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MAPPING VIRTUAL AND AUGMENTED REALITY TRAINING SYSTEMS TO SUPPORT THE UNITED STATES COAST GUARD TRAINING NEEDS

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THESIS

MAPPING VIRTUAL AND AUGMENTED REALITY TRAINING SYSTEMS TO SUPPORT THE UNITED STATES COAST GUARD TRAINING NEEDS

by

Steven W. Arnold

December 2022

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This thesis addresses, discusses, and analyzes how to identify and map the use of contemporary virtual and augmented reality (VR/AR) training systems that have been developed by the United States Navy (USN) and how they may be incorporated to resolve United States Coast Guard (USCG) training needs. Through interviews, site visits, and research, data on different training methods was compiled and used to develop a system map. Using this system map and System Engineering principles, this research is able to analyze known VR/AR systems to determine which best fits the requirements of a new system. With the ability to look across military branches to address training needs, the time and money invested in research and development of new training programs could be significantly reduced. A case study is included to provide both a basic outline and explanation on how this system mapping and the follow-on analysis can be used. This research also discusses the advantages and disadvantages associated with using different training methods and how that should affect decision making when choosing a training system.

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MAPPING VIRTUAL AND AUGMENTED REALITY TRAINING SYSTEMS TO SUPPORT THE UNITED STATES COAST GUARD TRAINING NEEDS

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis addresses, discusses, and analyzes how to identify and map the use of contemporary virtual and augmented reality (VR/AR) training systems that have been developed by the United States Navy (USN) and how they may be incorporated to resolve United States Coast Guard (USCG) training needs. Through interviews, site visits, and research, data on different training methods was compiled and used to develop a system map. Using this system map and System Engineering principles, this research is able to analyze known VR/AR systems to determine which best fits the requirements of a new system. With the ability to look across military branches to address training needs, the time and money invested in research and development of new training programs could be significantly reduced. A case study is included to provide both a basic outline and explanation on how this system mapping and the follow-on analysis can be used. This research also discusses the advantages and disadvantages associated with using different training methods and how that should affect decision making when choosing a training system.

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	three-dimensional
AR	augmented reality
CBA	cost-benefit analysis
COTS	commercial off-the-shelf
COVE	Conning Officer Virtual Environment
DOD	Department of Defense
HUD	heads-up display
IRB	Institutional Review Board
LCS	Littoral Combat Ship
MR	mixed reality
NPS	Naval Postgraduate School
SE	systems engineering
VR	virtual reality
VR/AR	virtual and augmented reality
USCG	United States Coast Guard
USMC	United States Marine Corps
USN	United States Navy
WMEC	Medium Endurance Cutters

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EXECUTIVE SUMMARY

In recent years the technology and availability of virtual and augmented reality (VR/AR) solutions have seen significant improvements. The emergence of cost-effective commercial-off-the-shelf (COTS) products, along with the improved performance of technological systems, has helped lead to a new wave of efforts that sought to employ VR and AR technology in the learning and training domains. With this, many organizations, inside and outside the Department of Defense (DOD), have begun using those systems to augment or completely replace current training methods, such as live fire exercises or open ocean navigation. However, the DOD is compartmentalized to some extent between different service branches, and each branch acquires training solutions that best suit its mission. That can lead to VR and AR training capabilities being available to the United States Navy (USN), but the United States Coast Guard (USCG) may be unaware of their existence. Exploring how the existing training solutions and approaches of one group could be repurposed to support the needs of another group has the potential of significantly reducing the time and financial investment that would otherwise be required to develop completely new training systems.

When discussing VR/AR training capabilities, it is important to understand what VR is and its distinction from AR and mixed reality (MR). Kishino and Milgram detail the difference between VR and AR as a continuum instead of a hardline separation [1]. In this continuum, VR is associated with a virtual environment where the user is "immersed in, and able to interact with, a completely synthetic world," while AR is the implementation of computer-generated (virtual, synthetic) overlays over the real environment. For a system to be considered VR, it must be able to meet four specific criteria: it represents a computer-generated virtual world or virtual environment, provides the user with immersion into that generated virtual world, produces real-time sensory feedback to the user, and finally allows the user to interact with the same virtual world [2].

This thesis investigates the advantages that can be achieved with different VR/AR systems and simulators used in training programs and how a systems engineering (SE) method to analyze these programs can be developed. This method can be used to evaluate

the feasibility of transferring and adapting VR and AR training systems between different organizations. The same approach can help decision-makers to make more informed decisions when evaluating VR/AR training systems and their possible use in their organizations.

This thesis proposes a decision-making tool in the form of a system map that uses a mix of different SE principles to conduct a needs evaluation and develop requirements that represent the proposed training objective. This allows the decision-makers to compare a proposed training objective to training methods that are currently available and determine if those VR and AR training methods can adequately meet the new training needs. To perform this evaluation, this thesis focuses on two SE value hierarchy methods: the Pugh Matrix and cost-benefit analysis (CBA). In a Pugh Matrix, a baseline system or component of a system is compared to alternatives across a set of categories to determine an overall better performer [3]. A CBA allows the user to provide weights to each category based on their importance [4]; the CBA also incorporates cost factors in a separate portion of the analysis. In the case of the domain investigated, the systems compared are different VR, AR, and simulator training methods, and categories are determined based on data collected from site visits and research.

Though this thesis focuses on training methods that use VR, AR, and training simulators, many of the principles can be used or replicated in other domains. The basis of the system mapping was developed from standard SE principles and can be found in other applications; good examples are risk evaluation [5] and evaluation of flow through a system [6]. With the correct application of SE approaches, the development of systems and overall decision-making processes can be improved dramatically. That can help prevent future rework, redevelopment, or a complete overhaul of systems.

The research presented in this thesis is far from all-encompassing. Out of the total number of military bases that are in existence, only a small number were visited due to time and funding constraints; the author ensured that installations visited in this study had training solutions typically available at places that were not visited. The research focused on the use of training systems from the USN and USMC to the USCG, so very little data was collected on potential systems developed by the United States Air Force, Army, and foreign militaries. Future analysis of other areas can be conducted to further expand the scope of the mapping system and allow for improved decision making.

The military's limited use of VR/AR also limited the research. As previously mentioned, most of the training aids that were identified as being used on a regular basis are simulators. Large simulators support team experiences and training of team-centric skills. They use the interface that is a mock-up of the actual user interface from the operational environment and bring the level of realism that VR or AR environments may lack. They are also better suited for practicing skill integration, and over time, they became programs of record with well-defined funding lines. Therefore, it is not a surprise that they are more frequent training options than VR/AR.

The inevitable issue that any organization must deal with is the cost of acquiring and maintaining any training system. The budget provided to USCG is modest and it is important that decision makers minimize cost while maximizing the potential training benefits. For example, if there are training courses that would benefit from having large facilities but are conducted infrequently, the same facilities can be in major locations rather than in every single installation. This minimized the number of facilities needed, but it results in increased travel costs. The USCG can also investigate sharing facilities with other local branches of the military or building joint facilities, allowing benefits for both groups.

This research identified the absence of training aids that used COTS VR/AR systems. These types of display solutions have not been used to the extent expected, given the level of maturity of that technology. Very few training solutions took advantage of the readily available COTS VR systems. Large training simulators are staffed with personnel that are trained to support trainees in improving their skill sets. VR/AR training solutions, on the other hand, are typically used as personal training solutions. Since their footprint is reasonably small and solutions are inexpensive when compared to large simulators, that type of training would most likely take place at the individual's command. While the affordability and distribution of VR/AR training resources is a good thing, the management of those training systems would place the burden on the individual or senior members of that command. Additionally, tracking the progress of training would be more difficult for organizations responsible for training.

There are several other hurdles that would need to be addressed prior to implementation of any COTS VR/AR training program. One of the biggest and most difficult is its adoption by potential trainees. In addition to training system, one needs to create a full training program that includes a set of high-quality scenarios, training plan, comprehensive evaluation of knowledge and skill acquisition, progress tracking, etc. The same training solution will still need to be advertised amongst the potential adopters and its use endorsed by individuals who can provide that type of influence. As a culmination of that process, becoming the program of record would provide much needed longevity of that effort.

While COTS VR/AR training solutions face barriers to implementation and adoption by a large number of potential users there is a still a lot of potential for their use. Many military training programs demonstrated that providing training systems that support immersion and user interaction can improve trainees' engagement and willingness to learn. The ability to replace static power point materials with interactive virtual simulations could allow individuals to grasp complex concepts and remove the tediousness of traditional training approaches.

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I. INTRODUCTION

In recent years the technology and availability of virtual and augmented reality (VR/AR) solutions have seen significant improvements. The emergence of cost-efficient commercial-off-the-shelf (COTS) products along with the improved performance of technological systems has helped lead to a new wave effort that sought to employ VR and AR technology in learning and training domains. With this many organizations, inside and outside the Department of Defense (DOD), have begun using those systems to augment or completely replace current training methods, such as live fire exercises or open ocean navigation. However, the DOD is compartmentalized to some extent between different service branches, and each branch acquires training solutions that best suit its mission. That can lead to a VR and AR training capabilities being available to the United States Navy (USN), but the United States Coast Guard (USCG) may be unaware of their existence. Exploring how the existing training solutions and approaches of one group of trainees could be repurposed to support the needs of another group has the potential of significantly reducing the time and financial investment that would otherwise be required to develop completely new training systems.

When discussing VR/AR training capabilities, it is important to understand what virtual reality (VR) is and its distinction from augmented reality (AR) and mixed reality (MR). Kishino and Milgram detail the difference between the physical world and world that is fully simulated as a continuum instead of having a hardline separation between different mixes of each world [1]. In this continuum, VR is associated with a virtual environment where the user is "immersed in, and able to interact with, a completely synthetic world," while AR is the implementation of computer-generated (virtual, synthetic) overlays over the real environment. For a system to be considered VR, it must be able to meet four specific criteria: it represents a computer-generated virtual world or virtual environment, provides the user with immersion into that generated virtual world, produces real-time sensory feedback to the user, and finally allows the user to interact with the same virtual world [2].

A well-known example of AR is the video game application “Pokémon Go” where a smartphone camera is used to capture the real world. The application then overlays images on a virtual environment on the phone’s screen as an augmentation to the real physical environment captured by the camera. While VR places the user in a fully simulated environment by using systems like the popular video game “Beat Saber,” MR falls somewhere between AR and VR where it creates a mix of both virtual and real environments. Examples of MR would be a hologram or images of the virtual, environment projected on a physical prop [3].

It is also important to understand what is meant by a simulator or how that is different from VR, AR, or MR. Unlike the well-defined requirements and definitions associated with the other aforementioned technologies, there is no standardization of what classifies as a simulator. Simulators can make use of VR, AR, or MR technologies as well. For the purposes of this research topic, a simulator is defined as a computer-based real-time simulation whose user interface is a mock-up of the actual user interface from the operational environment. Visual displays in simulators are typically in the form of large screens, and user interactions are supported by a range of input devices that resemble devices used in operational environments. A good example of a simulator is a flight simulator with a user interface like the mock-up instruments that exist on real aircraft.

This thesis investigates the advantages that can be achieved with different VR/AR systems and simulators used in training programs and how they can develop a systems engineering (SE) method to analyze these programs. This method can be used to evaluate the feasibility of leveraging VR/AR training systems between different organizations. The same approach can help decision-makers to make informed decisions when evaluating VR/AR training systems and their possible use in their organizations.

This thesis proposes a decision-making tool in the form of a system map that uses a mix of different SE principles to conduct a needs evaluation and develop requirements that represent the proposed training objective. That will allow the decision makers to compare proposed training objective to currently available training methods and determine if the available VR and AR training solutions can adequately meet the new training needs. To perform this evaluation, this thesis focuses on two SE value hierarchy methods, the

Pugh Matrix and cost-benefit analysis (CBA). In a Pugh Matrix, a baseline system or component of a system is compared to alternatives across a set of categories to determine an overall better performer [4]. A CBA allows the user to provide weights to each category based on their importance [5]. The CBA also incorporates cost factors in a separate portion of the analysis. In this instance, the systems compared are the different VR/AR and simulator training methods, and the categories used are determined based on data collected from site visits and research. A more detailed description of the method used to develop the system map is explained in the Data Analysis and Case Study sections in Chapter I.

This thesis uses the analysis research method [6] and begins with an in-depth literature review that analyzes training programs that use VR and AR technology. This thesis examines key aspects of SE fundamental principles and explores SE methods to evaluate training program carryover for the USCG. To establish a baseline on how the value brought by VR and AR training programs was evaluated, many research related journal articles were analyzed. This thesis reports the results of visits to USCG facilities to acquire better understanding about training practices, identify a set of needs specific to those unit, and collect data that reflect current training results and training system capabilities. Technology market research allowed us to evaluate capabilities of current COTS equipment, training systems, and examine their potential in addressing the needs of the USCG. This thesis used a previously created analysis method to evaluate current USN utilization of VR and AR training solutions, focusing on their determined effectiveness and potential to be transferred to the USCG. That analysis helped us analyze the usefulness of the road map in aiding in USCG decision-making and selection usage of VR and AR to fill their training needs optimally.

The structure of this thesis is based on the "manuscript option." Following that structure, Chapter I contains background details that are the basis of this research project. Chapter II contains the journal manuscript prepared for submission to the Multidisciplinary Digital Publishing Institute's Systems journal for peer review. Chapter III provides the closing remarks and observations along with potential future work that could build off this thesis.

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II. MANUSCRIPT SUBMISSION

A. MAPPING VIRTUAL AND AUGMENTED REALITY TRAINING SYSTEMS TO SUPPORT THE UNITED STATES COAST GUARD TRAINING NEEDS

A version of this chapter is prepared for submission as: Arnold, S.; Van Bossuyt, D.L.; Sadagic, A., "Mapping Virtual and Augmented Reality Training Systems to Support the United States Coast Guard Training Needs," Multidisciplinary Digital Publishing Institute (MDPI) Systems. It will be submitted in December 2022.

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B. INTRODUCTION

Recent years have seen significant improvement in the quality and variety of VR/AR solutions. The emergence of COTS products along with the improved performance of technological systems has helped lead to a new wave of efforts that sought to employ VR/AR technology in learning and training programs.

This article explores the use of a systems analysis approach to identify a set of VR/AR training solutions that were designed and developed for one group of users and maps them to support the training needs of another group of users. In practical terms, we examine training capabilities that have been developed by the USN and USMC and map them to training needs expressed by the members of the USCG. The same method is generalizable, and it could be used for in other communities.

Many organizations, inside and outside the DOD, have begun using some form of VR/AR simulations to augment or completely replace current training methods, such as live fire exercises that involve costly resources or open ocean navigation. However, the DOD is compartmentalized to some extent between different service branches, which can lead to a VR/AR training capability being available to the USN, but the USCG may not be aware of its existence. Similar siloing can occur in major corporations. Exploring the ways in which the existing training solutions and approaches of one group of trainees could be repurposed to support the needs of another group has the potential of significantly reducing the time and financial investment that would otherwise be required to develop new VR/AR training systems.

To address this issue of re-use of VR/AR training solutions, we designed a data collection apparatus to capture information about current training solutions made available to the trainees. The apparatus included interviews and collections of training data from the originating (USN) and targeted groups of trainees (USCG), as well as data that reflected the needs of the targeted groups of trainees. SE processes and principles were used to evaluate the information gathered in the data collection apparatus and was used to develop a mapping process that the USGC and other organizations can use to determine VR/AR training methods that best fit their needs. The steps of the approach are elaborated in the rest of this paper.

1. VR/AR Training Solutions

The concepts that are synonymous with VR—3D data sets, fully immersive stereoscopic displays, user interaction, and multisensory information—have a longer history than the term Virtual Reality that was coined in 1980s [7]. Stanley G Weinbaum wrote a science fiction book in 1935 titled *Pygmalion's Spectacles*, in which he described a pair of goggles that, when worn, allowed the wearer to see an entirely different world [8]. These goggles would allow the wearer to view a different world that allowed the user to experience taste, touch, and smell. In 1849, a Scottish scientist, Sir David Brewster, used the principle of the stereoscope that was originally invented by Sir Charles Wheatstone in 1838 [9]—that device was rather cumbersome and not practical for daily use. Sir Brewster's contribution was the invention of a portable, practical viewing device called the lenticular stereoscope which allowed for viewing while giving the appearance of depth or three dimensions [10]. The lenticular stereoscope allowed viewing of two pictures of the same object, originally taken from different points horizontally shifted from each other. When viewed through prisms and mirrors, the device enabled humans to see both images–

one with each eye–and experience the illusion of depth and the three-dimensional (3D) space [11]. An even earlier stereoscope was invented by Sir Charles Wheatstone in 1838 [9].

In the 1950s, the next significant advancement in working towards VR technology occurred when the cinematographer Morton Heilig invented Sensorama Simulator, a multisensory device that allowed one to experience several types of sensory information including: visual, auditory, haptic, olfactory, and environmental cues [12]. In 1965 Ivan Sutherland wrote a short essay titled the *Ultimate Display*. This work talks about the way in which computer displays may continue to advance by improving system responses and user interactions. For example, imagine how it feels to turn a doorknob: the shape and texture, the force required to turn it, the noises associated with it, how the doorknob looks from different angles. If one takes all those principles and apply them to a mechanical nob that interacts with the computer system and get presented via displays so that they are identical phenomena [13]. Though devices like the Sensorama Simulator were making significant advances, they still lacked a major capability that helped make VR devices so useful and widespread today—they did not support user interaction and did not use 3D data sets (scenes) that could be viewed from any viewpoint. The images that the Sensorama Simulator and similar devices used were either prerecorded photos or video footage and only allowed users to proceed on one or a very limited number of paths.

The first system that incorporated a see-through headset as a visual display solution and used 3D data sets was designed by Ivan Sutherland and his students in 1968 [14]; this device was an AR display Myron Krueger introduced a visual experience called Videospace in 1975 [15]; the users were able to interact with and manipulate computer-generated images projected onto a wall. The ability to interact in some form with a user's surroundings in a virtual display was one of major achievements towards greater and more versatile applications of VR technologies.

In recent years, rapid advancement in VR/AR has been made with commercial and consumer headsets being available from a variety of manufacturers. The entertainment domain with video games and phone applications, industry, and education—they all make use of VR/AR in a variety of capacities [16]. Hobbyists now have the ability to rapidly develop content and VR/AR applications by using a variety of open and closed-source VR/AR game engines [17].

At this juncture, it is important to understand what VR is and its distinction from AR and mixed reality (MR). Kishino and Milgram detail the difference between VR/AR as a continuum instead of a hardline separation [1]. In this continuum, VR is associated with a virtual environment where the user is "immersed in, and able to interact with, a completely synthetic world," while AR is the implementation of computer-generated overlays over the real environment. For a system to be considered VR, it must be able to meet four specific criteria: it represents a computer-generated virtual world/environment, provides the user with immersion into that generated virtual world, produces real-time sensory feedback to the user, and finally allows the user to interact with the virtual world [2].

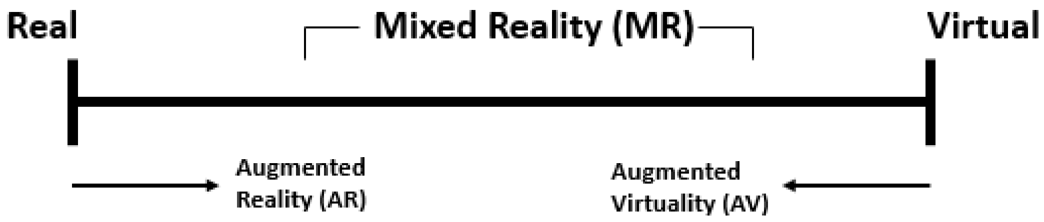

Figure 1. Virtuality Continuum. Adapted from [1].

A well-known example of AR application that captured the imagination of millions of users is the video game application "Pokémon Go." There a smartphone camera is used to capture the real world and the phone overlays images on that environment; the combined image displayed on the phone's screen gives an impression of an augmentation to the real physical environment while allowing the user to interact with both the physical and virtual environments. While VR places the user in a fully simulated environment by using systems like the popular video game "Beat Saber," MR falls somewhere between AR and VR where it creates a mixing of both virtual and real environments. Examples of MR would be a hologram or images of the virtual environment projected on the physical prop, like in case of the Virtual Sand Table [3].

Currently the use of VR/AR in all branches of the DOD are very limited. However, the data collected during our site visits and online research helped us identify several specific areas where VR solutions are used to train individual skills. For example, the Zumwalt Training Facilities use a virtual maintenance trainer that allows a user to interact with the 3D objects and check technical manual while practicing specified actions. The Littoral Combat Ship Training Facilities also use a VR ship that can be toured by new sailors to familiarize themselves with the ships' layouts while learning basic ship-specific information.

A primary focus of many USN and USMC training facilities is to learn and develop team skills and practice skill integration in an environment that resembles their operational environment as much as possible. As a result, many training facilities have developed simulator-based training. Large simulators allow team members to physically see each other and experience the same events while operating together. The ability to observe visual cues and body language from team members is very important when developing team communication and cohesion. Therefore, our goal is to take the existing aspects of VR/AR and find ways they can be incorporated and improve the USCG training experience through a systems analytical mapping approach.

Again, it is important understand what is meant by a simulator or how that is different from VR, AR, or MR. For the purposes of this research topic, we define a simulator as a computer-based real-time simulation whose user interface is a mock-up of the actual user interface from the operational environment. Visual displays in simulators are typically in the form of large screens, and user interactions are supported by a range of input devices that resemble devices used in operational environments. A good example of a simulator is a flight simulator with a user interface like the mock-up instruments that exist on real aircraft.

The success of this research may enable significant cost savings for organizations such as the USCG and across DOD. For instance, cost savings may be realized by using VR/AR systems in the USCG that have been transferred from the USN or USMC. The USCG's 2023 budget of $13.8 billion is small compared to the USN and USMC ($230.8 billion [18]), and cost savings in training could be used to invest in other important aspects of the USCG's mission [19]. Reducing training costs could free up funds for pressing needs such as purchasing more Sentinel Class Cutter ships to help offset the some of the missions intended for USN's Littoral Combat Ships (LCS) [20]. This has been one of the recommended solutions to dealing with continued issues with the LCS.

2. Specific Contribution

This article develops an SE analysis method specific to VR/AR training that evaluates the feasibility of transferring and adapting VR/AR training systems between different organizations. The method can help decision-makers to make more informed decisions when evaluating VR/AR training systems for transfer into their organizations. A case study of re-use of VR/AR training solutions from the USN and USMC to the USCG is provided to show how this method can be used for national defense applications although the method can be used in civilian applications as well.

The rest of this article is laid out as follows: first, we begin with an in-depth literature review that analyzes training programs that use VR/AR, examine key aspects of SE fundamental principles, and explore SE methods that are later developed to evaluate training program carryover for the USCG. We establish a baseline on how VR/AR training programs are currently evaluated via our literature review. We next discuss several visits to local USCG facilities to collect a set of needs specific to individual units, and current data on training results and training system capabilities. Technology market research is then conducted to evaluate the current capabilities of commercial off-the-shelf (COTS) equipment, training systems, and training programs; and we examine their potential to address the needs of the USCG. Next, an evaluation of USN's currently utilized VR/AR training solutions is performed, focusing on their determined effectiveness and potential to support USGC training needs. The collected data sets were used to develop our analysis method that helped evaluate training options. The results of the analysis can help the USCG identify the potential VR/AR training systems that may fit USCG training needs and make informed decisions on the re-use of USN and USMC VR/AR training solutions.

C. LITERATURE REVIEW

This section provides a literature review of several important topics related to the research presented in this article. A discussion of recent VR/AR implementations in a variety of domains is presented. This includes civilian applications and national defense applications.

VR/AR has slowly become more ingrained in training and learning, providing more efficient solutions for a number of domains. The availability of those systems has improved quite dramatically over the last decade. For instance, there is an increasing number of research efforts related to VR/AR training integration into school systems. Zhang and Wang outline a detailed analysis of VR/AR research studies related to teaching and learning science in the K-12 school system [21]. Their review of 61 studies categorizes them by learning method, grade level, study topic, analyzed learning aspect, and types of devices used. While Zhang and Wang have only a partially completed list of research in K-12 VR/AR, their work demonstrates the broad scope of the possibilities that VR/AR have as a teaching or learning aid in schools. In many instances, VR/AR allows students to understand complex concepts, see or interact with virtual worlds. Examples of this enhanced learning include the use of three-dimensional (3D) model of the solar systems to help kids learn astronomy [22], an AR application to view chemical reactions of different atoms and molecules [23], and the study of cells [24]. Colleges are also beginning to incorporate VR/AR into their curriculums and in variety of research areas [25].

The medical field represents one of the largest domains that embraced the use of VR/AR in both the educational and professional settings. For instance, at the Enea China Service and Research and Development Center, an interface system that uses a hybrid VR/AR technology was created for smart devices [26]. That interface can perform a variety of tasks for medical personnel from improving patient interactions by explaining complex topics like the cause and possible treatments of diseases to surgical procedure practices. The medical field also incorporates VR/AR training in areas that can be difficult to visualize or comprehend in a 2-dimensional space. Shaanxi University studied the effects of using VR/AR to teach anatomy and related surgical procedures [27]. This system allowed students to perform virtual inspections of 3D anatomical parts such as a diseased heart. That has many benefits, including not having to maintain real world specimens and allows for better ease of access for students. The possible applications of VR/AR in the medical field are immense, from treatment of phobias [28], phantom limb syndrome [29], and improving disabilities related to autism [30]. Additionally, many institutes explore the use of VR/AR in surgical training [31], [32], [33].

The military has embraced many forms of virtual immersive learning. Examples, include the use of VR/AR to train aircraft maintenance skills [34], to aid training in places and situations that are too expensive, dangerous, or time consuming to conduct using real systems. For instance, the launch of a missile can be very expensive, so it is more cost effective to train a soldier on missile launch procedures in virtual environment instead.

Early use of simulations—in this case physical simulations— for military training started in the late 1920s with the use of flight simulators created by the Link Company [35]. Simulators still represent the major form of training solutions. They support skill integration for both individuals and teams, and in most cases, they integrate the interfaces found in operational environments. Many pilots, especially in the flight schools, still conduct large portions of their flight time in simulators [36]. Other examples of training simulators include simulators for training of Bradley tank crews [37], different bridge simulators for ships [38], and an assortment of vehicle driving simulators [39].

AR also has its own place in military applications. The typical AR display is AR Heads-Up Display (HUD) that can use either an optical see-through visor or a video see-through display. HUDs can use screens or lenses to overlay important information over a view of the real world without obstructing the users' view [40]. Information overlays have many practical military uses ranging from overlays with building names and street markings for easier movement in urban environments [41] to important navigation and flight control information for pilots [42]. HUD is also found in some civilian luxury automobiles [43] and civilian planes with advanced glass cockpits [44]. The major advantage of AR in the field of training is that a trainee can interact directly with objects while providing a virtual overlay [45]. Though AR has these advantages, it still requires the infrastructure for live training and all the associated costs with maintaining that training facility or platform.

VR training systems use fully virtual environments thus removing the need for large facilities and physical infrastructure. While AR thrives in applications that require presence of the real-world objects, VR offers more flexibility as it assumes that the entire environment is fully virtual; the quality of images presented on VR displays is also much better. Additionally, VR can even allow for low cost and large-scale battle simulations involving many participants [46]. Even though these large-scale events are possible, they are still rare in practice as any multiuser application requires additional infrastructure to support its work. As a result, many of the current uses are focused on individual training or a small group training. An example of military use of individual VR training exercises is decision-making training, which can cover a wide range of tasks from mission rehearsals [47] to ocean navigation [48]. There are even examples of soldiers training in virtual firing ranges using full scale rifles as passive haptic devices [49].

The reason we have built an understanding of civilian and military aspects of VR/ AR simulators in this article is to apply SE principles to these systems and develop a method of mapping one existing training program that uses VR/AR training solutions to a new training program. A systems engineer examines the basic needs of stakeholders and determines fundamental aspects that a system must have to be able to accomplish those needs. In this case, the need of the stakeholder is expressed in a system mapping of VR/ AR training solutions.

SE is still a relatively new discipline, with the term “systems engineering” only appearing around the 1940s and with the first SE curriculum being developed at MIT in 1950 [50]. NASA defines SE as “a methodical, multi-disciplinary approach for the design, realization, technical management, operations, and retirement of a system” [51].

To create a system map, we choose between two different SE principles to conduct a needs evaluation and develop requirements that represent the proposed training objective. This can then be used to compare a proposed training objective to current available training solutions and determine if the available VR/AR training systems can adequately meet the new training needs. To conduct this evaluation, we perform a value hierarchy using a Pugh Matrix or a CBA. In a Pugh Matrix, a baseline system or component of a system is compared to alternatives across a set of categories to determine an overall better performer

[4]. A CBA uses a weighting system to assign importance to attribute categories to evaluate different systems [5]. In this instance, the systems we compare are the different VR/AR and simulator training solutions, and the categories used are determined based on data collected from the site visits and literature. The Data Analysis section provides a more detailed description of the method used to develop the system map.

D. DATA COLLECTION

This section details the process taken for gathering data as well as the Naval Postgraduate (NPS) requirements that must be followed when performing specific methods of data collection.

Gathering data for this project was done by several methods. First, we conducted interviews with active-duty students attending NPS to define the instruments for the future formal data collection and get the firsthand factual data about the military training solutions that they had used; we did not collect personal opinions and recommendations, only factual data about different training systems. Second, we conducted research on current and future uses of VR, AR, and simulators in the area of both the military and civilian training. Finally, we conducted on-site visits to multiple training facilities that currently utilize different forms of immersive training.

Since much of the data collected was done through interviews with human subjects, our approaches and questions had to be screened and pre-approved by the NPS Institutional Review Board (IRB). The questions we asked were determined to be only factual data related to training systems, and therefore our study was approved with no need to conduct full IRB process.

Site visits were conducted at Camp Pendleton, San Diego Naval Base, and local USGC facilities. At each site we conducted interviews with base personnel responsible for training program. The questions asked had two major purposes: 1) to allow for the cataloging of VR, AR, and simulators used for training, and 2) to gain information that can help develop the categories to be used in the evaluation of training systems and the mapping process. These categories are determined by observing overlapping characteristics and commonalities between different training systems.

Each of these categories is then used as an evaluator in a value hierarchy. Individual categories can then be compared and weighted across systems that are being reviewed. Since there is a clear distinction between the chosen categories and cost factors, they are evaluated separately.

E. DATA ANALYSIS

The data analysis section describes how the data collected in interviews was transformed into system attributes that were used in the analysis process.

From all the data collected during the site visits, interviews, and research, we chose seven attributes for mapping and evaluation of the training systems' potential and its consideration for system transfer:

1. Skill(s) the system supports
2. Skill transfer capability between the two systems
3. How easy the system is to modify
4. Training systems size requirements
5. Maximum throughput
6. Training location (fixed/portable)
7. Number of personnel required for operation and upkeep

Attributes one and two both focus on the systems' abilities to incorporate and impart the desired skills to the individual(s) being trained. While the remaining five attributes are important, without the first two attributes specific systems would lose their purpose. We first briefly describe the latter five attributes with further discussion of these attributes later in this section.

System modification or system adaptability is an important measure of a system's ability to be upgraded or to evolve [52]. More importantly for this research, the easier a system is to modify, the easier it can be adapted to a new training program. Throughput was chosen as it is an important measure in a system that provides production or processing [53]. In this instance, what is being processed is people through a training program.

Throughput and personnel required for operation are also measures that affect military manning. The importance of manning is even more important as many of the branches have had large recruiting shortfalls [54]. Training system size and location are both attributes that affect how the system infrastructure is built and complexity of design. Next, we discuss the first two attributes that are most critical to our efforts.

The first attribute, skill(s) the system supports, compares the skills the new system needs to be able to train and the skill(s) available for each of the existing VR/AR training systems. This is an important verification that the proposed systems will indeed meet the baseline requirements of having the required skills. In instances where the new system is desired to train multiple skills, not every proposed system may meet all needed skills. This can allow decision makers to remove potential skill training from the new system to allow for easier system transfer; they may also understand what additional modification might need to be made to the existing system to meet the desired requirements.

Skill transfer capability (attribute 2) analyzes whether clinical research on the system being evaluated has been performed. To prove that a training system and training method are truly effective at training the desired skill(s), research must be conducted. It should be noted that this research is separate from research related to transfer of training studies. This research should directly examine if the skills that were trained by the system transfer to operational capability improvement. As an attribute it will be evaluated binarily as a “yes” or “no.” “Yes” signifies that research has been conducted and it shows that skill acquisition and skill advancement is possible while “no” indicates that research was unable to prove a correlation or that no research has been performed yet.

Another important aspect is how easy the original system is to modify to suit the needs of the new system (attribute 3). This can be achieved by modifying the hardware, software, or training methods. In practice, that modification may not be easy to accomplish due to the complexities of contractual work with DOD. In case an easy modification is all that is needed, that serves as the best indicator of the flexibility integrated in the system.

Size requirement (attribute 4) is the amount of space required to house the system or how large the system itself is depending on the system’s infrastructure. The system size requirements for most COTS products (those are generally handheld, lightweight devices) are relatively small. The large integrated simulators, however, require a substantial amount of space; after all, the simulators try to recreate a specific operational space accurately, and that can vary in size. The system size has many important implications, such as its ability to be transported, how it can be stored, and possibly how many individuals can use it at one time, to name a few.

Maximum throughput (attribute 5) is a measure of the number of individuals that can complete the training program in a given time. One of the most challenging aspects of the military is personnel management; individuals are constantly transferring, joining, and retiring, which creates a constant demand to train those individuals for new positions and skills. Job openings and transfers are planned months in advance, and delays can cause major personnel shortages, which drastically reduces unit effectiveness or operations. Therefore, understanding training pipeline timing is vital for optimal personnel planning. Many civilian companies experience the same situation in their work.

A training system being either fixed or portable (attribute 6) is related with the complexity of the system hardware and infrastructure requirements. A system that requires a fixed location is likely to have much more infrastructure involved in its operation and be much more time-consuming and expensive to maintain. Whether the system is fixed or portable also affects the system's availability. If a system is only at fixed locations (especially if it is available at very few locations), it requires trainees' travel or potentially temporary duty assignments depending on the length of the training period required. Portable training systems can be sent to locations where training is needed and, in that way, avoid travel expenses for the trainees. Depending on demand for the system, the entire operation will require the system that is capable of tracking many pieces of hardware across many facilities.

Like the discussion of throughput, the number of personnel required to operate and maintain the system (attribute 7) is very important; the personnel are the military's and most companies' most significant resource. For each individual that is required for system operation, that one less individual that is available to carry out another important job somewhere else. All individuals also must undergo training on VR/AR system operation and study the course material to ensure trainees are receiving effective training. Requiring too many people for system operation can lead to manpower shortages at other locations or lead to the training location to be understaffed, which can negatively impact training value of the entire system.

We use two different SE processes to analyze these seven attributes: the Pugh Matrix and CBA. The Pugh Matrix is best used when there is already a system of interest or a predetermined set of standards, and the users want to compare alternatives [55]. The Pugh Matrix uses neutral, plus, and minus values to determine differences across categories and treats all values and categories as having equal weight [56]. A CBA allows the user to provide weights to each category based on their importance [5]. The CBA also incorporates cost factors in a separate portion of the analysis. Since the category analysis is separated from the cost analysis, we chose to perform the same cost analysis, whether using the Pugh Matrix or the CBA.

The division of attributes and their respective analyses are rather straightforward; however, the analysis of cost is much more difficult. As there are multiple different ways the same training can be performed, there is also no set cost for training a specific skill. To account for this and allow for a more accurate comparison, we developed four cost options that can be estimated for each potential system. These options are as follows:

1. Cost to perform live training
2. Cost to own and maintain the system
3. Cost to travel (if applicable)
4. Cost to rent system from others

These options were chosen based on data collected what was observed from our site visits and personnel interviews. Each of the four cost-related options concerns the existing system training options available to the DOD. Those three primary options are live training, performing training at a training facility owned by the branch, or using another branch's training facility. Travel cost can be common across all forms of training, which is why it was separated into its own category.

Live training (cost option 1) is the performing of the actual event being trained for. For example, firing live artillery rounds on a firing range is live training. The cost to perform live training is a comparison cost for the other cost metrics, as the system in question is to be used to supplement live training. This allows the user to see potential cost savings of using alternative solutions or that the cost difference is not worth the development of a new training system.

The cost to own and maintain (cost option 2) covers a large range of systems costs, including land purchasing (if required), infrastructure for the system, utilities, and staff costs, among others. Since this category covers such a large range of costs, it is split into two parts: a) the initial startup cost and b) the yearly upkeep costs. Splitting the cost in this manner allows the user to understand how this system will impact the department budget annually. Another aspect of both cost aspects is that the user must evaluate how many sites are required to perform the required training effectively. Many training programs will likely require either a sizable individual site or multiple smaller sites to meet desired throughput requirements for military needs, for instance.

Travel costs (cost option 3) apply to all of the cost options unless the system is portable and can be shipped to different locations when required. For instance, due to a large number of USCG stations spread across the United States and the globe, even with several centralized training centers, there will still be significant incurred travel costs. As the number of training locations decreases, the travel costs incurred increase. One portion of travel costs we do not address in this article is the loss of man-hours due to travel. The longer the travel time and the more times travel is required to complete training, the more it affects productivity and increases the number of lost working hours. As this is difficult to assign an actual dollar value to, we do not consider it in our evaluation. However, lost man-hours are still something the system owners should recognize.

System rental (cost option 4) is the final option we use in cost evaluation. This option, for example, is the USGC paying other branches of the military to use their pre-established VR/AR training systems. Though this is likely the least expensive option, it has many downsides that may not be initially apparent. Existing systems used by other military branches were developed to meet the training needs of those branches, and therefore there may be differences that could lead to negative training or learning habits that are not well aligned with targeted techniques and procedures. In this scenario, the USCG would also be reliant on an outside entity for training and, therefore, may have less control over the material that is taught and the focus of that training. Finally, the USCG would also likely receive lower priority on being given seats in each class or training group which could lead to significant delays in personnel receiving required training.

F. MAPPING STEPS

This section outlines each step that should be performed while conducting the system analysis to allow an easier understanding of the process that was applied in the case study.

1. Step 1

After completing the data gathering and category determination discussed in the previous sections, the first step in conducting the analysis is to choose what systems need to be compared. It is best to analyze many systems that may fit the requirements. Removing systems from consideration before conducting the analysis may prevent one from seeing benefits or advantages that could be incorporated into the new system.

2. Step 2

The second step is to determine the SE analysis method that will be used. We discussed the use of the Pugh Matrix and the CBA and will use them when conducting further analysis and our case study. There are many other forms of analysis that could be used, so it is important to understand what methods represent the best fit the specific needs.

3. Step 3

Since there are two potential selections for Step Two, Step Three will vary depending on which SE method gets chosen. If the Pugh Matrix is chosen as the analysis method an ideal system or baseline system must be chosen as the basis for comparison. As previously stated, the Pugh Matrix uses +/-'s to indicate if the comparison system is better or worse than the baseline. The selection of the baseline system can vary based on the project; it could be the system that the user views as the best candidate, the system that stakeholders want to use, or several other possibilities. Regardless of how the system is chosen, the baseline system is critical as all other systems in the analysis will be directly compared to that system. The CBA step three involves placing weighted values on each of the categories. The weighted values are assigned to each category as a measure of importance that each category holds in the overall selection of the final system. The total sum of all the weights should not exceed 1 (or 100%). These weights will then be used in a later step to determine our final system rankings.

4. Step 4

Step Four determines the initial value estimates for each attribute category. This step will be the same for the Pugh Matrix and the CBA. Initial value estimates are the real-world values that would be associated with that specific attribute category. For example, if the attribute is top speed, the initial value estimate would be that system's top speed, ensuring that the units are consistent for all systems.

5. Step 5

Next, Step Five replaces these values with the values that will be used for analysis. For the CBA, the values of each attribute category will be normalized. Normalizing a set of values depends on whether a large number or small number is preferred. If a large number is preferred, each number in that attribute category will be divided by the largest number in that attribute category. After this, the largest number of each attribute should now be a maximum of 1. If a small number is determined to be preferred than the smallest number in that attribute category will be divided by each of the initial values. The smallest number should now be a value of 1, with all other values being less than 1. For binary attribute categories, a 1 is assigned if it is the preferred response and a 0 if not. The process is different for the Pugh Matrix where, instead of normalizing the initial value estimates, they are compared to the baseline system. If the value for that attribute category for that system performs better than the baseline system a "+" is placed in the box. Additional "+"s can be used if there are significant performance differences that the evaluator believes should be noted. Conversely, if the performance is worse than the baseline, than a "-" will be used. Again, additional "-"s can be used to denote a significant performance difference from the baseline.

6. Step 6

Step Six in the attribute analysis is to tabulate the final overall attribute scores of each system. For the Pugh Matrix, this is a simple summing of the "+" and "-" values. The system with the highest positive value will be the system determined to fit the user's chosen bounds best. The CBA ranking tabulation is a sum of the normalized values multiplied by the weighting for that attribute category. Again, the system with the highest value is the system that is evaluated as the best fit.

7. Step 7

Step Seven, the final step in the analysis is to calculate the costs for each category decided on in Section E. Since cost calculation is very significantly depending on the system or training method being analyzed there will be no set procedure. The person performing the analysis must use their best judgement in determining what values are important. An example of simplified cost estimation can be found in the case study below.

G. CASE STUDY

A case study is an example of how we used the mapping steps from section F and incorporate the data that has been collected during the course of the research.

As an example of how a practitioner can use the mapping system we proposed, we provide a case study using a USCG Medium Endurance Cutter (WMEC) Famous class ship driving simulator. All estimated values used in this study are explained in full detail to ensure that reasoning for the estimates is clear and understandable.

1. Step 1

As the first step in our analysis, we choose three potential training solutions to compare in our mapping process: 1) the Conning Officer Virtual Environment (COVE) III trainer, 2) an integrated navigation team trainer, and 3) a COTS Oculus Quest 2. There are significantly more systems that could be applicable for analysis, but as this case study is only provided as an example or outline of the process we will limit the number of potential system solutions.

2. Step 2

There is no existing baseline solution, and so for the step two of our analysis, we use the CBA to compare three possible training solutions. If there was a baseline solution, or a particular training method already chosen, the Pugh Matrix would be the preferred method of analysis.

3. Step 3

The third step is for the evaluator to assign a weight to each attribute category based on its importance; the sum of all weights should be equal to 1.0. For this scenario, we assign the highest weight to skills the system supports because the system loses its purpose if it does not meet skill requirements. The required personnel and throughput are assessed as the next most important as they are directly related to personnel. As previously established in Section 4, personnel requirements or burdens are critical in military system evaluations. Skill transfer capability is set to have the lowest importance because, unfortunately, there are no research studies focused on system transfer.

4. Step 4

Step four concerns a determination of our initial value estimates (details are presented in section E). For this step it is important to understand the bounds of analysis and appropriately apply those same bounds to each system analyzed. For example, when selecting initial value estimates for throughput the same time scale must be used. Whether it is one day, one week, or one year all the systems must be analyzed over that same time scale for throughput to be appropriately evaluated. This is also true for attributes that may be more subjective such as system modification. For subjective attributes the individual conducting the analysis must set guidelines to reduce the subjectivity and apply those equally to each system. Table 1 lays out the culmination of the first four steps of the analysis in an easy-to-read format:

Table 1. Initial Value Estimates for CBA

Attributes	Weight	COVE III	Integrated Trainer	Oculus Quest
Skill(s) the System Supports	0.25	6	10	2
Skill Transfer Capability	0.05	no	no	no
System Modification	0.1	1	8	10
Size Requirements	0.1	100 sq ft	900 sq ft	0.34 sq ft
Throughput	0.2	5 people	25 people	1 person
Training Location	0.1	fixed	fixed	portable
Personnel Required	0.2	1	3	1

5. Step 5

Next, for Step Five, we will take the estimated values from Table 1 and normalize them in Table 2. Value normalization allows us to take attributes with different ranges or data values and create a normalized ranking that can be summed in step six. Refer to step 5 of section F for detailed explanation on how normalization is performed. As displayed in Table 2, following the normalization of values for each attribute, the maximum value a system can have is one.

Table 2. Normalized Values for CBA

Attributes	Weight	COVE III	Integrated Trainer	Oculus Quest
Skill(s) the System Supports	0.25	0.6	1	0.2
Skill Transfer Capability	0.05	0	0	0
System Modification	0.1	0.1	0.8	1
Size Requirements	0.1	0.0034	0.0004	1
Throughput	0.2	0.2	1	0.04
Training Location	0.1	0	0	1
Personnel Required	0.2	1	0.33	1

6. Step 6

The final step for the attribute analysis, Step Six, is executed in Table 3. Each normalized value is multiplied by the weight of the attribute category to create a weighted rank for each attribute category and system pair. These weighted ranks are then summed for each system to find the total weighted rank. This total weighted rank is a numerical estimate of the systems' value. The system with the highest total weighted rank is the system that best fits the evaluators' set conditions.

Table 3. Weighted Rankings Calculations for CBA

		COVE III		Integrated Trainer		Oculus Quest	
Attributes	Weight	Rank	Weighted Rank	Rank	Weighted Rank	Rank	Weighted Rank
Skill(s) the System Supports	0.25	0.6	0.15	1	0.25	0.2	0.05
Skill Transfer Capability	0.05	0	0	0	0	0	0
System Modification	0.1	0.1	0.01	0.8	0.08	1	0.1
Size Requirements	0.1	0.0034	0.00034	0.0004	0.00004	1	0.1
Throughput	0.2	0.2	0.04	1	0.2	0.04	0.008
Training Location	0.1	0	0	0	0	1	0.1
Personnel Required	0.2	1	0.2	0.33	0.067	1	0.2
		Total=	0.400	Total=	0.597	Total=	0.558

Of the three systems' final total weighted ranks, the one that best fits the chosen attributes is the Integrated Trainer. When looking at the weighted rank values for each attribute, it can be seen how important the initial weighting assigned to each attribute is for the result. Our highest weighted attribute category is the skill(s) the system supports which the Integrated trainer has a large advantage, and that weighted value is attributed to slightly over 40 percent of its total weighted rank value. Slight changes in the attribute weightings or initial value estimates can drastically alter the results of the analysis. Therefore, evaluators must be very thorough when determining each value being used.

7. Step 7

Cost evaluation is the final portion of the decision analysis. To simplify the cost analysis, for this example, we will only look at one year of operation. Typically, when evaluating system costs, a full life cycle cost should be determined. Also, to simplify the analysis, it will be assumed that only one location with one version of the system will be built for both the COVE III and the Integrated Trainer. That one instance of the system will be located in Monterey, CA. This training only needs to be completed once during this one-year period for each qualified individual and takes one day to complete.

Table 4 shows the calculated values of each of the four potential cost categories that were developed in section E.

Table 4. Cost Estimations Analysis

	COVE III	Integrated Trainer	Oculus Quest
Live Training	$135,496.10	$135,496.10	$135,496.10
Own and Maintain	$250,000	$600,000	$1599.96
Travel	$55,825	$55,825	N/A
Rental	$0	$0	N/A

To estimate live training costs for the WMEC Famous class the total number of ships in this class had to be determined. From *The Cutters, Boats, and Aircraft of the U.S. Coast Guard* we were able to find the number of ships in that class, thirteen, as well as the home port location of each; this will be used later for travel estimates [57]. Next, we need to determine the amount of fuel spent during the training time underway. For this a weighted average was calculated using an USGC report published in 2000 pertaining to fuel consumption [58]. The weighted average was calculated by determining the percentage of total hours operated in specific modes and speed with how much fuel those modes consumed. A final weight average total of 112.8 gallons per hour was determined. The cost of diesel was assigned as 6.16 dollars per gallon, as the average cost of diesel fuel in California at the time of writing this report [59]. The last two numbers required are both estimated: the number of hours required to complete the training and the number of individuals that require the training per ship. We will assume that a total of three hours is required to complete the training and that there are five individuals per ship that are required to complete the training. Using all these values allows us to arrive at the final total of $135,496.10 for a live training cost.

The cost to own and maintain was only calculated based on yearly operating cost and was estimated from data obtained from interviews of personnel operating training facilities. Since we are only looking at one instance of a COVE III or Integrated Trainer infrastructure costs for building training facilities associated with COVE III or Integrated Trainers, which would cost on the order of tens of millions of dollars, was not considered. For the Oculus Quest cost, it was assumed that only one was required at each of the four base locations for the individuals to complete their training requirements.

Travel costs were calculated using the home port locations mentioned above [57]. Flight costs were calculated using those home port locations. Per Diem, or lodging, meals, and incidentals, rates were found on the USGC website [60]. The cost of travel for each individual that requires training was calculated by summing the cost of flights and Per Diem rates. Total cost was then determined by summing the travel cost of each individual.

System rental cost was obtained from interviews with personnel operating training facilities. The value we use may not be accurate with all training facilities; for this specific facility, individuals from other branches are not charged any additional fees, and they are only responsible for their travel costs.

It must be noted that these cost values are not all-inclusive, nor take into account all potential aspects that the evaluator should consider. That was meant to provide a simple example of how the process could be performed. For example, other aspects that could be considered during live training include putting run hours on all the equipment, potential maintenance that could be required following the underway, and a risk of injury or accident while underway. While those items do not necessarily have a monetary value, they should still be considered by the evaluator.

The most effective solution is not necessarily apparent from the evaluation of both cost and system attributes. The integrated trainer performed better in the attribute analysis, while the COTS Oculus Quest is the most cost-effective. In this instance, the individual would have to either include additional attributes to the analysis or decide whether the difference in costs or capabilities is more important.

H. DISCUSSION

Though this article focuses on training methods that use VR, AR, and simulators, many of the principles used throughout can be replicated in many other domains. This is especially true in the domain of transfer of training and this research. This process is not limited to the USCG and the USN but could be used by any organization that is looking at incorporating new training methods from already existing possibilities. The basis of the system mapping was developed from standard SE principles and can be found in many other applications. With the correct application of SE, system development and overall decision-making processes can be improved dramatically and help prevent future rework, redevelopment, or a complete overhaul of systems.

The research presented in this article is not all encompassing. Out of the total number of military bases that could be surveyed, only a small number were surveyed. The study also focused on the transfer of training systems from the USN and USMC to the USCG, so very little data was collected on systems developed in support of training needs of the United States Air Force and Army, let alone foreign militaries. Limiting the scope of those surveyed removed many potential systems that could have been analyzed, though transferring training systems between foreign militaries may add additional constraints in other areas. These limits were specifically put in place to reduce the complexity of the study and develop a pilot of a mapping system that can be further expanded upon in the future. Future analysis of other areas can be conducted to expand the scope of the mapping system further and allow for improved decision-making.

The current limited use of VR/AR also affected our research. As previously mentioned, most of the training aids we evaluated are simulator based. Simulators have been used for much longer time; they became programs of record and they benefited from that investment and years of experience that training sites accumulated. VR and AR training solutions, however, are still a novelty in military domain, they are not programs of record and have no secured funding every year. All that resulted in their current modest rate of utilization in training regimen.

The cost of acquiring any training solution is an important hurdle that any organization has to deal with; it often impacts the final decision. It is therefore vital that the decision-makers minimize cost while maximizing the potential training benefits due to the limitations in budget; this is especially the case with the USGC. For example, if there are training courses that would benefit from having large facilities but are conducted infrequently, the same training facilities can be established in a location that minimizes the cost of travel for the trainees who need to use those training systems. It is, of course, true that by minimizing number of facilities (not having them on each base) travel costs will be increased, and the cost-benefit analysis will need to be carried out. The USCG can also investigate sharing facilities with other local branches of the military or building joint facilities, allowing benefits for both groups.

I. CONCLUSION AND FUTURE WORK

As previously mentioned, the USN and USMC use of VR/AR is fairly limited. Even though there have been dramatic advances in VR/AR technology, their benefits to military domain still needs to be studied. One way of achieving that is by establishing new programs of record with secured funding lines that will include studies of training effectiveness and transfer of training. Simulators are also staffed with personnel that are trained to teach and improve specific skill sets while COTS VR/AR training would most likely take place at the individual's command. While the affordability and distribution of VR/AR training resources is a good thing, the management of those training systems would need to be done by the local commands. Additionally, tracking the progress of training would be more difficult for organizations responsible for training.

There are several other hurdles that would need to be addressed prior to implementation of a COTS VR or AR training program. One of the biggest and most difficult is individual buy-in. If there is no push for use of the training program or proof of concept the training will not be taken seriously and with the removal of supervisory personnel, there will be a major degradation in the quality of the training received. The next issue is the actual program creation, training plan, progress tracking, etc. It is possible that some branch has already begun work on some of these aspects, but during our research and site visits there were no programs developed around COTS VR/AR. This means that many of these program aspects would need to be developed from scratch. Government policies also create certain issues in implementation of system transfer not only between branches but even within the same branch. When new software and hardware is being developed or built, they are put up for contract bidding. If a specific system was designated as the desired system to be used for transfer, it is likely that a completely different company than designed that system would be tasked with the new system development. This can lead to aspects of the system changing or functions missing during the new development that were the reasons behind that system being chosen in the first place.

For potential future work, expanding the scope of research represents the largest area of potential investment. For this research, we were limited to just the USN and USMC for locations to pull potential VR/AR training methods. There are many more potential areas that could be drawn from such the other military branches where there may be many overlapping training requirements that could lend to shared training. Methods can also be drawn from other places that have any overlap with USGC training such as local police, the FBI, U.S. Border Patrol, and other similar organizations, fire fighters, or medical institutions where there is some overlap with USGC missions.

As this approach can be used across multiple domains and communities there needs to also be research conducted confirming that flexibility. Verifying that this approach works outside of the military domain like in areas of industry is an important step in being able to incorporate this process across the DOD. Allowing for implementation in multiple areas and not just training can further reduce budgeted spending.

Finally, research should be performed looking into what is limiting or preventing COTS VR/AR from being implemented into the military training program. Determining what the barriers to implementation are can allow for corrections and adaptations in newer systems. Incorporating COTS VR/AR systems into the DOD training program will allow for more flexibility in when and where training can occur and allow for easier access of immersive training.

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III. CONCLUSION

Though this thesis focuses on training methods that use VR, AR, and simulators, many of the principles used throughout can be replicated in many other domains. This is especially true in the domain of transfer of training and this thesis. This process is not limited to the USCG and the USN but could be used by any organization that is looking at incorporating new training methods from already existing possibilities. The basis of the system mapping was developed from standard SE principles and can be found in many other applications. With the correct application of SE, system development and overall decision-making processes can be improved dramatically and help prevent future rework, redevelopment, or a complete overhaul of systems.

The research presented in this article is not all encompassing. Out of the total number of military bases that could be surveyed, only a small number were surveyed. The study also focused on the transfer of training systems from the USN and USMC to the USCG, so very little data was collected on systems developed in support of training needs of the United States Air Force and Army, let alone foreign militaries. Limiting the scope of those surveyed removed many potential systems that could have been analyzed, though transferring training systems between foreign militaries may add additional constraints in other areas. These limits were specifically put in place to reduce the complexity of the study and develop a pilot of a mapping system that can be further expanded upon in the future. Future analysis of other areas can be conducted to expand the scope of the mapping system further and allow for improved decision-making.

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