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ARTIFICIAL INTELLIGENCE APPLICATIONS FOR AUTOMATED BATTLE MANAGEMENT AIDS IN FUTURE MILITARY ENDEAVORS

by

Geoffrey B. Grooms

June 2019

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13. ABSTRACT (maximum 200 words)

This thesis seeks to study artificial intelligence (AI) technologies that can improve decision-making in complex military tactical environments. Tactical environments can become highly complex in terms of threats, the tempo of events, the element of surprise or unexpected events, the limits of battlespace awareness, and the potential deadly consequences. This type of environment translates into a highly challenging decision space for tactical warfighters. Tactical decision-making tasks quickly surpass the cognitive abilities of humans in terms of identifying decision options, weighing the relative value of numerous options, calculating the predictive success of options, and performing these tasks under extremely short timeliness. The Navy has identified the need to develop automated battle management aids (ABMA) to support human decision-makers. The concept is for ABMAs to process large amounts of data to develop battlespace knowledge and awareness and identify and prioritize warfare resource and course of action options. Recent developments in AI methods show promise as a critical enabler of ABMAs to support tactical decision-making. This thesis studies AI methods with an objective of identifying specific applications to the realm of tactical decision-making.

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ARTIFICIAL INTELLIGENCE APPLICATIONS FOR AUTOMATED BATTLE MANAGEMENT AIDS IN FUTURE MILITARY ENDEAVORS

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This thesis seeks to study artificial intelligence (AI) technologies that can improve decision-making in complex military tactical environments. Tactical environments can become highly complex in terms of threats, the tempo of events, the element of surprise or unexpected events, the limits of battlespace awareness, and the potential deadly consequences. This type of environment translates into a highly challenging decision space for tactical warfighters. Tactical decision-making tasks quickly surpass the cognitive abilities of humans in terms of identifying decision options, weighing the relative value of numerous options, calculating the predictive success of options, and performing these tasks under extremely short timeliness. The Navy has identified the need to develop automated battle management aids (ABMA) to support human decision-makers. The concept is for ABMAs to process large amounts of data to develop battlespace knowledge and awareness and identify and prioritize warfare resource and course of action options. Recent developments in AI methods show promise as a critical enabler of ABMAs to support tactical decision-making. This thesis studies AI methods with an objective of identifying specific applications to the realm of tactical decision-making.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABMA	Automated Battle Management Aid
AEGIS	Advanced Electronic Guided Interceptor System
AI	Artificial Intelligence
AI/ML	Artificial Intelligence/Machine Learning
BFT	Blue Force Tracking
C2	Command and Control
CCIR	Commander’s Critical Information Requirements
CIC	Combat Information Center
CNO	Chief of Naval Operations
COA	Course of Action
CONUS	Continental United States
COP	Common Operational Picture
DARPA	Defense Advanced Research Projects Agency
DBM	Decision Battle Management
DoD	Department of Defense
DoN	Department of the Navy
EW	Electronic Warfare
GCCS	Global Command and Control System
IP	Internet Protocol
IoT	Internet of Things
MTC2	Maritime Tactical Command and Control
SME	Subject Matter Expert
VTC	Video Teleconference

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I. INTRODUCTION

A. BACKGROUND

Artificial intelligence (AI) technologies have the ability to improve decision-making in complex military tactical environments. Warfighters in different tactical environments become overwhelmed due to the complexity in the environments. Warfighters are challenged to make quick decisions with the information available in order to achieve operational success. The development of automated battle management aids (ABMA) will support human decision-makers and increase tactical decision superiority. ABMAs will process large amounts of data to increase situational awareness to aid warfighters. AI methods will increase the functionality of ABMAs through leveraging new capabilities for warfighters to utilize.

B. PROBLEM STATEMENT

The Navy has identified a need to utilize and exploit the benefits of AI particularly in the realm of tactical decision-making. A growing number of sensors and networks are providing tactical commanders with an abundance of information. Tactical commanders must process an abundant amount of information and rely on their ability to disregard useless information and prioritize that which is relevant and actionable. Commanders are also constrained by timing and whether or not they have the correct information to make critical decisions that can present dire consequences. AI, through the implementation of ABMAs, provides a technology which can be used to assist commanders in processing information and making decisions. The utilization of AI needs to be studied and analyzed in order to be properly implemented into the battlespace to provide positive results to commanders.

C. PURPOSE STATEMENT

The purpose of this thesis is to better understand how existing and future AI methods can improve tactical decision-making. The benefits to the warfighter from this study include increased battlespace awareness, improved usage of warfighting resources, increased tactical advantages over adversaries, and increased decision superiority. The study explores how AI methods could specifically support the Navy's tactical missions. The study's objective is to support the Navy's development of ABMAs through increased knowledge.

D. RESEARCH QUESTION

The following research question serves as a focus of the study: How can AI methods be implemented to develop ABMAs to improve tactical decision-making?

E. RESEARCH METHOD

The research method that is used for this study is qualitative in nature with a post-positivism worldview. The research includes studying current and future AI methods and technologies, applying these methods and developing recommendations for AI technology integration. Guided interviews from subject matter experts and analysis of current developmental AI technologies inform these recommendations.

F. PROPOSED DATA, OBSERVATION, AND ANALYSIS METHOD

Data is to be gathered and analyzed from literary sources, subject matter experts, and tactical scenario development. Qualitative methods will be used to analyze data to identify and study current and future AI methods and their applications to tactical decision-making. A set of complex tactical scenarios are identified and studied to understand specific decisions that require ABMA support. Concepts for AI applications to support these tactical decisions are developed.

G. POTENTIAL BENEFITS, LIMITATIONS, AND RECOMMENDATIONS

Potential benefits of this thesis include increased naval tactical decision superiority, improved offensive and defensive warfighting, increased battlespace awareness, improved efficiency in the use of warfare resources, increased tactical advantages over adversaries, and the advancement of the state-of-the-art artificial intelligence techniques for warfighting ahead of the competitor advancements. The study is limited in scope to the tactical realm and the initial set of specific tactical decisions identified. It is also limited by the data available concerning AI current and future methods. Potential recommendations resulting from this thesis include concepts for increased implementation of ABMAs in conjunction with AI.

This study results will inform OPNAV N2/N6 and other organizations involved in developing solutions to improving battlespace awareness. An in-depth characterization of the four categories of battlespace awareness provide a framework for the application of AI and data analytic methods. Additionally, a mapping of these methods to specific tactical awareness scenarios, is an important step in developing a solution.

H. THESIS ORGANIZATION

This thesis is organized into five chapters. The first chapter provides an overview of the topic and describes the background, the problem this thesis is exploring, the purpose of this thesis, and the methodology and scope of the research. The second chapter gives a comprehensive background review of the definitions and concepts discussed within the thesis to include the concept of automated battle management aids, decision complexity and artificial intelligence and autonomous systems. The third chapter describes the research method that was used for coordinating data acquisition and understanding the requirements for retrieved data. The fourth chapter provides the results of the analysis and explores the potential benefits and limitations derived from the results of the analysis. The final chapter of this thesis contains final conclusions and recommendations for future work.

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II. LITERATURE REVIEW

A. INTRODUCTION TO AUTOMATED BATTLE MANAGEMENT AIDS

Command and control (C2) in the military will always be a difficult task requiring a view of reality with a focus on a multitude of factors that influence military command (Van Creveld, 1985). Decision makers in tactical environments are faced with a plethora of impactful decisions that need to be made in order for success to be possible. Even though each tactical environment is comprised of different complex issues, a universal theme seen across the board is that it is no easy task to make quick decisions which will impact the mission. Different decision support tools and concepts have been designed to help make the task of making decisions easier such as automation. The Cambridge Dictionary defines automation as "the use of machines or computers instead of people to do a job, especially in a factory or office" ("Automation," n.d.). Automated battle management aids focus on helping provide decision makers with a means to help them make the right decision.

1. Private Sector and DoN

As technology constantly grows and provides benefits to the U.S. military, it is becoming far more advanced and widely available around the world which enables adversaries to develop capabilities that outmatch U.S. forces (Jones, n.d.). Completely ignoring the responses to technological growth from adversaries has the potential to lead to catastrophic events. Lt. Col. Jones (n.d.) states that in order to overcome enemy threats, the U.S. military has shifted a substantial amount of its focus to developing increasingly complex systems to provide an advantage on the battlefield. A downside to the complexity introduced to the system through the expanded number of utilized alternatives is the introduction of battle management challenges (Jones, n.d.). Lt. Col. Jones (n.d.) states that "with both the complexity of coordinating innovative systems of systems, and the sophistication of adversary capabilities expected to grow, automated decision aids become vital". Automated battle management aids are currently being used by the military to originate operational pictures and increase situational awareness through the transfer of data (Johnson, 2017). ABMA utilization is key to ensuring future successes.

The realization of the potential to ascertain impactful benefits to naval decision-makers has not gone unnoticed to naval leadership. After thorough analysis, the U.S. Navy picked nine U.S. defense companies to develop and maintain military software for battle-management systems in 2015 (Keller, 2015). The nine companies that were chosen to compete for individual task orders are:

- BAE Systems Information Solutions Inc. in San Diego
- DCS Corp in Alexandria, Va
- Dynetics Inc. in Huntsville, Ala
- Progeny Systems Corp in Manassas, Va
- The Raytheon Co. Intelligence, Information and Services segment in Dulles, Va
- Tapestry Solutions Inc., a Boeing Co., in San Diego
- The Northrop Grumman Corp Information Systems segment in Herndon, Va
- QinetiQ North America Inc. in Reston, Va
- The Lockheed Martin Information Systems and Global Solutions segment in King of Prussia, PA. (Keller, 2015)

The Defense Advanced Research Projects Agency (DARPA) established a decision battle management (DBM) program centered around the development of automated decision aids to provide pilots and battle managers with software tools to oversee air and ground combat through increased C2 (Jones, n.d.). Refer to Figure 1 for an overview of the DBM program. Lt. Col. Jones (n.d.) highlighted one of the inherent challenges in the DBM program as expanding “foundations to develop new algorithms that are reliable in realistic peer threat environments”. Virtual combat simulations will play an important role in the integration of the advanced algorithms to reveal its benefits (Jones, n.d.). The identification of benefits when utilizing advanced algorithms will propel future integration and increase the development of more advanced algorithms.

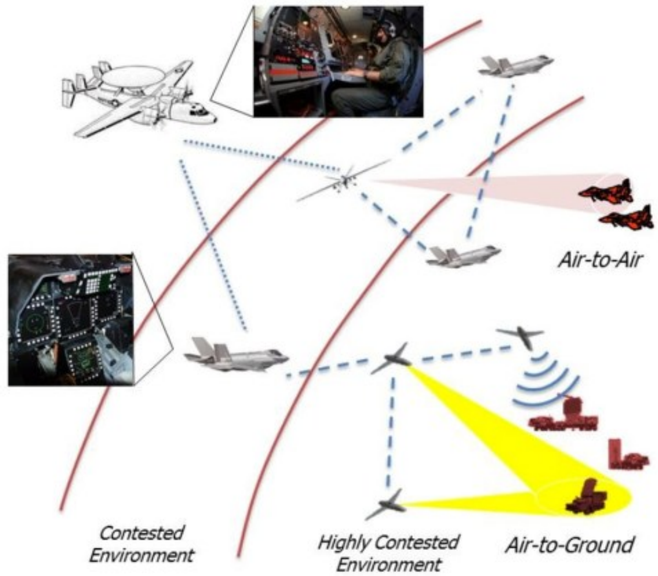

Figure 1. DARPA's Developed Automated Decision Aid. Source: International Defense, Security & Technology (2018).

The DBM program is focused on collecting and analyzing information to be delivered to operational warfighters though AI computing methods an effort to increase situational awareness on the battlefield (International Defense, Security & Technology, 2018). The ability to account for the dynamic robustness of communications networks while inputs from blue force tracking (BFT) data and mission planning information are populated is an important factor of DBM which is being developed (International Defense, Security & Technology, 2018). BFT enables the complexity of positioning forces on the battlefield to be available for display so that a complete picture of placement is enabled.

The BAE Company recently developed semi-autonomous software to enhance combat missions thus improving combat mission effectiveness (BAE Systems, 2018). The focus of BAE's software is to provide operators and pilots with timely and significant data to enable increased C2 of air and ground combat in different challenging tactical environments (BAE Systems, 2018). Increased information such as situational awareness provided through the utilization of semi-autonomous software needed to be turned into a positive factor (BAE Systems, 2018). BAE Systems looked into how to change the landscape of future military operations with the goal of providing assistance to the warfighter.

Developments from companies leading technology innovation greatly improves the U.S. Navy's ability to gain advantages over adversaries. Being able to implement software to alleviate tasking by decision makers leads to proper allocation of time and resources to be delegated to accomplishing tasks and ensuring mission success on the battlefield. Pitting companies to compete against each other leads to the limits being tested and pushed to greater heights resulting in new discoveries to be exploited for use in different tactical environments.

B. AUTOMATED BATTLE MANAGEMENT AIDS

1. Concepts of Automated Battle Management Aids

The ability to enhance and improve tactical decision making in tactical environments is the main focus of ABMAs which are comprised of computer–aided decision support systems (Johnson, 2017). In order to increase the overall human-machine team performance, a warfighter or decision maker must be able to carry out the most logical decision-making tasks in a timely manner through ABMA utilization (Soller & Morrison, 2008). Figure 2 provides an overview of a standard decision support system. Automation helps to provide standard plans. Automation also assists with detailed planning and collaboration in order to execute a plan of action. ABMAs provide a decision maker with the ability to make better decisions through increasing the overall speed in which decisions are made, increasing the confidence in decisions, developing complex decision courses of action (COAs), providing increased comprehension of consequences, and/or refining resource usage (Johnson, 2017).

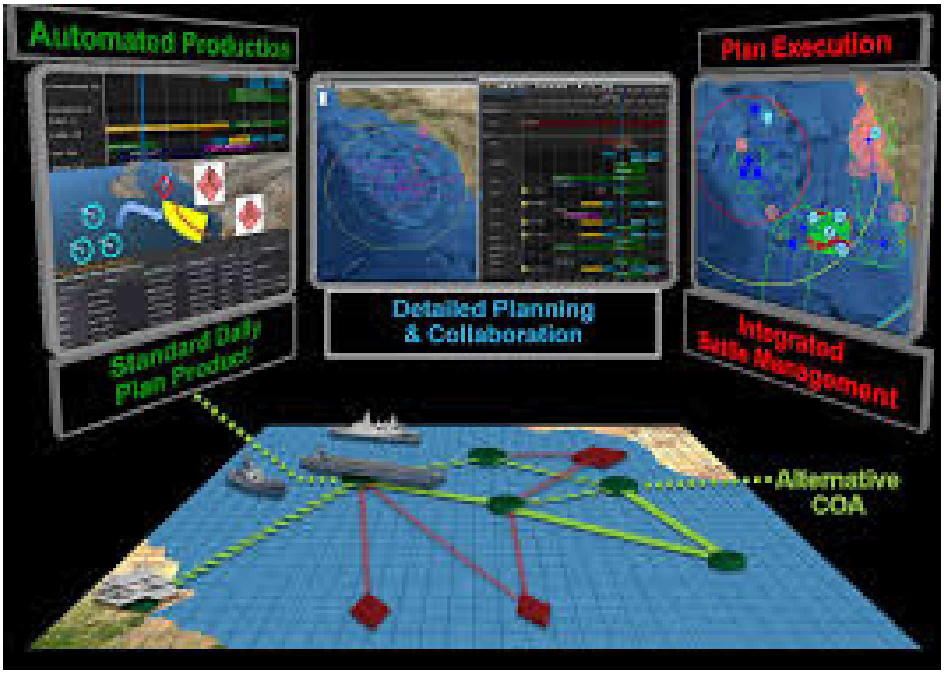

Figure 2. Maritime Tactical Command and Control (MTC2).
Source: U.S. Navy (2017).

A combination of critical factors has far-reaching effects in improving situations in a tactical environment. Being able to view a tactical environment from a holistic viewpoint provides a decision maker with a vantage point to ensure that the most efficient decisions are being made to affect the outcome of a tactical mission. The ability to view a plan as well as collaborate with the different tactical nodes necessary for mission success is extremely important. Framing the problem space provides as advantage to a decision maker.

2. Implementation of Automated Battle Management Aids

In order to achieve mission success, a majority of the decisions made in tactical environments require the utilization or positioning of warfare assets (Johnson, Green, & Canfield, 2001). Warfare assets used against an adversary to negate their warfare assets are weapons, warfighters, maritime vessels, aircrafts, submarines, sensors, and communication equipment (Johnson, Green, & Canfield, 2001). The implementation of ABMAs assists the utilization or positioning of the aforementioned warfare assets. Figure 3 illustrates a view of the holistic landscape in which ABMAs aim to assist.

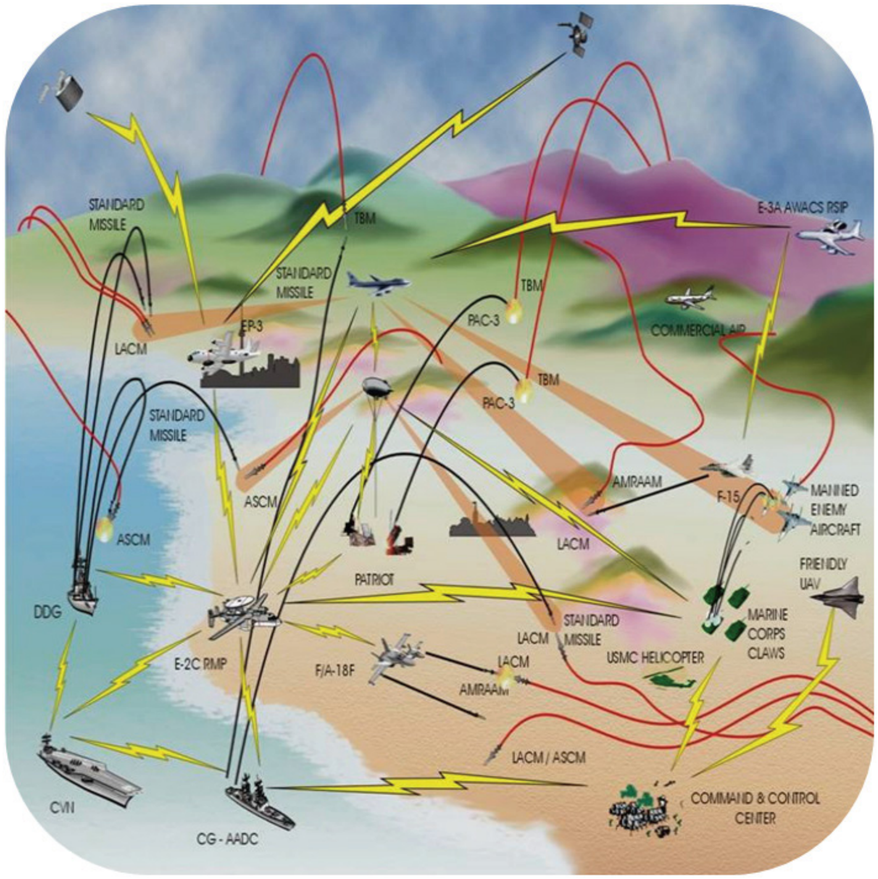

Figure 3. Artificial Intelligence—An Enabler of Naval Tactical Decision Superiority. Source: Johnson and Treadway (2018).

ABMAs can assist human decision makers through multiple implementations. Instead of a human collecting, storing, processing and analyzing the information deemed important in order to execute decisions in a complex environment, a semi-automated model can be adapted (Johnson, 2017). In addition to managing important information, ABMAs are heavily relied on by warfighters display a multitude of decision factors (Johnson, 2018). In the completely automated model of automated decision aids, human operators play a minimal role by simply monitoring automated system decision processes and overriding or changing decision when they deem it necessary (Johnson, 2017). An autonomous model through the implementation of artificial intelligence would isolate the human operator out of the loop and focus on the decision aid making decisions through analyzing processed information and being able to adapt to the changing environment without a need of human oversight and permission.

3. Automated Battle Management Aid Strengths

The implementation and utilization of ABMAs offer benefits to human decision makers. Due to human decision makers becoming overwhelmed in the face of increased information and shortened periods of time to make the right decision, automated decision aids are able to cut down on processing time and display information to human decision makers. ABMAs address complexity and assist the decision makers. In order for a warfighter to be able to allocate time to the accomplishment of complex cognitive tasks, ABMAs can execute tedious tasks which would eliminate the need for the warfighter to allocate time and energy on them (Soller & Morrison, 2008). ABMAs benefit human operators through the alleviation of task complexity provided by the design of an operator's display (Soller & Morrison, 2008). In addition to completing tedious tasks, ABMAs can also supplement human activity by executing tasks that humans are not able to perform due to physical limitations or by carrying out tasks that humans have limitations at such as real-time complex calculations (Soller & Morrison, 2008).

4. Automated Battle Management Aid Weaknesses

ABMAs are susceptible to errors within the system which can lead to the wrong decision being made. Adding additional complexity to the utilization of ABMAs, in future conflicts against adversaries, U.S. forces face the possibility of degraded or denied services which will need to be overcome in order to achieve success (Jones, n.d.). Although ABMAs are intended to decrease an operator's workload, research has shown that they may increase the overall level of knowledge required by the operator which is counterproductive to achieving operational success (Soller & Morrison, 2008). An automated system would introduce limitations through requiring a warfighter to both balance using cognition to formulate independent decisions as well as receiving the automated system's decisions and conducting comparative analysis to eliminate presented decision errors (Hilburn, 2004). Inexperienced warfighters would be faced with the requirement of additional training and professional development in order to effectively manage the utilization of automated battle management aids in order to not hamper operations. (Hawley & Mares, 2006). The introduction of automation bias can be detrimental to warfighters when using ABMAs because the warfighter can over rely on the outputs from the autonomous system rather than trusting their own decision-making abilities. (Mosier, Stitka, Heers, & Burdick, 1998). Overreliance on ABMAs can result in catastrophic incidents, if automated systems fail (Sheridan & Parasuraman, 2006). A complete reliance on ABMAs will lead to failures in complex decision making. The tool is best used in a complementary roll to assist decision makers.

C. DECISION COMPLEXITY

Bonnie Johnson's article, "A Systems Approach to Battle Management Aids," identifies four unique domains of battle management warfare decisions as "the temporal domain, the spatial domain, the proactive/reactive domain, and the domain of rules and policies" where each domain will require the increased reliance on battle management aids by decision makers due to the constantly changing domains (2017). The four domains of battle management warfare decisions are displayed in Figure 4.

Each of the domains of battle management warfare decisions contain a different level of complexity to be analyzed. The temporal domain delineates between the planning and time that goes into making decisions. The time factor holds increased importance in the temporal domain by setting the frame in which planning takes place. More time available enables utilization of different types of planning. While strategic decisions allow more time to be allocated for the development of higher-level objectives, planning level decisions are made during a much shorter time frame and are proactive in nature while tactical decisions involve near term decisions which take place in the shortest time frame (Johnson & Treadway, 2018). The proactive/reactive domain focuses on the type of decision being made as either planned such as an offensive operation or a responsive decision such as defensive maneuvering being made (Johnson, 2017). The proactive/reactive domain shapes a given environment by setting the stage for the way operations need to be conducted. Proactive actions can involve stealth operations, positioning of forces, offensive attacks, or degrading/denying enemy capabilities through jamming (Johnson, 2017). Reactive actions include positioning forces into a defensive posture, removing forces from a threat environment, or assessing battle damage (Johnson, 2017). The spatial domain categorizes space, air, maritime, underwater and land as different environments where threats vary and warfare systems have to be developed to address a certain environment (Johnson, 2017). Battle management decisions fluctuate from simple to complex as operations change and environments adapt to the changing landscape (Johnson, 2017). Each of the spatial domains are inherently different and complex which leads to the need for battle management aids which align with the particular realm that they are introduced into. The rules and policies domain deals with the alignment of near real time decisions and longer-term plans and strategies that support effective tactical decisions while continuing to be consistent with higher-level objectives (Johnson, 2017). This domain sets the baseline for continuation during planning. Guidelines are established in order to effectively navigate through planning stages and operations. Without the rules and policies domain, regulation would not be feasible. Order is key to fundamental planning. Knowing what limits will be imposed directly impacts the feasibility of actions being able to take place. The rules and policies domain provides a decision framework as well as constraints for courses of action in any given situation to increase the chances for success. (Johnson, 2017).

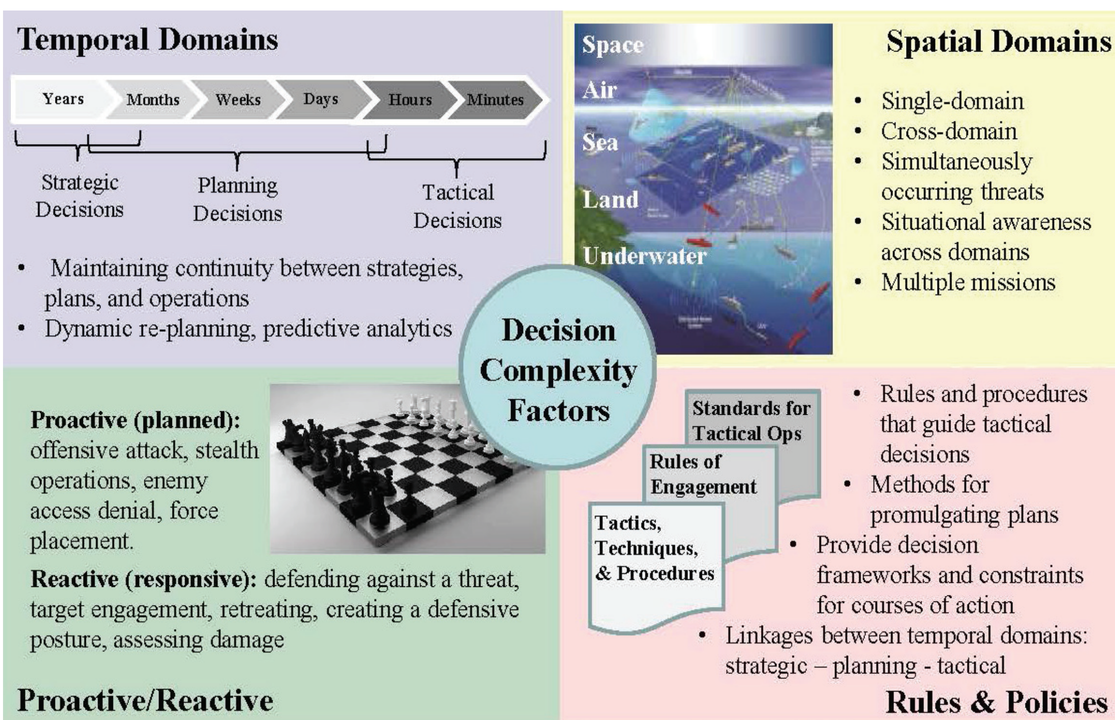

Figure 4. Tactical Decision Domains.
Source: Johnson and Treadway (2018).

Decision making in complex environments is a process which requires thorough analysis. In general, as a task becomes more complex in nature, the response from a human operator is a lower level of overall performance (Soller & Morrison, 2008). Making the optimal decision with limited information provided can lead to catastrophes if not properly analyzed (Denby & Gammack, 2014). The workload of a human operator directly correlates to the overall effort which is required by a human operator when performing a set task in order to achieve a goal (Soller & Morrison, 2008).

Different decision-making models attempt to understand and provide insight into how complex decisions are made. The dynamic model of situated cognition helps to view the environment as a whole and evaluate the different aspects of recognition that go into making the best decision possible. The breakdown of the dynamic model of situated cognition delineates the difference between technological systems and perceptual and cognitive systems that impact the decision-making process as shown in Figure 5 (Shattuck & Miller, 2006). The model is applicable in all realms of decision making where technology is utilized by humans to make the best decision possible (Shattuck & Miller, 2006). Before experimental evidence was presented in 1955, it was believed that the amount of information that a human could cognitively process at a single instant increased as the amount of information presented increased. (Soller & Morrison, 2008).

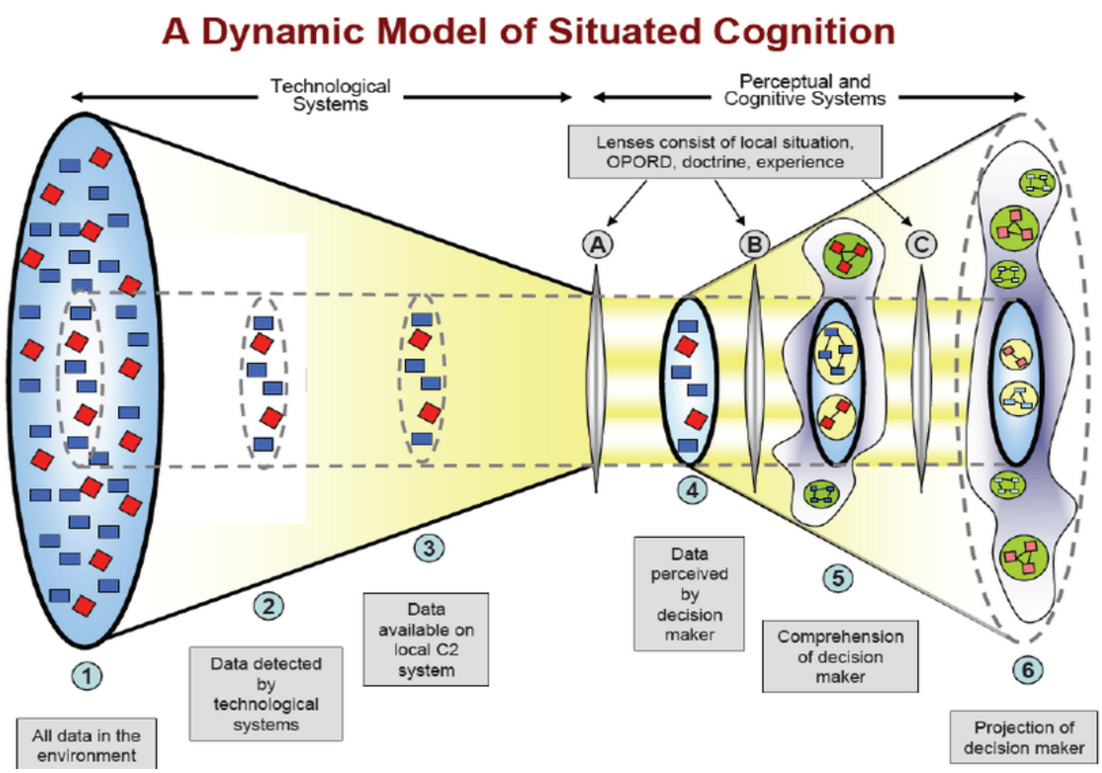

Figure 5. Factors of Technological Systems and Situated Cognition. Source: Shattuck and Miller (2006).

The separation of technology and perception by a human operator is vital to transparency. The two-fold delineation of the model assists the evaluator of decision-making. The focus of the data presented by technology compliments the human perception of presented data in order to make the best decision possible. In today's complex world, technology plays a massive role in decision-making. If utilized correctly, it can greatly enhance the ability of a human to make decisions. In the technological systems portion of the model, the make-up includes all of the data collected in the battlespace environment, data detected by the sensor systems, and data displayed on C2 systems (Shattuck & Miller, 2006).

D. AUTONOMOUS SYSTEMS AND ARTIFICIAL INTELLIGENCE

1. Introduction

The Chief of Naval Operations' 2018 article, "A Design for Maritime Superiority," laid out the future plans for the U.S. Navy and included the implementation of a comprehensive operational architecture to support rapid decision making by providing "accurate, timely, and analyzed information to units, warfighting groups, and fleets" through the inclusion of artificial intelligence/machine learning (AI/ML) (2018, p. 10). The CNO has made it clear that an emphasis on future plans includes incorporating the implementation of future technology (Richardson, 2018). Prior to discussing artificial intelligence, it is important to develop and understanding of an autonomous system which establishes the baseline for artificial intelligence. The terms autonomous systems and artificial intelligence are sometimes used interchangeably but it is important to delineate the exact differences between the semantics of the two to further a deeper understanding. Artificial intelligence will mature, only on repeated usage, and how you use it. Quality to help you, will depend on the data it has, how much it learns from the data, the less the data, the less the results.

2. Autonomous System Architecture

Autonomous systems are not stagnant in nature and are defined by their ability to alter behavior in order to counter unforeseen instances during a wide range of operations (Watson & Scheidt, 2005). The ability to be heterogeneous allows for the accomplishment of a wide range of tasks. The inability to utilize direct, physical human control in different battlespace environments presents a void where the potential benefits of utilizing autonomous systems to provide cost reduction in addition to risk reduction to yield completely new technological capabilities (Watson & Scheidt, 2005). The ability to utilize and autonomous system is beneficial to warfighters. Being able to respond to unanticipated events provides increased situational awareness through accounting for unknowns that could occur as well.

An autonomous system observes its environment through the usage of sensors to gather information and process it into data to be further acted upon as shown in Figure 6. The model of autonomous systems utilizes knowledge as a focal point which encapsulates all the information necessary for the analysis of sensor data, the application to the world model and the dissemination of new information (Belkin, Kuwertz, Fischer, & Beyerer, 2012). The figure delineates information in the form of boxes while processes are illustrated through the use of circles (Belkin et al., 2012). The world of interest is comprised of autonomous systems which make real world decisions and are constantly induced with an inflow and outflow of information (Belkin et al., 2012). Sensor data is important to autonomous systems and provides the data to be analyzed in conjunction with the application of knowledge to transfer information to the world model (Belkin et al., 2012). Plans are applied to the real world while observations of the real world are collected by sensors and translated into sensor data to be analyzed through the integration of knowledge which is obtained over time through a constant flow of learning (Belkin et al., 2012). Increased learning correlates to increased knowledge. The world model is dynamically changing and inferences made to and from the application of knowledge affects the world model which in turn directly affects plans to be carried out by an autonomous system. (Belkin et al., 2012).

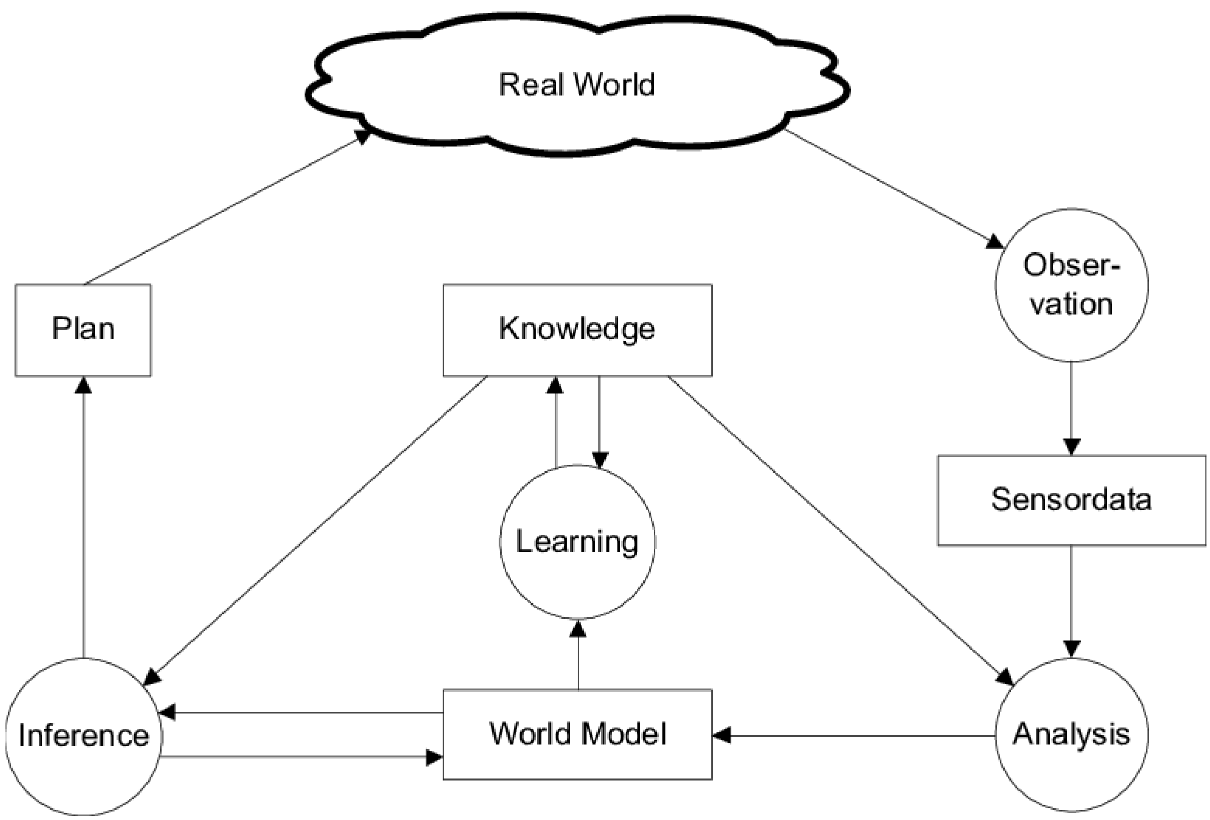

Figure 6. General Information Flow in Autonomous Systems. Source: Belkin, Kuwertz, Fischer, and Beyerer (2012).

Autonomous systems enable assistance to operators in a continuously changing environment. Factors that directly impact an outcome are processed and analyzed in order to present information in a way that assists an operator. The operator is given the ability to process information at an increased speed and at a deeper level in order to make the right decision based upon the perception of the information into data. As increased levels of information is presented into an environment, the importance placed on turning that information into useable data is paramount.

a. Levels of automation

Different levels of automation, shown in Table 1 describe the interaction between a human operator and the autonomous system as the system has increased capabilities, developed by Sheridan and Verplank (1978). Sheridan and Verplank (1978) describe automation through the usage of various levels of system involvement. A highly automated system enables independent decision making while a minimally automated system may only offer a human operator a list of possible actions to be taken and allow to the human operator to make the final decision (Sheridan & Verplank, 1978).

Table 1. Levels of Automation. Source: Sheridan and Verplank (1978).

1	The computer offers no assistance, human must do it all.
2	The computer offers a complete set of action alternatives, and
3	narrows the selection down to a few, or
4	suggests one, and
5	executes that suggestion if the human approves, or
6	allows the human a restricted time to veto before automatic execution, or
7	executes automatically, then necessarily informs the human, or
8	informs him after execution only if he asks, or
9	informs him after execution if it, the computer, decides to.
10	The computer decides everything and acts autonomously, ignoring the human.

Highly automated systems are extremely useful for many rigid tasks. Sheridan and Verplank believe that highly autonomous systems have the ability to circumvent the need for a human operator to execute tasks (1978). Highly automated systems are not the best option for decisions in an environment where the automation utilized may not be able to adapt to the changing environment (Sheridan & Verplank, 1978). This failure to adapt to changing situations can lead to failure for which the human operator isolated and ill prepared. Utilizing the best-fit level of automation is vital to successful operations.

3. Artificial Intelligence

Artificial intelligence (AI) has taken on many different definitions since its introduction into the scientific world. Research has looked at determining different parameters for the utilization of artificial intelligence. AI is not completely understood at this time due in part to its constantly changing definition as more research is conducted over time (Button, 2017). As more computers are able to master more complex tasks that were thought only possible by humans, clearer definitions are able to be presented (Button, 2017). Currently, the "One Hundred Year study of Artificial Intelligence" study defines artificial intelligence as enabling machines to carry out more complex tasks, in which increased intelligence enables a system to function at a high level with attentiveness in a particular environment (Stone, et al., 2016). The "One Hundred Year study of Artificial Intelligence" has produced different domains for artificial intelligence such as "transportation, home/service robots, healthcare, education, low-resource communities, public security and safety, employment and workplace, and entertainment" (Stone et al., 2016, pp. 7–8).

AI will be evaluated in the most adequate domain to increase operation efficiency. AI applications can increase U.S. military success through replacing inoperable software with systems that do not need to be constantly refreshed which creates the potential for creating flexible systems that can lessen operating costs (Button, 2017). AI can also be used to train warfighters through using systems that provide unpredictable and adaptive adversaries (Button, 2017) AI applications can also include preventing the loss of human life though automated future combat operations (Button, 2017).

The field of AI has been evolving throughout time with a shift towards developing intelligent systems that are able to effectively collaborate with humans regardless of certain trends which influence the future of AI research (Stone et al., 2016). The "One Hundred Year study of Artificial Intelligence" study identified the main trends that drive AI research as

- Large scale machine learning
- Deep learning
- Reinforcement learning
- Robotics
- Computer vision
- Natural Language Processing
- Collaborative systems
- Crowdsourcing and human computation
- Algorithmic game theory and computational social choice
- Internet of Things (IoT)
- Neuromorphic computing. (Stone et al., 2016, p. 9)

The "One Hundred Year study of Artificial Intelligence" study defines large-scale machine learning as the focused development of new algorithms while also improving the state of current algorithms to enable high functionality work with growing data sets as opposed to deep learning which requires valid data sets and concentrates on a focus of achieving object recognition and the increased ability of systems to process human language (Stone et al., 2016). Both large-scale machine learning and deep learning enable machines to perform at an increasingly high level. Decision-making which is influenced by experiences to enable executable actions is the idea behind reinforcement learning while the focus of training robots to a higher level of executing tasks and interacting with humans is the focal point of robotics research. (Stone et al., 2016). The "One Hundred Year study of Artificial Intelligence" study states that "computer vision is currently the most prominent form of machine perception" (Stone et al., 2016, p. 9). The ability of many computers to capture visuals better than humans propels the research of computer vision to focus on instantaneous image and video captioning which allows for the removal of humans as visual aid identifiers (Stone et al., 2016). Natural language processing enables systems to develop the ability to communicate with humans through the human language (Stone et al., 2016). Research on enabling autonomous systems to have high functionality interactions with people and other systems is the nucleus of collaborative systems research while crowdsourcing and human computational research looks to increase computer system abilities to solve issues that computers are unable to solve by connecting systems to human subject matter experts for workarounds (Stone et al., 2016). Algorithmic game theory and computational social choice are centered around enabling AI systems to be able to operate independently even when presented with deception. (Stone et al., 2016). It is important for IoT research to continue to grow due to the importance of different systems being able accumulate and disseminate information for increased combined intelligence insight amongst each other (Stone et al., 2016). Interconnectivity is the main component of successful integration of newer technologies in an ever-changing landscape. Neuromorphic computing is extremely complex in nature due to seeking improvements to AI systems in biological neural networks (Stone et al., 2016). The many different trends of AI research will impact future evolutions for years to come. As newer developments are introduced into the environment, finding the perfect fit and being able to seamlessly integrate the capabilities will need to be addressed.

a. Challenges

There are a multitude of challenges that directly affect the design and development of artificially intelligent systems. To survive and successfully perform during specific missions, artificially intelligent systems must be able to "sense, perceive, detect, identify, classify, plan for, decide on, and respond to a diverse set of threats in complex and uncertain environments" (Ilachinski, 2017, p. 12). Different threats will require a different set of actions in order to successfully respond and overcome them. Ilachinski (2017) states that "while aspects of all these 'problems' have been solved to varying degrees, there is, as yet, no system that fully encompasses all of these features" (p. 12).

In order to overcome complex environmental conditions, an AI system must be able to adapt and learn without human oversight (Ilachinski, 2017). When a human is not included in the loop, the AI system must operate independently. The difficulty presented when attempting to predict and account for an unanticipated action depends on the interaction between a human operator and the system (Ilachinski, 2017). Recent AI breakthroughs have found that AI can reach a given performance level but humans are unable to fully understand how the system is achieving set objectives (Ilachinski, 2017). The challenge presents understanding that a system could achieve a set goal without the operator being able to fully comprehend and trust the process that was used to achieve the goal.

From the onset of the implementation of a new technology or process, acquisition poses a challenge, and this is the case when dealing with DoD acquisitions. The acquisition process is detailed, tedious and very time consuming. A change to the current way technology is utilized takes time to be universally accepted and used. There is much growth that needs to be accomplished before AI systems are capable of being fully utilized by the U.S. Navy in tactical environments. An important factor to consider is a reliance on commercial off-the-shelf technology which is not likely to support complex military missions and although recent advances in machine learning are promising, enthusiasm for the use of machine learning in military applications should be tempered by the need for embedded computation and retraining, as well as such systems' potential vulnerability to countermeasures (Martin et al., 2019).

E. SUMMARY

ABMAs offer decision makers the ability to increase accuracy and increased cooperation between different nodes. The implementation of AI can lead to increased information extraction and increased scalability. Decisions will continue to be complex for military decision makers. Alleviating some complex tasks benefits the decision maker. Viewing complex decision through the view of tactical decision domains helps to narrow the battlespace and provide more insight into the deeper level of analysis that is required to achieve the highest level of operational success. Being able to increase operational efficiency in tactical environments will continue to be at the forefront of military decision-making. Artificial intelligence that is able to learn and adapt to changing environments will lead to increased functionality. Resources will be allocated properly to account for unpredicted changes. As technology continues to evolve, the U.S. Navy will have to find the best fit and reap the benefits to stay ahead of adversaries. More and more data is available to be analyzed and acted upon. It is inherently difficult to completely trust a system that cannot be understood but it is necessary to build upon the foundation in order to stay ahead in the tumultuous times. The uses for AI are endless as the technology is further explored and adopted.

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III. RESEARCH METHOD

A. INTRODUCTION

This thesis used qualitative research methods to study how artificial intelligence methods can be leveraged to enable automated battle management aids. Qualitative data collection encompassed obtaining tactical experience knowledge from subject matter experts and seasoned naval officers with firsthand operational experience. The data was analyzed to study the Navy's need for battle management aids and to support recommendations for AI technology integration. Guided interviews from subject matter experts and analysis of current developmental AI technologies guided the research results and recommendations.

B. RESEARCH METHOD

1. Qualitative Research Methods Overview

Qualitative research greatly differs from the utilization of quantitative research methods. The ability to gather and analyze data without numerical inputs is a focal point of qualitative research (Anderson, 2010). Qualitative research focuses on enabling the understanding of a particular problem through the dissection of the complexity issues that make up a problem (DeFranzo, 2011). Qualitative research can utilize interviews to highlight the complexity issues of a specific problem (DeFranzo, 2011). The utilization of qualitative research is highly useful to obtain deep insights which have the potential to identify the framework for additional qualitative or even quantitative studies (Sutton & Austin, 2015). Qualitative research tends to be creative and interpretive due in part to the fact that a researcher is unable to obtain empirical data for analysis before proceeding to writing conclusions (McLeod, 2017). Being able to take experiences from subject matter experts who have spent time in the field yielded insurmountable results for analysis and set the basis for future work.

Qualitative research and quantitative research can be compared against each other to show differentiation. Variegated points of comparison establish differentiating characteristics between the two types of research. The breakdown of qualitative research and quantitative research provided serviceable insight as shown in Table 2. Being able to holistically view differences between the two research approaches allowed for the decision to utilize a qualitative research method approach. Since the focus of research stayed away from quantifying data, a quality approach proved most effective. Goal of investigation was highly prioritized throughout the research process leading to an emphasis on qualitative research. Qualitative data collection in this study proved to be the most effective through interviews with subject matter experts to gather data. Inductive reasoning to determine generalized characteristics is highly valued in this study. Findings from this study are intended to provide insight to future implementation of ABMAs through leveraging AI. An expansiveness was highly prioritized in order to map out future recommendations.

Table 2. Differentiating Characteristics of Qualitative versus Quantitative Research. Adapted from Sorin-Peters (2004).

Point of comparison	Qualitative research	Quantitative research
Focus of research	Quality (nature, essence)	Quantity (how many, how much)
Philosophical roots	Phenomenology, symbolic interaction	Empiricism, logical positivism
Associated phrases	Fieldwork, ethnographic, naturalistic, grounded, subjective	Experimental, empirical, statistical
Goal of investigation	Understanding, description, discovery, hypothesis generating	Prediction, control, confirmation, hypothesis testing
Design characteristics	Flexible, evolving, emergent	Pre-determined structure
Setting	Natural, familiar	Unfamiliar, artificial
Data collection	Researcher as primary instrument, interviews, observations	Inanimate instruments (scales, tests, surveys, questionnaires, computers)
Mode of analysis	Inductive (by researcher)	Deductive (by statistical methods)
Findings	Comprehensive, holistic, expansive	Precise, narrow, reductionistic

Qualitative and quantitative research differs in every aspect from the focus of the research to the findings of the research. The ability to properly evaluate the problem space and determine the best course of action for proceeding towards a conclusion is just as important as the end result. In the search to discover how artificial intelligence can be utilized by the Navy, qualitative research provided the best results due to the goal of the investigation being to understand, discover, and describe future applications for implementation. Data collection through interviews with subject matter experts yielded the best results through a flexible design to produce findings which were not only comprehensive but also expansive.

2. Strengths of Qualitative Research

Qualitative research is extremely beneficial to developing thorough analysis to solve a complex problem. Qualitative research enables the examination of problems in great depth as well as in great detail (Anderson, 2010). Qualitative research methods are particularly useful for addressing problems that are not well defined. A major strength of qualitative research is the ability to take advantage of interviews that are not limited to specific questions and can be guided by the researcher in order to adjust the direction of the interview as new information is diverged. (Anderson, 2010). The ability to gather data to be further analyzed in order to establish an appropriate solution must be focused on as well. Qualitative research can explore problems within systems that are unable to be thoroughly articulated (Sauro, 2015). The quantification of complicated problems allows for some numerical analysis but the ability to describe the complexity of a problem enables qualitative research to be utilized to break down the complexity into easily understood concepts for a more thorough analysis (Sauro, 2015). A qualitative method is fruitful when the ability to explain correlations and causality is fully explored (Sauro, 2015). Even though there are adequate ways to measure usability, quantification can still be difficult to apply. Qualitative data helps uncover the right measurable through being able to observe users talk about the process for accomplishing goals and diving deeper into the source of the inherent problems (Sauro, 2015).

3. Limitations of Qualitative Research

Qualitative research has limitations that need to be considered prior to conducting research. One limitation is that interviewing skills can directly affect the qualitative research quality (Anderson, 2010). Interviewing skills affect the potential for the same information presented during an interview to be concluded differently post analysis (Maxwell, 2005). An interviewer with poor skills is unable to extract the same answers as a skilled interviewer. Problems can occur during qualitative research due to the researcher's presence during interviews, which can directly affect some interviewees responses (Anderson, 2010). The volume of data retrieved during a qualitative study can make analysis and interpretation time consuming as well (Anderson, 2010). Another limitation is that qualitative study requires an in depth analysis process which is laborious in nature (Elo & Kyngäs, 2008). The problem of adequate validity is a major drawback of qualitative research because qualitative research is subjective in nature and it is difficult to apply universal standards of validity for complete acceptance (McLeod, 2017).

Prior to the conducted research, interview methods and tactics were studied in an attempt to alleviate personal biases and idiosyncrasies as well as increase researcher skill. Talking to individuals that have conducted many interviews before, proved to be effective. All interviews were kept confidential to ensure subject's responses were not affected. The volume of data limitation was overcome through meticulous organization to keep all data categorized and classified by date, time, and the particular spatial domain they provided relevancy. Reliability and validity issues were combatted through constant interaction with thesis advisors to maintain focus on topics and beneficial insights as a conclusion

C. PROBLEM DOMAIN

1. Spatial Domain

In order to ensure that analysis conducted throughout the research process did not become useless by being open ended, it was vital to bound the problem space to ensure that a unique focus is present to yield the best results. Of the four decision complexity factors which are the temporal domain, proactive/reactive domain, spatial domain, and rules & policy domain, the spatial domain was the focus of research and analysis (Johnson & Treadway, 2018). Focus on the spatial domain narrowed the scope of the research while also allowing for freedom to interview subject matter experts in different tactical environments to garner a wide range of data.

The spatial domain encompasses undersea, maritime, land, air, and space to complete the tactical operational picture. The different environments work independently at times as well as in coaction with each other as shown in Figure 7. Information is transferred between different nodes to lead to effective communication and a more complete understanding of the operational environment. Being able to gather data about the different tactical environments in the spatial domain provided a thorough analysis for future recommendations. The multi-domain overview of the spatial domain allowed for command and control to increase when accounting for all of the environments that directly impact operational efficiency. Ignoring the operations in a particular environment is costly and negatively affects operations. Proper planning and execution of missions require taking all factors into account. This concept directly applies to the study of thesis work.

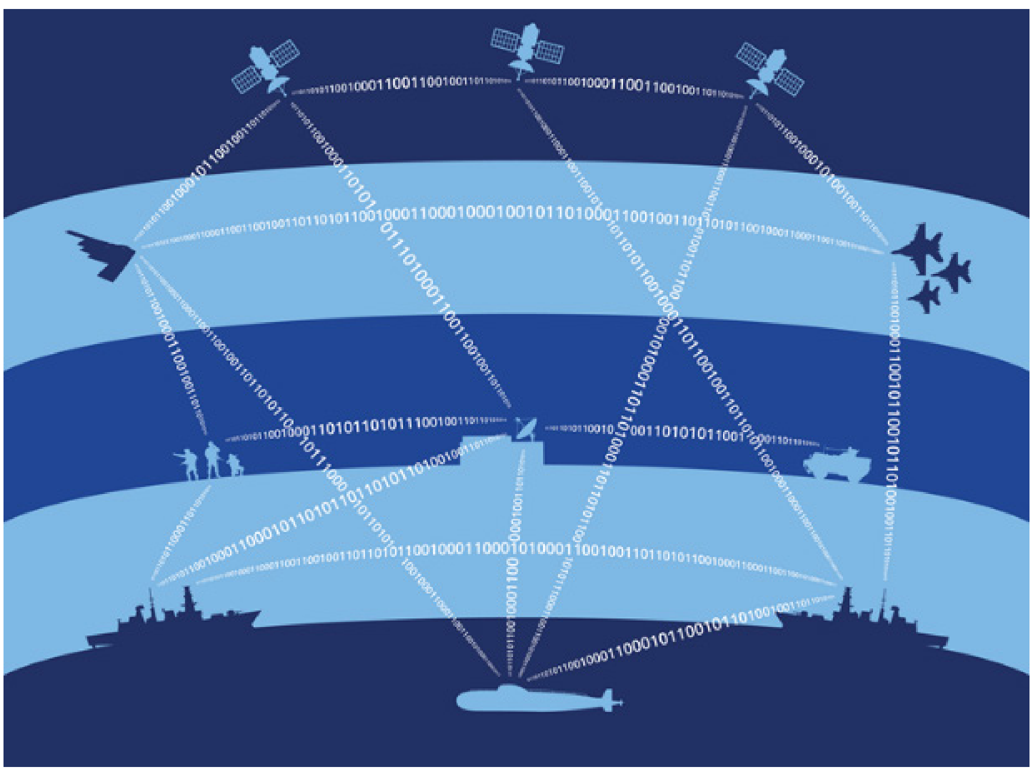

Figure 7. Spatial Domain Environment. Source: Polaris Alpha (n.d.).

The different naval spatial domains: undersea, maritime, land, air, and space each have different complexity issues yet require a level of connectivity as displayed and threats vary greatly in each different operational environment (Johnson, 2017). Data is transferred between nodes and researching the environments independently will uncover some interrelationships to be explored. Artificial intelligence methods can alleviate decision complexity in a multitude of ways each being unique to the tactical environments. Methods that will help tactical warfighters on ships will not be directly the same as a warfighter in the aviation community or a cyber-warfare decision maker. Each of the domains will shed light on aiding future implementation and utilization efforts.

D. GUIDED INTERVIEW QUESTIONS

In order to conduct interviews that were beneficial to the focus of this thesis, it was important to develop and analyze questions for the SMEs in order to gather data. The guided research questions were meant to steer the interview down a well thought of path in order to enhance the quality of data through asking thought provoking questions that elicit connections with previous experiences in tactical environments to provide deeper responses. The interview questions were also designed to avoid subjects that were not relevant in order to streamline the process.

The responses from the guided interview questions were thoroughly analyzed to provide insight and results for future recommendations. The process for qualitative analysis began with the meticulous preparation and organization of the interviews and the responses. A review and exploration of the data collected proceeded the interviews. Categorization was conducted to identify recurring themes and patterns during the interviews pertaining to the guided interview question. Recurring opinions, language, and beliefs were identified as well. Trends were identified in order to codify responses prior to the presentation of cohesive thoughts in chapter four. Cohesive thoughts revolved around the identification of ways to utilize ABMAs and leverage AI for future military applications and operations.

The following subsections contain the six questions that were asked and a discussion concerning each question.

(1) What factors make decisions complex in tactical environments?

Before diving into direct usage of AI and ABMAs, it was of the upmost importance to further discover the factors that make decisions complex from warfighters that have experienced making decisions in complex environments. The identification of these factors provided the basis for which to build upon. Being able to have a solid starting point to build upon sets the foundation of research analysis. Tackling the problem from a point of view in which the issues are identified provides greater depth to the data that is provided for analysis. Attempting to solve a problem without identifying what is causing problems is detrimental to achieving a feasible end state due to disorganization.

Since the spatial domain encompasses different environments, different complexity issues were discussed with different SMES depending on their expertise. Navigating through these decision-making complexity issues shaped the rest of the interviews by focusing on ways these issues could be resolved by integrating new technology into the playing field. Solving decision complexity issues was the main focus of implementing AI and ABMAs.

(2) What factors may be necessary to increase naval tactical decision superiority?

In addition to the identification of factors that decision makers are faced with, being able to identify the factors that directly impact naval tactical decision-making were addressed. The Navy must have decision superiority over adversaries in order to ensure dominance in an extremely tumultuous and ever changing landscape. This question was constructed to build upon questioning the factors that make decisions complex in tactical environments in order to provide more insight into current operations. Figure 8 incorporates the main domains necessary for focus to be applied to in order for battlespace awareness to be maintained.

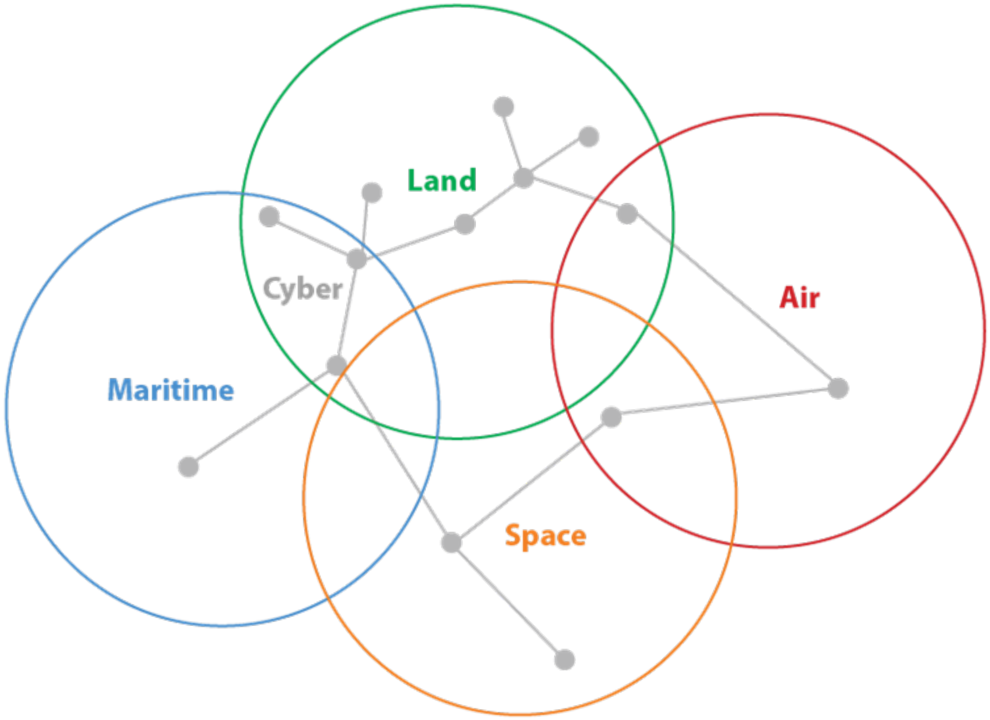

Figure 8. Multidomain Concept.
Source: Bartels, Tormey, and Hendrickson (2017).

Naval tactical decision superiority spans over multiple environments but in order for effectiveness to be achieved, it is paramount for connectivity to be prioritized. The absence of this concept fails to properly address the landscape of tactical environments and thusly does not aid attempts to offer solutions. When the spatial domain is not only looked at by its individual make up but also a holistic view, adequate analysis can occur to view problems through a full circle approach to address interoperability. This question focuses on naval decision superiority with the hope of yielding data that can be used to mitigate complexity.

(3) How can the Navy support the development of automated battle management aids?

When discussing automated battle management aids, it is important to emphasize the context in which an ABMA is utilized. Automation of a process occurs but a human is still in the loop to make ultimate decisions. The adoption of new technologies and practices is not one that occurs quickly in any environment if done correctly. The Navy is not an exception. The process for introducing a new technology or system undergoes intense scrutiny and analysis in order to make the best decision for implementation and utilization purposes. It is important to identify inherent choke points in different environments that will hinder further advancements.

For further ABMA adoption to be helpful to naval operations, seamless integration and transition should be the ultimate goal. To believe that this will be the case is extremely ambitious but should be worked towards. Identifying areas where integration will be extremely difficult is important in order to figure out ways to solve the issues. This question aimed at going deeper than standard responses such as incorporating additional training to increase efficiency. It looks at identifying overlooked practices and processes to increase structure and productivity.

(4) How can AI methods be implemented to develop automated battle management aids to improve tactical decision-making?

Identifying AI methods to benefit warfighters in tactical environments will greatly influence future implementation. This question will take experiences from SMEs and convert them into further methods to be adopted in efforts to enhance decision-making abilities. Different AI methods can influence tactical environments in a multitude of ways. Application of AI methods will be discussed in hopes of formulating practical ways to utilize AI. The inability to identify practical application will negate the functionality of AI methods by warfighters. The hope was to be able to take different examples of AI methods and create a framework for actual implementation. Being able to have detailed examples of possible AI implementation will yield the best results. SMEs that have years of experience will be able to uncover potential naval utilization of AI.

(5) What are the costs and benefits of implementing Artificial Intelligence in the Navy?

In order to properly analyze the ability to utilize a completely new application in a tactical environment, it is important to take into account possible negative effects as well as benefits. Monetary costs of implementing new technologies will be exponentially large but if the benefits of the technology can offset or counterbalance the immense costs, it is important to keep that in mind for consideration. Being able to objectively analyze a new technology for potential leverage can provide immense insight. Taking experiences from tactical environments and identifying the way that AI could potentially hurt or enhance tactical decision making is essential to evolved environmental operations. A focus on gathering data on the costs and benefits of AI that goes deeper than the generic responses is crucial. Real world examples of AI implementation are key to providing data that is useful for analysis. Taking the real world examples from the previous question and examining possible drawbacks will garner further insight necessary to pursuing utilization.

(6) What ABMAs or AI methods are already employed in tactical environments?

In order to discover methods to be used in the future, an emphasis on current operations and systems is imperative. In addition to research conducted on current systems and technologies, interviews with warfighters that been forced to operate in tactical environments will shed light on current technological aids. This question will help to provide a basis from which to build upon. Automation is present in current environments from one level to another. The level of automation is not universally equal in the different environments. Gathering additional information on the levels of automation in current operations will aid further development as more technology is introduced to the landscape and increased capabilities are discovered through the usage of AI and ABMAs.

IV. DATA ANALYSIS

A. INTRODUCTION

Interviews with subject matter experts provided hours of data to process for analysis. The subject matter experts have a wide range of expertise and experiences in different tactical environments and providing narrated knowledge for data collection. The guided interviews provided the data necessary to present recommendations for future integration of artificial intelligence to enable automated battle management aids. The data is organized according to the spatial domains: maritime, air and cyberspace environments. These environments are made up of very different and complex issues in terms of tactical decision. This chapter is organized according to these three tactical spatial domains.

Five subject matter experts provided data for the maritime environment. One of the SMEs has 19 years of active duty service in the maritime domain serving onboard a variety of platforms from cruisers and destroyers to aircraft carriers. Role onboard ships include operations officer, executive officer, and commanding officer. One SME has 28 years of active duty service with experiences on both the officer and enlisted side. Navy platforms served on include destroyers, cruisers, and aircraft carriers. One SME is a retired naval officer with 20 years of service onboard ships serving as a communications officer, chief engineer, battle group communicator for a carrier battle group, operations officer, and navigator. Two SMEs have served for ten years onboard Navy ships and worked in a variety of departments onboard ships including navigation, combat systems, communications, and engineering.

Three subject matter experts provided data for the air environment. One of the SMEs has 19 years of active duty service in the air environment flying in the A-6E Intruder and the EA-6B Prowler with many additional air environment shore billets. One of the SMEs has 12 years of active duty service in the air environment with three operational tours in the E2 Hawkeye. One SME has fifteen years of governmental research and development experience with a focus on battle management in the air environment.

Three subject matter experts provided data for the cyberspace environment. One SME has 28 years of active duty service in the cyberspace environment serving as a communications officer onboard shipboard platforms and serving in network administrator roles at different shore commands. One SME has 14 years of active duty service in the cyber space environment with operational tours onboard ships as a communications officer as well as chief information security officer. Additional experiences come from service at communication stations. One SME has 15 years of active duty service in a variety of roles including communications officer and service at a naval computer and telecommunications area master station.

B. MARITIME ENVIRONMENT

1. Decision Complexity Factors

Subject matter experts argued that warfighters in the maritime environment face a plethora of decision complexity factors. When it comes to operations onboard a ship, the various ship departments carry out different roles in order for the ship to function smoothly. No department can operate independently of the others and expect operational success. Integration is a key component onboard ships. The SME data reveals that maritime decision complexity relates to the introduction of increased levels of information for processing. All of interviewed maritime SMEs expressed concerns over the requirements to make the best decisions possible in the quickest amount of time while using more systems with increased capabilities and data processing. Shipboard systems display a wide variety of information, and it is up to the watch standers on the bridge of a ship to examine all of the information displayed on different systems and make the best decisions possible. Data collection from SMEs reveal that in the combat information center (CIC) watch standers have to remain in the loop in order to evaluate the output of information from combat systems and ensure that the information is reliable though validation methods before a decision can be made. Figure 9 displays the CIC standard architecture. The process of ensuring reliable information is extremely time consuming and requires the input from different warfighters before an ultimate decision can be made. This time factor adds complexity to the decision making process.

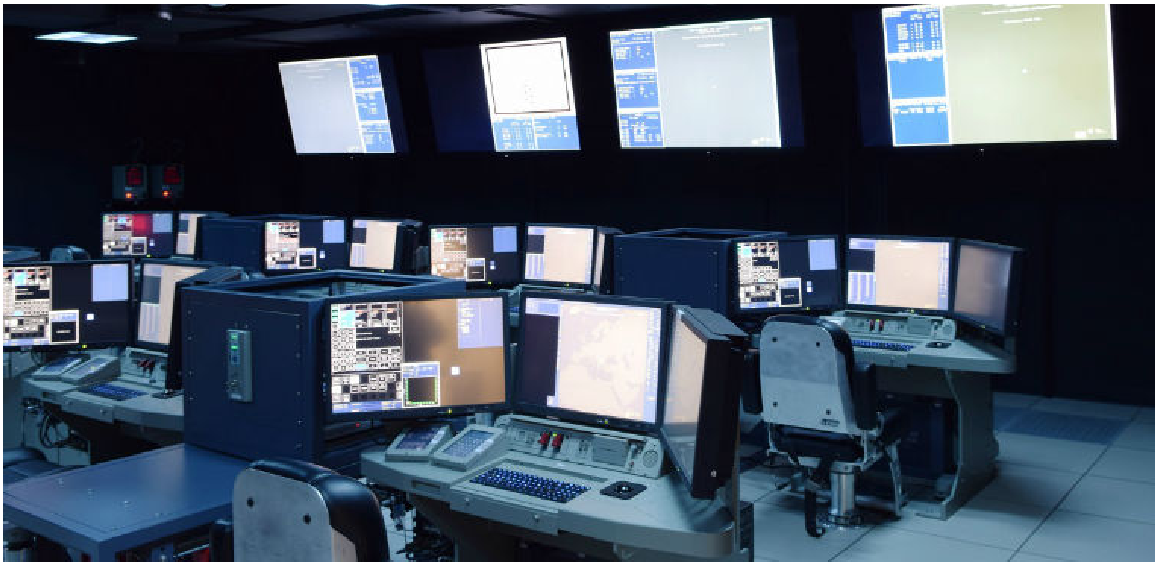

Figure 9. Combat Information Center. Source: Williams (2018).

The CIC is a vital component of shipboard operations in the maritime environment and is very demanding and stress inducing to a warfighter. The pressure of making the right decision under intense conditions is prevalent and must be accounted for. SMEs with operational experience out to sea argued that the maritime combat systems for both air and missile defense, surface and subsurface warfare have very little persistence. The combat systems are unable to execute at a high level when faced with interference or degradation. Sensors for combat systems take in a tremendous volume of data but only display the output for as long as the sensor has contact. This leaves the human operator to attempt to quickly account for all factors for analysis before making a decision.

2. Increased Naval Tactical Decision Superiority

SMEs argued that the Navy must increase its tactical decision superiority through the seamless integration of systems to provide increased situational awareness capabilities in the maritime environment while not abandoning the warfighters need for competence and understanding. The introduction of newer systems with increased capabilities provides an advantage to warfighters but only when the proper mental calibration is prioritized. All of the interviewed SMEs contended that user-friendly software design and adequate management of systems are both essential to increased tactical decision superiority in the maritime environment. A system that has cluttered displays as a result of increased levels of automated information is detrimental to operations. In addition to user-friendly displays, an increase in the level of training on any new system must be a priority. Additionally, training on the principles behind a system must be a priority. Leaving a decision maker to simply ingest the output of a system and not understand the fundamental factors that enable the decision-making cause a level of disassociation and division. Trust in systems will be developed over time to increase usability and acceptance.

One of the SMEs expressed the need for a better process of fixing broken sensors and equipment. The increasingly complex process of obtaining additional parts and systems to replace legacy systems degrades tactical decision superiority. Having to rely on faulty or inoperable equipment due to the lag time of obtaining additional parts and systems leaves the warfighter with the requirement to still achieve mission success through the utilization of available secondary and tertiary means. Mission success heavily relies on the utilization of equipment that is fully operational and able to fully execute set tasks with a full range of capabilities. Internal degradation hampers the ability of warfighters to perform to the highest levels of success when overreliance on only a portion of available systems is present.

The SMEs highlighted the need to invest in better internal communication systems on ships. This issue is specific to certain sea platforms but must be accounted for when seeking to understand decision superiority. Internal communications onboard ships are essential to the dissemination of information on all levels. The ability for communications within the CIC to be transmitted over one network, but unable to be communicated to the bridge where the ship is driven from or where the commanding officer is postured as well as to the engineer officer who has the most complete situational awareness of the ship's capabilities, and the combat system officer that has the best situational awareness to the status of the ship's sensors and weapons is extremely problematic. This negatively impacts tactical decisions. The need for everyone to utilize the same communications network would make sure that tactical actions officer can be aware of the ship's fighting ability and can better fight and defend the ship. A fully integrated communications system on board ships to ease the flow of information is essential.

SMEs argued that another problem in the maritime environment is the manning and the amount of sleep watch standards get on board ships. The up-tempo nature of shipboard operations requires increased attention to detail from human operators. The inability to ensure that watch standers have properly rested in order to remain alert and cognizant so that they do not miss pertinent information is a huge component of ensuring tactical decision superiority. The inability to process information that can be influential to making the right decision is key to success.

3. Supported Development of ABMAs

Data collected supports the future development of ABMAs but reinforces the idea that ABMAs will not undergo instantaneous adoption. SMEs argued that displaying the capabilities of ABMAs will require time, effort and buy in. The Navy is not ready to completely abandon the ways of the past to adopt new technology that could increase complexity into the decision making process through unreliability or increasing required cognitive understanding. Developed ABMAs will need to endure a thorough lab testing phase in addition to operational testing and training with warfighters that will be the ABMA users. SMEs argued that isolating the testing environment to lab settings where the operational warfighter is left out of the loop leads to inefficiencies. Once the acceptance of aids to alleviate mundane tasks is fully accepted, a slow integration process will be more heavily supported and encouraged. Introducing new technologies and capabilities is not new to the Navy. It will not be a quick integration in the case of ABMAs. Full development for maritime usage will need to be prioritized. SMEs argued that the advanced electronic guided interceptor system (AEGIS) has a crude and extremely laborious replay functions of output data. Ships are unable to instantaneously pull up past AEGIS data for display and analysis. Data has to be sent to analysis centers in order for data to be processed and utilized as lessons learned. The ability of an aid to improve the functionality of AEGIS while providing warfighters with an ability to recall replay data to be analyzed for operational effectiveness can be extremely useful during operations. Being able to see AEGIS data onboard ships without lag time enables warfighters to adjust components of the system to maximize effectiveness. The ability to better track and guide weapons will be increased through additional functionally features of replaying track data.

4. AI Method Implementation

Data collected reinforces the idea that AI methods which employ engagement measurements are not yet accepted as an option for operations and will require humans in the loop to make the ultimate decision. The acceptance of AI technological levels of maturity in this realm will not occur for much time.

SMEs agreed that deep learning pattern recognition presents a huge AI option to the surface warfare community. Watch standers on a ship get into a pattern of life which translates into an inherent understanding of the maritime environment over time. Complacency increases as normalcy in day-to-day operations occurs. The notification of sensor identifications on systems can be overlooked as complacency sets in. As a warfighter learns to recognize the normal day-to-day operations, increased attention to outputs details decrease. A deep learning AI method integration provides the ability for complex identification of tracks on display modules.

SMEs argued that a combat system with a populated track designed to display all of the identification factors with contextual prompts included enables the workload of a warfighter to be lessened. AI pattern recognition presents information to allow for a kinematic match to be identified. The system presents all of the necessary data to the warfighter in a display that is easily understood and eliminates the need for a full human checkprint which involves humans in the loop to identify and verify populated tracks with multiple human verification efforts to ensure the reliability of sensor data. A system that allows for the cognitive load to be alleviated by presenting the track information at a high level through deep analysis of previous patterns is highly significant. The fidelity of displayed information and the alleviation of misidentification presents attainable levels of AI integration. The digestion of information to be later recalled for warfighters to utilize and act upon is vital to AI method implementation.

SMEs argued that AI methods can be used to assist bridge instrumentation onboard ships require the interpretation of humans to conduct navigation of the seas. Figure 10 and Figure 11 show a view of the bridge onboard a Navy ship.

Figure 10. Aircraft Carrier Bridge View. Source: Kelby (2013).

Figure 11. Navy Bridge View. Source: U.S. Navy (2011).

Onboard the bridge, the advanced radar piloting aid (ARPA) is heavily utilized by watch standers to identify radar contacts. Electronic navigation systems focus on looking at the layout of navigation charts for safe navigation. Warfighters onboard ships have to commit the rules of the road to memory to adhere to the safe navigation practices of the sea. SMEs argued that an AI system that could take all of the inputs from the different navigations radars and systems such as course and speed, closest point of approach, rules of the road, as well as automatic identification system settings and employ large scale machine learning to display a solidified navigation picture for use when traversing through contested waters is powerful. This deconflicting information provides warfighters with a clearer picture of the maritime environment for enhanced decision-making. It also provides a solidified display of the multitude of factors the must be accounted for during maritime operations.

Data collected from SMEs examine the usability of AI methods to reveal the performance efficiency of equipment onboard ships. SMEs argued that equipment data output can be analyzed by AI methods to produce composite reports on the functionality of utilized equipment. Taking output parameters from equipment can predict the failure of equipment to ensure operational success and the elimination of ineffective equipment.

Utilizing AI methods for weather recognition to identify maneuver tactics is a viable option for future AI implementation. The ability to use AI sensors that collect dangerous weather patterns and warn of impending threats can provide a great resource. Computer vision would enable instantaneous image and video capture to predict future weather patterns and suggest alternate navigation courses to shorten the time factor that is present when communicating back with a ground station to receive corrective actions and weather updates. This shortens the time necessary for processing alternatives during operations.

5. Cost and Benefits

SMEs argued that the benefits of AI methods when implemented with ABMAs to improve tactical decision-making outweigh the costs when the proper level of integration is achieved. Warfare on the seas will continue to be dynamically evolving. SMEs expressed major concerns about the utilization new technologies that provide more information for sound decision making yet create and increased level of clutter on a display screen. This in turn leads to not being able to process enough information quickly enough even though the information is presented on a display screen. All of the SMEs argued that the monetary costs associated with implementing AI software will impact the overall adoption of new technology. Contracts for new technology developments will play an immense role in the integration of new technologies.

6. Current ABMA and AI Method Utilization

SMEs argued that the current low-level utilization of automated aids assist warfighters and establish a refined common operational picture (COP) yet much room for improvements exists. Low levels of automation require immense levels of human input and interaction. Systems are used to display information for warfighters but low-level integration between multiple systems can be useful. The recent increase in autonomous maritime vessel development enhances the operational efficiency of the maritime environment through the ability to complete a variety of tasks. Mapping of the sea and transmitting information to warfighters without a human operator is highly sought after and will continue to be at the forefront of maritime environment operations.

C. AIR ENVIRONMENT

1. Decision Complexity Factors

Decision complexity factors range from operational planning phases to operational mission execution in the air environment. SMEs explained that a factor that makes decisions complex in the air environment is the constant transmission of airborne tactical network data links from aerial platforms to ground receiving nodes in order to complete a highly comprehensive picture of the aerial environment. Constant transmission of information in the cockpit leads warfighters to become overwhelmed with the process of not only carrying out a mission but also ensuing transparency for other operating platforms. The inflow and outflow of information can be overwhelming when added to the already complex process of monitoring aviation equipment. Constant communication is required in order to ensure the success of set objectives. SMEs argued that ensuring secure communications is an additional component to the factors that make decisions complex. Enemies that are able to degrade services present aviators with a need to process situations quickly and be able to maneuver around the problem areas to achieve mission success. Degraded services from an aviation platform to a ground station or receiving node cause the likelihood of success to dramatically decrease. The aviation electronic warfare (EW) suite is a component that is evolving continuously but presents an area for the introduction of complexity to warfighters. The infusion of EW to the situational awareness display requires the diversion of attention to another component area that can negatively impact the warfighter when ensuring that different links communicate together which is vital for decision-making success.

2. Increased Naval Tactical Decision Superiority

SMEs argued that improvements to aviation navigation will increase naval tactical decision superiority. The air environment requires not only the usage of systems to provide navigation aids but also visual navigation from the human operator. Increased tactical decision superiority will be enabled through the focus of increasing situational understanding of the factors that can impact navigation. Current air navigation methods include visual navigation, global positioning systems, and radio navigation. Degradations in the air environment including jamming and inclement weather lowers the effectiveness of navigation methods. AI can aid in this human/machine air navigation problem through alerting warfighters to impending obstacles in the air environment and offering alternate COAs for the continuation of objective accomplishments.

Further understanding of the capabilities of adversaries will play an immense role in increasing tactical decision superiority. This knowledge can improve decision superiority through identifying necessary tactics overcome advanced adversarial threats. Stressed networks that are forced to overcome enemy obstacles will need to be integrated in order to increase decision superiority. The wealth of information in the air environment must be used to increase tactical decision superiority. The use of over the horizon, airborne radar capabilities reinforce tactical decision superiority. The E-2C/D aircraft’s ability to fly many miles away from a platform and utilize its airborne radar to transmit possible future threats while sharing the operation picture to increase situational awareness aids tactical decision superiority.

3. Supported Development of ABMAs

SMEs argued that solutions to acquisition issues will increase the support for the development of ABMAs to be utilized in the air environment. A streamlined process for idea creation, development, testing, and utilization will increase as complications in acquisition processes become less complex. A delay in the time it takes for new technology to get to the fleet for wide spread utilization needs to be addressed to further support the development of ABMAs in the air environment. The necessary operational warfighters must be present in during the developmental phase of new aids. Their translated needs and concerns will change the trajectory of technological inventions. Systems will be developed with the warfighters inputs at the top of the priority list to ensure a high level of utilization and acceptance.

4. AI Method Implementation

SMEs argued that in the air environment, pre and post mission briefings present options for AI method utilization. These all important briefs give the warfighters a comprehensive overview of mission objectives to be carried out as well as an analysis of the objectives prior to a mission being conducted. The ability to capitalize on deep learning methods of pattern recognition during post mission briefings presents immense opportunities for growth. The ability to utilize AI to evaluate the execution of tactical mission objectives as well as identify room for improvements for subsequent missions is essential to improving the success of future operations. The ability to use a confidence level evaluator to assess mission objectives teaches warfighter in the air environment lessons that could have otherwise been missed such as a missed radio call or a missed target identification. Pre mission planning phase introduces room for AI utilization through the collection of data to be translated into key situational awareness information. Using a cycle of analysis to gain a deeper perspective of the air environment prior to a mission taking place increases the likelihood of a successful mission.

SMEs argued that AI methods can increase situational awareness in the cockpit as well. Figure 12 displays a cockpit of a Navy aircraft.

Figure 12. View of Navy Cockpit. Source: Navy Live (2015).

An in-cockpit application to display indications of systems up and running and performing to the highest levels of quality will reduce maintenance periods of equipment. Pilots will be able to concentrate on the execution of mission objectives in the tactical environment while maintenance personnel will be able to concentrate on optimizing performance efficiency of aviation platforms based upon the analysis of data collected from midflight sensors.

SMEs also argued that the use of object recognition through deep learning methods optimizes warfighter decision-making abilities. The ability to utilize sensors during midflight operations to enable increased air target recognition can be processed for a more complete air tactical picture. The misidentification of targets can lead to catastrophes occurring in the air environment. An in cockpit ABMA to process information from the environment and provide a reliable identification of a target to enable warfighter actions to be taken is essential.

SMEs argued that reinforcement learning methods of AI support advancements in drone technologies in the air environment. The ability to increase decision-making abilities through taking mission experiences and translating them into enabling actions for future missions conducted in the air environment through drone utilization is paramount. Feedback given to a warfighter from reinforcement learning assists in lessoning the complexity of decision making in future endeavors. Drone utilization assistance will map the landscape of the air environment for increased decision superiority.

All of the air environment SMEs agreed that providing a teaching tool to increase operational efficiencies and highlight successes as well as missed cues is a realistic use for AI utilization in the near future.

5. Cost and Benefits

SMEs argued that the fear of warfighters in the air environment not being in control of their platform is a detriment to initial AI implementation. A system that is too smart and has the perception of completely running all aspects of mission operations. Trust in a system to provide assistance will only occur over time and through the consistent delivery of positive results. Bad decision making recommendations will only hamper implementation and utilization. The monetary cost of implementing technology that does not benefit the warfighter can be extremely high. Benefits of ABMAs are endless in the air environment. A clear air environment tactical picture eases the load of a human operator. Increased information and navigational display systems allow for simplistic navigation and increased tactical superiority.

6. Current ABMA and AI Method Utilization

Current utilization of ABMAs enable automated jamming systems to increase jamming capabilities in specialized EW platforms without human interaction. EW systems sense threats and then employ jamming techniques to negatively impact adversaries. Drawbacks of some EW systems are an overwhelmed system integration that does not properly employ electronic support actions such as electronic action to counter a threat and effectively provide a benefit to warfighter.

SMEs argued the use of autonomous aerial platforms currently provide great benefits to warfighters in the air environment. Two of SMEs argued against the complete removal of humans in the loop in the air environment. Autonomous aerial platforms have transformed the air environment but have not eliminated the need for human pilots and operations to oversee the environment.

D. CYBER SPACE ENVIRONMENT

1. Decision Complexity Factors

The cyber space environment is in constant evolution as technological transformation occurs. SMEs argued that the introduction of newer and more advanced technology change the landscape of the cyber space environment and adds complexity to existing decision making processes. Warfighters in the cyber space environment must ensure the continual transmission of secure communications and data as well as ensure network security. The classification of network attacks is paramount to cyber security. A denial of service attack is different from a malware attack or phishing attack. The identification of intrusion levels and the level of compromised material aids in getting to the root of the problem. The inability to identify the level of risk to a particular network and remove the risk and/or neutralize the threat add complexity to the cyber environment. The constant theme of information overload is present in this operating environment. Network monitoring systems have increased inflows of information to be processed and delivered to the right network. The constant transmission of information over unclassified and classified networks require delicate monitoring to prevent spillage. SMEs argued that warfighters have to consider different ways to transmit data and voice over different network links. In the event of network intrusion, the dissemination of information is still a key objective. The inflow of information plays a role in the available ways that a warfighter can proceed in the operating environment. The allocation of bandwidth for networks limits the capacity of systems in a network. The requirement for constant communications such as video teleconferences (VTCs) along with still monitoring networks for security purposes put the warfighter at a disadvantage. The allocation of resources limits the ability to enable all systems to perform full capabilities. SMEs argued that something must give in order for something else to be fully utilized. Warfighters in the cyber space environment have to make the tough decisions to choke off bandwidth if the allocated bandwidth is necessary for another facet of operations. While the need for constant reports, emails, and feeds must be enabled, mission accomplishment is the highest priority.

2. Increased Naval Tactical Decision Superiority

An increased understanding of the cyber space environment and the importance to operations needs to be enhanced. The understanding behind the applications and services that are provided to warfighters in the cyber space environment constantly goes unnoticed and underappreciated. The status quo of a fully operational environment in which unimpeded transmission of data is the norm is not always realistic as increased complexity is introduced to the loop. An acknowledgment of the fundamental importance of this environment will increase tactical decision superiority. Increased tactical decision superiority is elevated through increased clear data transmission. The importance on developing procedures for reduced bandwidth in conflicted environments will increase tactical decision superiority. The inability to function in the cyber space environment when the presence of degraded transmission of information occurs will lower tactical decision superiority levels.

3. Supported Development of ABMAs

The supported development of ABMAs in the cyber space environment will continue to evolve as the cyber space environment is explored. SMEs argued that an increase in deployable, joint systems will require increased levels of support for implementation. The focus of enhancing the global command and control system (GCCS) and the COP will further support the development of ABMAs. The elimination of clutter on systems that provide track data will further support the development of ABMAs. A clear focus on the identification of problem areas in networking will increase the supported development of ABMAs.

4. AI Method Implementation

Network management provides a component in which AI method implementation can present an exorbitant amount of progress. SMEs stressed the ability to monitor network traffic and identify weaknesses in networks. Systems that have AI applications to test for pivot points into a network can be properly protected. AI algorithms that can learn from network traffic and increase firewall rolls can greatly help warfighters.

SMEs further argued that intrusion detection and mitigation will be at the forefront of AI implementation in the cyber space environment. The ability to conduct behavioral analytics to monitor and manage network cyber defense commands will increase the usability of AI. Reducing network intrusions and hardening defenses will increase the defensive posture of the U.S. cyber space environment.

An AI system that can utilize pattern recognition to identify the internet protocol (IP) addresses of malicious code attempts to infiltrate a network can be highly useful in ensuring network security. Artificially enabled email filtering to reduce phishing attempts into a network will increase network security measures. This will allow for the continual transmission of data on a network with minimal interruptions.

SMEs argued that deep learning AI methods can increase data storage processing through increased data extraction at naval data centers. Increased processing of extremely large data sets will provide warfighters will enable an increased amount of information to be applied to different tactical environments. Trends uncovered from data processing will enable further changes to operational practices. SMEs argued that the endless opportunities presented from being able to process the inflow of data at a high rate with high fidelity will uncover information that will assist with network management and situational awareness. The blocking of ports can be enabled to negate apparent weaknesses in networks.

SMEs argued that IoT research is key to future cyber space environment success. A focus on IoT providing cyber space warfighters with the ability to enable interconnected devices and systems to collect and share network information in an effort to alleviate network chokehold points and increase rerouted network traffic flow. Being able to monitor endpoints in to networks will be essential to increasing the interconnection of cyber devices such as laptops, routers, and other wireless and mobile devices. Interconnected devices will enable additional capabilities and intelligence aspects to operations.

5. Cost and Benefits

SMEs argued that the costs to ABMA implementation revolve around the normal dependency established between the human operators at a network center and the advanced capabilities. A failure to continue to increase the understanding of networking fundamentals will lead to blind following of ABMAs. Lab and beta environmental testing will be necessary to test a multitude of network intrusion techniques against systems with hardened defenses to identify flaws and shortfalls. Progression is essential to increased utilization. Network testing that adheres to a Commander's critical information requirements (CCIR) will be a priority. Integration of advanced technology that is unable to adhere to the comprehensive list of information requirements that are critical in transmitting timely information management and the decision-making process will be costly to operational successes. SMEs argued that the benefits of ABMAs and AI utilization are endless when properly calibrated. The alleviation of network intrusions and the increased speed in which data can be transmitted will be important to evolving the cyber space environment.

6. Current ABMA and AI Method Utilization

Data conducted from SMEs highlight the utilization of low-level automated battle management aids in providing monitoring of cyber network traffic. The ability to monitor network traffic at a high level is essential to increasing the level of protection provided to warfighters. Current systems are able to map out network traffic and enable displays of network and system health. System health is vital to ensuring the high fidelity of displayed information. Monitoring network traffic will increase as additional advancements are introduced into the cyber space environment. Systems that can neutralize malware introduction points is highly prioritized in the cyber space environment. The detection of malware is currently being further developed in the cyber space environment and will continue to increase in the future.

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V. CONCLUSION AND FUTURE WORK

A. FINAL CONCLUSIONS

This thesis research sought to answer the question: 1. How can AI methods be implemented to develop ABMAs to improve tactical decision-making? This thesis conducted a study of ABMA development through AI method integration with an objective of identifying specific ABMA applications to the realm of tactical decision-making. A better understanding of how existing and future AI methods can improve tactical decision-making to provide benefits to the warfighter from increased battlespace awareness, improved usage of warfighting resources, increased tactical advantages over adversaries, and increased decision superiority was the focus.

Decision complexity issues will be prevalent to warfighters for many years to come. Increased levels of information will continue to be introduced to warfighters and require processing and thorough analysis in order to make the best decisions possible. The ability to decrease some complexity through the utilization of automated battle management aids and artificial intelligence will be further developed in order to give warfighters an increased level of advantages over adversaries who are increasing their capabilities as well. Even though the full range of adversarial capabilities will not be completely revealed, a high level of confidence in U.S. naval systems to overcome any presented obstacle will be the driving factor of future development. The dynamic nature of technological advancements will continue to evolve as more technological capabilities are introduced to different domains and environments through ABMAs and AI. The focus on included warfighters in ABMA development and AI methods in order to deliver the best product to the fleet is a priority. Battle space awareness is essential to executing operational missions with the highest success rate. Enhanced ABMA development offers a way ahead to change the nature of warfare through displaying pertinent information that warfighters need. In addition to cutting back on operational inefficiencies, ABMAs offer the ability to decrease current system shortfalls. Ensuring reliable information is readily available to warfighters in different tactical environments is extremely important enhancing the situational awareness in tactical environments. AI enables many different application methods from machine learning to deep learning to collaborating systems. Harnessing the power of AI and properly integrating it into systems will be essential to success.

B. LIMITATIONS

Data collection limitations impacted this research. The ability to interview an exorbitant number of SMEs provides more data to for an even more in-depth analysis for future recommendations. AI method development is still ongoing and will continue to increase as more time and resources are devoted to furthering developed areas. New capabilities will be revealed over time.

C. RECOMMENDATIONS FOR FUTURE RESEARCH

A more comprehensive development of ABMAs and AI intelligence will aid the future implementation of new applications and technology in future warfare. Recommendations for future work are to increase the implementation efforts of ABMAs and AI through the requirement of an increased level of identified areas of need.

1. Operational Needs

Interviews with additional operational warfighters of all levels with a ride range of experiences will help to enhance the apparent voids in battle management. The inclusion of high-level strategic warfighters will assist in providing a more comprehensive understanding of the needs of the Navy. A larger pool to collect data from will inform researchers of new ways to incorporate ABMAs and AI into diverse tactical environments. Larger data sets will enable a more in depth correlation of trends to be analyzed for future implementation efforts. Inclusion of more spatial environments will provide even more areas for ABMA implementation.

2. Further Exploration

Further exploration of applicable AI methods to increase the employment of AI methods in the battlespace will reveal additional ways to incorporate the usage of AI to further increase the advantage of utilizing ABMAs.

3. Validation

Human-operator collaboration testing in the near future will test the feasibility of ABMAs in tactical environments. Being able to validate the application of aids to warfighters will produce shortfalls to be worked through as well as some not thought of benefits. The actual testing of systems designed to ease decision complexity issues and assist warfighters will need to be researched in the future.

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