slide 2). Trainees are taught very early in this lesson that judgement is the "most important trait required of security personnel to effectively employ force" (CENSECFOR DOT, 2018d, slide 3) and that employment of force is the "most significant decision you make" (CENSECFOR DOT, 2018d, slide 17). Proper judgement when deciding to employ force involves the recognition of one's mindset at the time, the ability to properly categorize the type of subject, and knowledge of the use of force continuum (CENSECFOR DOT, 2018d, slide 3). The ability to determine hostile intent of a subject is deemed a “core duty” (CENSECFOR DOT, 2018d, slide 17). This lesson also provides some important principles that underlie successful operations by an SRF team (CENSECFOR DOT, 2018d, slide 17):

1. Tailor the type and level of force to necessity.

2. Base use of force on actions of the individuals involved.

3. Once level of force is no longer required, de-escalate the situation.

4. Use of excessive force is subject to the Uniform Code of Military Justice (UCMJ).

Lesson 1.6 prepares the trainees for tactical movement as a two- to six-man team. This is a critical lesson that incorporates numerous topics including those listed in Table 3 (CENSECFOR DOT, 2018e):

Table 3. Lesson 1.6 Topics

Tactical Team Configuration	Reaction Force Fundamentals
Tactical Movement	Passageway Movement
Blow Through	Active Shooter
Room Entry Techniques	Navigating Ladders and Stairways
Tactical Withdrawal	External Area Movement
Open Space Movement	Tactical Lighting Techniques

Additionally, Lesson 1.6 clearly defines the roles and responsibilities of the SRF team leader and the individual SRF team members. The SRF team leader coordinates the team operations and is responsible for command and control, mission planning, team training, and directing weapon employment (CENSECFOR DOT, 2018e, slide 5). The remaining members of the SRF team provide backup for security elements; handle prisoners, hostages, and medical triage; carry extra equipment; augment fixed security positions; conduct searches; and conduct tactical movement (CENSECFOR DOT, 2018e, slide 6).

E. DESCRIPTION OF UNIT TWO TRAINING (TRANSITION FROM WALK TO RUN PHASE OF TRAINING)

In unit two, the trainees transition from the walk to the run phase of training. This transition consists primarily of final day performance testing in the classroom, debriefing of scenarios, and a final knowledge test (CENSECFOR, 2017b, p. 14). The trainees are evaluated during this phase with practical performance tests as team members and team leaders. They must achieve a score of at least 80% to pass the final knowledge test (CENSECFOR DOT, 2018a).

The classroom lesson provided in unit two focuses on tactical team management, the responsibilities of an SRF team leader, and the importance of additional training. The lesson explains the responsibilities of an SRF team leader and includes SRF team sustainment training, pre-planning, tactical planning, tactical briefing, and communication (CENSECFOR DOT, 2018f). Trainees are then provided source documents that outline required training for SRF team members and SRF team leader's responsibility within their assigned units. OPNAV Instruction (OPNAVINST) 3591.1F requires SRF team members to undergo semi-annual sustainment training, which includes marksmanship, safety, and weapon familiarization training. The instructors have the option to conduct this training in a live-fire or simulated environment (CENSECFOR DOT, 2018f, slide 3). The instruction also strongly encourages additional training involving moving targets and shoot–don't shoot drills (CENSECFOR DOT, 2018f, slide 3). The Navy emphasizes in NTTP 3–07.2.1, paragraph 8.3.1, that "CQB [close quarters battle] is surgical in nature and requires frequent sustainment training to maintain capability" (CENSECFOR DOT, 2018f, slide 3).

The testing portion occurs in a lab area. The SRF-A Testing Plan states that the lab area for the SRF-A course requires an area with separate rooms, hallways, and ladderwells or stairways (CENSECFOR, 2018b, p. B-7). The trainees are divided into multiple SRF teams, depending on the instructor-to-trainee ratio, and are given roles as team leader, assistant team leader, or team member. They are then equipped with their full tactical kit in addition to the simunition protective equipment, as discussed previously. The trainers then provide a scenario from a standard set of 11 different scenarios to the designated SRF-A team leader. While these scenarios are standardized, the instructors have the flexibility to modify the end-state or number of roles and players. This flexibility allows for repetition of the same scenarios while changing the appearance and experience for the trainees. The evaluators have the ability to increase or decrease the scenario complexity depending upon the trainees' progress (CENSECFOR, 2018b, p. B-7). The following are summaries of the standardized scenarios provided to the instructors to provide greater context on the role and expectations of an SRF (CENSECFOR, 2018b, pp. B-7–B-8; CENSECFOR, 2018c, pp. C-7–C-8).

The external scenarios are as follows:

- Responding to an unruly crowd outside the entry control point in a foreign port
- Responding to an unruly crowd of protesters at the entry control point with some breaching the perimeter in a foreign port
- Responding to a group confrontation inside the entry control point in a domestic commercial port
- Responding to an unruly crowd at the gate with an armed intruder breaching the entry control point
- Responding to a belligerent sailor assaulting the sentry at the entry control point
- Responding to an armed belligerent sailor at the entry control point
- Responding to an active shooter at the entry control point with third party casualties
- Responding to a missing watch and suspicious item at the entry control point

- Responding to multiple belligerent sailors and civilian mariners at the entry control point
- Responding to a standoff attack at the entry control point
- Responding to a pedestrian carried improvised explosive device at the entry control point at a NATO pier

The internal scenarios are as follows:

- Responding to an alarm in a restricted space (compliant intruder)
- Responding to a non-compliant sailor in a restricted space
- Responding to a non-compliant intruder in a restricted space
- Responding to a fight
- Responding to an active shooter
- Responding to a bomb threat
- Responding to an alarm in a restricted space
- Responding to a missing/nonresponsive armed watchstander
- Responding to a missing child (Code Adam)

The standardized scenarios indicate that SRF teams are reactive in nature and must be prepared to encounter a wide variety of unconventional situations. These scenarios reinforce the emphasis placed on the criticality of quick decision making for SRF teams based on situational awareness and their contextual understanding.

The end state of the SRF-A course is that the trainees have mastered the required SRF skills as outlined in the CTTL. The following are these 23 skills (CENSECFOR, 2018b):

1. Perform as reaction force member
2. Perform the Operational Risk Management process
3. Distinguish between use of force continuum levels

4. Perform tactical team movement
5. Perform tactical movement
6. Determine when deadly force is appropriate
7. Perform communication procedures
8. Perform reaction force equipment donning
9. Operate in accordance with all applicable safety precautions
10. Operate personnel restraint equipment
11. Perform search procedures
12. Perform restrained subject escort procedures
13. Perform Mechanical Advantage Control Holds (MACH)
14. Perform control techniques
15. Differentiate between active and passive subjects
16. Operate a tactical light during tactical operations
17. Perform as reaction force leader
18. Coordinate the development of Standard Operating Procedures (SOPs) and Preplanned Responses (PPRs)
19. Coordinate a plan of action
20. Direct the plan of action
21. Perform a tactical brief
22. Coordinate tactical communications using situational reports
23. Manage a sustainment training program

The CENSECFOR SRF-A scenarios and CTTL guide our research as we look for any gaps or opportunities in the existing training plan and then determine if immersive technologies could enhance the SRF-A training in those identified areas.

F. STUDY DEFINITIONS PHASE

The study definitions phase answers the overarching CBA question: What are we talking about? The outputs of this phase are a set of conditions in the form of scenarios, tasks required to accomplish the conditions, and a set of standards by which to assess existing military capabilities' ability to conduct the tasks required to accomplish the objectives of the scenarios (JCS J-8, 2009, pp. 36–41). A Quick Turn CBA is often possible due to the availability of required information, allowing the CBA team to skip many steps of the standard CBA process.

For our purposes, we have the CENSECFOR-provided SRF-A training documents as the guiding documents for the study definition phase. The SRF-A Course Training Task List (CTTL) identifies the 23 "tasks" that are taught at the course. The SRF-A testing plans found in Appendix B and Appendix C and previously mentioned in Chapter IV outline the "conditions" for these tasks by identifying the training scenarios. As shown in Figure 18, the "standards" are the final output of the study definition phase and are the metrics utilized to assess current capabilities' attainment of the associated objectives (JCS J-8, 2009, p. 41). A *standard* is defined as "a quantitative or qualitative measure for specifying the level of a performance of a task" (Manning, 2017).

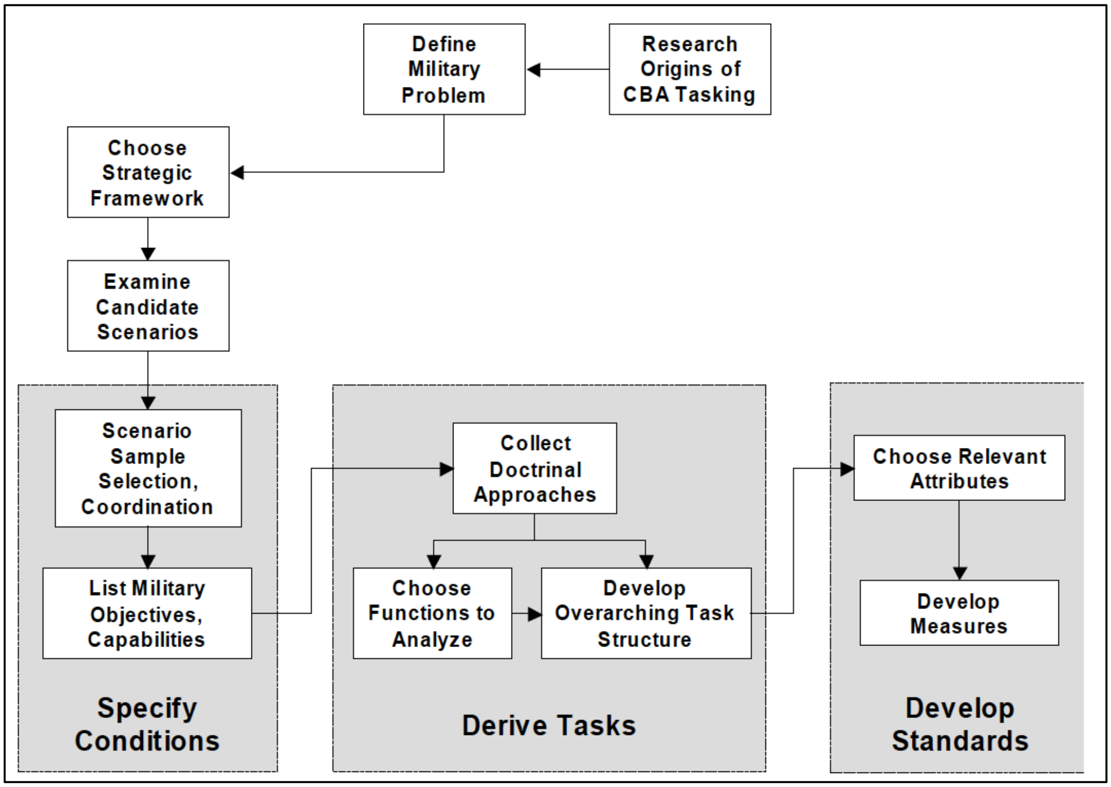

Figure 18. Major Study Definition Tasks and Flows. Source: JCS J-8 (2009).

Since our research is focused entirely on the application of immersive technology for CENSECFOR's SRF-A course, we modified our standards development process accordingly. For our purposes, we developed a list of 11 specific, qualitative "standards" in the form of needs statements related to the effective use of immersive technology in a training environment. As covered in Chapter III, we believe these standards incorporate the most critical aspects of effective immersive technology application for a training environment. Additionally, we intend to link these critical aspects to the SRF-A course requirements and our observations during the site survey. The standards we identified are provided in Table 4 and will guide the needs analysis of the current CENSECFOR SRF-A training program.

Table 4. CENSECFOR SRF-A Standards Definitions

	Standards Definitions	Source
1	Need tactical decision-making training with flexible scenarios	Testing Plan; CTTL Tasks 3, 6, 15; Site Survey observations
2	Need a non-obtrusive AAR/recording capability to reduce # of observers required to evaluate training	Site Survey observations
3	Need interactive and responsive training (e.g., voice recognition, role player)	Testing Plan; Site Survey observations
4	Needs to be realistic and provide for ship, building, and pier-based environments (separate rooms, passageways, ladderwells, or stairs)	Testing Plan, p. 7
5	Needs to allow for the wear of standard tactical personnel equipment and not impede tactical movement	CTTL Tasks 4, 5, 11, 16; Site Survey observations
6	Needs to be durable to handle CQB scenarios	CTTL Tasks 4, 5, 11, 16; Site Survey observations
7	Needs to accommodate standard Navy issue rifle and pistol	CTTL Tasks 4, 5, 11, 16; Site Survey observations
8	Needs to be reliable, sustainable, and upgradeable	Site Survey observations
9	Needs to operate in all light conditions	CTTL Task 16; Site Survey observations
10	Need to be able to conduct quicker scenario training iterations to increase efficiency and affect knowledge transfer	CTTL Tasks 3, 6, 15
11	Need a multiplayer capability for 2–6 people	CTTL

G. NEEDS ASSESSMENT PHASE

With the standards identified in the study definition phase, we moved to the needs assessment phase. In support of CENSECFOR’s request, we focused on assessing CENSECFOR’s current training capability to meet their SRF-A training objectives using the 11 qualitative standards developed in the study definition phase.

In our assessment, CENSECFOR is achieving the training objectives outlined in their SRF-A training program; therefore, there is no capability “gap” in the current training program in the traditional sense of a CBA. For the purposes of our research, we were looking for areas most applicable for enhancement by immersive technology based on the 11 standards we developed. This methodology revealed several opportunities for application of immersive technology in the CENSECFOR SRF-A training program.

To conduct this analysis, we assessed each standard individually and issued a score of 0, 1, or 2. These scores correspond, respectively, to the standard being not met, partially met, or fully met. We provide our justification for the scores in the right-hand column of Table 5.

Table 5. CENSECFOR's Current SRF-A Training Delivery Assessment

Standard	Met (2) Partial (1) Not Met (0)	Justification
1. Need tactical decision-making training with flexible scenarios	1	Current FPSS scenarios have flexibility built in and encouraged. FATS scenarios are limited in flexibility.
2. Need a non-obtrusive AAR/recording capability to reduce # of observers required to evaluate training	0	Current AAR is highly dependent on trainer observation. No recording capability. This was also one capability gap called out by instructors during our site survey.
3. Need interactive and responsive training (e.g., voice recognition, role player)	1	Current use of role players in the FPSS provides realism; however, the current FATS is only semi-interactive.
4. Needs to be realistic and provide for ship, building, and pier-based environments (separate rooms, passageways, ladderwells, or stairs)	1	FPSS meets this requirement adequately although limited in size in comparison to a ship. The FATS is only semi-immersive limiting the ability of the trainee to move in the environment.
5. Needs to allow for the wear of standard tactical personnel equipment and not impede tactical movement	1	Current FPSS-required protective gear is compatible with standard tactical equipment; however, it is not perfect and is cumbersome.
6. Needs to be durable to handle CQB scenarios	2	Current FPSS equipment is durable. FATS equipment appears durable, but experiences limited exposure to CQB scenarios (mainly dropping).
7. Needs to accommodate standard Navy issue rifle and pistol	2	Both the FPSS and FATS currently utilize modified versions of standard issue weapons.

Standard	Met (2) Partial (1) Not Met (0)	Justification
8. Needs to be reliable, sustainable, and upgradeable	1	FPSS is reliable and sustainable. Our observation is that it could be upgradeable in the form of expansion if necessary by addition of more containers. The FATS is somewhat outdated and experienced multiple technical issues during our site survey.
9. Needs to operate in all light conditions	1	FPSS allows for all light conditions. FATS has limited low light capabilities and is not designed to interact with a flashlight to simulate low-light conditions.
10. Needs to be able to conduct quicker scenario training iterations to increase efficiency and affect knowledge transfer	1	FPSS provides the capability to train multiple groups at once. The FATS is somewhat outdated and slow in its processing capability.
11. Need for a multiplayer capability for 2–6 people	1	FPSS provides for adequate multiplayer capability currently. The FATS is limited with its ability to allow for team work.

This analysis revealed potential opportunities for enhancement in CENSECFOR's current SRF-A training program. These areas include training scenario flexibility; unobtrusive AAR capability; interactive and responsive training; realistic movement of the trainee; integration of tactical gear; reliable, sustainable, and upgradeable system; operability in all light conditions; allowance for quick training iterations; and multiplayer capability for two to six people.

These are the areas we feel that CENSECFOR has the most room for improving upon or enhancing their current SRF-A training program and that should be a central part of any decision process for incorporating immersive technology into the SRF-A training. We assess that standards six and seven are met by the current SRF-A curriculum; however, they are still important considerations for any training enhancements considered in the future because any future training enhancements should perform as well as or better in each of these areas.

In Chapter V, we complete the solutions recommendation phase of the Quick Turn CBA and analyze the spectrum of immersive technologies (as outlined in Chapter III) for their potential application to the SRF-A training program.

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V. SUMMARY AND RECOMMENDATIONS

In this chapter, we conduct the solutions recommendation phase of the Quick Turn CBA. The outputs of this phase are our recommendations to CENSECFOR on technology options that we perceive could enhance their current SRF-A training program. We present these options in the form of courses of action (COAs).

From our literature, we learned that there are certain areas in which immersive technologies can enhance training when applied properly. These benefits come from cost savings gained when replacing all or a portion of required live training, more efficient retention of the training material as demonstrated in some of the literature, or the ability to perform quicker training repetitions, allowing for more training and thus better knowledge transfer. These benefits are highly dependent on the linkage between the training environment and the desired learning objectives. Also, since the choice of technology impacts both learning efficiency and user acceptance, our recommendations focus on identifying opportunities for effective application of immersive technology into CENSECFOR's SRF-A training program rather than recommending a specific product or technology.

A. QUICK TURN CBA STANDARDS

We utilized the data from our literature review, site survey observations, and our SRF-A training documentation review to develop 11 qualitative standards (see Figure 19). We believe these standards address the industry best practices in implementing immersive technology in a training environment similar to that of the SRF-A course.

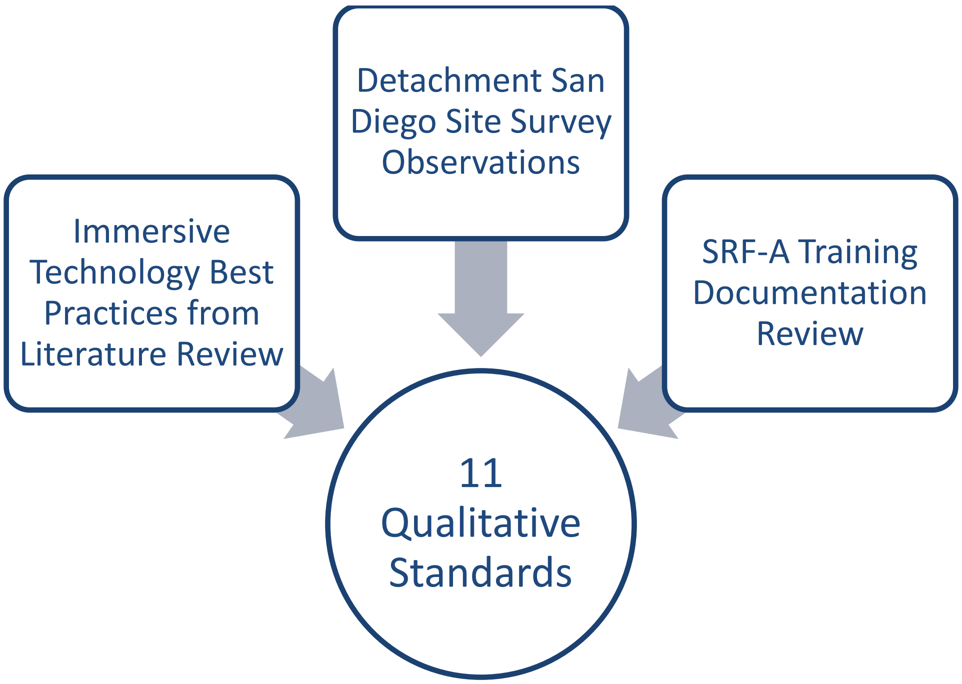

Figure 19. Qualitative Standard Development Process

These standards include the following:

1. The need for flexible tactical decision-making scenarios
2. The need for an unobtrusive AAR capability
3. The need for interactive and responsive role players
4. The need for a realistic environment
5. The need to accommodate standard issue tactical gear
6. The need for durability
7. The need to accommodate standard issue weapons
8. The need for reliability, sustainability, and upgradeability of a system
9. The need to operate in all light conditions
10. The ability to conduct quick training iterations
11. The need for multiplayer capability

These functional standards are the metrics by which we evaluated the spectrum of available immersive technologies for potential application to the SRF-A training program. The next section outlines our conclusions and recommendations for enhancing CENSECFOR training.

B. TECHNOLOGY CONFIGURATIONS

Due to the large quantity of available AR and VR systems currently on the market, we created 12 technology portfolios, as shown in Figure 20. We developed the portfolio descriptions to represent a low, middle, and higher end level of technology for both AR and VR. These descriptions guided our assessment of the associated technologies in each phase of training.

Additionally, we decided to incorporate two non-immersive technologies in the form of cameras and sensors. We made this decision based on our observations and the feedback we received during our site survey at Detachment San Diego. We believe that these technologies could potentially provide some enhancements to the SRF-A training program, so we decided to incorporate them into our analysis for consideration.

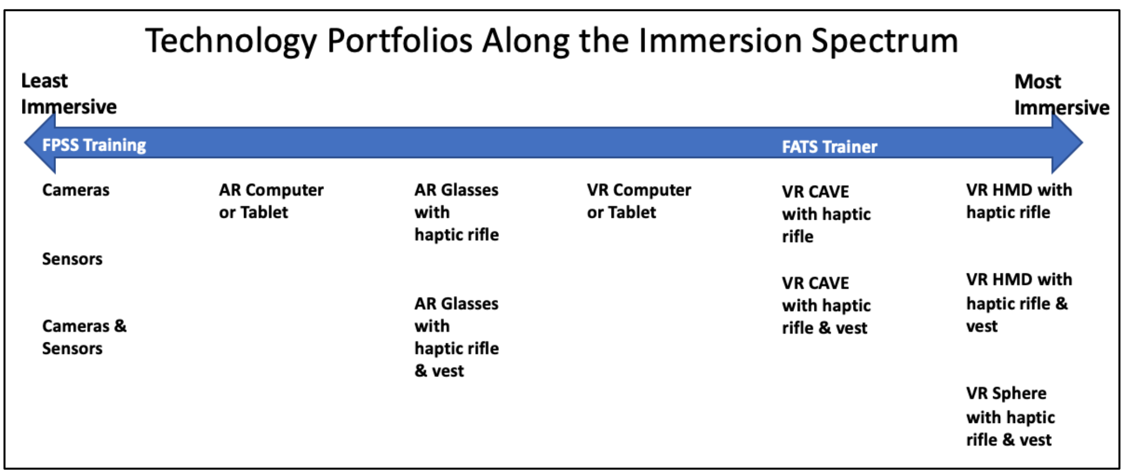

Figure 20. Twelve Technology Portfolios on the Immersion Spectrum

(1) Camera System

The camera system consists of wall/ceiling-mounted cameras placed throughout the interior and exterior of the FPSS. These cameras would be capable of tracking movement and recording in all light conditions for playback during AAR. This system augments the current FPSS system by providing an improved AAR capability.

(2) Sensor System

The sensor system consists of body and weapon sensors combined with the modified simunition M4 rifle and M9 pistol. These sensors are similar to those used in the AR/VR discussed in Chapter III. As users move through the FPSS scenario, the sensors provide positional tracking of the user and orientation of the weapon systems. This system augments the current FPSS system by providing an improved AAR capability.

(3) Camera and Sensor

The camera and sensor system consists of a combination of the camera and sensor systems.

(4) Computer/Tablet-Based AR without Haptic Device

The computer/tablet-based AR without haptic device system consists of a tablet and an AR marker system. As the user moves the tablet, the real environment is displayed on the screen through the use of the tablet's built-in camera. Once the tablet detects a marker, the computer image associated with the marker is displayed, requiring action from the user. The user input is provided through the touch screen of the tablet. Audio feedback is provided through the associated scenario sounds.

(5) AR Goggles with Haptic Rifle

The AR Goggles with haptic rifle consists of commercial AR goggles or glasses, a modified M4 rifle and M9 pistol, and an AR marker system. When the user looks through the AR goggles, the real environment remains visible. As the user moves through the real environment, the goggles read AR markers and display computer images associated with the markers through the goggles. These images may require action from the user. The user provides input through the modified weapon system. Haptic and audio feedback is provided to the user when they fire the weapon in the form of recoil and associated scenario sounds.

(6) AR Goggles with Haptic Rifle and Vest

The AR Goggles with haptic rifle and vest system consists of commercial AR goggles or glasses, a modified M4 rifle and M9 pistol, a haptic feedback vest, and a marker system. When the user looks through the AR goggles, the real environment remains visible. As the user moves through the real environment, the goggles read AR markers and display computer images associated with the markers through the goggles. These images may require action from the user. The user provides input through the modified weapon system. Haptic feedback is provided to the user through the weapon system and includes recoil, explosions, body strikes, and near miss feedback. Audio feedback is provided through the associated scenario sounds.

(7) Computer/Tablet-Based VR System without Haptic Devices

The computer/tablet-based VR without haptic device system consists of a tablet or computer and can be stationary. The virtual environment is displayed through tablet or computer screen without the need for a marker system. As the scenario is displayed, the user input can be provided through the use of the touch screen, game controller, or keyboard and mouse. Audio feedback is provided through the associated scenario sounds.

(8) VR CAVE with Haptic Rifle

The VR CAVE with haptic rifle system consists of a VR CAVE, modified M4 rifle, and modified M9 pistol. The virtual environment of the scenario is displayed on the surrounding CAVE, allowing the user to complete the training scenario without the uses of a head-mounted display. As the scenario progresses, the user provides input through the modified weapon system. Haptic and audio feedback is provided to the user when they fire the weapon in the form of recoil and associated scenario sounds.

(9) VR CAVE with Haptic Rifle and Vest

The VR CAVE with haptic rifle and vest system consists of a VR CAVE, modified M4 rifle and M9 pistol, and a haptic feedback vest. The virtual environment of the scenario is displayed on the surrounding CAVE, allowing the user to complete the training scenario without the uses of a head-mounted display. As the scenario progresses, the user provides input through the modified weapon system. Haptic feedback is provided to the user through the weapon system and includes recoil, explosions, body strikes, and near miss feedback. Audio feedback is provided through the associated scenario sounds.

(10) VR HMD with Haptic Rifle

The VR HMD with haptic rifle system consists of a VR HMD, modified M4 rifle, and modified M9 pistol. The virtual environment of the scenario is displayed through the HMD, with the real environment completely removed from the user's field of view. As the scenario progresses, the user provides input through the modified weapon system. Haptic and audio feedback is provided to the user when they fire the weapon in the form of recoil and associated scenario sounds.

(11) VR HMD with Haptic Rifle and Vest

The VR HMD with haptic rifle and vest system consists of a VR HMD, modified M4 rifle and M9 pistol, and a haptic feedback vest. The virtual environment of the scenario is displayed through the HMD, with the real environment completely removed from the user's field of view. As the scenario progresses, the user provides input through the modified weapon system. Haptic feedback is provided to the user through the weapon system and includes recoil, explosions, body strikes, and near miss feedback. Audio feedback is provided through the associated scenario sounds.

(12) VR Sphere with Haptic Rifle and Vest

The VR sphere with haptic rifle and vest system consists of a VR sphere, modified M4 rifle and M9 pistol, and a haptic feedback vest. The virtual environment of the scenario is displayed on the sphere, with or without the use of an HMD. The user is completely removed from the real environment in this system. The user navigates through the system by crawling, walking, running, and jumping in the sphere. As the scenario progresses, the user provides input through the modified weapon system and body motion that can be tracked through motion sensors in the sphere. Haptic feedback is provided to the user through the weapon system and includes recoil, explosions, body strikes, and near miss feedback. Audio feedback is provided through the associated scenario sounds. The sphere can also be configured to provide haptic feedback through temperature changes and smells.

C. DISCUSSION AND RECOMMENDATIONS

We discussed each standard and evaluated each of the 12 immersive technology portfolios against our developed standards, by training phase, deciding whether that technology is perceived to be more beneficial than the current SRF-A training. We reached a consensus score for each portfolio and recorded the results in a scoring table by phase of training. The maximum score an individual technology portfolio could obtain is a “++” with the minimum possible score being a “-.” We divided this range into four zones of perceived enhancement to the existing SRF-A training program:

- \- Negative perceived enhancement
- o No perceived enhancement or not applicable
- \+ Some perceived enhancement
- ++ Considerable perceived enhancement

1. Crawl Training Phase

We see some room for training enhancement using immersive technologies in the crawl phase of training(see Table 6). We observed a trend in our scoring results that the more immersive the technology, the greater the perceived enhancement against the current SRF-A training program. We chose not to evaluate the three camera and sensor portfolios as they are not applicable to this phase of training because they were specifically requested as enhancement options for the walk and run phases of training. Additionally, we did not evaluate two standards—non-intrusive AAR capability and multiplayer capability—because this phase of training focuses on individual team member tasks instead of collective training tasks. In this phase, training is primarily conducted in a classroom environment, which is not conducive to performing collective tasks, and instructors provide individual feedback, eliminating the need for a technology-enhanced AAR.

Table 6. Crawl Phase Portfolio Analysis

	Immersion Spectrum												
Standards	Current Training Curriculum	Camera	Trainee locating Sensors	Camera + Sensor	Computer/tablet based AR system (No haptics)	AR Goggles with haptic rifle	AR Goggles with haptic rifle & vest	Computer/tablet based VR system (No haptics)	VR CAVE with haptic rifle	VR CAVE with haptic rifle & vest	VR HMD with haptic rifle	VR HMD with haptic rifle & vest	VR sphere with haptic rifle & vest
1. Need tactical Decision Making training with flexible scenarios	o				+	o	o	+	o	o	+	+	+
2. Need a non-obtrusive AAR/recording capability to reduce # of observers required to evaluate training	o												
3. Need interactive and responsive training (e.g. voice recognition, role player)	o				+	o	o	+	+	+	+	+	+
4. Needs to be realistic (provide for ship, building, and pier environments with rooms, passageways, ladderwells/stairs)	o				-	-	-	-	+	+	+	+	+
5. Needs to allow for the wear of standard tactical personnel equipment and not impede tactical movement	o				-	o	o	-	+	+	-	-	-
6. Needs to be durable to handle CQB scenarios	o				-	-	-	-	-	-	-	-	-
7. Needs to accommodate standard Navy issue rifle and pistol	o				-	o	o	-	o	o	o	o	o
8. Needs to be reliable, sustainable, and upgradeable	o				+	-	-	+	-	-	-	-	-
9. Needs to operate in all light and environmental conditions	o				-	-	-	-	o	o	-	-	o
10. Need to be able to conduct quicker scenario training iterations to increase efficiency and affect knowledge transfer	o				+	-	-	+	o	o	o	o	-
11. Multi-player capability													

Both computer- and tablet-based AR systems showed improvements for standards 1, 2, 8, 9. We determined these technologies provide better decision-making enhancements when compared with the classroom environment. They are also more interactive than traditional classroom instructions and have the opportunity to appeal to the new generations of sailors to affect knowledge transfer of classroom instructional tasks. They are also deemed to be the most sustainable and upgradeable systems because units currently maintain life-cycle management of their traditional automation equipment. The computer- and tablet-based systems allow for quicker training scenario iterations to affect knowledge transfer when compared to classroom instruction.

AR goggle-based systems demonstrate no improvement over current SRF-A walk phase training. This family of systems provides the same level of training for standards 1, 2, 5, and 7. AR systems are deemed to demonstrate less perceived enhancement for standards 4, 6, 8, 9, and 10. This is a result of AR systems' limitations in the classroom environment, because AR augments a live environment with computer-generated images, which do not provide the desired training effect in the SRF-A classroom environment.

VR systems demonstrate improvement over current training in the classroom and FATS trainer for standards 1, 3, and 4. The more immersive VR systems provide improved decision making due to the tailorable increase in complexity of the scenarios and the immersion and presence they project, due to the interactive nature of more immersive systems These VR systems are also more realistic because of the additional immersion when compared to the wall-mounted FATS systems. This improves interaction and realism over the FATS simple scenarios, which can improve knowledge transfer.

VR systems demonstrate similarities to current training for standards 7, 9, and 10. The VR systems can accommodate Navy standard issue weapons and can execute the same number of training iterations when compared to the FATS trainer.

VR systems are deemed to provide less enhancement when looking at sustainability, maintainability, and upgradability. All systems are deemed upgradable, but sustainment planning is an important consideration to highlight. Investing in these technologies will require additional hardware and software that must be maintained. Their durability is considered lower than the current FATS systems because of the head-mounted displays which will require maintenance to ensure calibration of the system. CENSECFOR should consider robust sustainment planning if it pursues immersive VR systems to avoid conducting sustainment actions organically. Another drawback is training duration using immersive environments. Instructors must be aware of effects, impacts, and risks of cybersickness when developing training scenarios.

2. Walk Training Phase

The analysis in the walk phase of training indicates that the immersive AR and VR technologies show limited potential for enhancing SRF-A training (see Table 7). AR technologies demonstrate considerable improvement over current training for standards 1 and 3. AR tactical decision-making improvements in the walk phase revolve around the extensibility of the scenarios to incorporate live and virtual environments that are more dynamic than the current role players used in the scenarios. The trainees serve as the role players, requiring close supervision by the instructors to stay within the bounds of the scenario. Having additional scenario options could enhance the decision-making skills of the teams in the walk phase because the scenarios can be more elaborate than the current training. However, this can have a negative impact on realism because the teams cannot conduct live personnel searches when using AR technology.

Table 7. Walk Phase Portfolio Analysis

	Immersion Spectrum													
Standards	Current Training Curriculum	Camera	Trainee locating Sensors	Camera + Sensor	Computer/tablet based AR system (No haptics)	AR Goggles with haptic rifle	AR Goggles with haptic rifle & vest	Computer/tablet based VR system (No haptics)	VR CAVE with haptic rifle	VR CAVE with haptic rifle & vest	VR HMD with haptic rifle	VR HMD with haptic rifle & vest	VR sphere with haptic rifle & vest
1. Need tactical Decision Making training with flexible scenarios	o	o	o	o		++	++		+	+	+	+	+
2. Need a non-obtrusive AAR/recording capability to reduce # of observers required to evaluate training	o	+	+	++		+	+		-	-	-	-	-
3. Need interactive and responsive training (e.g. voice recognition, role player)	o	o	o	o		o	o		+	+	+	+	+
4. Needs to be realistic (provide for ship, building, and pier environments with rooms, passageways, ladderwells/stairs)	o	o	o	o		o	o		-	-	-	-	-
5. Needs to allow for the wear of standard tactical personnel equipment and not impede tactical movement	o	o	o	o		o	o		o	o	-	-	-
6. Needs to be durable to handle CQB scenarios	o	o	o	o		-	-		-	-	-	-	-
7. Needs to accommodate standard Navy issue rifle and pistol	o	o	o	o		o	o		o	o	o	o	o
8. Needs to be reliable, sustainable, and upgradeable	o	o	o	o		-	-		-	-	-	-	-
9. Needs to operate in all light and environmental conditions	o	+	+	+		o	o		o	o	o	o	o
10. Need to be able to conduct quicker scenario training iterations to increase efficiency and affect knowledge transfer	o	o	o	o		o	o		+	+	+	+	+
11. Multi-player capability	o	o	o	o		o	o		o	o	o	o	o

The VR systems demonstrate no perceived enhancement on current training for standards 7, 9, and 11. The VR systems use modified Navy weapons that have the same dimensions and weight as standard Navy weapons. VR HMDs operate in all light conditions; however, there is no perceived enhancement for multiplayer capabilities over current training.

VR systems provide negative perceived enhancement to current training for standards 2, 4, 6, and 8. The VR HMD is obtrusive to wear with the current protective gear worn during training. VR systems are not as realistic as the current training conducted at the pier and in the FPSS trainer. The VR equipment is not deemed durable and can easily be damaged when conducting CQB drills, which contributes to the perceived decrease in maintainability and sustainability.

AR and the non-immersive technologies demonstrate no enhancement or a negative perceived enhancement to training for each of the standards with the exception of camera and sensors combinations for standards 2 and 9. We perceive that these technologies can increase the AAR capabilities during the walk phase to capture how the trainees perform and allow the instructors to correct performance to increase knowledge transfer by discussing how they performed and how they improve during each training iteration.

3. Run Training Phase

The analysis of the run phase of training revealed the least perceived potential for immersive technology to enhance the SRF-A training program (see Table 8). Moving down the immersive technology spectrum from the most immersive systems toward realism increases the application of that portfolio to enhance training.

Table 8. Run Phase Portfolio Analysis

Standards	Immersion Spectrum												
	Current Training Curriculum	Camera	Trainee locating Sensors	Camera + Sensor	Computer/tablet based AR system (No haptics)	AR Goggles with haptic rifle	AR Goggles with haptic rifle & vest	Computer/tablet based VR system (No haptics)	VR CAVE with haptic rifle	VR CAVE with haptic rifle & vest	VR HMD with haptic rifle	VR HMD with haptic rifle & vest	VR sphere with haptic rifle & vest
1. Need tactical Decision Making training with flexible scenarios	o	o	o	o		-	-		-	-	-	-	-
2. Need a non-obtrusive AAR/recording capability to reduce # of observers required to evaluate training	o	++	++	++		+	+		o	o	-	-	-
3. Need interactive and responsive training (e.g. voice recognition, role player)	o	o	o	o		o	o		-	-	-	-	-
4. Needs to be realistic (provide for ship, building, and pier environments with rooms, passageways, ladderwells/stairs)	o	o	o	o		-	-		-	-	-	-	-
5. Needs to allow for the wear of standard tactical personnel equipment and not impede tactical movement	o	o	o	o		o	o		o	o	-	-	-
6. Needs to be durable to handle CQB scenarios	o	o	o	o		-	-		-	-	-	-	-
7. Needs to accommodate standard Navy issue rifle and pistol	o	o	o	o		o	o		o	o	o	o	o
8. Needs to be reliable, sustainable, and upgradeable	o	o	o	o		-	-		-	-	-	-	-
9. Needs to operate in all light and environmental conditions	o	+	+	+		o	o		o	o	o	o	o
10. Need to be able to conduct quicker scenario training iterations to increase efficiency and affect knowledge transfer	o	o	o	o		o	o		+	+	+	+	+
11. Multi-player capability	o	o	o	o		o	o		o	o	o	o	o

Camera and sensor portfolios are perceived to provide the greatest benefit during the run phase of training. Camera and sensor portfolios exceed the values of current training on standards 2 and 9. During our site visit, we observed that the instructors created obstacles in the FPSS trainer that decreased the level of realism. Trainees asked whether they were in play, and that seemed to cause confusion. The camera and sensor systems allow reduction in the number of instructors in the FPSS to capture performance of the team. Camera and sensor combinations provide an opportunity to reduce the number of instructors in the FPSS, which we perceive would increase the realism.

We perceive the highly immersive VR portfolios, VR HMD displays and VR sphere to be the same as existing training for standards 7, 9, and 11. We perceive these systems to be less enhancing than existing training for standards 1, 2, 3, 4, 5, 6, and 8 since they cannot replace the realism, fidelity, and live interactivity of live training during the run phase. The use of simunition rounds in current training used to provide realism cannot be replaced with haptic feedback. The haptic mechanism is similar but perceived as less valuable than current training. The only standard in which the highly immersive VR systems were perceived to enhance training was standard 10 because these systems can increase the iteration rate of training versus the reset of the FPSS, which requires all participants to exit the FPSS and return to the start point to begin the next iteration. This can take up to five minutes, whereas the immersive systems can immediately begin another training iteration upon completion. There are durability concerns with immersive systems operating in the FPSS that decrease their maintainability and sustainability. Additionally, the immersive technologies do not currently provide the ability to effectively replicate live training without the limitations and constraints of cybersickness that limited training duration. The training iteration we observed took approximately 20 minutes to complete, which exceeds the threshold for training duration in VR systems.

The CAVE VR systems were perceived to be slightly better than the fully immersive systems by providing the same perceived benefit of current live training on standards 2, 5,7, 9, and 11. The CAVE VR systems provide a playback system that can be the equivalent of the AARs conducted after live training. These systems are also compatible with the Navy standard equipment and would not be obtrusive to the scenario by adding additional gear. Like the fully immersive portfolios, the CAVE VR portfolio was perceived to be less beneficial for standards 1, 3, 4, 6, and 8 for the same reasons that they cannot replicate the realism, fidelity, and live interactivity of live training. Like the fully immersive technologies, there are durability concerns with immersive systems operating in the FPSS that decrease their maintainability and sustainability.

The AR systems were perceived to be slightly better than the CAVE VR systems on standards 2 and 3. We perceive that it can provide enhanced AAR capability and not negatively impact the interactive nature of the training. The AR systems scored lower than the CAVE systems in the ability to perform quicker scenario iterations due to the time required to reset a scenario.

D. CONCLUSION

Overall, each phase of training could benefit from technologies across the immersive spectrum. We identified the multiplayer requirement as an essential element we derived during our research. We used this requirement to develop a standard to address this requirement while conducting our analysis. As we conducted our analysis, we determined that each system performed essentially the same as current training and was not a delineating factor due to the standard size of the fire team. As CENSECFOR progresses from the crawl, to walk, to run phase, the training becomes more realistic and the potential for immersive technology to enhance training decreases. The crawl phase could implement VR systems to improve on their current classroom and FATS trainer curriculum. We assess that this phase of training is the most conducive for VR applications, because it offers a perceived increase in realism, fidelity, and knowledge transfer of individual tasks. The walk phase indicates some potential for enhancement of current training with some VR and AR technology to improve tactical decision making, training scenario complexity, and the transition to collective tasks. The current SRF-A run phase of training utilizes realistic simunitions in the FPSS, creating a very realistic, live-training environment that is difficult to replicate with AR or VR technologies. The camera and sensor portfolios could reduce the number of instructors, thereby improving realism by providing an unobtrusive AAR capability.

1. Courses of Action

We developed two potential courses of actions (COAs) for enhancing the SRF-A training program based on our research. These serve purely as potential ideas for consideration, as much more work is required for an actual procurement decision. We provide our thoughts on the next steps of this research following a description of the courses of action.

a. COA 1

COA 1 is to enhance the crawl phase with one of the highlighted AR or VR technology portfolios with haptics. This course of action targets the phase of training indicating the greatest potential for enhancement by addressing the identified needs. This could be accomplished by updating the existing FATS system, which could improve the reliability, scenario flexibility, realism, level of interaction with the system, and support of multiplayer scenarios.

b. COA 2

COA1 is to add a camera and/or sensor system for the walk and run training phases. Incorporating one of these systems into the FPSS would allow for use in both the walk and run phases of training. Additionally, it addresses some of the identified needs by allowing for the removal of the instructors from the FPSS during the live training and could provide an enhanced AAR capability to the instructors and trainees.

2. Research Risk, Limitations and Recommendations for Follow-On Research

There is inherent risk in the analysis of a Quick Turn CBA as it is, in fact, done quickly and is subjective. Our research was very much time-driven with a hard deadline. We could continue to add to our literature review in Chapter III, refine our assessments in Chapter IV, and consequently our analysis and conclusion in Chapter V given additional time and resources.

CBAs are also normally conducted by larger teams with some level of expertise in each field (e.g., immersive technology, military operations, human factors, business case analysis, etc.). We conducted our research as a team of three Army officers with the assistance of our three-person thesis advisor team.

Given these research constraints and limitations we find it important to communicate that our analysis relies heavily on "conclusions with some analysis tempered by experience" (JCS J-8, 2009, p. 76). This is in line with the group methodology for a Quick Turn CBA; however, we would have greater confidence in our analysis with the input of many more experts in various fields.

Realizing that our team was only able to conduct a Quick Turn CBA to assist with guiding decision makers on the potential of immersive technology to enhance SRF-A training program, additional work is required to support an informed decision. The following are our recommendations for the next steps in this process.

1. Further assess the usability issues associated with adopting AR/VR systems.

2. Further identify measures of learning and job effectiveness.

3. Conduct a policy feasibility study on the application of a new AR/VR system to the SRF-A training program (JCS J-8, 2009, p. 58).

4. Conduct a technological feasibility study on the application of AR/VR to the SRF-A training program with consideration of all of the SRF-A training locations (JCS J-8, 2009, p. 58).

5. Gather more data at the additional SRF-A training locations to compare the implementation of the training program as well as the available facilities to help guide the analysis.

6. Conduct an affordability study. The cost of procuring a system will generally increase as the complexity of the system increases (i.e., more haptic feedback and input devices; JCS J-8, 2009, p. 58). The affordability study should include system maintenance and upgradeability to account for the entire life-cycle system costs versus simple development and procurement costs.

7. Any AR/VR system implementation should be done as a pilot at one of the training locations first. We would recommend the Detachment San Diego location to allow for further Naval Postgraduate School evaluation, such as knowledge transfer studies.

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