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Unmanned Tactical Autonomous Control and Collaboration (UTACC) campaign of experimentation

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THESIS

UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION (UTACC) CAMPAIGN OF EXPERIMENTATION

by

Christopher P. Larreur

September 2016

Thesis Advisor:	Dan Boger
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13. ABSTRACT (maximum 200 words)

This thesis defines a campaign of experimentation to guide UTACC development from concept to reality. It also applies design methodologies to reduce costs and increase the quality, effectiveness, and speed of UTACC's development. UTACC is a system of systems that teams Marines with unmanned robotic systems to reduce the Marine's cognitive load and enhance mission accomplishment. Bringing UTACC from concept to reality requires extensive experimentation, but prior to this thesis no experimentation plan has existed.

A series of UTACC theses have been written starting with a CONOPS. Then theses red-celled the CONOPS, explored Coactive Design methodology, analyzed UAV alternatives, and generated measures of effectiveness and performance for the system. Using information learned from the previous theses, the campaign of experimentation described in this thesis identifies key developmental relationships, associates measures with them, and organizes them in an incremental order. This thesis also emphasizes Coactive Design and Model Driven Software Development to reduce cost and improve the quality and flexibility of the system. The goal of the campaign is to provide a plan to develop a robust, cost-efficient system that Marines can use as a part of their team to increase victory on the battlefield.

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UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION (UTACC) CAMPAIGN OF EXPERIMENTATION

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Submitted in partial fulfillment of the
requirements for the degree of

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This thesis defines a campaign of experimentation to guide UTACC development from concept to reality. It also applies design methodologies to reduce costs and increase the quality, effectiveness, and speed of UTACC's development. UTACC is a system of systems that teams Marines with unmanned robotic systems to reduce the Marine's cognitive load and enhance mission accomplishment. Bringing UTACC from concept to reality requires extensive experimentation, but prior to this thesis no experimentation plan has existed.

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LIST OF ACRONYMS AND ABBREVIATIONS

AC-MDSD	Architecture Centric Model Driven Software Development
BAMCIS	Begin the planning, Arrange Reconnaissance, Make Reconnaissance, Complete the plan, Issue the order, Supervise
C2	Command Control
CCRP	Command and Control Research Program
CMU	Carnegie Mellon University
COI	Critical Operational Issues
CONOPS	Concept of Operations
DOD	Department of Defense
HRI	Human Robot Interaction
HSI	Human System Integration
IA	Interdependence Analysis
IHMC	Institute of Human and Machine Cognition
LOE	Limited Objective Experiment
LTA	Limited Technical Assessment
MCDP	Marine Corps Doctrinal Publication
MCTL	Marine Corps Task List
MCWL	Marine Corps Warfighting Laboratory
MDSD	Model Driven Software Development
MOE	Measure of Effectiveness
MOP	Measure of Performance
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UTACC	Unmanned Tactical Autonomous Control and Collaboration

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EXECUTIVE SUMMARY

Rapidly evolving technology has created information overload for decision makers. They are expected to pull specific and relevant information from a vast sea of data and then make decisions that impact Marines on the battlefield. The abundance of information can overwhelm warfighters and lead to degraded mission performance (Rice, Keim, & Chhabra, 2015, p. 3). The Unmanned Tactical Autonomous Control and Collaboration (UTACC) system is designed to enhance mission accomplishment while reducing the information load on the warfighter. UTACC consists of Marines, an unmanned ground component, and an unmanned aerial component acting as a team to accomplish future operations.

This thesis is the sixth in a series of theses that support the Marine Corps Warfighting Laboratory's (MCWL) development of the UTACC system. It describes how a campaign of experimentation will help system developers advance UTACC from concept to functional system. This thesis also uses design methodologies to facilitate efficient and effective system development. The campaign of experimentation satisfies the system engineering criteria of detail design and development.

The campaign of experimentation is based on the concept of operations (CONOPS) that focuses system development. The campaign follows the Command and Control Research Program's guiding principles of variety and replication. Their use ensures that a successful system is developed in a comprehensive and incremental way. Seven Critical Operational Issues (COI) provided in the planning worksheet attached in the appendixes are the foundation for the hypotheses driving experimentation.

The campaign of experimentation uses Limited Technical Assessments (LTA) to organize experimentation into stages. Two LTAs are scheduled to take place each year. This allows a six month period for developers to conduct their own experimentation and address any issues that arise. MOEs and MOPs provide quantifiable standards to evaluate newly developed system capabilities. Using them as entrance and exit criteria ensures

that replication occurs throughout the experimentation process and that the needs of the Marine Corps are met.

Coactive design is one of the proposed design methodologies for UTACC developers. It focuses on human-machine interaction. The Marine Corps planning process is a framework for the UTACC coactive design process. Coactive design is used to identify the different variables associated with interdependence, tasks to be completed, and the relationship between the two. It is a unique combination of waterfall and spiral development models. The waterfall attributes of the process make it easier to follow and execute while the spiral model attributes facilitate adaptation throughout the design process (Satzinger, Jackson, & Burd, 2012, pp. 228, 230). The simplicity and flexibility of the coactive design method is a tremendous advantage for the UTACC development team. They can quickly identify interdependence variables and either add, subtract, or modify variables throughout the process.

Model driven software development (MDSD) is the second design methodology recommended in this thesis. MDSD fits the DOD standard for software development outlined in DOD publication 5000.02 Operation of the Defense Acquisition System. The goals of MDSD are to increase development speed, improve the quality of the software created, improve software maintenance, increase reusability, manage the complexity of system, and increase interoperability (Stahl et al., 2006, p.13–14). To accomplish these goals, software developers utilize models. The collection of models makes up an architecture. The architecture defines the system or system of systems and serves as a blueprint that software development teams can use as a foundation to create an application (Stahl et al., 2006, p. 22). The more detailed the architecture, the more thorough a blueprint is created, and the more efficient the software developers are because they can copy source coding rather than create new coding for a function.

UTACC is a unique, innovative system that teams a Marine with a machine to reduce the Marines’ cognitive load and enhance mission success. Going from concept to reality requires robust, incremental experimentation. This thesis proposes a campaign of experimentation to accomplish exactly that. It focuses resources and the efforts of developers to create a system that serves as teammate on the battlefield instead of a tool.

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I. INTRODUCTION

A. UTACC VISION

There are a large number of sensors and technologies used for war that are designed to increase mission accomplishment for the warfighter. These technologies have created information overload for the decision maker. Decision makers must pull specific information from a vast pool before making decisions that impact lives on the battlefield. This abundance of information can easily overwhelm the warfighter and lead to unintentional degraded mission performance (Rice, Keim, & Chhabra, 2015, p. 3).

As stated by Rice et al. (2015), the Unmanned Tactical Autonomous Control and Collaboration (UTACC) system's purpose is to enhance mission accomplishment while reducing the warfighter's information overload. Collaborative autonomy accomplishes that goal. The system will consist of a team member, an unmanned ground component, and an unmanned aerial component acting as a team to accomplish future operations. System developers analyze operational context, possible missions with associated tasks, human system integration (HSI) factors, and data exchange requirements to understand the inherent complexities of the system and plan a way forward. The Marine Corps will need to innovate new technology to create a UTACC system that can function as an integral part of the team.

This thesis is the sixth in a series of theses that discuss the Marine Corps Warfighting Laboratory's (MCWL) development of the UTACC system. This thesis is similar to the previous five theses because UTACC development utilizes the incremental design process. MCWL's mission is to rigorously explore and assess Marine Corps service concepts using war gaming, concept-based experimentation, technology assessments, and analysis. In addition to assessing service concepts, they aim to inform force development by validating, modifying, or rejecting concepts' viability while identifying capability gaps and opportunities ("MCWL," n.d., mission). The first thesis in this series developed a concept of operations for UTACC. The second thesis conducted a "Red Team" critique of the concept of operations (CONOPS). The third thesis explored

Marine and machine interdependence. The fourth thesis used CONOPS to develop specific measures of effectiveness (MOE) and measures of performance (MOP) for UTACC. The fifth thesis analyzes MCWL alternatives for an appropriate UTACC unmanned air vehicle. This thesis adapts the fourth thesis's development of UTACC MOEs and MOPs to propose a coherent campaign of experimentation to ensure that UTACC focuses on the most important operational and technical concepts.

B. RESEARCH QUESTION

This thesis proposes a campaign of experimentation that system developers can use to advance UTACC from concept to functional system. This thesis will answer the following questions: 1) What is a campaign of experimentation and how should it apply to UTACC? 2) What are the key operational and technical elements of UTACC? 3) How can one use MOEs and MOPs to determine if those elements have been met? 4) How should the campaign of experimentation arrange the order of these elements? 5) What are the associated entrance and exit criteria required to move from one element focus area to the next? 6) Can some elements be worked in parallel? 7) If so, which ones? These questions form the bedrock for understanding what a campaign of experimentation is, how UTACC developers can utilize it, and how the process of system development can occur. Successful UTACC system development requires the use of funds, new technologies, and a variety of novel innovations from diverse organizations. An incremental guide for experimentation will allow the Marine Corps to effectively focus the attention, skills, and resources needed to create UTACC (Alberts & Hayes, 2005, p. 63). The campaign of experimentation proposed in this thesis will attempt to accomplish just that.

C. THESIS ORGANIZATION

The thesis is organized into four chapters. The introduction explains how this thesis falls within the UTACC thesis series and uses content from the previous theses. The introduction explains the UTACC vision of creating a system that teams unmanned ground and aerial vehicles with Marines to reduce their cognitive load in combat. The introduction introduces the research questions that guided thesis research and describes the intended impact of the thesis on UTACC system development.

Chapter II, the literature review, summarizes background information regarding UTACC concepts and explains the intended impact of the system on the battlefield. The literature review explores autonomy in depth, a critical aspect of UTACC. It defines autonomy, the levels of autonomy, and the Department of Defense’s stance regarding autonomy and the potential benefits autonomy will offer in future conflicts. The chapter then explains measures of effectiveness and performance. Measures of effectiveness and performance are standards for the operation of a system. They focus experimentation efforts by functioning as entrance and exit criteria for those experiments. The chapter then describes of a campaign of experimentation and its various parts in detail. The campaign of experimentation is a system development roadmap designed to be a proactive, incremental guide to focus attention and resources (Alberts & Hayes, 2005, p. 63). The last two sub-sections of the literature review introduce different design methodologies developers can use to increase the speed, quality, and flexibility of the system throughout the development process.

Chapter III explains key elements and design methodologies of the UTACC campaign of experimentation. The chapter explains and expands upon concepts introduced during the latter half of the literature review. The third chapter pulls heavily from the fourth and fifth theses in the series. The chapter highlights the importance of measures of effectiveness and performance, interdependence, and the coactive design process because they ensure a quality product is delivered to the warfighter.

The fourth chapter of the current research moves away from the conceptual aspects of a campaign of experimentation and focuses on the practical application of the campaign. The chapter explains the logistical components of a recommended campaign of experimentation. The thesis includes a planning template for limited technical assessments and recommends a plan for future assessments. The chapter also lists entrance and exit criteria for each stage of the campaign. The chapter assesses which development efforts can be run in parallel to save system developers time. Finally, the chapter summarizes the thesis and recommends future areas of research for UTACC. The fourth chapter will briefly describe potential research areas to orient developers toward future development. An appendix containing supporting documentation is also included.

D. SECTION SUMMARY

UTACC is a complex array of mature and developing technologies that will need to work together and in tandem with humans to accomplish a mission. Significant advancement in autonomy and additional technology is required before unmanned systems are capable of functioning as Marine teammates. This thesis explains how various concepts and methodologies can enhance the development of UTACC. The thesis is a launching point for development teams and is intended to generate the conversation and debate needed to move UTACC from a concept to a team member.

II. LITERATURE REVIEW

A. BACKGROUND

Unmanned Tactical Autonomous Collaboration and Control (UTACC) was developed to reduce Marines' cognitive load. UTACC developers will increase the autonomy of unmanned ground and aerial systems to change the relationship between human and machine. Currently, unmanned system operators use a remote control to provide direct input to the system, called "human in the loop" operation (Rice, Keim, & Chhabra, 2015, p. 12). UTACC's increased autonomy places the operator in a supervisory role over the system, a status called "human on the loop" (Rice et al., 2015, p. 12). Marines give the machine mission parameters, intent, and tasks and afterwards the machine executes those tasks autonomously. When a task is complete or a critical decision point is reached, the system notifies the human operator to receive acknowledgement or input before continuing with its mission. Putting the human "on the loop" allows the warfighter to focus on warfighting tasks. The push and pull of information between human and machine facilitates a teamwork relationship between man and machine. The UTACC program is developing software for unmanned systems that develops collaboration between systems and Marines (Gelhaus, 2015, p. 7). To do this, system developers will utilize "agent-based reasoning and semantic technologies to plan an optimized method to complete a task(s), goal(s), or performance measure(s); then set off to accomplish those with (or without) human partners (vice operators)" (Gelhaus, 2015, p. 7).

To date, there have been two limited technical assessments to demonstrate and test the capabilities of the UTACC system. The first limited technical assessment (LTA) occurred on 26 February 2015 and the second on 18–22 April 2016; representatives from the Center for Naval Analysis (CNA) observed both and wrote reports (Gelhaus, 2015, p. 4). The first LTA was a proof of concept (POC) and occurred at Carnegie Mellon University's (CMU) campus in Pittsburgh, Pennsylvania. The POC occurred in four stages. The first demonstrated current Marine cognitive load and how much time is required to accomplish a mission while operating a legacy Dragon Runner unmanned ground vehicle (Gelhaus, 2015, p. 14). The second stage of the POC tested an unmanned ground vehicle developed by CMU. The focus of this part of the POC was mobility, 3D mapping, resource utilization, sensor capabilities, system prompts, and machine diagnostics (Gelhaus, 2015, p. 15). The third stage tested autonomous collaboration between CMU's unmanned ground and aerial vehicles. The vehicles worked together using a shared 3D map to find a green pad on a desk oriented so the ground vehicle could not "see" it with its onboard sensors (Gelhaus, 2015, p. 17). The final stage of the POC tested the autonomous control of the CMU system and its ability to adjust to changes in its environment. It demonstrated how much time an operator spends accomplishing tasks without the system as compared to how much time is spent when an operator uses the system. Additionally, the final stage tested how the system reacted to environmental changes (Gelhaus, 2015, p. 18). CNA concluded that the autonomous systems were faster at accomplishing their tasks than their human-operated counterpart. Although CNA recommended further experimentation, it ultimately concluded that unmanned autonomous systems reduced Marines' cognitive load (Gelhaus, 2015, p. 25).

LTA 2 took place from 18–22 April 2016 in Ellis Hall aboard Marine Corps Base Quantico. It tested the UTACC hardware and its collaborative capabilities in a controlled environment. The experiment took place in a mock village with adjacent forest, river, and river crossing point inside the auditorium at Ellis Hall. LTA planners prepared eight scenarios to test UTACC, but only two were executed because software and hardware issues left little time for the rest. The first scenario tested the system's ability to autonomously build a 3D model of the village and its surrounding area using data from the UGV and UAV. During the second scenario, the system searched for a high-value target while using and improving the map developed in the first scenario. The system used facial recognition software to identify the target. When either the UGV or the UAV found the target, the system requested confirmation from the Marine on the loop. When Marines gave confirmation and authorized target engagement, the system requested fires from an offshore platform. In this case, the offshore platform was the Navy's Stiletto test ship tied up on the Potomac River.

UTACC was successful in both of the scenarios despite hardware limitations. The issues arose from the UGV and UAV platforms themselves, not the onboard equipment. The system used data from the UGV and UAV to quickly and autonomously build an accurate map of the designated operating area, satisfying the first scenario's requirement. For the second scenario, the system effectively built on the first scenario map, identified its target, and, after receiving authorization, requested fire and engaged the target. Despite the limited scope of the LTA, the system demonstrated an acceptable level of hardware and collaborative capability. The system autonomously built a map and identified its designated targets using onboard equipment and accomplished all of its tasks through collaboration between the ground and aerial vehicles. LTA 2 reinforced UTACC's viability as a system and its potential to improve Marines' combat capability.

B. AUTONOMY

Little research explores the concept of UTACC; however, there is literature that describes automation and its application to future combat. Shaker and Wise (1988) explain the history of automation and robotics going back to World War I. The term autonomous, as used in robotics, is interpreted in a number of ways by people in the industry. Autonomy can range from direct control of a system to unmanned systems executing tasks with no human intervention (Bruemmer, Ferlis, Huang, Novak, Schultz, & Smith., 2004). Bruemmer et al. (2004) and Glotzbach (2004) define automation and provide guidelines for measuring levels of autonomy. UTACC is intended to develop a semi-autonomous system that enhances decision-making on the battlefield. The National Institute of Standards and Technology defines semi-autonomous as a form of operation where humans and machines execute missions by leveraging various levels of Human-Robot Interaction (HRI). In conjunction with the previous literary sources, Siegwart, Nourbakhsh, and Scaramuzza (2011) introduce the fundamentals of robotic and mobility autonomy.

The Role of Autonomy in Department of Defense (DOD) Systems is critical to UTACC development. The Role of Autonomy in DOD Systems defines the current and future role of autonomy within the DOD. The document, created by the Department of

Defense, identifies opportunities and challenges in the integration of autonomous vehicles in the military (DOD, 2012). The DOD recognizes that the strength of unmanned aerial vehicles (UAV) is their ability to provide persistent intelligence, surveillance, and reconnaissance (ISR) on the battlefield. Increased autonomy enhances these capabilities and the safety of the system. Increased autonomy also reduces human error during take-off, flight, and landing, increasing the safety of the system. The safety and ISR that increased UAV autonomy provides reduces Marines' cognitive load. UGVs similarly reduce Marines' cognitive load. The Role of Autonomy in DOD Systems describes what UGVs are, their benefits, and how increased autonomy can improve them. It explains that UGVs' major benefit is the standoff distance they provide the warfighter. It also mentions the need for a UGV capable of operating and making decisions in accordance with the rules of engagement (ROE) and a commander's intent. At its completion, UTACC will function as a teammate that operates in accordance with Marine Corps doctrine and ROE.

Gustavsson and Hieb (2013) address the challenges associated with integrating autonomous systems in the military. They introduced the "Operations Intent and Effects Model." Their model outlines the integration of future Command and Control (C2) systems in the DOD to help the military recognize the benefits of automation. Lin, Beckey, and Abney (2008) add to this discussion by listing future missions and task sets for robotic systems and describing possible ethical implications of robotic systems' use in war.

Another important aspect of UTACC is Human-Robot Interaction (HRI). Groom and Nass (2008, p. 496) suggest that the following question guides HRI model development: "which human inabilities can the robot perform, and what organizational structure best supports both human and robots?" They note that future robotic teammates will have high levels of autonomy and coordination skills to assist their human counterparts, but that system functionality may be limited to specific environments unless explicitly designed otherwise. Integrating an HRI framework into system development creates broad system application and increases the success of a system in unpredictable environments (Groom & Nass, 2008, p. 483).

UTACC's level of autonomy is significant to system development. As sophistication increases, human operators will assume a supervisory role over a system instead of actively controlling it (Chen & Barnes, 2014, p. 30). Maintaining a supervisory role over the system will be challenging if there is not a proper system interaction or interface to support the human operator (Chen & Barnes, 2014, p.23). Incoming sensor data will have to be relayed to C2 workstations and displayed in a comprehensible manner to be useful to the decision maker (Shattuck & Lewis Miller, 2006, p. 8). Key leaders must be supported with the most pertinent information, so that their perceptions, understanding, predictions, and decisions meet the requirements needed to accomplish the system's goals (Shattuck & Lewis Miller, 2006, p. 6). Trafton et al. (2006) argue that integrating a computational cognitive model in a robotic system will increase its intelligence and create superior decision-maker support capability.

Robot and Marine must exchange information to accomplish the goals of the UTACC system. Gold (2009) outlines four areas of information exchange: robot to human, environment to robot, human to robot, robot to environment. UTACC success also requires that information flows across the four areas in addition to a fifth, robot to robot. The UTACC system interacts with the environment through UGV and UAV on-board sensors while simultaneously transmitting and receiving information from other robots and humans via communication links.

UTACC must be included within the Marine Corps Task List (MCTL) to evaluate capability gaps and determine efficiencies (Rice, Keim, & Chhabra, 2015, p. 16). The concepts of collaborative autonomy and interoperability do not exist in Marine Corps doctrine. However, Marine Corps Doctrinal Publication (MCDP)-1 Warfighting along with MCDP-2 Intelligence, MCDP-3 Expeditionary Operations, MCDP-4 Logistics, MCDP-5 Planning, and MCDP-6 Command and Control are the fundamentals of Marine Corps warfighting and should be the basis for UTACC concepts.

C. MOE/MOP

In March 2014, the Marine Corps published Expeditionary Force 21 outlining the future of Marine Corps warfighting. It is a blueprint for the Marine Corps capabilities and capacity decision-making processes (USMC, 2014a, p. 7). Expeditionary Force 21 describes a modern force that actively integrates innovation and emerging technologies to create an advantage over future opponents (USMC, 2014a, p. 7). UTACC accomplishes that vision because it is an innovative technological concept that gives decision makers an edge over their enemies.

UTACC will provide commanders with an advantage by integrating all warfighting functions (intelligence, maneuver, fires, logistics, force protection, command and control). Initial development, however, will focus on the intelligence warfighting function. Future iterations of the system will address the other functions. Development will begin by analyzing the Marine Corps Tasks (MCTs) because they will be used to build measures of effectiveness (MOE) and measures of performance (MOP) (Rice et al., 2015, p. 17). The Joint Chief of Staff's directorate J-7 defines and explains MOEs and MOPs. The J-7 "is responsible for the six functions of joint force development: Doctrine, Education, Concept Development & Experimentation, Training, Exercises and Lessons Learned" (Glossary, n.d.). MOEs are created to analyze the effects, both good and bad, of a system on operations (JCS J7, 2011, p. III-4). They prompt an organization to assess its development efforts and track their progress toward accomplishing the system's ultimate goals (Rushing & Kirkpatrick, 2016). MOPs are incremental ties that link system tasks to the MCTL. System developers use MOPs to align their efforts to the needs of the service acquiring the system (Rushing et. al, 2016). For UTACC, the Marine Corps Warfighting Lab and Naval Postgraduate School are the developing organizations and the Marine Corps is the acquiring service. System developers must analyze the MCTs and the develop MOEs and MOPs to ensure incremental UTACC system development (Rice et al., 2015). Incremental development requires extensive experimentation that should be structured pursuant to a campaign of experimentation.

D. CAMPAIGN OF EXPERIMENTATION

Experimentation is a cornerstone of DOD's strategy to transform the current force into a technologically advanced, net centric force. UTACC experimentation will create a system that reinforces network capabilities, improves information sharing, and increases situational awareness and mission effectiveness (Alberts, Hayes, Kirzl, Leedom, & Maxwell, 2005, pp. 8–9). Semi-autonomous system experimentation enhances the abilities of decision makers and supports the physical, information, and cognitive domains of net centric warfare (NCW) (Alberts et al., 2005, p. 10). The physical domain of NCW refers to the land, air, sea, and space spheres where warfare is conducted and combat effectiveness is judged. The information domain is where information is created, shared, manipulated, and where most command and control is communicated. The cognitive domain is in the mind of the individual warfighter. The cognitive domain consists of the tangibles of the tactics, techniques, and procedures in addition to the intangibles of leadership, situational awareness and more (Alberts et al., 2005, pp. 11–12). The DOD's command and control research programs publication Code of Best Practices: Experimentation discusses the simultaneous relationships that take place between the domains of NCW to ensure mission success. Through experimentation, UTACC developers will leverage the relationships between domains to enhance mission accomplishment.

A comprehensive campaign of experimentation will guide incremental UTACC development. A framework of discovery, hypothesis, and demonstration experiments in the campaign of experimentation accomplishes incremental system development. Discovery experiments are experiments that introduce new concepts, technologies, or systems to an environment for analysis (Alberts et al., 2005, p. 19). They determine the military viability of a system, potential employment methods, and conditions for or the limits of the systems' use. Discovery experiments can be conducted in a number of ways—ranging from simulators to actual field usage—to facilitate innovation while reducing cost. Discovery experimentation is a precursor to hypothesis experimentation because hypotheses are created during this phase (Alberts et al., 2005, p. 20).

Hypothesis testing is the next phase of experimentation. Hypothesis testing determines the limiting factors of the system and tests the system as a whole (Alberts et al., 2005, p. 22). The primary goal of hypothesis experimentation is to gain knowledge about possible variables that affect the functionality of the system. Initial hypothesis are reformed through subsequent hypothesis testing. Because hypotheses are tested and reformulated through experimentation, system developers must carefully select initial hypotheses to test to avoid unnecessary complexity and data obfuscation (Alberts et al., 2005, p. 22). The hypothesis testing phase is broken into two parts, a preliminary and refined segment. The preliminary phase of experimentation addresses the original hypothesis and the results refine future hypotheses. The refined hypothesis is then tested to both ensure the viability of the refined hypothesis and to ensure that the system functions under a variety of conditions (Alberts et al., 2005, p. 22). The results identify the viability of a system for military use and refine the system for demonstration experimentation.

Demonstration experiments show the acquiring institution that the system enhances combat effectiveness and mission accomplishment under varying conditions (Alberts et al., 2005, p. 23). In contrast to hypothesis testing, demonstration experiments are not designed to create knowledge. Instead, they present known information to individuals who are not familiar with the system or data that has been created during the previous experimental phases. System developers should demonstrate the system under conditions specific to its use so that the experiment effectively conveys the viability of the capabilities of the system (Alberts et al., 2005, p. 23). System developers will identify a system’s specific conditions during the extensive discovery and hypothesis phases of the campaign. In all of the experiments, data collection is critical (Alberts et al., 2006, p. 22).

For a campaign plan to be successful, it must be focused and identify objectives. MOEs and MOPs give UTACC developers focus and objectives. A campaign of experimentation is a framework that identifies key variables and relationships while effectively reinforcing MOEs and MOPs (Alberts et al., 2006, p. 69). In addition, a campaign of experimentation creates a balance between variety and replication (Alberts et al., 2006, p. 64). Experimentation variety allows system developers to identify issues that require follow-on experimentation (Alberts et al., 2006, p. 65). The amount of variety in a campaign of experimentation influences how robust the conclusions from the analysis of data collected are. Replication is a critical principle in the execution of a campaign of experimentation because it shows that the results of the experimentation are not unique to a particular set of conditions (Alberts et al., 2006, p. 66).

The UTACC campaign of experimentation follows the principles of phase transition: stage acknowledgement, nonlinear progress, resource availability, steering group recognition, and a broad scope of experimentation (Alberts et al., 2006, pp. 124–125). It is necessary for the system development team to acknowledge the transition from one stage of the campaign to the next because stage recognition creates knowledge continuity during experimentation. Continuity provides clarity for researchers if experimentation does not follow a linear path. Developers need to be aware of the possibility of nonlinear development progression to avoid frustration and allow developers to adjust to unexpected data discoveries. Senior steering groups allocate resources. Their authority should be recognized throughout the experimentation process. Lastly, awareness of the need for a broad scope of experimentation reinforces the system's versatility (Alberts et al., 2005).

E. COACTIVE DESIGN

Coactive design is "a fresh design perspective built on interdependence, a more comprehensive understanding of interdependence, a model for human-machine systems, a design method, and a new tool to assist with system design and analysis called the Interdependence Analysis (IA) Table" (Zach, 2016, p. 16). Captain Matt Zach's thesis, "Unmanned Tactical Autonomous Control and Collaboration Coactive Design," introduced coactive design to the UTACC program. Coactive design is critical for the UTACC program because it defines where machine automation can be useful, identifies key machine human interactions, and improves the likelihood that unmanned systems will function as team members. Coactive design also describes how the close relationship between man and machine can be accomplished through the execution of a set of shared goals. Using interdependence analysis tables, designers are able to better understand the human-machine relationship and can therefore gain valuable insight into the coordination needed to accomplish different goals (Johnson, 2014, p. 46). There are three specific realms where interdependence exists: observability, predictability, and directability.

Coactive design's design flexibility and relationship understanding ensures that humans and machines operate together to accomplish goals while broadening the machines' capability to accomplish its immediate task and overall goals.

F. MODEL DRIVEN SOFTWARE DEVELOPMENT

Model driven software design (MDSD) is another design methodology that supports system development and flexibility. MDSD aims to increase development speed, improve software quality, improve software maintenance, increase reusability, manage system complexity, and increase interoperability (Stahl, Völter, Bettin, Haase, Helsen, & Czarnecki, 2006, p. 13). This methodology uses software models. A model is "an abstract representation of a system's structure, function or behavior" (Stahl et al., 2006, p. 18). Models are used to document the structure of software for complex development projects (Stahl et al., 2006, p. 18). The models are related to the system through mapping and should include information about the system, rules for the system, and the definitions for terminology used in the system (Siegel, 2014, p. 5). The modeling process itself creates an architecture. The architecture defines the system or system of systems. UTACC is a system of systems (Siegel, 2014, p. 6). The UTACC system uses several complex software suites working collaboratively to complete a specific task and/or series of tasks. The models creating the architecture will provide the software developers the "exact meaning of program code" for the finalized UTACC product improving the software quality and development speed (Stahl et al., 2006, p. 14).

Creating an architecture through the modeling process falls within the purview of Architecture-Centric MDSD (AC-MDSD). AC-MDSD is an approach developers can use to effectively organize complicated software structures. AC-MDSD is structured to assist the developer in avoided coding errors by increasing the quality, efficiency, and reusability of software (Stahl et al., 2006, p. 21). AC-MDSD uses the architecture developed through modeling as a blueprint that software development teams can use as a foundation to create an application (Stahl et al., 2006, p. 22). The more detailed the architecture, the more robust a blueprint is created. The more robust the blueprint, the more efficient software developers are because they can copy source coding rather than create new coding for a function (Stahl et al., 2006, p. 22). The increased efficiency, quality, and reusability of software generated by AC-MDSD method benefits both short-term and long-term UTACC development. Software developers working on future iterations of the system can use or modify previously generated architectures and coding to meet future requirements. UTACC system development that employs AC-MDSD techniques will create an enduring system that meets the warfighting needs of the Marine Corps.

G. SECTION CONCLUSION

UTACC is a unique program within the Marine Corps because it transitions unmanned systems from Marines' tools to their teammates. To accomplish this, the Marine Corps is increasing human-robot interaction by using and advancing the autonomy of unmanned systems. The literature review is a source for information about UTACC and how autonomy plays a role ensuring the success of the system. The next chapters of this thesis provide greater detail regarding the campaign of experimentation, its parts, and different design methods. This thesis includes templates for how to plan and organize future experimentation so that UTACC can evolve from a concept into an operational system.

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III. RESEARCH METHODOLOGY

A. SYSTEMS ENGINEERING APPROACH

This thesis utilizes the research methodology known as the systems engineering approach. All prior UTACC theses have described and applied this methodology. This methodology originates from Benjamin S. Blanchard's *Systems Engineering Management* (4th edition) textbook, where Blanchard outlines the systems engineering approach. Blanchard defines a system as "a construct or collection of different elements that together produce results not obtainable by the elements alone." Rice et al. explain in their thesis, "Unmanned Tactical Autonomous Control and Collaboration Concept of Operations," that UTACC will ideally function as a system of systems, collaborating to enhance mission accomplishment (Rice et al., 2015, p. 20). The campaign of experimentation for UTACC meets the systems engineering step of detail design and development. This thesis uses the concept of operations (CONOP) to outline the campaign of experimentation.

B. CAMPAIGN OF EXPERIMENTATION

The fundamental anatomy of a campaign of experimentation consists of a centralized focus, a set of objectives to gauge the success of the campaign, and variety and replication in how experiments are staged and hypothesis are refined (Alberts et al., 2006, p. 69). Each objective has a set of measures associated with it to help analyze the effects of specific capabilities being tested and tie them back to essential Marine Corps tasks (Alberts et al., 2006, p. 69). Variety and replication are the guiding principles used for planning experimentation for the campaign of experimentation. They ensure that a successful system is developed in a comprehensive and incremental way (Alberts et al., 2006, p. 64).

UTACC will ultimately be a system of systems that reduces the cognitive load felt by Marines in combat, thereby enhancing Marines' ability to accomplish missions. This will be accomplished by integrating autonomous robots into Marine Corps units (Rice et al., 2015, p. 20). This is the ultimate goal of UTACC and serves as a centralized focus over the course of the campaign of experimentation. The next step is to identify the objectives that must be accomplished to make UTACC goals a reality. The broadest concrete objective of UTACC is to develop a system prototype and evaluate its capabilities (Alberts et al., 2006, p. 70). To create the system prototype, system developers assess system efficacy by comparing experiment data against entrance and exit criteria, otherwise known as MOEs and MOPs. Preliminary MOEs and MOPs for UTACC are provided in the fourth thesis of the series, "UTACC Measures of Performance and Measures of Effectiveness" (2016) and they are reproduced here in Appendix C.

The previous chapter states that the DOD's strategy for transforming the military into a net centric, technologically advanced force relies on extensive experimentation. Experimentation for UTACC will occur during both limited technical assessments (LTAs) and limited objective experiments (LOEs). Although the current thesis describes how system developers can structure LTAs, developers may use limited objective experiments (LOE) to advance UTACC knowledge and development.

To thoroughly understand the campaign of experimentation, one must look at its most fundamental element, the experiment itself. The Command and Control Research Program's (CCRP) book Experimentation (2005) explains that there are three types of experimentation: discovery, hypothesis and demonstration experiments. Figure 1 illustrates the process of experimentation and what could result from it.

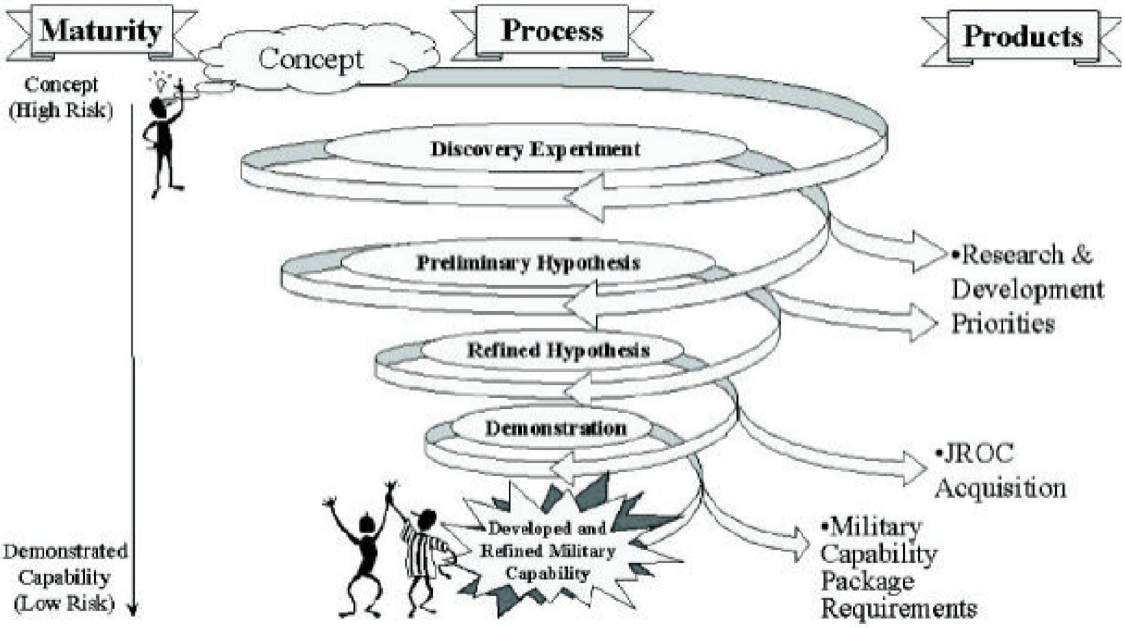

Figure 1. Process of Experimentation. Source: Alberts et al. (2005, p. 26).

Discovery experiments are experiments where system developers introduce new concepts, technologies, or systems to an environment where their impact can be recorded and analyzed (Alberts et al., 2005, p. 19). Military technologists have traditionally relied on discovery experiments to determine the utility of a technology before giving it to end users to create a concept of operations (Alberts et al., 2005, p. 20). The UTACC system is different because a preliminary concept of operations has been formulated and technology is currently being adapted to fit that role. Although a preliminary concept of operations was created, experimentation for UTACC fits within the parameters of discovery experimentation because the experiments use mature technologies to develop new applications for those technologies and potentially refine the use of those technologies. Ultimately, UTACC discovery experimentation will determine whether the system is militarily viable, how the system can be used, and what conditions extend or limit the systems' use (Alberts et al., 2005, p. 20).

After discovery experimentation, hypothesis experimentation investigates different variables that impact the system. Hypothesis testing is done in two phases, a preliminary phase and a refinement phase. Additionally, it requires a number of experiments to fully test the hypothesis (Alberts et al., 2005, p. 22). The preliminary phase of the experimentation addresses the hypothesis selected, with the results informing the hypothesis refining process. The newly refined hypothesis is then tested under a variety of conditions to verify the system's efficacy (Alberts et al., 2005, p. 22). UTACC hypotheses are based on critical operational issues (COI) identified to steer the conduct of experimentation. A critical operational issue is "key operational effectiveness or suitability issues that must be examined in operational test and evaluation to determine the system's capability to perform its mission" (Glossary, n.d.). This thesis proposes seven COIs: 1) Will the system reduce the cognitive load of the team? 2) Will the system render enhanced 3-dimensional reconnaissance products? 3) Will the system increase the safety of the team? 4) Will the system enhance identification and engagement of targets? 5) Does the system operate in accordance with Marine Corps doctrine? 6) To what extent does the digital plan provide context to the machines as well as the Marines? 7) Does the system demonstrate flexibility to changes in the environment/plan?

The final form of experimentation identified by the CCRP is demonstration experimentation. Demonstration experimentation will show that UTACC enhances combat effectiveness and mission accomplishment under a variety of conditions described in Chapter IV (Alberts et al., 2005, p. 23). Conducting the experiments in settings that the system will be used in will properly showcase its capabilities (Alberts et al., 2005, p. 23). These conditions are identified based on the nature of the previous two experimental phases (Alberts et al., 2005, p. 23). UTACC experimentation is designed in increments. As each increment builds on the last, the conditions the system is tested in evolve in complexity. The conditions or scenario remain the same for each stage of experimentation, only the technological capabilities of the system change/evolve. Figure 2 displays the nature of a campaign of experimentation and demonstrates how it follows an incremental incline as it progresses. As experimentation continues, the complexity of the system increases, refining the conditions for experimentation and advancing the knowledge of system capabilities (Alberts et al., 2005, p. 49).

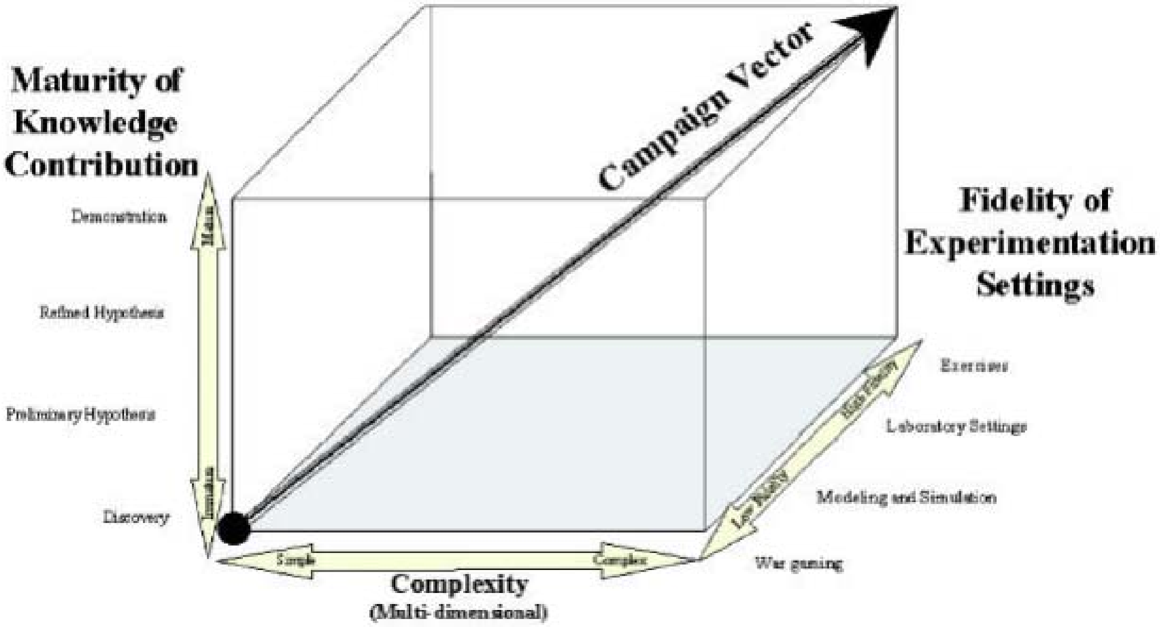

Figure 2. Nature of a Campaign of Experimentation.
Source: Alberts et al. (2005, p. 49).

Following this type of trajectory, the proposed campaign of experimentation will drive the progress of the UTACC system from concept to reality.

C. COACTIVE DESIGN

Coactive design is a design methodology that focuses on human-machine interaction which will be useful to UTACC developers. It is “a fresh design perspective built on interdependence, a more comprehensive understanding of interdependence, a model for human-machine systems, a design method, and a new tool to assist with system design and analysis called the Interdependence Analysis (IA) Table" (Zach, 2016, p. 16). Captain Matt Zach's thesis, "Unmanned Tactical Autonomous Control and Collaboration Coactive Design," applies the design process to UTACC using the Marine Corps planning process BAMCIS (Begin the planning, Arrange reconnaissance, Make reconnaissance, Complete the plan, Issue the order, and Supervise). Appendix A models how BAMCIS applies to UTACC. This section gives an overview of the coactive design process and explains how its use throughout the execution of the campaign of experimentation will greatly enhance UTACC development.

Dr. Matt Johnson of the Florida Institute of Human and Machine Cognition (IHMC) believes that the coactive design process is superior to others because it focuses on the interdependent relationship between human and machine (Zach, 2016, p. 17). The coactive design method captures the concepts of coordination, cooperation, and collaboration and conveys them in a requirements based format. The method consists of three processes: 1) the identification process, 2) selection and implementation, and 3) the evaluation of change processes (Zach, 2016, p. 24). Each process is then broken down into a series of subordinate processes. The inputs and outputs required for those sub-processes are defined. Figure 3 provides a visual representation of the coactive design process.

Zach (2016) modified the original coactive design task analysis worksheets into UTACC interdependence analysis (IA) tables. Appendix B is an example of an IA table. The modified tables address the overarching tenets identified within the CONOPS while also identifying and addressing shortfalls that were not conceived by Rice et al. (2015) (Zach, 2016, p. 3). These tables assist developers in identifying the different variables associated with interdependence, tasks to be completed, and the relationship between the two.

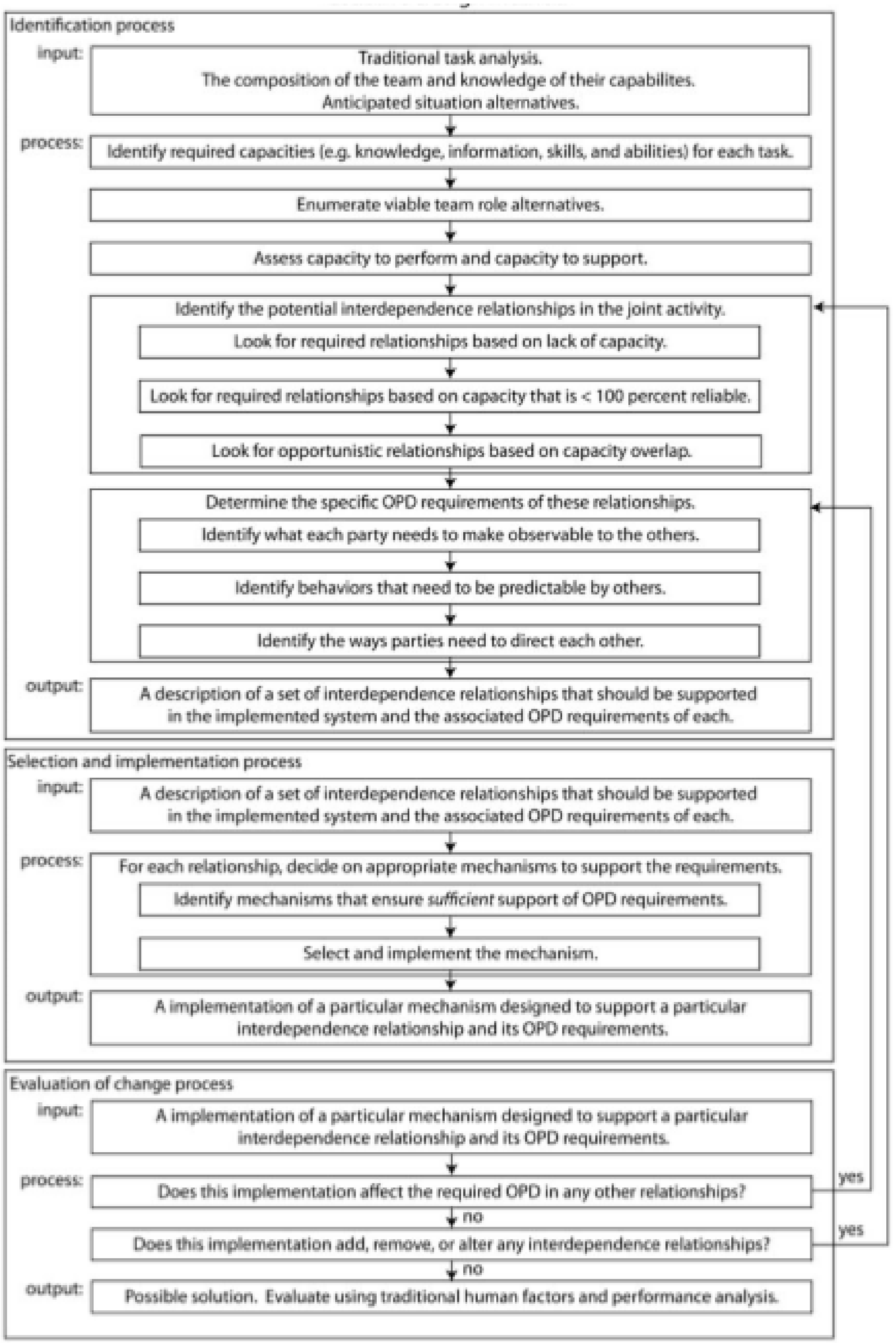

Figure 3. Coactive Design Method. Source: Johnson (2014).

Coactive design is a unique combination of the waterfall and spiral design models. The waterfall attributes of the process make it easier to follow and execute while the spiral model attributes facilitate adaptation throughout the design process (Satzinger, Jackson, & Burd, 2012, pp. 228, 230). The simplicity and flexibility of the merged design methods give the UTACC development team an advantage because they can quickly identify interdependence variables and either add, subtract, or modify variables throughout the process. The method also helps developers generate what Dr. Johnson (2014) states is a better understanding of the human-machine relationship because developers must identify variables that impact that relationship. Therefore, developers gain valuable insight into the coordination needed to accomplish different goals. With the insight provided by the coactive design process, developers will be able to create a system that can better function as an autonomous robotic team member rather than a tool for Marines to operate on the battlefield.

D. MODEL DRIVEN SOFTWARE DEVELOPMENT

The UTACC campaign of experimentation described in this thesis also includes model driven software development as a design methodology. DOD publication 5000.02 Operation of the Defense Acquisition System outlines the requirements for software development for DOD programs. It states that the development of software should be executed in a comprehensive, incremental, and efficient way in order to reduce cost and schedule overruns (DOD, 2015, p. 10). Model driven software development best fits the DOD standard for software development. The goals of MDSD are to increase development speed, improve the quality of the software created, improve software maintenance, increase reusability, manage the complexity of system, and increase interoperability (Stahl et al., 2006, p.13–14). To accomplish these goals, software developers utilize models to individually represent the system's characteristics, like its function and structure (Stahl et al., 2006, p.18). These models can be completed in a number of program languages; however, the most commonly used is the unified modeling language (UML) 2.5. As a result, this thesis recommends using UML 2.5. System developers create models by mapping the system, which includes defining system rules and defining the terms used in the system (Siegel, 2014, p. 5).

The most important step of the MDSD process is meta-model creation. The meta-model provides a description of the models' structure and defines the modeling language (Stahl et al., 2006, p. 85). Classes make up the models' structure and are a category that describes an object or thing. Each class contains common attributes or specific descriptors (Satzinger, 2012, p. 96). For UTACC, the classes for the meta-model would be derived from BAMCIS with each planning phase being its own class (Satzinger, 2012, p. 101). For example, begin planning is its own class, with attributes of system initialization and mission parameters (Rice et al., 2015, p. 39).

After system developers create a meta-model, they should create an UML profile to define the structure of the model and model constraints (Stahl et al., 2006, p. 19). With the meta-model complete, the models themselves are created. Like the meta-model, the models are made up of classes with their own attributes, but they are created using the structure and language defined by the meta-model. With UTACC, the meta-model describes the use of BAMCIS for the creation of the models. The individual models will address the planning phases. The resultant models make up an architecture that serves as an overarching definition of the systems, or for UTACC a system of systems (Siegel, 2014, p. 6).

Architecture-centric MDSD is integrated into the UTACC software development process. AC-MDSD is structured to assist the developer in avoided coding errors by increasing the quality, efficiency, and reusability of software (Stahl et al., 2006, p. 21). The ability to attain these goals falls within DOD 5000.02 requirements for software development. By taking the time up front to create a thorough architecture, efficiency is increased. The architecture facilitates the creation of source code developers can use as a blueprint. The blueprints of source coding that are created and can be used, reused, or modified are called generative software architectures. As different UTACC software teams begin to build code that satisfies different functions within UTACC software architecture, other teams are able to copy that source coding rather than create it anew. The use of generative software architecture increases the efficiency of the development process, the interoperability of UTACC software, and the ability to easily modify the system in more sophisticated phases of development (Stahl et al., 2006, p. 22).

Generative software architecture is a key component of AC-MDSD because it facilitates the modular development of an application.

Before software development begins, developers must read and understand the concepts introduced in the CONOPs. The structure of the model as well as the behaviors intended for the system to exhibit are built within the BAMCIS planning process and are described in the CONOPs. The architecture and models describe the system, and generate coding that will be used throughout software development. The ability to generate coding in the design process that can later be reused and/or modified is a tremendous strength of MDSD and helps to further increase speed, quality, and efficiency, while reducing cost.

E. SECTION CONCLUSION

The systems engineering approach is the research methodology most applicable to UTACC and for this thesis. The campaign of experimentation falls within the detailed design and development stage of the systems engineering model. The campaign starts with discovery experimentation, evolves to hypothesis experimentation, and finally extends to demonstration experimentation. Discovery experiments refine the uses of technologies being adapted for UTACC. Demonstration experiments will display the system’s developing capabilities, interoperability, and the interdependence with its human counter-parts. System developers will conduct experiments during LTAs when all development parties are present.

A campaign of experimentation can incorporate different methodologies to produce the best results. The methodology to facilitate the quality, speed, and efficiency of interdependence development, as required by DOD 5000.02, for UTACC is coactive design. Using interdependence analysis tables, developers can identify the different UTACC specific variables that will move the technology from tool to teammate. Another method that improves quality, speed, and efficiency of software development is model driven software development. Utilizing the UTACC CONOPs, software developers will be able to thoroughly outline and build models and architectures that are in line with Marine Corps doctrine. Being able to create blueprints with associated coding that can be used by a number of development teams improves the efficiency of the development process, saves money, and enhances the quality of the software. Ultimately, the campaign of experimentation and recommended methodologies take UTACC from concept to functional, mission enhancing reality.

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IV. UTACC CAMPAIGN OF EXPERIMENTATION

UTACC is a unique combination of software and hardware that functions autonomously while collaborating with Marines. The ability of the system to reduce Marines' cognitive load is critical to mission and system success. A campaign of experimentation ensures UTACC meets these goals. The campaign of experimentation incrementally balances software and hardware capabilities in accordance with the CCRP's principles of variety and replication. The campaign is structured around limited technical assessments because they serve as the primary setting for UTACC experimentation.

A. ORGANIZATION

Appendix D is a Microsoft Project Gantt chart outlining the proposed timeline, iterations, and focus of future LTAs. Because funding for UTACC is currently guaranteed until 2019, the chart begins where LTA two finished and runs through 2019. The chart is organized by LTAs and displays the primary focuses, design methodology, acceptance testing, follow-on acceptance testing, and correction times for each LTA. Two LTAs are scheduled to take place each year. This allows a six month period for developers to conduct their own experimentation/testing and address any issues that arise. Figure 4 is an example timeline for LTAs four and five.

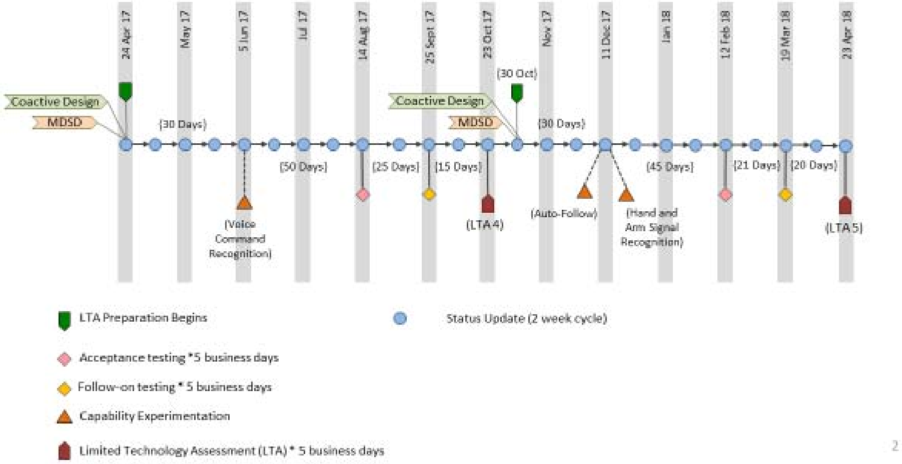


Figure 4. LTA Timeline

Each LTA advances the ability of UTACC to function as a teammate by building on the accomplishments of the previous LTAs. LTA two took place indoors and demonstrated the ability of the system to autonomously build a 3D map, search for a designated target, and engage the target. The environment the experiment was conducted within was a simulated urban environment. The target was identified using facial recognition technology, and the target was engaged by an offshore platform. The unmanned air and ground vehicles both executed 3D mapping and facial recognition. that the air and ground vehicles also worked collaboratively to create a robust and accurate picture of both the physical and human terrain. The focus of LTA three is to transfer these capabilities from an indoor environment to an outdoor one. During LTA three, UTACC will be given the additional tasks of reacting to a new environmental variable and building a plan for the approach to a designated target or location. The system must accomplish the measures outlined in the MOEs and MOPs for this stage of experimentation before the system qualifies for the next stage. Coactive design and model driven software development are incorporated into LTA three and all follow-on LTAs as parallel efforts.

LTA four experiments with voice command recognition capabilities to reduce Marine’s cognitive load when operating the system. Voice recognition allows the team leader to communicate with the system like he or she would with any member of their team, reducing and possibly eliminating the need for the Marine to interact with the system through a physical interface like a tablet. Voice recognition experimentation may take place in parallel with or after the measures accomplished in previous LTAs are repeated. It should be understood that the voice recognition referenced here does not mean full dialogue between the Marine and the machine. This stage of experimentation tests the system’s ability to receive basic, directional voice commands. The commands “forward,” “reverse,” “left,” “right,” and “stop” are the suggested goals. Anything more complex than this can be reached in future experimentation/development.

LTA five develops Marine-machine communication by testing the system’s ability to auto-follow and understand hand and arm signals. Marines on patrol maintain formation and communicate non-verbally with one another. During early-stage experimentation, the system should be able to recognize and maintain formation while following a designated member of the team. The system’s autonomous-follow ability allows Marine teammates to maintain situational awareness of their surroundings without distraction from the machine. Hand and arm signal recognition similarly increases Marines’ situational awareness, thereby enhancing combat capability. The UTACC CONOPS describe a scenario where a small reconnaissance team is inserted into a region. As the team moves through its area of operations, nonverbal communication maintains the covertness and safety of the team and mission. Hand and arm signals can be used to communicate everything from a moment’s pause to a change in patrol formation. At this stage, the hand and arm signals that LTA four tests are basic directional commands “forward,” “reverse,” “left,” “right,” and “stop.” This establishes a baseline that can be built on in future iterations of the system. Multiple means of communication and confidence in the functionality of the system facilitates Marines’ intuitive use of the machine.

LTA six tests the planning and maintenance capabilities of the system, with a focus on threat analysis and self-diagnostics. Early stage planning ability testing begins in LTA three. In LTA three, the system must provide a basic plan for an approach to a designated target. The planning at that stage does not take into account potential threats to the team; it only recommends the most straightforward approach available. LTA six will test if the system can identify potential threats to the team and incorporate that information into a plan. The plan is presented to the team leader as a recommendation subject to acceptance, rejection, or modification. Because this is early stage experimentation, the expectation for threat analysis must be simple. At this stage, the system should be able to identify a basic linear danger area, like a road. The second focus of LTA six is self-diagnostic ability. Like any team member capable of communicating current physical condition information to the team leader, UTACC must be able to express its condition to the team leader. Information regarding the condition of the system is not only critical for maintenance reasons, but it also plays a role in the decision-making process of the team-leader. If the system has degraded for any reason, knowing this will allow the team leader to decide whether or not to use the system and its remaining functional capabilities. Self-diagnostic capabilities means maintainers can quickly identify and repair issues, thereby saving time and money during maintenance

Lastly, all LTAs should include acceptance and follow-on testing. During LTA two it became clear that experimentation and technology tests had not occurred prior to the LTAs execution. This resulted in slower progress. During acceptance and follow-on testing, project managers and the Marine Corps Warfighting Laboratory assess the progress of development teams and technology, facilitate coordination between team efforts, and identify capability gaps prior to the LTA. The current campaign of experimentation schedules acceptance testing 60 days prior to the LTA and follow-on testing 30 days prior to the LTA. Both acceptance and follow-on testing are scheduled to occur over a five-day period. Correction time occurs after acceptance testing and after follow-on testing. During correction time, development teams return to their respective design facilities and address any identified shortfalls before LTA execution.

B. LIMITED TECHNICAL ASSESSMENTS

The LTAs serve as the primary setting for all campaign experimentation. LTAs take place twice annually in periods of five business days in order to ensure that development teams have the time to acquire and build the technologies needed. The LTAs incorporate the principles of variety and replication. To ensure variety, experiments rotate which components of the system are being tested. To ensure replication, the experimentation environment remains constant. During later LTAs, measures met during prior LTAs must be repeated. The environment for LTAs three through six is a relatively flat, outdoor training area with a simulated urban setting. This environment will allow new variables to be introduced and reduces mobility challenges for the unmanned system at an early development stage. As the system matures and the capabilities of the unmanned systems increase, the environment must change to present new, realistic challenges to the system. Future environments should test the system’s functionality during increasingly difficult terrain and longer distances.

Appendix E is a modified letter of instruction provided by 3D Low Altitude Air Defense Battalion. The letter is a template to organize and focus the requirements of

LTAs. The document serves as an easily understandable planning. The worksheet prompts developers to explain the situation and intent of the experimentation and LTA. It also prompts developers to create a mission statement to help focus the efforts of the development teams involved in the LTA. Developers also identify the critical operational issues being addressed through the template. The critical operational issues (COIs) serve as hypotheses for experimentation. The UTACC team has created seven COIs and they are disclosed in the modified template in the appendix. The template prompts developers to provide a concept of operations, clearly explaining how the LTA will be executed. Developers should use phases because they provide clear lines of delineation between the stages of experimentation. Lastly, the template requires that developers create coordinating instructions. These are instructions that highlight information important to all teams, such as entrance and exit criteria for the LTA and individual phases. Appendix E is filled out describing the recommended execution of LTA three.

Developers must identify entrance criteria, exit criteria, and critical operational issues that are key prior to LTA execution. Measures of effectiveness and measures of performance are the entrance and exit criteria for UTACC experimentation. Appendix C displays MOEs and MOPs developed for UTACC. The MOEs and MOPs provide quantifiable standards to evaluate newly developed system capabilities. Using them as entrance and exit criteria ensures that replication occurs throughout the experimentation process and that the needs of the Marine Corps are met.

In conjunction with entrance and exit criteria, COIs must be identified. The Defense Acquisition University defines critical operational issues as “key operational effectiveness or suitability issues that must be examined in operational test and evaluation to determine the system’s capability to perform its mission” (Glossary, n.d.). Seven COIs for UTACC are:

1) Will the system reduce the cognitive load of the team?
2) Will the system render enhanced 3-dimensional reconnaissance products?
3) Will the system increase the safety of the team?
4) Will the system enhance identification and engagement of targets?

5) Does the system operate in accordance with Marine Corps doctrine?
6) To what extent does the digital plan provide context to the machines as well as the Marines?
7) Does the system demonstrate flexibility to changes in the environment/plan?

These COIs satisfy the requirement for all LTAs in the campaign of experimentation.

C. SUMMARY

UTACC is a unique system of systems that enhances mission accomplishment by reducing the Marines' cognitive load in combat. It does this through increased autonomy of unmanned ground and air systems and improved interdependence between human and machine. Taking a machine from tool of war to teammate is not easily accomplished. A campaign of experimentation facilitates the accomplishment of this transition. The campaign of experimentation is based on the ideas introduced in the UTACC CONOPs and utilizes the MOEs and MOPs (Appendix C) developed in the fourth thesis of the UTACC series. The goal of the campaign is to create an incremental plan for experimentation that focuses development resources and the attention of developers to ensure the success of the system (Alberts et al., 2006, p. 63). The campaign of experimentation uses the guiding principles of variety and replication to ensure success. Variety allows developers to identify variables that may require further experimentation (Alberts et al., 2006, p. 65). Replication demonstrates that the results of experimentation are not unique to a specific set of conditions (Alberts et al., 2006, p. 65). Creating a balance between these principles facilitates a robust series of experimentation that advances system development (Alberts et al., 2006, p. 64).

The campaign of experimentation takes advantage of limited technical assessments to provide the setting for experimentation. A Gantt chart (Appendix D) outlines the timeline, link, and subject of experimentation for each of the LTAs. With funding for the project guaranteed until 2019, the campaign of experimentation covers that time period. Two LTAs a year will provide developers the time needed to acquire technologies and conduct functionality testing on their own. The LTAs integrate coactive design and model driven software development as preferred design methodologies. The LTA schedule also integrates acceptance and follow-on testing. These testing periods are important for the success of experimentation taking place during the LTAs. With acceptance and follow-on testing, MCWL can assess system development and technologies, identify capability gaps, and improve coordination between development teams prior to the LTA.

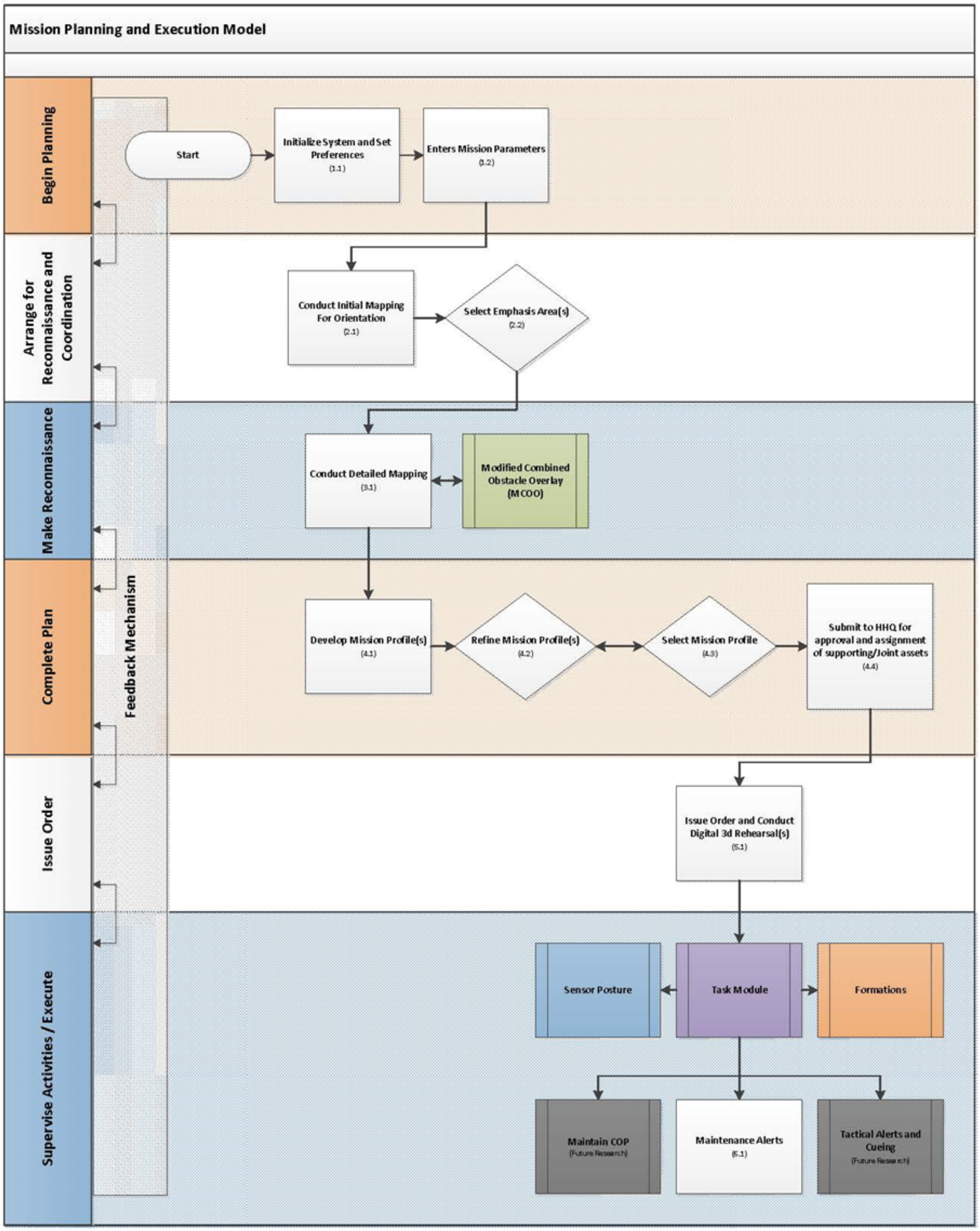
The LTA schedule integrates variety and replication. Experimenting with different technologies during each LTA satisfies the requirement for variety. Experiments meet the requirement for replication when each LTA uses the same environment and each LTA repeats the accomplishments the prior LTA . The MOEs and MOPs provide the performance standards and entrance and exit criteria for each LTA. The environment for each LTA is a relatively flat, outdoor training area with a simulated urban setting. The same training area should be used for each LTA if possible. Appendix E provides a worksheet template to facilitate planning for the LTAs. The worksheet is a modified letter of instruction used by Marine Corps field units to communicate how the execution of an event, such as a field exercise, will occur. A unique requirement of the worksheet is that critical operational issues are identified. This thesis provides seven COIs that can remain consistent across all LTA efforts. The COIs provided address the breadth of the UTACC system as it currently exists.

D. RECOMMENDATIONS

This thesis plans for how future experimentation should occur. Going forward, the campaign of experimentation should be modified to incorporate future areas of experimentation so that future system development is incremental. UTACC’s success depends upon further experimentation on interdependence and the planning capability of the system. Interdependence enhances the system’s ability to serve as a team member. The smooth push and pull of information puts the Marine on the loop with the system. On the loop status reduces Marines’ cognitive load and increases mission accomplishment. Specifically, experiments testing different interfaces between the human and machine are essential to UTACC success.

Experiments focused on integrating information into a plan are critical for the system to be successful in the field. The system must be capable of taking on and simplifying tasks carried out by Marines to be successful. Planning requires time, energy, and resources and can take place during any stage of a mission. Spontaneous mission events require planning updates. UTACC's ability to collect information on the terrain, to identify potential threats, and to incorporate threats and terrain into a plan for a team leader is invaluable. The system is merely suggesting a plan; the ultimate decision to accept, reject, or modify the plan rests with the Marine. Regardless of the team leader's decision, having critical information consolidated and organized facilitates rapid planning and execution for Marines. With future experimentation, UTACC will evolve from a machine to a functioning Marine teammate.

APPENDIX A. BAMCIS MODEL



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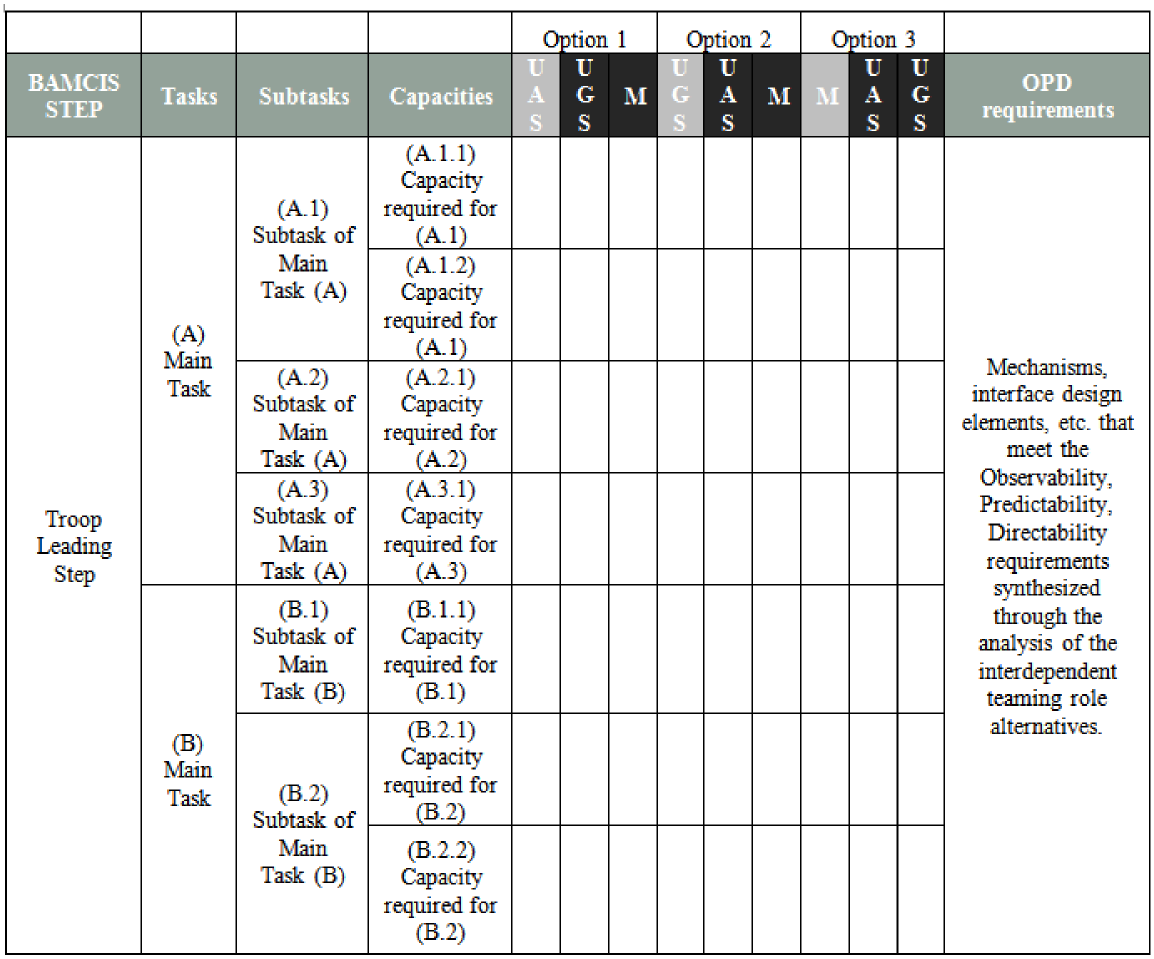
APPENDIX B. INTERDEPENDENCE ANALYSIS TABLE



				Option 1			Option 2			Option 3			
BAMCIS STEP	**Tasks**	**Subtasks**	**Capacities**	**UAS**	**UGS**	**M**	**UGS**	**UAS**	**M**	**M**	**UAS**	**UGS**	**OPD requirements**
Troop Leading Step	(A) Main Task	(A.1) Subtask of Main Task (A)	(A.1.1) Capacity required for (A.1)										Mechanisms, interface design elements, etc. that meet the Observability, Predictability, Directability requirements synthesized through the analysis of the interdependent teaming role alternatives.
			(A.1.2) Capacity required for (A.1)										
		(A.2) Subtask of Main Task (A)	(A.2.1) Capacity required for (A.2)										
		(A.3) Subtask of Main Task (A)	(A.3.1) Capacity required for (A.3)										
	(B) Main Task	(B.1) Subtask of Main Task (B)	(B.1.1) Capacity required for (B.1)										
		(B.2) Subtask of Main Task (B)	(B.2.1) Capacity required for (B.2)										
			(B.2.2) Capacity required for (B.2)										

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APPENDIX C. MOE AND MOP EXAMPLE

Case	**Priority**	**Objective**			
MCT	MCT Description	MOP	Result	Unit	Description
1	**High**	**Jointly Produce Map**			
UTAC C 1.2	Enter Mission Parameters	M1	75	%	Input Orientation: Upload the present location, direction of attack and objective, and known key terrain data
UTAC C 1.2	Enter Mission Parameters	M2	80	%	Situation: Contains information on enemy (which will include SALUTE, DRAW-D, EMLCOA and EMDCOA) and friendly (which includes locations and missions of higher, adjacent and supporting units)
UTAC C 1.2	Enter Mission Parameters	M3	55	%	Mission: Upload the UXV's mission as related to the mission of the team (Who, What, When, Where, Why). Include tactical tasks.
UTAC C 1.2	Enter Mission Parameters	M4	60	%	Execution: Upload Concept of Operations (Commander's Intent, Scheme of Maneuver, Fire Support Plan), Tasks and Coordinating Instructions
UTAC C 1.2	Enter Mission Parameters	M5	67	%	Admin and Logistics: Define number and roles of humans and robots collaborating in team environment, and establish refueling and RTB points if different from origin
2.2.1.2	Conduct Area Reconnaissance	M1	0.2	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.2	Conduct Area Reconnaissance	M2	Y	Y/N	Provide photographic and descriptive data of the Named Area of Interest to the Commander and staff.
2.2.1.3	Conduct Zone Reconnaissance	M1	0.5	Hrs	From receipt of tasking, unit reconnaissance assets in place.

2.2.1.3	Conduct Zone Reconnaissance	M2	N	Y/N	Provide photographic and descriptive data of the Named Area of Interest (NAI) to the Commander and staff.
2.2.5.2	Conduct Aviation Reconnaissance	M3	34	%	Of equipment ready and available to provide air reconnaissance operations.
2.2.5.2	Conduct Aviation Reconnaissance	M4	Y	Y/N	Product (sensor) dissemination/distribution network available.
2.2.5.2	Conduct Aviation Reconnaissance	M7	N	Y/N	Able to communicate relevant reconnaissance information using line-of-site (LOS)/beyond-line-of-site (BLOS) means.
2.7	Conduct Ground Reconnaissance and Surveillance	M2	45	%	Of equipment ready and available to provide reconnaissance and surveillance operations (i.e., communications, target designation, crew served weapons, infiltration/exfiltration equipment, mobility assets).
2.7	Conduct Ground Reconnaissance and Surveillance	M4	1	Hrs	From receipt of tasking, unit reconnaissance/surveillance assets in place.
2.7	Conduct Ground Reconnaissance and Surveillance	M5	70	%	Of collection requirements fulfilled by reconnaissance/surveillance assets.
UTACC 2.1	Conduct Initial Mapping - Depart Friendly Lines	M1	Y	Y/N	Resolve airspace deconfliction and meet safety threshold for launch.
UTACC 2.1	Conduct Initial Mapping - Geo Scan	M2	2	Hrs	Understand the size of area to scan between origin and objective. Scan the area between origin and objective for specific geographic features. Scan objective area for basic geography. Execute mapping protocol. Generate actionable information.
UTAC	Conduct Initial	M3	1.5	Hrs	Transmit map info, identify urban

C 2.1	Mapping - Build Map				and wooded areas, identify masked areas, and fill in gaps in intel.
UTAC C 2.2	Select Emphasis Area - Review Map	M1	0.5	Hrs	Different angle, higher resolution, different sensor, camera direction, multiple directions. Identify potential danger areas, routes, LZ's, water features…etc.
2.2.1.1	Conduct Route Reconnaissance	M4	1	Hrs	To conduct initial route study (dismounted/mounted).
UTAC C 3.1	Conduct Detailed Mapping	M1	70	%	Scan Emphasis Areas. Execute detailed mapping protocol (the protocol will be different for why we selected the area for additional emphasis) i.e. If for LZ, execute the LZ protocol, if for route then etc. Build detailed map collaboratively.
UTAC C 3.2	MCOO	M2	25	%	Depict Surface Drainage. Depict water sources (width, depth, velocity, bank slope, height, and potential flood zones)
2.2.1.1	Conduct Route Reconnaissance	M2	Y	Y/N	Route/road confirmed.
1.5	**High**	**Jointly Produce Map of Alternate Environment**			
UTAC C 1.2	Enter Mission Parameters	M1	75	%	Input Orientation: Upload the present location, direction of attack and objective, and known key terrain data
UTAC C 1.2	Enter Mission Parameters	M2	80	%	Situation: Contains information on enemy (which will include SALUTE, DRAW-D, EMLCOA and EMDCOA) and friendly (which includes locations and missions of higher, adjacent and supporting units)
UTAC C 1.2	Enter Mission Parameters	M3	55	%	Mission: Upload the UxV's mission as related to the mission of the team (Who, What, When, Where, Why). Include tactical tasks.
UTAC C 1.2	Enter Mission Parameters	M4	60	%	Execution: Upload Concept of Operations (Commander's Intent, Scheme of Maneuver, Fire Support

					Plan), Tasks and Coordinating Instructions
UTACC 1.2	Enter Mission Parameters	M5	67	%	Admin and Logistics: Define number and roles of humans and robots collaborating in team environment, and establish refueling and RTB points if different from origin
2.2.1.2	Conduct Area Reconnaissance	M1	0.2	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.2	Conduct Area Reconnaissance	M2	Y	Y/N	Provide photographic and descriptive data of the Named Area of Interest to the Commander and staff.
2.2.1.3	Conduct Zone Reconnaissance	M1	0.5	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.3	Conduct Zone Reconnaissance	M2	N	Y/N	Provide photographic and descriptive data of the Named Area of Interest (NAI) to the Commander and staff.
2.2.5.2	Conduct Aviation Reconnaissance	M3	34	%	Of equipment ready and available to provide air reconnaissance operations.
2.2.5.2	Conduct Aviation Reconnaissance	M4	Y	Y/N	Product (sensor) dissemination/distribution network available.
2.2.5.2	Conduct Aviation Reconnaissance	M7	N	Y/N	Able to communicate relevant reconnaissance information using line-of-site (LOS)/beyond-line-of-site (BLOS) means.
2.7	Conduct Ground Reconnaissance and Surveillance	M2	45	%	Of equipment ready and available to provide reconnaissance and surveillance operations (i.e., communications, target designation, crew served weapons, infiltration/exfiltration equipment, mobility assets).
2.7	Conduct Ground Reconnaissance and Surveillance	M4	1	Hrs	From receipt of tasking, unit reconnaissance/surveillance assets in place.

2.7	Conduct Ground Reconnaissance and Surveillance	M5	70	%	Of collection requirements fulfilled by reconnaissance/surveillance assets.
UTAC C 2.1	Conduct Initial Mapping - Depart Friendly Lines	M1	Y	Y/N	Resolve airspace de-confliction and meet safety threshold for launch.
UTAC C 2.1	Conduct Initial Mapping - Geo Scan	M2	2	Hrs	Understand the size of area to scan between origin and objective. Scan the area between origin and objective for specific geographic features. Scan objective area for basic geography. Execute mapping protocol. Generate actionable information.
UTAC C 2.1	Conduct Initial Mapping - Build Map	M3	1.5	Hrs	Transmit map info, identify urban and wooded areas, identify masked areas, and fill in gaps in intel.
UTAC C 2.2	Select Emphasis Area - Review Map	M1	0.5	Hrs	Different angle, higher resolution, different sensor, camera direction, multiple directions. Identify potential danger areas, routes, LZ's, water features…etc.
2.2.1.1	Conduct Route Reconnaissance	M4	1	Hrs	To conduct initial route study (dismounted/mounted).
UTAC C 3.1	Conduct Detailed Mapping	M1	70	%	Scan Emphasis Areas. Execute detailed mapping protocol (the protocol will be different for why we selected the area for additional emphasis) i.e. If for LZ, execute the LZ protocol, if for route then etc. Build detailed map collaboratively.
UTAC C 3.2	MCOO	M2	25	%	Depict Surface Drainage. Depict water sources (width, depth, velocity, bank slope, height, and potential flood zones)
2.2.1.1	Conduct Route Reconnaissance	M2	Y	Y/N	Route/road confirmed.
2	**High**	**Target Only Visible to UGV**			
2.2.1.	Conduct Area	M1	0.2	Hrs	From receipt of tasking, unit

2	Reconnaissance				reconnaissance assets in place.
2.2.1.2	Conduct Area Reconnaissance	M2	Y	Y/N	Provide photographic and descriptive data of the Named Area of Interest to the Commander and staff.
2.2.1.3	Conduct Zone Reconnaissance	M1	0.5	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.3	Conduct Zone Reconnaissance	M2	N	Y/N	Provide photographic and descriptive data of the Named Area of Interest (NAI) to the Commander and staff.
2.2.5.2	Conduct Aviation Reconnaissance	M3	34	%	Of equipment ready and available to provide air reconnaissance operations.
2.2.5.2	Conduct Aviation Reconnaissance	M4	Y	Y/N	Product (sensor) dissemination/distribution network available.
2.2.5.2	Conduct Aviation Reconnaissance	M7	N	Y/N	Able to communicate relevant reconnaissance information using line-of-site (LOS)/beyond-line-of-site (BLOS) means.
2.7	Conduct Ground Reconnaissance and Surveillance	M2	45	%	Of equipment ready and available to provide reconnaissance and surveillance operations (i.e., communications, target designation, crew served weapons, infiltration/exfiltration equipment, mobility assets).
2.7	Conduct Ground Reconnaissance and Surveillance	M4	1	Hrs	From receipt of tasking, unit reconnaissance/surveillance assets in place.
2.7	Conduct Ground Reconnaissance and Surveillance	M5	70	%	Of collection requirements fulfilled by reconnaissance/surveillance assets.
2.2	Collect Data and Intelligence	M1	25	%	Of targets accurately identified.
2.2	Collect Data	M2	25	%	Of targets accurately located.

	and Intelligence				
3	**High**	**Target Only Visible to UAV**			
2.2.1.2	Conduct Area Reconnaissance	M1	0.2	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.2	Conduct Area Reconnaissance	M2	Y	Y/N	Provide photographic and descriptive data of the Named Area of Interest to the Commander and staff.
2.2.1.3	Conduct Zone Reconnaissance	M1	0.5	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.3	Conduct Zone Reconnaissance	M2	N	Y/N	Provide photographic and descriptive data of the Named Area of Interest (NAI) to the Commander and staff.
2.2.5.2	Conduct Aviation Reconnaissance	M3	34	%	Of equipment ready and available to provide air reconnaissance operations.
2.2.5.2	Conduct Aviation Reconnaissance	M4	Y	Y/N	Product (sensor) dissemination/distribution network available.
2.2.5.2	Conduct Aviation Reconnaissance	M7	N	Y/N	Able to communicate relevant reconnaissance information using line-of-site (LOS)/beyond-line-of-site (BLOS) means.
2.7	Conduct Ground Reconnaissance and Surveillance	M2	45	%	Of equipment ready and available to provide reconnaissance and surveillance operations (i.e., communications, target designation, crew served weapons, infiltration/exfiltration equipment, mobility assets).
2.7	Conduct Ground Reconnaissance and Surveillance	M4	1	Hrs	From receipt of tasking, unit reconnaissance/surveillance assets in place.
2.7	Conduct Ground Reconnaissanc	M5	70	%	Of collection requirements fulfilled by reconnaissance/surveillance assets.

	e and Surveillance				
2.2	Collect Data and Intelligence	M1	25	%	Of targets accurately identified.
2.2	Collect Data and Intelligence	M2	25	%	Of targets accurately located.
4	**High**	**Target Not Present**			
2.2.1.2	Conduct Area Reconnaissance	M1	0.2	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.2	Conduct Area Reconnaissance	M2	Y	Y/N	Provide photographic and descriptive data of the Named Area of Interest to the Commander and staff.
2.2.1.3	Conduct Zone Reconnaissance	M1	0.5	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.3	Conduct Zone Reconnaissance	M2	N	Y/N	Provide photographic and descriptive data of the Named Area of Interest (NAI) to the Commander and staff.
2.2.5.2	Conduct Aviation Reconnaissance	M3	34	%	Of equipment ready and available to provide air reconnaissance operations.
2.2.5.2	Conduct Aviation Reconnaissance	M4	Y	Y/N	Product (sensor) dissemination/distribution network available.
2.2.5.2	Conduct Aviation Reconnaissance	M7	N	Y/N	Able to communicate relevant reconnaissance information using line-of-site (LOS)/beyond-line-of-site (BLOS) means.
2.7	Conduct Ground Reconnaissance and Surveillance	M2	45	%	Of equipment ready and available to provide reconnaissance and surveillance operations (i.e., communications, target designation, crew served weapons, infiltration/exfiltration equipment, mobility assets).
2.7	Conduct Ground Reconnaissanc	M4	1	Hrs	From receipt of tasking, unit reconnaissance/surveillance assets in place.

	e and Surveillance				
2.7	Conduct Ground Reconnaissance and Surveillance	M5	70	%	Of collection requirements fulfilled by reconnaissance/surveillance assets.
2.2	Collect Data and Intelligence	M1	25	%	Of targets accurately identified.
2.2	Collect Data and Intelligence	M2	25	%	Of targets accurately located.
4.5	**Low**	**Evasive Target**			
2.2.1.2	Conduct Area Reconnaissance	M1	0.2	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.2	Conduct Area Reconnaissance	M2	Y	Y/N	Provide photographic and descriptive data of the Named Area of Interest to the Commander and staff.
2.2.1.3	Conduct Zone Reconnaissance	M1	0.5	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.3	Conduct Zone Reconnaissance	M2	N	Y/N	Provide photographic and descriptive data of the Named Area of Interest (NAI) to the Commander and staff.
2.2.5.2	Conduct Aviation Reconnaissance	M3	34	%	Of equipment ready and available to provide air reconnaissance operations.
2.2.5.2	Conduct Aviation Reconnaissance	M4	Y	Y/N	Product (sensor) dissemination/distribution network available.
2.2.5.2	Conduct Aviation Reconnaissance	M7	N	Y/N	Able to communicate relevant reconnaissance information using line-of-site (LOS)/beyond-line-of-site (BLOS) means.
2.7	Conduct Ground Reconnaissance and Surveillance	M2	45	%	Of equipment ready and available to provide reconnaissance and surveillance operations (i.e., communications, target designation, crew served weapons,

					infiltration/exfiltration equipment, mobility assets).
2.7	Conduct Ground Reconnaissance and Surveillance	M4	1	Hrs	From receipt of tasking, unit reconnaissance/surveillance assets in place.
2.7	Conduct Ground Reconnaissance and Surveillance	M5	70	%	Of collection requirements fulfilled by reconnaissance/surveillance assets.
2.2	Collect Data and Intelligence	M1	25	%	Of targets accurately identified.
2.2	Collect Data and Intelligence	M2	25	%	Of targets accurately located.
5	**High**	**Only Incorrect Target(s) Present**			
2.2.1.2	Conduct Area Reconnaissance	M1	0.2	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.2	Conduct Area Reconnaissance	M2	Y	Y/N	Provide photographic and descriptive data of the Named Area of Interest to the Commander and staff.
2.2.1.3	Conduct Zone Reconnaissance	M1	0.5	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.3	Conduct Zone Reconnaissance	M2	N	Y/N	Provide photographic and descriptive data of the Named Area of Interest (NAI) to the Commander and staff.
2.2.5.2	Conduct Aviation Reconnaissance	M3	34	%	Of equipment ready and available to provide air reconnaissance operations.
2.2.5.2	Conduct Aviation Reconnaissance	M4	Y	Y/N	Product (sensor) dissemination/distribution network available.
2.2.5.2	Conduct Aviation	M7	N	Y/N	Able to communicate relevant reconnaissance information using

	Reconnaissance				line-of-site (LOS)/beyond-line-of-site (BLOS) means.
2.7	Conduct Ground Reconnaissance and Surveillance	M2	45	%	Of equipment ready and available to provide reconnaissance and surveillance operations (i.e., communications, target designation, crew served weapons, infiltration/exfiltration equipment, mobility assets).
2.7	Conduct Ground Reconnaissance and Surveillance	M4	1	Hrs	From receipt of tasking, unit reconnaissance/surveillance assets in place.
2.7	Conduct Ground Reconnaissance and Surveillance	M5	70	%	Of collection requirements fulfilled by reconnaissance/surveillance assets.
2.2	Collect Data and Intelligence	M1	25	%	Of targets accurately identified.
2.2	Collect Data and Intelligence	M2	25	%	Of targets accurately located.
6	**High**	**Both Correct and Incorrect Targets Present**			
2.2.1.2	Conduct Area Reconnaissance	M1	0.2	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.2	Conduct Area Reconnaissance	M2	Y	Y/N	Provide photographic and descriptive data of the Named Area of Interest to the Commander and staff.
2.2.1.3	Conduct Zone Reconnaissance	M1	0.5	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.3	Conduct Zone Reconnaissance	M2	N	Y/N	Provide photographic and descriptive data of the Named Area of Interest (NAI) to the Commander and staff.
2.2.5.2	Conduct Aviation Reconnaissanc	M3	34	%	Of equipment ready and available to provide air reconnaissance operations.

	e				
2.2.5.2	Conduct Aviation Reconnaissance	M4	Y	Y/N	Product (sensor) dissemination/distribution network available.
2.2.5.2	Conduct Aviation Reconnaissance	M7	N	Y/N	Able to communicate relevant reconnaissance information using line-of-site (LOS)/beyond-line-of-site (BLOS) means.
2.7	Conduct Ground Reconnaissance and Surveillance	M2	45	%	Of equipment ready and available to provide reconnaissance and surveillance operations (i.e., communications, target designation, crew served weapons, infiltration/exfiltration equipment, mobility assets).
2.7	Conduct Ground Reconnaissance and Surveillance	M4	1	Hrs	From receipt of tasking, unit reconnaissance/surveillance assets in place.
2.7	Conduct Ground Reconnaissance and Surveillance	M5	70	%	Of collection requirements fulfilled by reconnaissance/surveillance assets.
2.2	Collect Data and Intelligence	M1	25	%	Of targets accurately identified.
2.2	Collect Data and Intelligence	M2	25	%	Of targets accurately located.
8	**High**	**Start Hunt for Target at Suspected Location**			
2.2.1.2	Conduct Area Reconnaissance	M1	0.2	Hrs	From receipt of tasking, unit reconnaissance assets in place.
2.2.1.2	Conduct Area Reconnaissance	M2	Y	Y/N	Provide photographic and descriptive data of the Named Area of Interest to the Commander and staff.
2.2.1.3	Conduct Zone Reconnaissance	M1	0.5	Hrs	From receipt of tasking, unit reconnaissance assets in place.

2.2.1.3	Conduct Zone Reconnaissance	M2	N	Y/N	Provide photographic and descriptive data of the Named Area of Interest (NAI) to the Commander and staff.
2.2.5.2	Conduct Aviation Reconnaissance	M3	34	%	Of equipment ready and available to provide air reconnaissance operations.
2.2.5.2	Conduct Aviation Reconnaissance	M4	Y	Y/N	Product (sensor) dissemination/distribution network available.
2.2.5.2	Conduct Aviation Reconnaissance	M7	N	Y/N	Able to communicate relevant reconnaissance information using line-of-site (LOS)/beyond-line-of-site (BLOS) means.
2.7	Conduct Ground Reconnaissance and Surveillance	M2	45	%	Of equipment ready and available to provide reconnaissance and surveillance operations (i.e., communications, target designation, crew served weapons, infiltration/exfiltration equipment, mobility assets).
2.7	Conduct Ground Reconnaissance and Surveillance	M4	1	Hrs	From receipt of tasking, unit reconnaissance/surveillance assets in place.
2.7	Conduct Ground Reconnaissance and Surveillance	M5	70	%	Of collection requirements fulfilled by reconnaissance/surveillance assets.
2.2	Collect Data and Intelligence	M1	25	%	Of targets accurately identified.
2.2	Collect Data and Intelligence	M2	25	%	Of targets accurately located.

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APPENDIX D. GANTT CHART OUTLINE

Task Name	Duration	Start	Finish
LTA 2	5 days	Mon 4/18/16	Fri 4/22/16
LTA 3 Preparation	**255 days**	**Mon 4/25/16**	**Fri 4/14/17**
Outdoor Transition/ Software Development	205 days	Mon 4/25/16	Fri 2/3/17
Acceptance Testing	5 days	Mon 2/6/17	Fri 2/10/17
Correction Time	15 days	Mon 2/13/17	Fri 3/3/17
Follow- on Acceptance Testing	5 days	Mon 3/6/17	Fri 3/10/17
Correction Time	25 days	Mon 3/13/17	Fri 4/14/17
LTA 3	5 days	Mon 4/17/17	Fri 4/21/17
LTA 4 Preparation	**130 days**	**Mon 4/24/17**	**Fri 10/20/17**
Coactive Design	30 days	Mon 4/24/17	Fri 6/2/17
Model Driven Software Development (MDSD)	30 days	Mon 4/24/17	Fri 6/2/17
Voice Command Recognition	50 days	Mon 6/5/17	Fri 8/11/17
Acceptance Testing	5 days	Mon 8/14/17	Fri 8/18/17
Correction Time	25 days	Mon 8/21/17	Fri 9/22/17
Follow- on Acceptance Testing	5 days	Mon 9/25/17	Fri 9/29/17
Correction Time	15 days	Mon 10/2/17	Fri 10/20/17
LTA 4	5 days	Mon 10/23/17	Fri 10/27/17
LTA 5 Preparation	**125 days**	**Mon 10/30/17**	**Fri 4/20/18**
Coactive Design/MDSD	30 days	Mon 10/30/17	Fri 12/8/17
Auto-Follow Development	45 days	Mon 12/11/17	Fri 2/9/18
Hand and Arm Signal Recognition	45 days	Mon 12/11/17	Fri 2/9/18
Acceptance Testing	5 days	Mon 2/12/18	Fri 2/16/18
Correction Time	21 days	Fri 2/16/18	Fri 3/16/18
Follow- on Acceptance Testing	5 days	Mon 3/19/18	Fri 3/23/18
Correction Time	20 days	Mon 3/26/18	Fri 4/20/18
LTA 5	5 days	Mon 4/23/18	Fri 4/27/18
LTA 6 Preparation	**125 days**	**Mon 4/30/18**	**Fri 10/19/18**
Coactive Design/MDSD	30 days	Mon 4/30/18	Fri 6/8/18
Threat Analysis	45 days	Mon 6/11/18	Fri 8/10/18
Self Diagnostic	45 days	Mon 6/11/18	Fri 8/10/18
Acceptance Testing	5 days	Mon 8/13/18	Fri 8/17/18
Correction Time	20 days	Mon 8/20/18	Fri 9/14/18
Follow- on Acceptance Testing	5 days	Mon 9/17/18	Fri 9/21/18
Correction Time	20 days	Mon 9/24/18	Fri 10/19/18
LTA 6	5 days	Mon 10/22/18	Fri 10/26/18

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APPENDIX E. LTA WORKSHEET

UTACC LTA 3	**May 2016**
References	(1) COBP Campaigns of Experimentation (2) COBP Experimentation (3) LTA 2 Scenario Tasks
Enclosures	(1) MCT List
Task org:	Marine Corps Warfighting Lab
SITUATION: Marine Corps Warfighting Lab (MCWL) has tasked Naval Postgraduate School (NPS) and industry partners with the development of the Unmanned Tactical Autonomous Control and Collaboration system. To accomplish this task a series of Limited Technical Assessments (LTA) and Limited Objective Experiments (LOE) are needed to create a viable system that meets the requirements of MCWL and enhance the warfighting ability of the Marine Corps as a whole. These LTAs and LOEs will follow the fundamental concepts of variety and replication as put forward in the Code of Best Practices Campaigns of Experimentation.	
MISSION: NLT 17 April 2017, MCWL sponsors LTA 3, location to be determined in order to replicate LTA 2 performance accomplishments, and advance the UTACC system in an outdoor environment.	**Intent**: 1. Purpose. The purpose of LTA 3 is to take the UTACC system from an indoor controlled environment to an outdoor controlled environment while further testing the capabilities of the system interface, onboard sensors, and software as well as new robotic platforms. 2. Method. Having met the requirements for a) UTACC software utilization in the GUSS autonomous system and Phoenix UAV, and b) demonstration of successful outdoor transition in acceptance and follow-on testing, LTA 3 will be conducted in an outdoor environment with a simulated urban setting. This venue will allow the system developers to replicate

COI: **1)** Will the system reduce the cognitive load of the team? **2)** Will the system render enhanced 3-Dimensional reconnaissance products? **3)** Will the system increase the safety of the team? **4)** Will the system enhance identification and engagement of targets? **5)** Does the system operate in accordance with Marine Corps doctrine? **6)** To what extent does the digital plan provide context to the machines as well as the Marines? **7)** Does the system demonstrate flexibility to changes in the environment/plan?	results from LTA 2- specifically MCTs 1, 1.5, and 2- while advancing the capabilities demonstrated in these MCTs in an outdoor environment. LTA 3 will be conducted in three phases utilizing the GUSS autonomous vehicle and Phoenix 90 UAV as robotic platforms. The system will be tasked with creating a 3D model of the environment, facial recognition of a person of interest, reaction to a newly introduced variable in the environment, and deriving/building a digital plan for the approach to the target. 3. <ins>End state</ins>. The UTACC system demonstrates the ability to meet previously tested MCT performance requirements in an outdoor environment while identifying shortfalls/ advancing the capabilities of the system interface, onboard sensors, and software.

EXECUTION:

Concept of Operations:

1. On 17 April 2017, required personnel involved in the UTACC system development will arrive at a testing and evaluation location selected by MCWL. The desired location for testing and evaluation is a relatively flat, outdoor training area with a simulated urban setting. This environment will allow the system to be newly introduced to an outdoor environment that will not provide unnecessary mobility challenges at such an early stage of development. This environment will simultaneously provide a setting that facilitates the advancement and replication of previous LTA accomplishments. The environment will also facilitate testing of the capabilities of the GUSS autonomous vehicle and Phoenix 90 UAV under the control of UTACC software and interfaces.

2. Testing will be broken into three phases. Phase I will begin with a Marine operator inputting mission parameters and releasing the system to begin reconnaissance. The system will conduct a reconnaissance of an identified area of interest (AOI), building a 3D map as it does so. Upon recognizing that it cannot complete the mission as required, the system alerts the Marine and the Marine authorizes the launch of the systems UAV to assist in the completion of the mission. When reconnaissance is completed, the system requests permission from the Marine to return to base (RTB). When the Marine operator gives authorization, the system will return to its original start point. Exit criteria for Phase I will be that all performance standards established in MCTs 1, 1.5, and 2 are met.

3. Phase II will replicate the results of Phase I with the addition of the system being required to conduct facial recognition of a person and/or object of interest. After receiving verification from the Marine operator that the system has accurately recognized the target, the system will request permission to engage. When the Marine operator authorizes engagement, the system will relay a request for fire to a “firing element.” Exit criteria for Phase II are that previous MCTs are met and successful target recognition and engagement has been completed.
4. Phase III will begin at the completion of Phase II and will accomplish the performance goals of Phases I and II while reacting effectively to the introduction of a new variable and demonstrating basic planning capabilities. Utilizing the currently generated 3D map of the AOI, the system will be required a deliver a plan for approval, disapproval, or modification to the Marine operator. The plan will orient the Marine to the AOI and suggest a potential approach route to an operator selected waypoint. Also in this phase, a vehicle, previously uploaded to the system as a BOLO, will enter the AOI. The system must accurately identify the vehicle as the BOLO vehicle, notify the Marine operator for verification, and request guidance for follow-on action. Follow-on action can consist of targeting, observation utilizing either the UGV or UAV (the decision for asset usage will be left to the Marine operator), or to ignore the vehicle and continue with previous mission tasking.
5. Phase III exit criteria are as follows;
    a. Successful completion of MCTs 1, 1.5, and 2,
    b. Successful facial recognition and engagement of a target,
    c. Successful identification of a newly introduced BOLO vehicle with requests for action; targeting, observation utilizing either the UGV or UAV, or to ignore the vehicle and continue with previous mission tasking,
    d. A mission plan, created from the 3D map, utilizing a Marine operator selected waypoint is successfully generated for approval, disapproval, or modification.
6. LTA 3 is complete when all three phases and their associated entrance and exit criteria are met.

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