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**THESIS**

**UNMANNED TACTICAL AUTONOMOUS CONTROL  
AND COLLABORATION (UTACC) QUICK-WIN ROBOT  
ANALYSIS**

by

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September 2018

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**UNMANNED TACTICAL AUTONOMOUS CONTROL AND  
COLLABORATION (UTACC) QUICK-WIN ROBOT ANALYSIS**

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## **ABSTRACT**

In order to continue the Unmanned Tactical Autonomous Control and Collaboration (UTACC) program, an accurate understanding of the current unmanned vehicles (UxVs) available on the commercial market is required. This thesis used site visits, conference attendance, trade shows, and online databases to evaluate and rank both unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs).

This thesis identified 10 out of 46 UAVs and five UGVs that could be quick-wins for the Marine Corps if adopted. These identified platforms received the highest scores based on five measures of effectiveness (MOEs): technology readiness level (TRL), mission capability, interdependence, modularity, and security. This thesis also addressed the need to evaluate systems based on their level of interdependence instead of level of autonomy, acknowledging the importance of human-machine teaming.

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# TABLE OF CONTENTS

<b>I.</b>	<b>INTRODUCTION.....</b>	<b>1</b>
<b>A.</b>	<b>AREAS OF CONSIDERATION .....</b>	<b>2</b>
	1. The Operating Environment.....	2
	2. The Marine Corps' Rapid Capabilities Office Priorities .....	3
	3. The DoD Acquisition Process.....	4
<b>B.</b>	<b>PLATFORMS .....</b>	<b>4</b>
	1. Unmanned Aerial Vehicles.....	4
	2. Unmanned Ground Vehicles.....	8
<b>C.</b>	<b>CHAPTER CONCLUSION.....</b>	<b>9</b>
<b>II.</b>	<b>LITERATURE REVIEW .....</b>	<b>11</b>
<b>A.</b>	<b>WORK DONE TO DATE .....</b>	<b>11</b>
	1. UTACC .....	11
	2. Other MCWL Robotic Efforts.....	12
<b>B.</b>	<b>KEY CONCEPTS .....</b>	<b>13</b>
	1. Autonomy.....	13
	2. Interdependence.....	15
	3. Coactive Design .....	16
	4. Observability, Predictability, and Directability .....	17
	5. Confidentiality, Integrity, and Availability .....	17
	6. Situational Awareness .....	18
	7. Size, Weight, and Power (SWaP).....	19
	8. Modularity .....	20
<b>C.</b>	<b>DESCRIPTION OF MISSIONS.....</b>	<b>20</b>
	1. Local Security.....	20
	2. Targeting.....	22
<b>D.</b>	<b>CHAPTER CONCLUSION.....</b>	<b>24</b>
<b>III.</b>	<b>RESEARCH METHODOLOGY .....</b>	<b>25</b>
<b>A.</b>	<b>ANALYSIS OF ALTERNATIVES .....</b>	<b>25</b>
<b>B.</b>	<b>STUDY SCOPE.....</b>	<b>27</b>
	1. Constraints.....	28
	2. Limitations.....	28
	3. Assumptions .....	29
<b>C.</b>	<b>ANALYSIS FRAMEWORK.....</b>	<b>30</b>
	1. Ordinal Rankings.....	30
	2. Weighting Methodology .....	30

3.	Nominal Category .....	31
D.	MEASURES OF EFFECTIVENESS .....	31
1.	Mission Tasks .....	31
2.	Measures of Effectiveness.....	32
3.	Effectiveness Analysis.....	34
E.	CHAPTER CONCLUSION.....	36
IV.	ANALYSIS OF ALTERNATIVES .....	37
A.	ORDINAL ANALYSIS .....	37
B.	ALTERNATIVES CONSIDERED .....	38
1.	Unmanned Aerial Vehicles.....	38
2.	Unmanned Ground Vehicles.....	48
C.	CHAPTER CONCLUSION.....	53
V.	SUMMARY OF RESULTS AND RECOMMENDATIONS FOR FUTURE RESEARCH.....	55
A.	SUMMARY OF RECOMMENDATIONS.....	55
1.	UAVs .....	55
2.	UGVs.....	62
B.	FUTURE TECHNOLOGIES .....	63
1.	System Designs .....	63
2.	Subsystem Advances.....	63
C.	RECOMMENDATIONS FOR FUTURE RESEARCH.....	64
1.	Future of Airspace Deconfliction.....	64
2.	Universal Urgent Needs Statement Sponsorship .....	65
3.	Continued Technology Scouting.....	65
4.	Three Types of Machine Learning: Edge, Collective, External.....	65
5.	Acquisition Requirements for Unmanned Systems .....	66
D.	CHAPTER CONCLUSION.....	66
	APPENDIX A. SUMMARY OF RESULTS FOR UAVS.....	67
	APPENDIX B. SUMMARY OF RESULTS FOR UGVs.....	69
	LIST OF REFERENCES .....	71
	INITIAL DISTRIBUTION LIST .....	77

## LIST OF FIGURES

Figure 1.	Generic UAV system. Source: Fahlstrom and Gleason (2012). .....	5
Figure 2.	Elements of an unmanned aircraft system. Adapted from Barnhart et al. (2011). .....	6
Figure 3.	DoD UAS categories. Source: Assistant Secretary of Defense for Research and Engineering (2012). .....	7
Figure 4.	Interdependence model. Adapted from Johnson (2014). .....	16
Figure 5.	D3A process model. Source: Chief of Naval Operations et al. (2007). .....	23
Figure 6.	DAU Proposed AoA study plan. Adapted from Defense Acquisition University (2017). .....	27
Figure 7.	SkyRanger R80. Source: Aeryon (n.d.). .....	39
Figure 8.	AR4 Light Ray. Source: Tekever (n.d.). .....	40
Figure 9.	Hivemind Nova. Source: Shield AI (n.d.). .....	41
Figure 10.	Switchblade. Source: AiroVironment: SwitchBlade (n.d.). .....	41
Figure 11.	Neo. Source: AceCore Technologies (n.d.). .....	42
Figure 12.	Zoe. Source: AceCore Technologies (n.d.). .....	43
Figure 13.	Avenger. Source: Leptron Avenger (n.d.). .....	44
Figure 14.	Vapor 55. Source: Pulse Aerospace (n.d.). .....	45
Figure 15.	Silent Falcon. Source: Silent Falcon (n.d.). .....	46
Figure 16.	CAMCOPTER S-100. Source: Schiebel CAMPCOPTER S-100 (n.d.). .....	47
Figure 17.	CHAOS. Source: Autonomous Solutions Inc (n.d.). .....	48
Figure 18.	Model M. Source: AION Robotics (n.d.). .....	49
Figure 19.	THEMIS. Source: Milrem Robotics (n.d.). .....	50
Figure 20.	Scorpion. Source: NXT Robotics (n.d.). .....	51
Figure 21.	GR Vision. Source: Ghost Robotics (n.d.). .....	52

Figure 22.	Jump 20. Source: Arcturus UAV (n.d.).	57
Figure 23.	Orion. Source: ElistAir (n.d.).	57
Figure 24.	Black Swift S2. Source: Black Swift Technologies (n.d.).	58
Figure 25.	Shearwater. Source: Planck Aerosystems (n.d.).	59
Figure 26.	Nightingale Security. Source: Nightingale Security (n.d.).	60
Figure 27.	Navig8 Electric. Source: 4 Front Robotics (n.d.).	60
Figure 28.	Elroy Air. Source: Elroy Air (n.d.).	61
Figure 29.	Hybrid Advanced Multi-Rotor. Source: Advanced Aircraft Company (n.d.).	62

## LIST OF TABLES

Table 1.	Example effectiveness analysis results .....	34
Table 2.	Technology readiness level measures of effectiveness. Source: Defense Acquisition University (2017). .....	34
Table 3.	Mission capability measures of effectiveness .....	35
Table 4.	Interdependence measures of effectiveness .....	35
Table 5.	Modularity measures of effectiveness .....	35
Table 6.	Security measures of effectiveness. Adapted from Harvey and Trevino (2018). .....	36
Table 7.	Marine Corps supportable units .....	36
Table 8.	UAVs .....	37
Table 9.	UGVs .....	38
Table 10.	SkyRanger R80 evaluation .....	39
Table 11.	AR4 Light Ray evaluation .....	40
Table 12.	Hivemind Nova evaluation .....	41
Table 13.	Switchblade evaluation .....	42
Table 14.	Neo evaluation .....	42
Table 15.	Zoe evaluation.....	43
Table 16.	Avenger evaluation .....	44
Table 17.	Vapor 55 evaluation.....	45
Table 18.	Silent Falcon evaluation.....	46
Table 19.	CAMCOPTER S-100 evaluation.....	47
Table 20.	CHAOS evaluation .....	48
Table 21.	Model M evaluation.....	49
Table 22.	THeMIS evaluation.....	50

Table 23.	Scorpion evaluation .....	51
Table 24.	GR Vision evaluation.....	52
Table 25.	Jump 20 evaluation .....	57
Table 26.	Orion evaluation.....	58
Table 27.	Black Swift S2 evaluation.....	58
Table 28.	Shearwater evaluation.....	59
Table 29.	Nightingale Security evaluation.....	60
Table 30.	Navig8 Electric evaluation.....	61
Table 31.	Elroy Air evaluation.....	61
Table 32.	Advanced Aircraft Co, Hybrid Advanced Multi-Rotor evaluation .....	62

## LIST OF ACRONYMS AND ABBREVIATIONS

ACE	Aviation Combat Element
AoA	Analysis of Alternatives
AUVSI	Association for Unmanned Vehicle Systems International
BLOS	Beyond Line of Sight
CIA	Confidentiality, Integrity, and Availability
CONOPS	Concept of Operations
CRUSER	Consortium for Robotics and Unmanned Systems Education and Research
DARPA	Defense Advanced Research Projects Agency
DAU	Defense Acquisition University
DoD	Department of Defense
DSB	Defense Science Board
D3A	Decide, Detect, Deliver and Assess
EAB	Expeditionary Advanced Based
FOB	Forward Operating Base
FOE	Future Operating Environment
GCE	Ground Combat Element
GCS	Ground Control Station
GPS	Global Positioning System
IHMC	Institute for Human and Machine Cognition
IROC	Intuitive Robotic Operator Control
ISR	Intelligence, Surveillance and Reconnaissance
LCE	Logistics Combat Element
LOS	Line of Sight
LTA	Lighter-than-Air
MCCDC	Marine Corps Combat Development Command
MCRCO	Marine Corps' Rapid Capabilities Office
MCT	Marine Corps Task
MCWL	Marine Corps Warfighting Lab

MOC	Marine Corps Operating Concept
MOE	Measures of Effectiveness
MT	Mission Task
NIST	National Institute of Standards and Technology
NPS	Naval Postgraduate School
NTA	Navy Tactical Task
OPD	Observability, Predictability and Directability
QRF	Quick-Reaction Force
OTA	Other Transaction Agreement
RDT&E	Research, Development, Test, and Evaluation
RPV	Remotely Piloted Vehicle
RSTA	Reconnaissance, Surveillance and Target Acquisition
RV(M)	Robot Vehicle Modular
SoS	System of Systems
SWaP	Size, Weight, and Power
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
USMC	United States Marine Corps
UTACC	Unmanned Tactical Autonomous Control and Collaboration
UUNS	Universal Urgent Needs Statement
UxV	Unmanned Vehicle
VTOL	Vertical Takeoff and Landing

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## I. INTRODUCTION

This thesis was originally developed in coordination with the Marine Corps Warfighting Laboratory (MCWL) as an effort to further the Unmanned Tactical Autonomous Control and Collaboration (UTACC) program. Ultimately, MCWL did not fund continuing thesis research, so this thesis continued under the funding, and oversight of the Consortium for Robotics and Unmanned Systems Education and Research (CRUSER). However, it remains important to understand the UTACC program to understand the objectives of this thesis. Additionally, MCWL has remained engaged in tracking the progress of this thesis, and will be provided a copy of the finished report.

UTACC is a system of systems approach designed to develop the necessary human-machine teaming that could reduce the cognitive load on the warfighter (Roth & Buckler, 2016). As of 2016, MCWL's efforts have focused on intelligence, surveillance, and reconnaissance (ISR), and reconnaissance, surveillance, and target acquisition (RSTA) missions (Marine Corps Warfighting Lab, 2016). Ultimately, UTACC was designed to leverage autonomous unmanned vehicles (UxVs) in a manner that increased the warfighter's effectiveness while it decreased the cognitive demands.

The original MCWL tasking was to find a *quick-win* robotic system that could immediately have a positive impact on a particular set of Marine Corps missions. Identifying this quick win involved conducting an abbreviated analysis of alternatives (AoA) designed to identify systems that were mature, and ready to field. Based on this goal, the authors focused on systems that were a technology readiness level (TRL) seven, or higher. There are nine total TRLs, and TRL seven is defined as a system prototype demonstrated in an operational environment (Defense Acquisition University, 2017). The authors chose to focus on this level because it was best positioned to rapidly leverage mature technologies that had not been widely identified by the Marine Corps, or the Department of Defense (DoD) at large. The authors also investigated systems less than TRL seven, but showed potential to be a *quick-win* system.

## A. AREAS OF CONSIDERATION

Three separate topics serve as a framework for defining the problem space. First, it covers the operating environment which is designed to lay out how the authors see these *quick-win* systems fitting into the Marine Corps based on the Future Operating Environment (FOE), taken from the Marine Corps Operating Concept (MOC). Second, it reviews the priorities that the Marine Corps Rapid Capabilities Office (MCRCO) uses to prioritize acquiring new technologies into its portfolio. Last, it relates the DoD acquisition process to this thesis.

### 1. The Operating Environment

The MOC lays the foundation for how Marine Corp forces will operate over a broad range of military operations while meeting the guidelines of Title 10 (Headquarters United States Marine Corps, 2016). With an ever-changing operating environment, identifying what could lead to changes in the way Marines are trained, organized, and equipped is important. The MOC identified the following causes for change in the FOE: complex terrain, technology proliferation, information as a weapon, a battle of signatures, and an increasingly contested maritime domain (Headquarters United States Marine Corps, 2016). *Complex terrain* introduces information and human aspects to those of the traditional geophysical aspects (Headquarters United States Marine Corps, 2016). The enemy learned that they can use complex terrain to reduce the impact of the Marine Corps technological advantage. *Technology Proliferation* is the enemy's ability to gain a tactical advantage through the use of anti-access/area denial capabilities, and other tactics to reduce the Marine Corps' strategic reach and operational freedom of maneuver (Headquarters United States Marine Corps, 2016). With the ability to utilize 3D printers and obtain commercial-off-the-shelf products, adversaries acquire technology at a much faster rate, making it critical to identify and procure advanced technologies more quickly. *Information as a weapon* is critical to today's operating environment given that so much information flows continuously over the internet. Navigating the network in order to gain knowledge and perception is imperative, while also protecting friendly networks (Headquarters United States Marine Corps, 2016). *Battle Signatures* will allow the enemy to locate and target

friendly forces; additionally, the Marine Corps must acquire the technology to detect enemy signatures (Headquarters United States Marine Corps, 2016). *Increasingly Contested Maritime Domain* entails the enemy's ability to challenge friendly forces' control of the sea and limit access to certain regions. These driving forces will quickly and drastically alter the environment in which the Marine Corps operates. This, coupled with the quickly evolving technology of unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs), necessitates the continuous exploration and implementation of these technologies in order to bridge the gaps.

## **2. The Marine Corps' Rapid Capabilities Office Priorities**

The MCRCO's mission is to "...implement a capability development mechanism that will harness operational experience, and creativity by providing a pathway to rapidly develop, and deliver operational prototypes, and emerging capabilities to begin assessing their value in exercise, and experimental settings more quickly than current processes support" (The Marine Corps Rapid Capabilities Office, 2016, p. 4). This helps the Marine Corps identify the same *quick-win* systems as this thesis. Accordingly, the authors included several of the key thresholds used by the MCRCO in order to better align the output of this thesis with its goals. One of the first thresholds was that initiatives should be less than \$13.5 million (The Marine Corps Rapid Capabilities Office, 2016). The authors have used this amount as an order of magnitude for cost estimation and not a detailed cost estimate. A lack of time and resources limited the authors' ability to accurately estimate costs for the evaluated systems; instead this thesis collected an order of magnitude estimate for each system. The next identified requirement from the MCRCO is that sustainment be "...minimal; limited to Contractor Logistic Support" (The Marine Corps Rapid Capabilities Office, 2016, p. 5). The final threshold identified as critical to this thesis from the MCRCO is that the timeline for procurement be less than one year (The Marine Corps Rapid Capabilities Office, 2016, p. 5). This threshold indirectly informs the requirement of specific TRLs in the systems being analyzed. As stated previously, the authors used TRL level seven as the bench mark for systems to ensure rapid fielding if selected. Although additional thresholds have been identified by the MCRCO, these relate more closely to

requirements on funding sources and risk analysis that are specific to the MCRCO, and not this thesis.

### **3. The DoD Acquisition Process**

The traditional DoD acquisition process has a well-defined structure and body of laws that govern its implementation. By design, this process is deliberate and slow preventing the adoption of new technologies in DoD agencies rapidly. Other methods are well suited and fully established for the rapid acquisition of new technologies, or platforms. The authors believe that the majority of these platforms are compatible with Other Transaction Agreements (OTAs). Title 10 U.S.C. 2371B allows for transactions including prototypes used for testing, evaluation, demonstration, or low-rate production (McMartin, 2018). This method has been widely used and successful since 2016. A smaller body of law surrounds the 2371B than the Federal Acquisition Regulation that governs the traditional acquisition process, making it well suited for the rapid acquisition of new technologies (McMartin, 2018). While not a workaround for traditional contracts, this type of OTA is how the authors recommend acquiring the platforms identified in this thesis. The OTAs would provide for the quick fielding of a platform, but not necessarily the full operational capability of a long-term program designed to support that platform over the duration of its life cycle.

## **B. PLATFORMS**

This section covers both types of UxVs that the authors investigated during this research: UAVs and UGVs.

### **1. Unmanned Aerial Vehicles**

The development of UAVs has largely been pushed forward by military applications (Fahlstrom & Gleason, 2012). UAVs, remotely piloted vehicles (RPVs), and drones are all aircraft which by definition do not require pilots. For the purpose of this paper we will be using UAVs in regards to all three systems. While an RPV may be a UAV, a UAV is not always an RPV because it has the potential to operate autonomously or on preplanned missions. RPVs are controlled from a remote location. A basic UAV

system is made up of an air vehicle, a ground control station, and data link as seen in Figure 1 (Fahlstrom & Gleason, 2012).

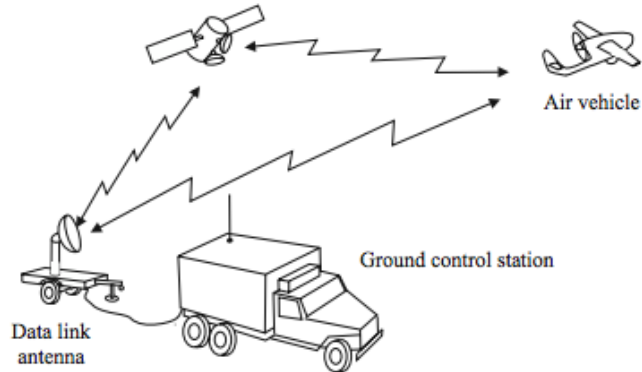


Figure 1. Generic UAV system. Source: Fahlstrom and Gleason (2012).

Beyond the three elements that make up a UAV system identified above, the model may be expanded. A more detailed model includes the “...unmanned aircraft, human element, payload, control elements, and data link communication architecture” (Barnhart, Hottman, Marshall, & Shappee, 2011, p. 43). Additionally, a military UAV should have the added elements of weapon systems and supported soldiers (Barnhart et al., 2011). Figure 2 depicts the elements that make up a UAV system.

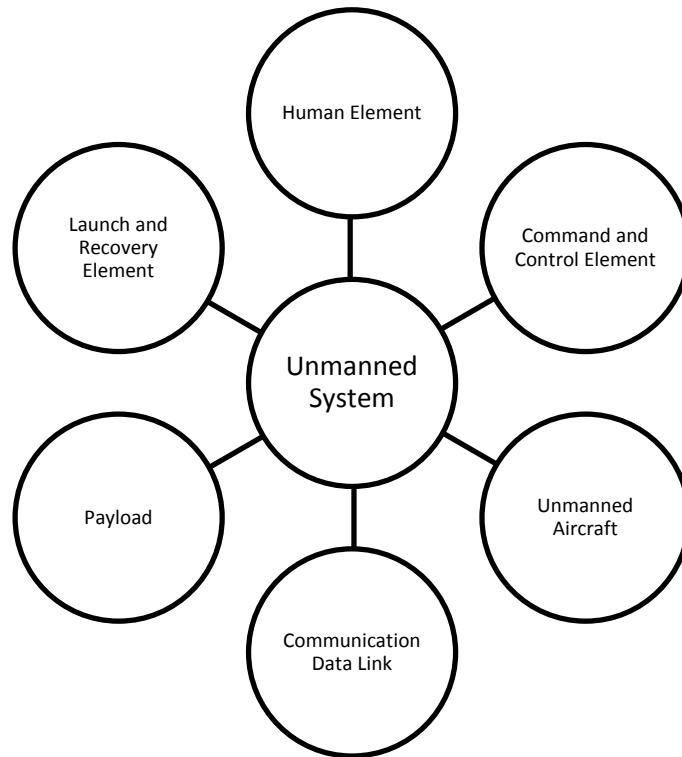


Figure 2. Elements of an unmanned aircraft system. Adapted from Barnhart et al. (2011).

The first element to make up the UAV system is the unmanned aircraft itself. These vehicles fly without a human on board and can be broken down into three categories: fixed-wing, vertical takeoff and landing (VTOL), and lighter-than-air (LTA) (Barnhart et al., 2011). Fixed-wing UAVs have many of the same components as a normal manned aircraft. The benefits of fixed-wing UAVs include longer flight duration, increased time on station, increased range of operations, and the ability to complete missions at higher altitudes (Barnhart et al., 2011). The disadvantages include an increased logistical requirement, to include an area from which to takeoff or launch (Barnhart et al., 2011). VTOL aircraft come in different configurations such as helicopters, fixed-wing aircrafts that can hover, and tilt-rotors (Barnhart et al., 2011). The advantages of a VTOL aircraft include a reduced logistical requirement for takeoff and recovery, and the ability to hover in a small area, reducing the amount of airspace required to operate (Barnhart et al., 2011). LTA aircraft are categorized as either a conventional or hybrid airship (Assistant Secretary of Defense for Research and Engineering, 2012). Conventional airships create lift by using a lifting

gas to provide static buoyancy, while hybrid airships use a combination of static lift, hull shape and dynamic lift such as thrusters (Assistant Secretary of Defense for Research and Engineering, 2012). The DoD separates UAVs into five distinct categories summarized in Figure 3.

UAS Category	Max Gross Takeoff Weight	Normal Operating Altitude (ft)	Airspeed
Group 1	<20 pounds	<1200 above ground level (AGL)	<100 knots
Group 2	21–55 pounds	<3500 AGL	< 250 knots
Group 3	<1320 pounds	<18,000 mean sea level (MSL)	
Group 4	>1320 pounds		Any airspeed
Group 5		>18,000 MSL	

Figure 3. DoD UAS categories. Source: Assistant Secretary of Defense for Research and Engineering (2012).

Command and control is a crucial element in regards to UAVs. A wide array of possibilities from no autonomy to full autonomy exist, where the aircraft would be able operate on its own from takeoff to landing (Barnhart et al., 2011). Regardless of the capabilities of the autonomous software, UAVs have an autopilot system which will aide in the flight of the aircraft. The autopilot uses an electronic control system and feedback loops to affect the UAV flight path, attitude, altitude, and airspeed (Fahlstrom & Gleason, 2012). Another element of command and control is the Ground Control Station (GCS). These stations may be land or sea based, and facilitate human control of the systems (Barnhart et al., 2011).

The communication data link is the element of a UAV that transmits information between itself and the GCS and autopilot (Barnhart et al., 2011). This function may be categorized as either radio frequency line-of-sight (LOS), or beyond line-of-sight (BLOS). A UAV using LOS is being controlled via radio waves, limiting the range of operations (Barnhart et al., 2011). BLOS utilizes satellite communications, or relay vehicles in order to control the vehicles, increasing the range of operations. However, a disadvantage is the time delay between the controls and the system (Barnhart et al., 2011).

The utilization of the attached payload allows UAVs to complete their assigned mission. There are numerous types of payloads, and the UAV may be configured accordingly for missions such as surveillance, weapons delivery, communications, aerial sensing, or cargo (Barnhart et al., 2011). It is possible for UAVs to carry more than one payload to increase its' mission set. Payload weight deserves careful consideration in designing UAVs as well as the ability to switch out payloads to increase interoperability (Barnhart et al., 2011).

There are numerous methods to launch and recover UAVs, all requiring a different amount of equipment, logistical support, and space to operate. Popular approaches for taking off include catapult systems, both pyrotechnic or pneumatic and hydraulic, rotary wing vertical take offs, and hand-launched systems (Fahlstrom & Gleason, 2012). There are multiple retrieval options for recovering UAVs. If a fixed-wing UAV needs to land in a small space it is common for nets, arresting gear, parachutes, or para-foils to be used in order to decrease the required area for recovery (Fahlstrom & Gleason, 2012).

The last element of the model which is crucial to UAV operations is the human element. Considering the state of robotics at this time the human must be involved with the operation, however, the machine is able to take on some of the responsibilities previously held by the human (Barnhart et al., 2011). As technology advances the responsibility of the human will also decrease. It is this reduction of the human requirements and increasing interdependence that is important to the UTACC model (Rice, Chhabra, & Kiem, 2015).

## **2. Unmanned Ground Vehicles**

UGVs are systems that travel across the ground in order to move something other than a human being, often times completing what are considered dirty and dangerous jobs with its payload, referred to as effectors (Gage, 1995). UGVs operate on a similar model to that of the UAVs, consisting of command and control, communication data link, human element, payload, and launch and recovery element. Similar to UAVs, UGVs may be operated autonomously, or remotely, but the biggest difference in classification is based upon the mobility platform or type of locomotion (Khurshid & Hong Bing-rong, 2004). A

UGV can be one or combination of the three locomotion platforms: artificial rotational devices, legs, or articulated bodies (Hirose, 1991).

Artificial rotational devices encompass both wheels and crawler tracks, and are not efficient in adapting to the current terrain (Hirose, 1991). Their efficiency on flat ground and mechanical simplicity make them valuable to some organizations. The efficiency, quickness of the robot, simplicity to build, and simple control system provide many advantages compared to other platform configurations (Khurshid & Hong Bing-rong, 2004).

Utilizing legs for locomotion improves the UGVs ability to handle diverse terrains (Khurshid & Hong Bing-rong, 2004). There is much debate on the optimal number of legs for an UGV, however legs provide three benefits. The first benefit is that the legs may act as a rest for the platform while not moving, providing stability on uneven terrain for use of the effectors (Hirose, 1991). The next benefit is that legs touch the terrain at arbitrary points, making them ideal to handle uneven terrain (Hirose, 1991). The last benefit is that the legs' ground contact area may be configured as large as necessary to support the UGV, and with joints the UGV may switch directions more quickly (Hirose, 1991).

The articulated body robot is made up of multiple segments, connected linearly (Hirose, 1991). By coordinating the motion of its segments, the UGV may pass uneven terrain, narrow paths, cross ditches, and marshes (Hirose, 1991). Another benefit is that it is easily transportable because of the ability to split the UGV into multiple segments, which also raises one of the disadvantages of reliability and maintainability due to individual segment failures (Hirose, 1991).

## **C. CHAPTER CONCLUSION**

This chapter discussed how the sponsors and MCWL chose the topic and how it changed once MCWL was no longer formally involved. The chapter also discusses the areas that helped to determine the path for this research effort: the operating environment, priorities of the MCRCO, and how the DoD acquisitions process relates to this thesis. Last, this thesis gave a broad outline of the categories of UxVs that were evaluated.

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## **II. LITERATURE REVIEW**

This literature review covers three sections. The first section summarizes the work completed under the Unmanned Tactical Autonomous Control, and Collaboration (UTACC) program. This section includes both previous theses and additional robotics programs undertaken by the Marine Corps Warfighting Laboratory (MCWL). The second section of this chapter covers key concepts under the UTACC program and their relation to this thesis. Finally, the chapter concludes by reviewing the relevant doctrine associated with the two selected key mission tasks: local security and targeting.

### **A. WORK DONE TO DATE**

This section covers the work done to date under the UTACC program as well as other robotic efforts completed, or ongoing with MCWL that is relevant to this thesis.

#### **1. UTACC**

Nine theses have been completed as a part of UTACC and an additional four theses are ongoing. These theses have been selected through coordination between MCWL and the Naval Postgraduate School (NPS) in order to align the efforts of both organizations. The first thesis developed a concept of operations (CONOPS) (Rice et al., 2015). The second thesis conducted a vulnerability and threat analysis of the UTACC program (Batson & Wimmer, 2015). The third thesis examined the concept of interdependence in human-machine teaming (Zach, 2016). The fourth thesis proposed specific measures of performance and measures of effectiveness for MCWL's use (Kirkpatrick & Rushing, 2016). The fifth thesis was an AoA for Unmanned Aerial Vehicles (UAVs) (Roth & Buckler, 2016). The sixth thesis developed a campaign of experimentation (Larreur, 2016). The seventh thesis examined situational awareness at the small unit level (Beierl & Tschirley, 2017). The eighth thesis sought to identify suitable interfaces for the UTACC program and the requirements that should be used for future development (Kulisz & Sharp, 2017). The ninth thesis identified interdependence requirements for a human-machine team for a specific immediate action drill (Wilcox & Chenoweth, 2017). As of September 2018, there were four theses ongoing, including this one. The other three theses are an additional

AoA focusing on sub-systems, one further studying situational awareness, and one studying cognitive load.

These theses introduced important concepts to the authors that were relevant to the study. In the CONOPs thesis two important concepts emerged: first, humans should have input into the autonomous process and second, explicit feedback loops will allow the UxS systems to pair with humans (Rice et al., 2015). This thesis also introduced the concept of modularity, which provides the system with the potential to be configured multiple ways in order to meet a specific mission (Rice et al., 2015). The vulnerability and threat assessment thesis provided useful information about both technical and non-technical security controls which should be included in the design of a system, such as extensive training with the operational unit and remote zeroing capabilities (Batson & Wimmer, 2015). The coactive design thesis was beneficial to the authors because it introduced the concept of interdependence between humans and machines, while working as a team to finish tasks (Zach, 2016).

## **2. Other MCWL Robotic Efforts**

The following MCWL projects are reviewed to understand MCWL's research direction and goals. This list is not all-inclusive and has no ordinal ranking.

The Robot Vehicle Modular (RV(M)) is an unmanned ground vehicle (UGV) designed for small units (squad and below) and has a payload that is highly modular (Marine Corps Warfighting Lab [MCWL],2016). This modularity was designed to rapidly adapt the vehicle in order to best support a unit's current mission. The RV(M) supports an Expeditionary Landing Team by providing a multiuse ground platform that is MV-22 transportable (MCWL,2016).

The Picatinny Pallet is a UAV designed to provide autonomous aerial resupply to maneuver units in urban, or other complex environments (MCWL,2016). This capability allows small maneuver units to carry less equipment, or supplies with them and instead rely on an aerial resupply if required. This concept gives flexibility to dismounted maneuver units and allows for rapid resupply in contested environments.

The Intuitive Robotic Operator Control (IROC) provides more intuitive controls and less complex interfaces to control UxVs (MCWL,2016). This program leverages new advances in human system interfaces, including voice or haptic concepts of control.

Squad X, primarily sponsored by the Defense Advanced Research Projects Agency (DARPA), empowers platoons to conduct distributed maneuver while maintaining the ability to mass effects when required (MCWL,2016). In theory, Squad X is enabled through the effective collaboration, or human-machine teaming that includes both UAVs and UGVs.

The Tactical Robot Controller is a collaborative effort with the United States Marine Corps (USMC), the United States Navy, and the United States Army to develop a single controller capable of controlling multiple unmanned assets in order to lighten the warfighter's load and reduce the number of systems that require training (MCWL,2016). This single controller would reduce the logistical support required across the USMC and could be used for a multitude of missions to include intelligence, surveillance, and reconnaissance (ISR), and reconnaissance, surveillance, and target acquisition (RSTA).

## **B. KEY CONCEPTS**

### **1. Autonomy**

The Department of Defense (DoD) and the USMC seek to leverage autonomous technologies through investment in research and development. UTACC was initially one of these endeavors that thought it would rely on the concept of autonomy to achieve its goals of integrating human and machine teams more closely. That is no longer true.

It is important to first define and differentiate autonomy from the related concept of automation. The National Institute of Standards and Technology (NIST) defines autonomy as an unmanned system's "...own ability of sensing, perceiving, analyzing, communicating, planning, decision-making, and acting to achieve its goals as assigned by its human operator(s) through designed [human-robot interaction] HRI" (National Institute of Standards and Technology, 2004b, p. 8). Automation involves a finite amount of predefined responses to some action where a machine can conduct the task better, faster, or cheaper (Johnson, 2014).

Many fields working with autonomous systems have developed some variation of an ordinal list defining the levels of autonomy used to rank individual systems (Bradshaw, Hoffman, Johnson, & Woods, 2013). Scholars at the Institute for Human and Machine Cognition (IHMC) argued this is not helpful as one particular system may be less autonomous than another, but not necessarily less valuable (Bradshaw et al., 2013). They referenced the Defense Science Board's (DSB) recommendation to abandon the debate over levels of autonomy. Their first argument was that functional differences in work are important (Bradshaw et al., 2013). This refers to the differences in an individual task, or a joint task. For example, the task of conducting an analysis of thousands of data points may be assigned to a particular system. There is no cooperation between the system and other systems (human, or machine), so it will accomplish the task independently. However, the task of interpreting and acting upon the results of the prior data analysis may be assigned to a human-machine team (joint task). In this case, there would be dynamic interaction between the machine system and the human. A predefined level of autonomy in this scenario would not be useful in explaining the capabilities and limitations of a particular system.

The second argument the IHMC scholars made was that levels are not consistently ordinal and that machines may be highly self-directed, but not highly self-sufficient (Bradshaw et al., 2013). These authors indicated that it is not always possible to say that one particular characteristic of an autonomous system is "lower", or "higher" in its level of autonomy (Bradshaw et al., 2013). The idea that self-directedness may differ greatly from self-sufficiency is transferable to the acquisition of new technologies. As with any organization, the DoD consistently must make decisions to limit the scope, or capabilities of a new system in order to meet deadlines and budget requirements. It is not likely that the future autonomous systems the DoD fields will be both highly self-directed and highly self-sufficient; this reality means that a single assigned level of autonomy would not be useful for describing a particular system, or requirements.

## **2. Interdependence**

Interdependence is a common element in any team and is critical to the UTACC program. As autonomous systems are becoming more common, the degree to which these systems work with humans will become increasingly important. Dr. Matthew Johnson (2014), a robotics research scientist in human-machine teaming, argued the importance of understanding interdependence when dealing with human and machine teaming. His work on interdependence crossed several fields of study including organizational studies, social psychology, and linguistics. He first identified three categories of interdependence: pooled, sequential, and reciprocal. Dr. Johnson states that these categories are “...relevant for human machine-design but insufficient...” and further identifies two overarching types of interdependence: required (hard) and opportunistic (soft) (Johnson, 2014, p. 25).

Required interdependence is a complete level of dependence of other team members in order to be successful. Opportunistic interdependence comes from the team members’ recognition that there are opportunities for higher levels of effectiveness, efficiency and a more robust set of options through teamwork (Johnson, 2014). This concept is critical to future efforts by the DoD to develop robotics that team with humans instead of the common one-way interactions. The understanding of interdependence led Dr. Johnson and his fellow researchers to develop the concept of coactive design. Figure 4 shows a model for understanding different types of interdependence.

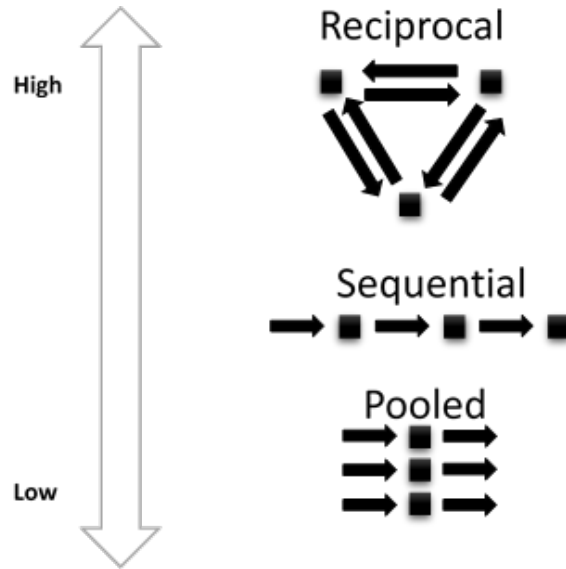


Figure 4. Interdependence model. Adapted from Johnson (2014).

### 3. Coactive Design

Coactive Design is a process in which a system is designed to allow for teamwork through support for interdependence (Johnson, 2014). Coactive design is how interdependence is baked into the design of a system. UTACC seeks to instill this concept in the design of future systems to facilitate human-machine teaming. Coactive design is unique in its focus on interdependencies; in the UTACC program these interdependencies exist between the human and the machine. Because coactive design focuses on interdependencies involved with tasks, it has the potential to create more capable and flexible systems. This process provides a clear example of why levels of autonomy are not helpful. For example, which of the following two systems would be qualified as better, or more autonomous: one requiring no human intervention and completing the assigned task correctly 60% of the time, or a second system requiring periodic human intervention and completing the task correctly 95% of the time? Either system could be labeled as more appropriate depending on what the user required.

#### **4. Observability, Predictability, and Directability**

When determining how to ensure coactive design is being implemented correctly, engineers need to understand several core principles of interdependence. Supporting the interdependence of a team requires mutual observability, predictability, and directability (OPD), differentiating a joint activity from an individual activity (Johnson, Bradshaw, Hoffman, Feltovich, & Woods, 2014). OPD allows UTACC researchers to understand to what degree systems will interact and what potential they have to adapt to one another. Team members must be capable of observing what the other members are doing as well as predicting what they will do in particular situations. Finally, each member must be capable of directing the other members of the team. It is this directability that allows human-machine teams to take full advantage of the capabilities of each member. When examining OPD, it is important to note that the directionality between the human and machine is not important. The human needs to be capable of directing the machine just as much as the machine must be capable of directing the human. The same goes for observability and predictability. Machine to machine relationships must also exercise OPD. OPD is therefore not a characteristic of a human-machine team exclusively, but rather characteristics of any team that is interdependent.

#### **5. Confidentiality, Integrity, and Availability**

Confidentiality, integrity, and availability (CIA) make up the CIA triad. This triad explains the three objectives of security practices in different information domains. NIST defined computer security as “The protection afforded to an automated information system in order to attain the applicable objectives of preserving the integrity, availability, and confidentiality of information system resources” (National Institute of Standards and Technology, 1995, p. 5).

Confidentiality “assures that private, or confidential information is not made available, or disclosed to unauthorized individuals” (Stallings, 2011, p. 43). In a UTACC scenario, confidentiality focuses on the ability of the system to assure that enemy forces cannot access the data while in transit, in process, or at rest. If any unauthorized user were

to gain access to the information that was protected, this would be a loss of confidentiality (National Institute of Standards and Technology, 2004a).

Integrity is the assurance that information is only altered in an authorized manner by an authorized user (Stallings, 2011). In a UTACC scenario, integrity would be the assurance that no enemy forces, or unauthorized users were able to change, or manipulate the data while in transit, in process, or at rest. If an unauthorized user was able to access the information and change it, this would be a loss of integrity (National Institute of Standards and Technology, 2004a).

Availability is the assurance that a system is working and able to provide the required services when authorized users require them (Stallings, 2011). In a UTACC scenario, availability would focus on the ability of authorized users to gain and maintain access to required services throughout the duration of a mission. If the users lost access, this would be considered a loss of availability (National Institute of Standards and Technology, 2004a).

## **6. Situational Awareness**

In June of 2017, Captains Beierl and Tschirley completed a thesis that examined situational awareness in the human-machine team construct. Their work identified what situational awareness may look like inside a human-machine team (a USMC infantry fire team in this instance). They identified shared mental models and a common language as key drivers in the successful integration of humans and machines toward an effective and shared situational awareness. Beierl and Tschirley suggested that these key drivers will be developed between humans and machines in the same way as humans develop them; through extensive training. The concept that machines will need to train with Marines is critical to the development and acquisition of future unmanned systems. If these concepts are not included in the system requirements developed by DoD agencies, industry will not build machines capable of teaming with humans, or will do so in a suboptimal manner. UTACC must leverage this information as it looks to prototype new technologies and move into procurement.

Another source of critical information for the future building of systems requirements will be the ongoing study by Lieutenant Colonel Alan Clark and Major Daniel Knudson of the Naval Postgraduate School that is focused on the concept of cognitive load. This study aims to develop the future requirements the DoD should utilize in the acquisition of new unmanned and autonomous systems while taking the effects of cognitive load into account.

## **7. Size, Weight, and Power (SWaP)**

With the influx of new and improved technologies there has been an increased use of unmanned vehicles. With the increased use of sensory systems to include cameras, radar, LIDAR, and acoustic sensors onboard UxVs, there has been a need to reduce the SWaP of the systems (Jones & Gross, 2014). UTACC has experienced limitations imposed by SWaP with some of its robotic testing platforms. It is through this struggle that UTACC has recognized the importance of finding the balance within the SWaP equation. The requirements for new technology that incorporate devices with multiple capabilities into one to reduce SWaP is growing. Smaller UxVs increase transportability, reduce payload, fuel requirements, cost, and detection (Jones & Gross, 2014). Overall, it is the increased use of UxVs and their range of missions that is driving the requirements to reduce the SWaP in these systems.

The authors identified a gap in the literature and doctrine that is worth noting. While the DoD has laid out categories for UAVs (Groups 1–5) based on size, altitude, and speed, there is no clear definition of categories for UGVs (Assistant Secretary of Defense for Research and Engineering, 2012). Likely, this is due to the difference in current capabilities between UAVs and UGVs; UAVs do not deal with some of the major obstacles that UGVs must such as navigation of changing terrain and obstacles. A clear method for categorizing UGVs has not been developed. The authors see this as a gap that must be addressed as the DoD looks to incorporate more UGVs into operations. A category-based delineation of UGV types would allow for ease of communication and a shared understanding between industry and the DoD.

## **8. Modularity**

With the increasing utilization of UxVs for multiple mission sets, it is necessary to utilize systems that are modular. Modularity is the ability to switch payloads of a system in order to change the functionality of the system to align with a specific mission it is about to conduct (Canning, 2005). With the increased use of UAVs and UGVs, payloads and systems need to be produced as modules so that it is possible to share components between platforms. Modularity allows for the military to invest in standard system frames and then configure them modularly with different payloads to accomplish each mission (Canning, 2005).

### **C. DESCRIPTION OF MISSIONS**

This thesis was assigned to look at four missions for the UTACC concept: a quick-reaction force (QRF), targeting, local security, and ambush detection. In order to ensure the topic was properly scoped, the authors chose to focus on targeting and local security. These two mission sets were clearly defined in official publications, allowing for a clearly defined set of requirements. Targeting and local security also offered the best opportunities for autonomous systems to have an impact based off current research and development.

#### **1. Local Security**

Navy Tactical Task (NTA) 6 defines protecting the force as “To protect the tactical forces fighting potential so that it can be applied at the appropriate time and place” (Chief of Naval Operations, Commandant of the Marine Corps, & Headquarters United States Coast Guard, 2007, p. 151). Further, it defines protecting individuals and systems as “To use protective positions, measures, or equipment to reduce the effects of enemy and friendly weapon systems, and to enhance force effectiveness” (p. 151). This thesis combined these two definitions to create an overarching definition for local security; to use protective positions, measures, or equipment “...to protect the tactical forces’ fighting potential so that it can be applied at the appropriate time and place” (Chief of Naval Operations et al., 2007, p. 151).

This definition of local security will be used to evaluate systems at the tactical and operational levels of war. NTA 6 has three subsections that further detail what is required in protecting the force: NTA 6.1 Enhance Survivability, NTA 6.2 Rescue and Recover, and NTA 6.3 Provide Security for Operational Forces and Means (Chief of Naval Operations et al., 2007).

NTA 6.1, Enhance Survivability, is designed into “personnel, equipment, ships, aircraft, supplies, areas, and installations” (Chief of Naval Operations et al., 2007, p. 151). In reference to local security, enhancing survivability is directly applicable to the smallest units such as a fire team conducting local security while on patrol. Additionally, enhancing survivability can be understood as the Aviation Combat Element (ACE) protecting the forward operating base (FOB) where it is conducting flight operations. Inside both of these examples, the opportunities to enhance survivability extends to areas such as logistics. If the logistical burden of resupply is shifted by an autonomous platform, it would be considered enhancing survivability by not requiring friendly units to expose themselves to enemy fire to gain needed supplies.

NTA 6.2, is defined as “...rescue and recover military and civilian personnel, equipment, and systems” (Chief of Naval Operations et al., 2007, p. 154). As a part of local security, rescue and recovery operations are planned and resourced at the operational level, and then executed by tactical units. Based on the Marine Corps Operating Concept (MOC), it is possible that tactical units will be required to launch recovery operations from an Expeditionary Advanced Based (EAB) in the future (Headquarters United States Marine Corps, 2016). This requirement would place specific demands on unmanned and autonomous systems; modularity of sensors and payloads and the ability to operate securely inside the CIA framework will be critical to success in a contested environment.

NTA 6.3, Provide Security for Operational Forces and Means, enhances “...freedom of action by identifying and reducing friendly vulnerability to hostile acts, influence, or surprise” (Chief of Naval Operations et al., 2007, p. 156). “This task includes actions for protecting and securing the flanks and rear area of operational formations, and protecting and securing critical installations, facilities and systems. It also includes protection of harbors, ports, and installations against acts, which may undermine the effectiveness of

friendly forces” (Chief of Naval Operations et al., 2007, p. 156). In addition to NTA 6.1 and 6.2, NTA 6.3 is a broad subsection of protecting the force that covers many applicable areas for local security such as establishing area security, protecting critical facilities and systems, protecting lines of communication, conducting surveillance, and assisting in law enforcement operations (Chief of Naval Operations et al., 2007).

## **2. Targeting**

Targeting, for the purpose of this thesis, is defined as “the process of selecting and prioritizing targets in the physical domain and matching the appropriate response to them, taking into account operational requirements and capabilities” (Chief of Naval Operations et al., 2007, p. 278). Minimizing risk, time, and resource expenditure is vital in today’s operational environment as the decision-making cycles are occurring in condensed timelines and financial constraints are impacting commanders’ options. Autonomous targeting systems have the potential to minimize risk and reduce decision-making cycles and resource expenditure.

Targeting conducted by an autonomous system would utilize the same Decide, Detect, Deliver, and Assess (D3A) process as is described in Marine Corps Task (MCT) 3.1, Conduct Targeting (Chief of Naval Operations et al., 2007). There are six subtasks described in MCT 3.1: “(1) Receiving commander’s objectives, guidance, and intent, (2) Target development, validation, nomination, and prioritization, (3) Capabilities analysis, (4) Obtain the commander’s decision and force assignment, (5) Mission planning and force execution, and (6) Combat assessment” (Chief of Naval Operations et al., 2007, p. 278). These subsections of MCT 3.1 are explained below in order to understand the detailed requirements that inform the analysis of an autonomous targeting system designed to reduce the cognitive load of the warfighter. These subsections were used to determine the overall mission capability of the evaluated systems. No subsections are considered required for a system to be evaluated, or defined as a suitable candidate for a “quick win.”

MCT 3.1.1, receiving the commander’s objectives, guidance, and intent is designed to “...support the national strategies/desired end state for the conduct of military actions, while the guidance provided with the objectives stipulates particular conditions related to

the execution of operations (e.g., limitations on collateral damage)” (Chief of Naval Operations et al., 2007, p. 279). A subsection of this task is effects-based targeting. Effects-based targeting involves operations that produce specific effects based on the commander’s intent, while considering all available resources, and minimizing risk, time, and resources expended (Chief of Naval Operations et al., 2007). An autonomous system would need to be capable of matching the available resources to the target that best achieves the commander’s objective. This would involve some level of situational awareness on the part of the system, which could be developed organically, or pushed to the system. It is this subsection of MCT 3.1.1, effects-based targeting, that would be advantageous if present in the capability set of an autonomous system. Figure 5 shows the D3A process as described in MCT 3.1.

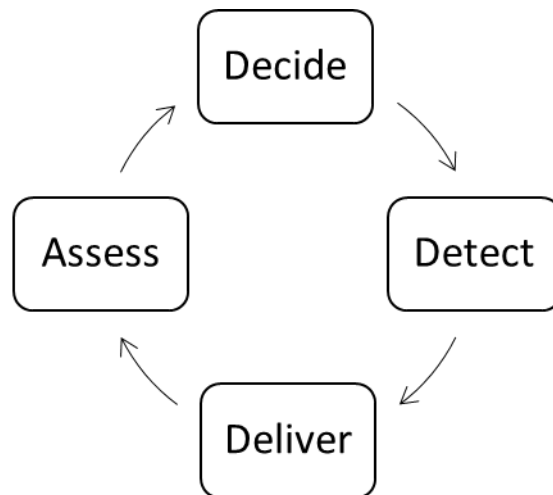


Figure 5. D3A process model. Source: Chief of Naval Operations et al. (2007).

MCT 3.1.2, target development, validation, nomination, and prioritization, encompasses target development operations (Chief of Naval Operations et al., 2007). These operations evaluate “exploitable vulnerabilities and provide validation as to whether a target is lawfully viable,” and subsequently prioritize the targets based upon the commander’s guidance (Chief of Naval Operations et al., 2007, p. 280). This component of targeting has potential for autonomous systems. The prioritization of targets in accordance with the commander’s guidance could quickly be accomplished in a dynamic environment by an autonomous system (Defense Science Board, 2012).

MCT 3.1.3, the capabilities analysis, is used to “determine the most promising forces for application against targets, estimating the effects of lethal, or non-lethal attacks against specific targets, and the physical, functional and psychological vulnerability of the target” (Chief of Naval Operations et al., 2007, p. 284). On a dynamic battlefield, the number and types of friendly forces combatant commanders have access to changes rapidly and it can become difficult to ensure that a capability analysis is current. There is potential for an autonomous system to assist in the dynamic recalculating of a capability analysis.

MCT 3.1.4, obtaining the commander’s decision and force assignment, involves receipt of the commander’s decisions based on the previous three subsections of targeting, MCT 3.1.1-3. This is a critical step in the flow of information, but will not have a significant impact on the analysis of potential autonomous targeting systems.

MCT 3.1.5, conducting mission planning and force execution, is the comprehensive development of fire support and distributing of the subsequent target information (Chief of Naval Operations et al., 2007). The degree to which this task is assigned to an autonomous system, a human team, or mixture is highly variable. Elements of planning are well suited for machines, while other parts are reserved for the human decision-maker.

MCT 3.1.6, the combat assessment, is the final action within MCT 3.1. This step involves conducting the battle damage and munitions effects assessments in order to determine re-attack recommendations (Chief of Naval Operations et al., 2007). Multiple sensors and rapid computational analysis make this particular task well suited for an autonomous system to assist DoD organizations.

#### **D. CHAPTER CONCLUSION**

This chapter highlighted the importance of key concepts such as autonomy, interdependence, coactive design, OPD, situational awareness, and SWaP. Doctrine was used to formalize definitions for the two mission tasks selected. Additionally, the doctrine aided in the development of measures of effectiveness, and measures of performance in later chapters.

### **III. RESEARCH METHODOLOGY**

The authors used the Defense Acquisition University (DAU) to inform the development of the research methodology used in this thesis. Based on the DAU's recommendations concerning an Analysis of Alternatives (AoA), four sections are included in this chapter. First, an explanation of the process of an AoA and the categories the authors selected for this thesis. Second, the chapter includes a section on the scope of this thesis. Third, the chapter presents the actual analysis framework that was used to evaluate the unmanned vehicles (UxVs). Last, a section is included that covers the Measures of Effectiveness (MOEs) that were used when evaluating the UxVs.

#### **A. ANALYSIS OF ALTERNATIVES**

This thesis used the outline for an AoA proposed by the DAU. In the guidebook, DAU describes an AoA as, "an analytical comparison of the operational effectiveness, suitability, and life-cycle cost of alternatives that satisfy established capability needs" (Defense Acquisition University, 2017, p. 105). While the Marine Corps Warfighting Laboratory's (MCWL) original statement of work did not explicitly reference an AoA, the framework provided by the AoA study plan served as an appropriate analytical foundation for evaluating a large number of systems. Because of both the intent of the thesis and its limited resources, the authors did not utilize the entire AoA outline proposed by the DAU guidebook. Instead, the authors chose which sections to use for the development of a methodology that would allow for a comprehensive review of the technology field in the given time frame.

The introduction of the study plan, including the background, purpose, and scope are covered in this chapter and Chapter I. The ground rules, including the environment and limitations, constraints, and assumptions, also appear there. The alternatives and measures of effectiveness categories are explained in this chapter and the results for these two categories are presented in Chapter IV. All other sections, seen in Figure 6 were not evaluated.

The AoA study plan proposed by the DAU calls for a comprehensive review of the tradeoffs (cost, schedule, and performance) for each alternative considered (Defense Acquisition University, 2017). As a part of a holistic review process, a traditional AoA would involve considerable simulation and testing of all alternatives to determine the performance parameters for each system. Given time and resource constraints, however, this thesis uses five measures of effectiveness (MOEs) to evaluate the systems, in addition to the systems' size, weight, and power (SWaP) characteristics. Figure 6, the DAU proposed AoA study plan, includes main sections of an introduction, ground rules, alternatives, determination of effectiveness measures, effectiveness analysis, cost analysis, cost effectiveness comparisons, and organization and management (Defense Acquisition University, 2017). The DAU study plan is not designed to be a strict checklist for all analyses, rather a guide for any DoD acquisition program to tailor for its specific needs. Not all of the sections, or subsections will be included in this thesis due to constraints, or applicability. The sections in yellow were used in this thesis.

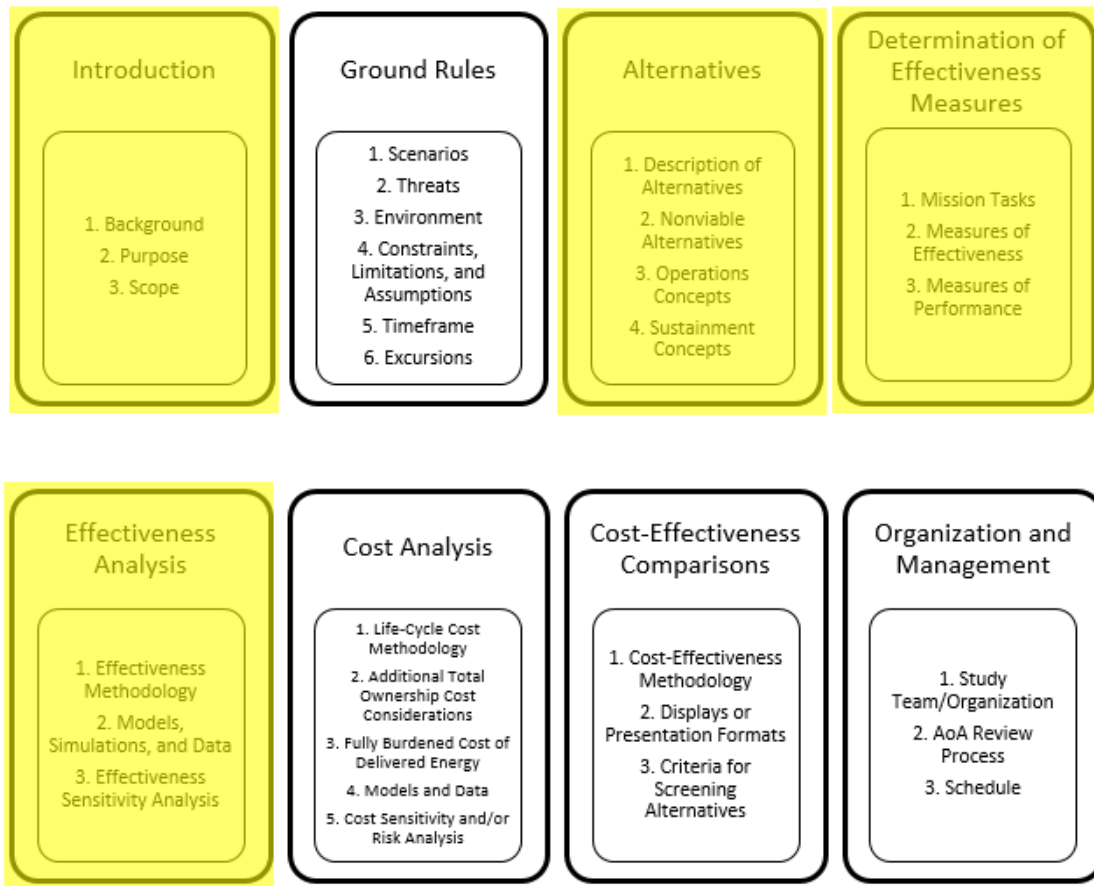


Figure 6. DAU Proposed AoA study plan. Adapted from Defense Acquisition University (2017).

## B. STUDY SCOPE

The authors identified the associated constraints, limitations, and assumptions that determined the scope of the thesis. The constraints are a “restriction imposed by the study sponsor that limits the study team’s options in conducting the study” (United States Army TRADOC Analysis Center, 2012, p. 6). The limitations are “an inability of the study team to fully meet the study objectives, or fully investigate the study issues” (United States Army TRADOC Analysis Center, 2012, p. 6). The assumptions are any “statement related to the study that is taken as true in the absence of facts, often to accommodate a limitation” (United States Army TRADOC Analysis Center, 2012, p. 6). The requirement to make evaluations based on technical specifications, site visits, and limited demonstrations limited the scope of the systems identified for evaluation.

## **1. Constraints**

The authors identified two broad constraints that would have an impact on the systems identified and the evaluation process for those systems. First, the authors selected two mission tasks as the focus for this thesis: local security and targeting. These two tasks limited the scope to a manageable size, but also limited the types of systems that qualified for evaluation.

The second constraint was a short timeline in which the evaluations could be conducted. The authors submitted the thesis proposal and it was returned in August of 2017. This left the authors with only one year to build the requisite knowledge, identify systems, conduct the evaluation, and write the thesis.

## **2. Limitations**

The authors identified three limitations during this thesis. First, the authors were unable to conduct a cost analysis, risk analysis, or sensitivity analysis. These analyses require extensive resources and time that the authors did not have. Additionally, these analyses work most efficiently when there is a baseline alternative, or problem set to compare against. This thesis is not designed to find a suitable alternative to an existing system, or concept, rather to identify possible systems that could be quickly integrated and provide a tangible benefit to the Marine Corps.

Second, the need to make decisions based on external technical specifications from the sourcing companies, site visits, limited demonstrations, and attendance at the Association for Unmanned Vehicle Systems International (AUVSI) Exponential 2018 limited the scope. Due to a lack of experience and technical expertise in the field, the authors were not able to independently verify the statements made by companies regarding their systems. The AUVSI Exponential 2018, the most significant source of data collection for this thesis, is a large and comprehensive trade show for unmanned and robotic systems that takes places each year.

Third, the data collection was limited to attendance at the AUVSI Exponential 2018, direct contact with the sourcing companies and site visits. The authors first identified possible systems through online searching; one of the biggest contributors was the website

<http://www.unmannedsystemstechnology.com>. From this site, the authors made direct contact with companies to request information. Additionally, the authors used professional connections through the Naval Postgraduate School's Information Sciences Department to identify possible systems.

### **3. Assumptions**

The authors identified six distinct assumptions in the process of writing this thesis that affected the evaluation of systems. First, the authors interpreted the concept of a “quick win” as referring to a system that could be fully fielded in less than two years. The Marine Corps Rapid Capabilities Office (MCRCO) has identified a one-year timeline for their efforts in accelerated capability development (The Marine Corps Rapid Capabilities Office, 2016). The authors added one year to this concept to account for emerging technologies that may have been close to mainstream adoption. Second, the authors determined that systems being developed by partner nations may be considered for evaluation, as this is done in the DoD acquisitions process. Third, the authors assumed that the systems evaluated could operate at both the tactical and operational levels of war. This means that the evaluated systems could be implemented at the fire team level, or as a part of Expeditionary Advanced Base (EAB) operations, or any level in between.

The fourth assumption was that the effectiveness analysis explained later in this chapter would provide the Marine Corps with sufficient information to make an informed decision. The goal was not to provide enough information to make an acquisition-based decision, rather to make a decision to investigate a particular system further, or to begin work on prototypes. The fifth assumption was that the five MOEs identified by the authors are sufficient to evaluate unmanned and autonomous systems for the Marine Corps' needs. Input from Dr. Matthew Johnson's work on interdependence, the Marine Corps Operating Concept and the Marine Corps Rapid Capability Office informed the selection of these MOEs. Finally, the assumption that size, weight, and power (SWaP) was not appropriate to include in the ordinal evaluation of systems. SWaP was identified as difficult to compare among systems due to the different levels in which the systems would operate (tactical

versus operational). SWaP is still critical to the evaluation of the systems, and will be included through a nominal evaluation.

## **C. ANALYSIS FRAMEWORK**

In accordance with the Marine Corps Operating Concept, Marine Corps Rapid Capability Office, and Dr. Johnson's study on interdependence; the authors formulated five MOEs listed in Section D. The authors determined that these MOEs were critical in evaluating the effectiveness of systems. In order to rank these systems, the authors used an ordinal analysis in regards to the MOEs. Based upon the Concept of Operations (CONOPs) developed by Rice et al. (2015), the authors included a nominal analysis of SWaP. These characteristics may be important to the Marine Corps when determining which system to field for a unit of a certain size.

### **1. Ordinal Rankings**

Ordinal data uses numbers to indicate superiority and ranking (Pariseau & Oswalt, 1995). The ordinal number indicates the place in which the item stands in an ordered sequence and indicates relative rank within a data set (Pariseau & Oswalt, 1995). The authors used ordinal rankings while rating the five MOEs. The highest number indicates the most superior system within the ordinal data. For the evaluation of this study each MOE was assigned scoring criteria, between three and nine depending on the MOE. After ranking each system by MOE, the numbers assigned to that system will be combined in order to present an overall ordinal ranking.

### **2. Weighting Methodology**

Based on the recommendations of MCWL, the authors developed a weighting methodology based on the research conducted for this thesis. The authors focused on the MOC as well as input from engineers at MCWL to determine the order of precedence for the MOEs.

Mission capability was determined to be the most critical MOE and assigned a weight of five. Interdependence and modularity were the next most important MOEs, and each received a weight of four. Security ranked fourth out of the five MOEs and received

a weight of three. Technology readiness levels (TRLs) were ranked as the least important and received a weight of one.

When applying the weighting factor, each platform first received a score based on the MOE tables in this chapter. This numeric value was then multiplied by the assigned weighting factor. For example, if a platform received a score of three in interdependence, it would then be multiplied by a weighting factor of four and achieve a final score in this category of 12. After applying weighting factors, the total number of points across the five MOEs were added together to determine the total score for each platform. The minimum total score any platform could receive was 17. The highest total score any platform could receive was 92.

### **3. Nominal Category**

Nominal data relates to data that is given a name or label (Pariseau & Oswalt, 1995). This data may be counted; however, there is no order of precedence, or superiority associated with the numerical data. It is not possible to use arithmetic to manipulate the data in order to affect the model. Nominal data is useful in the categorization of data (Pariseau & Oswalt, 1995), which is why the authors used it to categorize the unit size that a certain system could support based upon the SWaP characteristics. See Table 7 for the list of possible nominal rankings. A system may be categorized into more than one group. The nominal category is included in every Effectiveness Analysis Table, see Table 1 for an example.

## **D. MEASURES OF EFFECTIVENESS**

### **1. Mission Tasks**

Mission tasks (MTs) are normally pulled from the Initial Capabilities Document (ICD), or the Capabilities Development Document during the acquisitions process (Defense Acquisition University, 2017). However, UTACC is not a program of record and therefore does not require either of these documents. Through discussions with MCWL and the authors' advisors, two mission tasks were selected for this thesis: local security and targeting. The authors viewed the two MTs from a tactical and operational perspective,

increasing the number of viable systems that could be evaluated. Each MT has specific measures of effectiveness that allowed the authors to evaluate the systems against one another and provide the ordinal ranking found in Chapter IV.

## **2. Measures of Effectiveness**

MOEs are “...qualitative, or quantitative measure of a system’s performance, or characteristic that indicates the degree to which it performs the task, or meets a requirement under specified conditions” (Air Force Materiel Command, Office of Aerospace Studies, 2010, p. 9). The authors chose five MOEs to evaluate the individual systems. These measures covered five areas: technology maturity, mission capability, interdependence, modularity, and security.

### ***a. MOE 1: Technology Readiness Level***

MOE 1 concerns the overall maturity of the technology involved with all aspects of a system. This MOE uses the nine Technology Readiness Levels (TRLs) previously mentioned. MOE 1 is *the current system technology readiness level*.

### ***b. MOE 2: Mission Capability***

MOE 2 concerns the ability of a system to complete the overall mission task and determine the level of human involvement. This MOE relied on the Universal Naval Task List to determine levels of mission capability based on the subtasks. MOE 2 is *the system’s ability to complete the assigned mission task with an appropriate level of human involvement*.

The authors broke down the three subtasks in local security identified in Chapter II into four subtasks to delineate between capabilities. Navy Tactical Task (NTA) 6.1 and 6.2 remained as defined by the Universal Naval Task List. The authors broke NTA 6.3, Provide Security for Operational Forces and Means, into two subtasks. NTA 6.3.1, is designed to enhance freedom of action through a focus on the *identification* of friendly vulnerabilities to hostile acts. NTA 6.3.2, is designed to enhance freedom of action through a focus on *reducing* friendly vulnerabilities to hostile acts. The critical difference between these two subtasks is the ability to detect vulnerabilities versus the ability to reduce vulnerabilities.

The authors determined that this difference was significant when looking at platforms that have different capabilities, such as a platform capable of conducting only intelligence, surveillance, and reconnaissance (ISR), and a platform capable of conducting ISR and interdicting enemy forces, or establishing a defensive posture. The six subtasks associated targeting, MCT 3.1.1–3.1.6, remain unchanged for the evaluation of the systems. The authors evaluated systems in this MOE based on their ability to complete any combination of the ten total subtasks that make up both NTA 6.3 and MCT 3.1.

***c. MOE 3: Interdependence***

MOE 3 concerns a system’s ability to participate in joint activities, as identified in Chapter II, with other systems and/or humans in an interdependent manner. This MOE relied on the three levels of interdependence defined previously: pooled, sequential, and reciprocal. MOE 3 is *the system’s ability to recognize that there are opportunities for higher levels of effectiveness and efficiency, and to act upon these opportunities.*

***d. MOE 4: Modularity***

MOE 4 concerns a system’s ability to change out payloads for different mission tasks, mission requirements, or changing environments. This MOE referenced the ability to change mission configurations through common modules. Common modules simply refer to any payload/sensor that is not specific to one manufacturing company. MOE 4 is *the system’s ability to change payload and/or sensors with minimal operational impact.*

***e. MOE 5: Security***

MOE 5 concerns a system’s ability to operate securely in a contested environment. It relied on an analysis based on all three tenets of the confidentiality, integrity, and availability (CIA) triad identified in Chapter II. During evaluation systems were evaluated based upon the current encryption built into the platform. For example, a system that utilizes a higher level of encryption (AES 256) receives a higher score than a system in which no encryption was built in. MOE 5 is *the system’s ability to provide confidentiality, integrity, and availability of the system’s data at rest, in transit, and in use.*

### 3. Effectiveness Analysis

The authors inserted the MTs and MOEs into the rows of an Excel spreadsheet, while the alternatives were inserted into the columns. Below the alternatives, the nominal analysis results are provided in regards to the supportable unit size. The alternatives were then analyzed by MOE, in accordance with Table 2 through Table 6. After completion of the Effectiveness Analysis, each alternative was multiplied by the weighting factor in order to determine overall MOE accomplishment. A score of 92 was the highest possible score, while a score of 17 was the lowest possible score based upon the criteria shown in Table 2 through Table 6. The final column showed results and contained the ordinal analysis of every alternative. Table 1 gives an example effectiveness analysis, similar to the actual results found in Chapter IV.

Table 1. Example effectiveness analysis results

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
9	8	3	3	3	$(9*1) + (8*5) + (3*4) + (3*4) + (3*3)$ 82	S	<a href="https://www.example.com">https://www.example.com</a>

Table 2. Technology readiness level measures of effectiveness. Source: Defense Acquisition University (2017).

MOE 1: Technology Readiness Levels	
1	Basic principles observed and reported.
2	Technology concept and/or application formulated.
3	Analytical and experimental critical function and/or characteristic proof of concept.
4	Component and/or breadboard validation in laboratory environment.
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model, or prototype demonstration in a relevant environment.
7	System prototype demonstration in an operational environment.
8	Actual system completed and qualified through test and demonstration.
9	Actual system proven through successful mission operations.

Table 3. Mission capability measures of effectiveness

<b>MOE 2: Mission Capability</b>	
<b>1</b>	System can complete 10% of the subtasks of NTA 6 and MCT 3.1
<b>2</b>	System can complete 20% of the subtasks of NTA 6 and MCT 3.1
<b>3</b>	System can complete 30% of the subtasks of NTA 6 and MCT 3.1
<b>4</b>	System can complete 40% of the subtasks of NTA 6 and MCT 3.1
<b>5</b>	System can complete 50% of the subtasks of NTA 6 and MCT 3.1
<b>6</b>	System can complete 60% of the subtasks of NTA 6 and MCT 3.1
<b>7</b>	System can complete 70% of the subtasks of NTA 6 and MCT 3.1
<b>8</b>	System can complete 80% of the subtasks of NTA 6 and MCT 3.1
<b>9</b>	System can complete 90% of the subtasks of NTA 6 and MCT 3.1
<b>10</b>	System can complete 100% of the subtasks of NTA 6 and MCT 3.1

Table 4. Interdependence measures of effectiveness

<b>MOE 3: Interdependence</b>	
<b>1</b>	Pooled interdependence - System can only receive direction from the human operator. There is no bidirectional sharing of information, or tasks during the mission.
<b>2</b>	Sequential interdependence - The system can receive direction from the human operator and provide information/direction in return during the mission.
<b>3</b>	Reciprocal interdependence - The system and human can both send and receive directions from each other throughout the entirety of the mission. The system and human operator can dynamically change mission, or task.

Table 5. Modularity measures of effectiveness

<b>MOE 4: Modularity</b>	
<b>1</b>	No changes possible to payload/sensor modules.
<b>2</b>	Accepts changes in modules from the sourcing company only.
<b>3</b>	Multiple mission configuration possible through common modules.

Table 6. Security measures of effectiveness. Adapted from Harvey and Trevino (2018).

<b>MOE 5: Security</b>	
<b>1</b>	C – Data is not encrypted while at rest, or in transit. I – No credentials required for access controls. A - No redundant communications and no less than 90% reliability in up time.
<b>2</b>	C – Data is encrypted while in transit only. I – Single factor authentication required for access controls. A - Redundant communications and no less than 99% reliability in up time.
<b>3</b>	C – Data is encrypted while at rest and in transit. I – Dual factor authentication required for access controls. A - Redundant communications, no less than 99.999% reliability in up time.

Table 7. Marine Corps supportable units

<b>Unit</b>	<b>Nominal Identifier</b>
Fire Team	F
Squad	S
Platoon	P
Company	C
Battalion	B
Expeditionary Advanced Base	E

## **E. CHAPTER CONCLUSION**

This chapter developed the systematic process used to evaluate the UAVs and UGVs. The five MOEs and SWaP characteristics provide a holistic view of the systems under consideration and should allow the Marine Corps to make an informed decision on how to apply resources and time. Chapter IV includes the results of this process and Chapter V presents additional recommendations based on these results and the process of derivation.

## IV. ANALYSIS OF ALTERNATIVES

This chapter provides the results of the evaluation of 51 UxVs, including 46 UAVs. First, the ordinal results for UAVs and UGVs is presented. Next, the top 10 UAVs and all five UGVs are described in detail to provide the readers with an understanding as to why these systems were considered top performers.

### A. ORDINAL ANALYSIS

This section lists the top ten platforms based on the weighted scores assigned by the authors. It also includes the nominal information showing what sized units the platforms would support. The next section will provide a written explanation of the systems and their capabilities, as well as a more detailed view of the scores assigned to each platform. Table 8 and Table 9 detail the top results from the effectiveness analyses that were conducted for both unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs). The entirety of the results are listed in Appendix A. Summary of Results.

Table 8. UAVs

Company Name & Platform	Total Score	Nominal Information
Aeryon, SkyRanger R60/R80	82	S
Tekever, AR4 Light Ray	78	S
Shield AI, Hivemind Nova	75	F
AiroVironment, SwitchBlade	74	S
AceCore Technologies, NEO	73	C
AceCore Technologies, ZOE	73	C
Leptron Avenger	73	B
Pulse Aerospace, Vapor 55	73	B
Silent Falcon UAS Tech, Silent Falcon	73	B
Schiebel, CAMCOPTER® S-100	70	B

Table 9. UGVs

Company Name & Platform	Total Score	Nominal Information
Autonomous Solutions Inc, CHAOS	72	P
AION Robotics, Model M	66	C
Milrem Robotics, Tracked Hybrid Modular Infantry System (THeMIS)	56	C
NXT Robotics, Scorpion	56	E
Ghost Robotics, GR Vision	49	S

**B. ALTERNATIVES CONSIDERED**

This section is not an exhaustive explanation of each product (links for the associated websites can be found in Appendix A. Summary of Results), rather an overview of the evaluated system’s intent, general design, and weighted score based on the measures of effectiveness (MOEs) from Chapter III. The authors evaluated a total of 46 UAVs and five UGVs, and identified 10 UAVs and five UGVs that were most likely to be a quick win for the Marine Corps. Evaluation of these systems follow in the next section.

**1. Unmanned Aerial Vehicles**

**a. SkyRanger R80, Aeryon**

The SkyRanger R80 platform is a man packable quadcopter UAV that is capable of a wide set of missions including intelligence, surveillance, reconnaissance/reconnaissance, surveillance, target acquisition (ISR/RSTA) missions (Aeryon, n.d.). This system is secure, rugged, and proven in operational environments. Using NVIDIA TX2 processors, the R80 is at the leading edge of object detection and classification. It is capable of Automatic In-Air Replacement, where a ready to launch system will take off automatically to switch with an UAV with a low battery. Four batteries rated under 99 Wh power the R80 which measures 31”x31”x26” and weighs 9.9 lbs. These batteries provide a flight time of 50 minutes. A tether system is available in order to provide continuous

flight time for missions such as over-watch, or surveillance. The R80 is highly modular and accommodates payloads up to 4.4lbs, making it highly versatile and able to adapt to the necessary mission. This platform would best support squad-sized units and up. Figure 7 is a photo of this system and Table 10 is the effectiveness analysis for it.



Figure 7. SkyRanger R80. Source: Aeryon (n.d.).

Table 10. SkyRanger R80 evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
9	8	3	3	3	82	S	<a href="https://www.aeryon.com">https://www.aeryon.com</a>

***b. AR4 Light Ray, Tekever***

The AR4 Light Ray by Tekever is a fixed wing mini-UAV is suitable for ISR/RSTA missions (Tekever, n.d.). This system is easy to use, transport and maintain while being highly versatile due to its payload flexibility. The AR4 Light Ray has been used by both security and military forces, and can detect, identify and track capabilities. It measures 71”x47” and weighs 11 lbs. Users hand-launch the AR 4 Light Ray and retrieve it via parachute. The AR4 has a flight time of up to two hours. It is highly modular and gives the user the ability to quickly alternate payloads up to 2.2 lbs. This platform would best support squad-sized units and up. Figure 8 is a photo of this system and Table 11 is the effectiveness analysis for it.



Figure 8. AR4 Light Ray. Source: Tekever (n.d.).

Table 11. AR4 Light Ray evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
9	8	2	3	3	78	S	<a href="http://airray.tekever.com">http://airray.tekever.com</a>

*c. Hivemind NOVA, Shield AI*

The Hivemind NOVA is a quadcopter based platform that has unique software that allows it to explore urban environments, including buildings, with minimal input from operators (Shield AI, n.d.). Various agencies in the DoD are testing the system. Shield AI has been in contact with the Marine Corps Rapid Capability Office (MCRCO). The Hivemind framework enables the NOVA to learn from real and synthetic experiences, allowing it to conduct a wide array of missions with minimal user input (Shield AI, n.d.). It is capable of autonomous exploration, while providing live streaming and map generation. Hivemind NOVA is 16.5”x16.5”x10.5”, weighs 2.75 lbs and is powered by 6,000 mAH li-Ion battery. It has a flight time of 12 minutes, with easily swappable battery packs. This platform would best support fire team-sized units and up. Figure 9 is a photo of this system and Table 12 is the effectiveness analysis for it.



Figure 9. Hivemind Nova. Source: Shield AI (n.d.).

Table 12. Hivemind Nova evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
6	8	3	2	3	75	F	<a href="https://www.shield.ai">https://www.shield.ai</a>

*d. Switchblade, AiroVironment*

AiroVironment, DoD trusted source, manufactures the Switchblade. It is a back-packable UAV capable of conducting beyond line of sight strikes (AiroVironment, n.d.). It is tube launched from a self-contained ground launcher, which fits in a pack and is capable of ISR/RSTA and precision strikes. This scalable unit weighs 5.5 lbs with an endurance of 15 minutes. It has modular payloads allowing for mission flexibility, and small visual, thermal, and acoustic signatures (AiroVironment, n.d.). This platform would best support squad-sized units and up. Figure 10 is a photo of this system and Table 13 is the effectiveness analysis for it.



Figure 10. Switchblade. Source: AiroVironment: SwitchBlade (n.d.).

Table 13. Switchblade evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
9	8	1	3	3	74	S	<a href="http://www.avinc.com">http://www.avinc.com</a>

*e. Neo, AceCore Technologies*

The Neo has eight electric motors that provide it with stability and precision in adverse weather conditions (AceCore Technologies, n.d.). This platform and the Zoe which is also manufactured by AceCore Technologies, have been used extensively in the film industry providing a reliable track record for their remote sensing capabilities (AceCore Technologies, n.d.). It is a modular system, with multiple locations in which payloads may be mounted quickly in order to configure for multiple missions. Neo is 44”x 44”x25,” weighs 15.96 lbs and is powered by two 22,000 mAH Lithium Polymer batteries. It has a flight time of 30 minutes and is capable of carrying payloads with a total weight of 19.84 lbs. This platform would best support company-sized units and up. Figure 11 is a photo of this system and Table 14 is the effectiveness analysis for it.



Figure 11. Neo. Source: AceCore Technologies (n.d.).

Table 14. Neo evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
8	8	1	3	3	73	C	<a href="https://www.acecoretechnologies.com">https://www.acecoretechnologies.com</a>

*f. Zoe, AceCore Technologies*

The Zoe is a different design than the Neo, although both are manufactured by AceCore Technologies. Smaller than the Neo, the Zoe is foldable and can be deployed in minutes, and also has a proven record within the film industry (AceCore Technologies, n.d.). It is a modular system, with multiple locations in which payloads may be quickly mounted in to be configured for multiple missions. Zoe is 28”x 28”x18”, weighs 8.58 lbs and is powered by two 16,000 mAH Lithium Polymer batteries. It has a flight time of 40 minutes and is capable of carrying payloads with a total weight of 14.33 lbs. This platform would best support company-sized units and up. Figure 12 is a photo of this system and Table 15 is the effectiveness analysis for it.



Figure 12. Zoe. Source: AceCore Technologies (n.d.).

Table 15. Zoe evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
8	8	1	3	3	73	C	<a href="https://www.acecoretechnologies.com">https://www.acecoretechnologies.com</a>

*g. Avenger, Leptron*

The Avenger is a high-performance helicopter UAV capable of supporting a wide range of sensor suites in order to fulfill multiple missions (Leptron Avenger, n.d.). The platform has been proven in operational environments and has a simple user interface that is capable of low altitude surveillance, photography, and sensor deployment (Leptron Avenger, n.d.). It measures 75”x58” and is can carry up to a 10 lbs payload. It has two power configurations; a battery operation that provides no power loss and quiet operation with flight time of 20 minutes, and a fuel engine which increases flight time to two hours. This platform would best support battalion-sized units and up. Figure 13 is a photo of this system and Table 16 is the effectiveness analysis for it.



Figure 13. Avenger. Source: Leptron Avenger (n.d.).

Table 16. Avenger evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
9	7	2	3	3	73	B	<a href="http://www.leptron.com">http://www.leptron.com</a>

*h. Vapor 55, Pulse Aerospace*

The Vapor 55 is a helicopter UAV with a gross weight of 53 lbs, a payload weight of over 30 lbs and over one hour of flight time (Pulse Aerospace, n.d.). The Vapor 55 uses a modular approach to its sensor suite, supporting any sensor the customer needs so long as it conforms to the size and weight restrictions. An advanced flight control system allows mission planning through an easy-to-use interface (Pulse Aerospace, n.d.). This platform has the capability to perform joint tasks with other Vapor 55 platforms to jointly lift external payloads. Currently, the special operations community is using this platform in the operational environment, providing the Vapor 55 with a proven track record. The capability to incorporate nearly any payload that is under 30 lbs into a vertical take-off and landing (VTOL) airframe with a one-hour flight time makes this platform well suited for local security and targeting. This platform would best support battalion-sized units and up. Figure 14 is a photo of this system and Table 17 is the effectiveness analysis for it.



Figure 14. Vapor 55. Source: Pulse Aerospace (n.d.).

Table 17. Vapor 55 evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
9	7	2	3	3	73	B	<a href="http://www.pulseaero.com">http://www.pulseaero.com</a>

*i. Silent Falcon, Silent Falcon UAS Tech*

The Silent Falcon is a fixed wing, solar powered UAV allowing five hours of flight time (Silent Falcon, n.d.). A modular payload design allows the Silent Falcon to carry any number of sensors and payloads (Silent Falcon, n.d.). The highly efficient and electric propulsion is quiet enough to avoid detection by the human ear at 100 meters (Silent Falcon, n.d.). The Silent Falcon has a 4.4 meter wingspan, a length of 1.9 meters, and weighs only 32 lbs (Silent Falcon, n.d.). Users can launch it via catapult and it currently lands via a repack-able parachute; a belly landing version is under development (Silent Falcon, n.d.). Requiring only 30 minutes to setup and launch, this platform would best support battalion-sized units and up. Figure 15 is a photo of this system and Table 18 is the effectiveness analysis for it.



Figure 15. Silent Falcon. Source: Silent Falcon (n.d.).

Table 18. Silent Falcon evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
8	8	1	3	3	73	B	<a href="http://www.silentfalconuas.com">http://www.silentfalconuas.com</a>

*j. CAMCOPTER S-100, Schiebel*

The CAMCOPTER S-100 is a helicopter based design that can operate in virtually any environment, streaming live, high-definition video back to the users (Schiebel CAMPCOPTER S-100,n.d.). The S-100 navigates via GPS waypoints and preplanned missions are configured through a graphical user interface (Schiebel CAMPCOPTER S-100,n.d.). The maximum dimensions for the S-100 are 122”x49”x44” with an empty weight of 243 lbs (Schiebel CAMPCOPTER S-100,n.d.). A robust sensor suite that includes “electric-optical/infra-red (EO/IR), synthetic aperture radar (SAR), maritime radar, ground penetrating radar (GPSAR), signal intelligence (SIGINT), communication intelligence (COMINT), and light detection, and ranging (LIDAR)” coupled with a six hour flight endurance make this platform very capable (Schiebel CAMPCOPTER S-100,n.d.). The ability to share information between this platform and other platforms brings a higher level of interdependence to the S-100. This platform would best support battalion-sized units and up. Figure 16 is a photo of this system and Table 19 is the effectiveness analysis for it.



Figure 16. CAMCOPTER S-100. Source: Schiebel CAMPCOPTER S-100 (n.d.).

Table 19. CAMCOPTER S-100 evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
8	8	1	3	2	70	B	<a href="https://schiebel.net">https://schiebel.net</a>

## 2. Unmanned Ground Vehicles

### a. *CHAOS, Autonomous Solutions Inc*

CHAOS uses four independent tracks to execute what the manufacturer calls a swimming motion, allowing the robot to traverse a variety of challenging environments (Autonomous Solutions Inc, n.d.). CHAOS is can carry up to 275 lbs, which allows the system to complete a majority of the mission tasks outlined in Chapter III. CHAOS also has basic mission planning capabilities, allowing it to move supplies to destinations, or conduct surveillance of areas. It has a top speed of 6.5 mph and can conduct operations on a single battery for up to eight hours (Autonomous Solutions Inc, n.d.). At 51.6” long, 26.2” wide and 153 lbs, this platform would best support company-sized units and up (Autonomous Solutions Inc, n.d.). Figure 17 is a photo of this system and Table 20 is the effectiveness analysis for it.



Figure 17. CHAOS. Source: Autonomous Solutions Inc (n.d.).

Table 20. CHAOS evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
7	8	1	3	3	72	C	<a href="https://www.asirobots.com">https://www.asirobots.com</a>

**b. Model M, AION Robotics**

The Model M series is a commercial grade UGV using a four wheel configuration (six wheel configuration available) that can perform a wide variety of tasks to include site security, physical inspection, and search and rescue (AION Robotics, n.d.). This is a smaller UGV with measurements of 22”x24”x10,” and a weight of just over 30 lbs (AION Robotics, n.d.). The battery provides 10 hours of continuous run-time, making it suitable for multiple mission tasks. The company stated that this platform can be scaled to fit the customer’s requirements. This platform would best support company-sized units and up. Figure 18 is a photo of this system and Table 21 is the effectiveness analysis for it.



Figure 18. Model M. Source: AION Robotics (n.d.).

Table 21. Model M evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
7	6	2	3	3	66	C	<a href="http://www.aionrobotics.com">www.aionrobotics.com</a>

*c. Tracked Hybrid Modular Infantry System (THeMIS), Milrem Robotics*

The Tracked Hybrid Modular Infantry System (THeMIS), is a highly modular UGV that can support a wide range of mission tasks at varying levels of organizational size (Milrem Robotics, n.d.). The platform is powered by a hybrid electric-diesel drive and measures 94”x84”x44” (Milrem Robotics, n.d.). With a gross weight of 3,200 lbs, THeMIS can carry a maximum payload of 1,650 lbs for a duration of eight to ten hours (Milrem Robotics, n.d.). It can be outfitted to carry large payloads for resupply, various sensors for targeting, or weapons for remote operation. The THeMIS can be used in a basic teleoperation mode, a “follow me” mode, waypoint, or basic mission planning mode, or as a part of a swarm, according to the manufacturer (Milrem Robotics, n.d.). This platform would best support company-sized units and up. Figure 19 is a photo of this system and Table 22 is the effectiveness analysis for it.



Figure 19. THeMIS. Source: Milrem Robotics (n.d.).

Table 22. THeMIS evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
7	6	1	3	1	56	C	<a href="https://milremrobotics.com">https://milremrobotics.com</a>

*d. Scorpion, NXT Robotics*

The Scorpion is a rugged all-terrain and all-weather UGV designed to provide physical security monitoring and reporting capabilities (NXT Robotics, n.d.). Proximity sensors, pressure sensors, optical sensors, environment monitors, and motion sensors enable the scorpion to proactively monitor physical areas (NXT Robotics, n.d.). The platform uses artificial intelligence to determine better routes and have more effective interactions with other UxVs and humans (NXT Robotics, n.d.). The Scorpion also uses GPS and LIDAR for navigation, circumnavigation and collision avoidance (NXT Robotics, n.d.). It can monitor for acoustics such as gun shots, or vehicle engines during autonomous missions (NXT Robotics, n.d.). It uses a gasoline engine and can carry a payload of 250 lbs, making this system best to support advanced expeditionary bases. Figure 20 is a photo of this system and Table 23 is the effectiveness analysis for it.



Figure 20. Scorpion. Source: NXT Robotics (n.d.).

Table 23. Scorpion evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
7	6	2	2	1	56	E	<a href="http://www.nxtrobotics.com">http://www.nxtrobotics.com</a>

*e. GR Vision, Ghost Robotics*

The GR Vision is a legged UGV designed for military and public safety use (Ghost Robotics, n.d.). The overall intent of the GR Vision is to provide a low cost, high endurance, and scalable (one to four feet in length) UGV that can operate in most environments while providing security capabilities (Ghost Robotics, n.d.). These scalable systems are still being prototyped, and do not have exact specifications provided. However, Ghost Robotics’ intent is to design platforms that meet the customer’s requirements and would be considered expendable due to their low cost. The GR Vision will soon integrate software from a Philadelphia based company, Exyn, that would allow the platform to navigate independently and react to new challenges in the environment. Based on the authors’ interaction with Exyn, and the demonstration of its software at AUVERSI Exponential 2018, the GR Vision would become exponentially more capable once the new software is integrated. This platform would best support squad-sized units and up. Figure 21 is a photo of this system and Table 24 is the effectiveness analysis for it.



Figure 21. GR Vision. Source: Ghost Robotics (n.d.).

Table 24. GR Vision evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
5	5	1	3	1	49	S	<a href="https://www.ghostrobotics.io">https://www.ghostrobotics.io</a>

## **C. CHAPTER CONCLUSION**

This chapter presented the results of the authors' research into and evaluation of 51 UxVs. The authors could only identify five UGVs likely to be quick wins and also previously unidentified by the Marine Corps. Chapter V discusses the likely reasons for this outcome. Chapter V also discusses platforms that did not make the top 10 list of UAVs, but are considered noteworthy by the authors.

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## **V. SUMMARY OF RESULTS AND RECOMMENDATIONS FOR FUTURE RESEARCH**

This thesis identified unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs) that could fulfill the mission tasks of local security and targeting. This chapter outlines recommendations for UAVs and UGVs that will fulfill the needs of the United States Marine Corps (USMC). It covers platforms that can be deployed immediately, unique platforms that did not score well but are noteworthy and concept systems that need to be reevaluated in the future.

### **A. SUMMARY OF RECOMMENDATIONS**

In order to ensure that the needs of the Marine Corps are being met, a constant evaluation of the state of UAVs and UGVs must be conducted. A comprehensive list of all UAVs and UGVs that the authors identified may be found in Appendix A and Appendix B. Recommendations for operational implementation, noteworthy platforms and platforms suited for Research, Development, Test, and Evaluation (RDT&E) are as follows.

#### **1. UAVs**

The following sections are the authors' recommendations for which UAVs should be implemented, investigated further, and further developed.

##### ***a. Operational Implementation***

The authors evaluated multiple UAVs that possess the capabilities and readiness necessary to be immediately deployed by the Marine Corps in support of targeting and local security missions. MCWL originally identified four mission tasks. The authors, after consulting with thesis advisors, narrowed the scope of the thesis to local security and targeting in order to conduct a more in-depth analysis. While supporting different sized units, all platforms found in Chapter IV can be deployed immediately. Of those in Chapter IV, Skyranger R80, AR4 Light Ray, Hivemind NOVA and Switchblade are the most relevant, capable, and mission ready.

The authors identified the Switchblade and AR4 Light Ray as the two most capable platforms for targeting. The Switchblade has the capability to locate and engage targets while operating BLOS. The AR4 Light Ray's small size and ability to intelligently detect human targets at long ranges help it stand out as a top performer in the targeting mission. For a more detailed description of these systems, see Chapter IV.

The authors identified the Skyranger R80 and the Hivemind NOVA as the two most capable platforms for local security. The Hivemind NOVA's small size and intelligent capabilities make it well positioned to conduct local security missions. The Skyranger R80's unique abilities to operate from a vehicle and interchange with other UAVs while in flight also make it well positioned to conduct local security missions. For a more detailed description of these systems, see Chapter IV.

***b. Noteworthy Platforms***

Although they did not score within the top ten platforms, the following UAVs were deemed noteworthy by the authors. Some of these platforms provide unique capabilities that could be easily be modified to better fulfill the needs of the Marine Corps.

(1) Jump 20, Arcturus UAV

The Jump 20 is a vertical takeoff, and landing (VTOL) fixed wing UAV designed and built by Arcturus UAV (Arcturus UAV, n.d.). This platform is capable of 9- to 16-hour endurance and has a modular design. It can carry up to 60 lbs of fuel and useable payload, making it highly versatile. The dimensions are 18'6"x9'5" and is powered by a 4 stroke MOGAS engine. This platform would best support a battalion-sized unit and up. Figure 22 is a photo of this system and Table 25 is the effectiveness analysis for it.



Figure 22. Jump 20. Source: Arcturus UAV (n.d.).

Table 25. Jump 20 evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
8	7	2	2	3	68	B	<a href="https://arcturus-uav.com/">https://arcturus-uav.com/</a>

(2) Orion, ElistAir

The Orion is a six engine tethered drone that can be employed from a vehicle (ElistAir, n.d.). Designed specifically for military and security use, this system can detect humans out to 10 kilometers and can be untethered to gain better situational awareness on a target area (ElistAir, n.d.). This platform is highly modular and fits into one pelican case when broken down. This platform would best support a company-sized unit and up. Figure 23 is a photo of this system and Table 26 is the effectiveness analysis for it.



Figure 23. Orion. Source: ElistAir (n.d.).

Table 26. Orion evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
8	6	2	3	3	67	C	<a href="http://elistair.com">http://elistair.com</a>

(3) S2, Black Swift Technologies, LLC

Designed for scientific research in adverse atmospheric conditions, the S2 can fly more than one and a half hours and reach a ceiling height of 14,000 feet (Black Swift Technologies, n.d.). Operators can hand launch this UAV, which can carry a number of different sensors (Black Swift Technologies, n.d.). The S2 measures 68"x47", weighs 6 lbs and is powered by an 8000mAh LiPo battery capable of powering one hour of flight time. This platform would best support a company-sized unit and up. Figure 24 is a photo of this system and Table 27 is the effectiveness analysis for it.



Figure 24. Black Swift S2. Source: Black Swift Technologies (n.d.).

Table 27. Black Swift S2 evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
9	6	2	3	3	68	B	<a href="https://bst.aero/black-swift-s1-uas">https://bst.aero/black-swift-s1-uas</a>

(4) Shearwater, Planck Aerosystems

The Shearwater is a quadcopter designed UAV that is operated in conjunction with moving vehicles, or ships (Planck Aerosystems, n.d.). This system can provide over watch as vehicles conduct operations, track enemy targets, or act as a communications antenna.

This platform launches and lands automatically based on a simple interface from which operators can plan missions. It is highly portable and comes with a traveling case. This platform would best support a company-sized unit and up. Figure 25 is a photo of this system and Table 28 is the effectiveness analysis for it.



Figure 25. Shearwater. Source: Planck Aerosystems (n.d.).

Table 28. Shearwater evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
8	6	3	3	1	65	C	<a href="http://planckaero.com/#page-4">http://planckaero.com/#page-4</a>

(5) Nightingale Security, Unmanned Aerial Specialists

Designed for industrial security solutions, the Nightingale Security UAV can respond to alarm events, or conduct preplanned security patrols (Nightingale Security, n.d.). This platform can conduct full missions, land, recharge, and continue conducting missions with no physical human intervention (Nightingale Security, n.d.). The system is 37”x33”x11,” can fly up to 40 minutes, while taking 45 minutes to recharge. This platform would best support a company-sized unit and up. Figure 26 is a photo of this system and Table 29 is the effectiveness analysis for it.



Figure 26. Nightingale Security. Source: Nightingale Security (n.d.).

Table 29. Nightingale Security evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
7	5	2	3	3	61	C	<a href="https://www.nightingalesecurity.com">https://www.nightingalesecurity.com</a>

(6) Navig8 Electric, 4 Front Robotics

The Navig8 Electric is a two engine UAV that can conduct flight operations in confined spaces such as buildings, or subterranean structures (4 Front Robotics, n.d.). This platform has unique capabilities to take off and land at sloped angles and has a large payload capacity of up to 10 lbs. The platform measures 123”x86”x28” and can carry payloads up to 70 lbs. When powered by gas, it has a 150-minute flight time, when powered by battery, it utilizes Lithium Ion batteries and has a flight time of 50 minutes. This platform would best support a battalion-sized unit and up. Figure 27 is a photo of this system and Table 30 is the effectiveness analysis for it.



Figure 27. Navig8 Electric. Source: 4 Front Robotics (n.d.).

Table 30. Navig8 Electric evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
6	6	1	3	1	55	B	<a href="https://www.4frontrobotics.com">https://www.4frontrobotics.com</a>

**c. RDT&E**

The following platforms are not yet mature, but have the potential to fulfill targeting and local security missions in the future. These systems would benefit from the RDT&E process.

(1) Elroy Air

This platform is a rotor-based VTOL UAV, while using fixed wing cruise flight for traveling (Elroy Air, n.d.). Designed as a logistics platform first, Elroy Air can carry 150 lbs, 300 miles. This platform also has the ability to integrate payloads at the user’s request which can support ISR missions. Figure 28 is a photo of this system and Table 31 is the effectiveness analysis for it.



Figure 28. Elroy Air. Source: Elroy Air (n.d.).

Table 31. Elroy Air evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
4	7	1	3	1	58	B	<a href="https://www.elroyair.com">https://www.elroyair.com</a>

(2) Advanced Aircraft Co, Hybrid Advanced Multi-Rotor (HAMR)

HAMR is a Multi-Rotor VTOL with a flight time similar to that of a fixed wing UAV. This platform has a flight time of 3.5 hours and can carry a payload of up to 7 lbs. Primarily powered by gasoline, but it also has battery power in order to provide a fail-safe power supply. It has multiple payload bays. Figure 29 is a photo of this system and Table 32 is the effectiveness analysis for it.



Figure 29. Hybrid Advanced Multi-Rotor. Source: Advanced Aircraft Company (n.d.).

Table 32. Advanced Aircraft Co, Hybrid Advanced Multi-Rotor evaluation

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5	Total Score	Nominal Group	website
7	5	1	3	1	51	C	<a href="http://www.advancedaircraftcompany.com">http://www.advancedaircraftcompany.com</a>

## 2. UGVs

In the authors opinion, that state of UGVs is significantly behind that of UAVs; a large gap in quality, quantity, and capability was noted while analyzing these platforms. While collecting data on UGVs a lack of relevant platforms became apparent. The demand for such systems has been low, mainly because of the restrictive nature over ground. Due to this difficulty, fewer systems have been produced, while a majority of funding and research focuses on UAVs. The DARPA Grand Challenges further demonstrate the difficulty in solving the biggest issues (mobility and SWaP) associated with UGVs (Darter,

2004). The authors believe that there is a benefit from having a UGV on the ground with Marine Corps' units, however, it will be necessary to further analyze and develop what is on the market before decisions are made. Of the systems evaluated by the authors, CHAOS, Model M, Tracked Hybrid Modular Infantry Systems, and Scorpion are ready to implement operationally. The GR Vision would benefit from additional RDT&E and has the highest upside of platforms identified during this thesis.

## **B. FUTURE TECHNOLOGIES**

### **1. System Designs**

The authors' attendance at the Association for Unmanned Vehicle Systems International (AUVSI) Exponential 2018 revealed the commercial industry's focus for future platform designs and capabilities. Two concepts dominated the conference. First, companies that had multiple platforms typically had at least one VTOL version, or were in the process of developing one. Both large and small platforms generally adhered to this rule of thumb. Additionally, these companies' focus for their next iteration of their platforms was towards increasing payload capacity and modularity of sensors.

Second, companies appear to be addressing a growing interest in the capability of tethering existing UAV platforms to ground control stations. Many companies identified at the conference were offering this capability. The tethering capability adds several important capabilities to existing systems that the Marine Corps could find useful. The tether provides a data link from the UAV's sensors to the ground station, increasing the security of that information. Additionally, a tethered UAV can provide persistent surveillance if powered by the ground control station. The authors see this as an important capability in achieving local security in many scenarios, specifically in Expeditionary Advanced Bases (EABs).

### **2. Subsystem Advances**

The authors' research into different unmanned vehicles (UxVs) revealed great advances into some of the technologies that will power highly interdependent systems going forward. While these technologies have great potential moving forward, they

currently have a small presence in the commercial industry. Two primarily software companies, Exyn Technologies and Shield AI, have developed two examples that the authors identified. Chapter IV has the evaluation for Shield AI's Hivemind Nova. Exyn Technologies' software is not currently in any of the evaluated UxVs. However, Ghost Robotics' GR Vision will incorporate Exyn's software before the end of calendar year 2018. Both of these software-based capabilities are on the leading edge of the industry as identified by the authors and warrant additional consideration by the Marine Corps.

### **C. RECOMMENDATIONS FOR FUTURE RESEARCH**

This section will cover five areas that the authors deemed important and in need of further research: future of airspace deconfliction, Universal Urgent Needs Statement (UUNS) sponsorship, continued technology scouting, three types of machine learning: edge, collective, and external, and acquisition requirements for unmanned systems.

#### **1. Future of Airspace Deconfliction**

As the Marine Corps continues to add UAVs to the fleet in large numbers (currently down to every rifle squad), airspace deconfliction will need to be readdressed. Besides the large influx in the number of UAVs, the types of commanders who own these aircraft are beginning to change as well. Where the Aviation Combat Element (ACE) previously owned the majority of aircraft, the Ground Combat Element (GCE), and Logistics Combat Element (LCE) are beginning to own more aircraft organically. These factors begin to change the ways airspace must be deconflicted. Many possible solutions address the issue of an increasingly crowded and complex airspace. Two examples would be increasing the number of Marines dedicated to deconfliction or the use of software capabilities to enhance existing methods.

The authors found the solutions offered by White Fox Defense Technologies to be an interesting starting point. Their solution primarily focuses on counter-UAVs with adaptability and scalability built in to the system (White Fox Defense Technologies, n.d.). The authors believe that this capability could be developed into a system capable of addressing friendly airspace control as well as countering neutral or enemy UAVs.

## **2. Universal Urgent Needs Statement Sponsorship**

The Universal Urgent Needs Statement (UUNS) provides “rapid acquisition of a capability in order to meet an urgent requirement” (Commandant of the Marine Corps, 2006). This process could benefit from research conducted by students at the Naval Postgraduate School (NPS). While the long lead time required for a full thesis may not be compatible with the rapid acquisition of technologies, students could be assigned to different Combatant Commands to provide short information papers on different topics related to specific UUNS. This would provide two benefits to the combatant commanders. First, the commanders who submit UUNS would have access to Marine Corps officers who are dedicated to addressing a very specific technology problem in a short time frame. There would not be a formal process of submitting a statement of work, rather a question asked and answered. Second, the commanders would be connected with students who are in the education domain, as well as being co-located with many Silicon Valley companies who may be able to provide a solution to the UUNS.

## **3. Continued Technology Scouting**

The authors believe that more students in the future should be assigned to identify *quick-win* systems. The research confirmed that many of the Marine Corps’ organizations designed to identify, develop, and field new systems are over-tasked and undermanned. This means that many capable platforms are identified too late or not at all. The students at NPS are well positioned to remain connected with technology companies in the region and can travel easily to conduct onsite visits and working groups. Students should also look into alternative sources for information such as [citizenscience.gov](http://citizenscience.gov), a site designed to solve governmental problems through public participation. The unmanned systems database sponsored by AUVSI is another example of an avenue to identifying unmanned platforms. The NPS library and Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) have begun investigating options to purchase access to this database.

## **4. Three Types of Machine Learning: Edge, Collective, External**

Shield AI has identified three types of machine learning that it employs to develop capabilities: edge, collective, and external (Shield AI, n.d.). Edge learning teaches

individual platforms, and focuses on improvements for doing tasks more efficiently and effectively (Shield AI, n.d.). Collective learning allows platforms working together to share information and learn from one another resulting in divisions of labor, specialized roles, and faster rates of task completion (Shield AI, n.d.). External learning focuses on how the systems interact and learn from elements in the operating environment, such as weather, or human interaction (Shield AI, n.d.).

These concepts have a large crossover with the concept of interdependence and the authors believe these three machine learning types will be critical to evaluating future systems. Research should be done to identify successful instances of the three types of learning in the commercial sector.

## **5. Acquisition Requirements for Unmanned Systems**

Unmanned systems are bringing new issues into the discussions concerning requirements definition in the acquisitions community. As mentioned in Chapter II, the use of levels of autonomy to determine what is required for an unmanned system to be fielded would be inadequate and inappropriate. The Marine Corps' acquisition community should instead focus on the level of interdependence that is required. This thesis used three simple categories to differentiate between levels of interdependence. Additional research could determine an effective way to measure the interdependence of unmanned systems. The authors propose a study sponsored by the Marine Corps Combat Development Command (MCCDC) to determine the best approach to develop a consistent approach.

## **D. CHAPTER CONCLUSION**

This chapter recommended specific UAVs and UGVs that the Marine Corps should research further. This chapter also addressed several areas that should be researched in the future to address developing issues. Airspace deconfliction, sponsorship of UUNSSs, continued technology scouting for *quick-win* systems and requirements for the future acquisitions of unmanned systems are areas that need additional research in the future.

## APPENDIX A. SUMMARY OF RESULTS FOR UAVS

Company Name & Platform	Total Score	Nominal Information	Website/Link
Aeryon, SkyRanger R60/R80	82	S	<a href="https://www.aeryon.com">https://www.aeryon.com</a>
Tekever, AR4 Light Ray	78	S	<a href="http://airray.tekever.com">http://airray.tekever.com</a>
Shield AI, Hivemind Nova	75	F	<a href="https://www.shield.ai">https://www.shield.ai</a>
Airo Vironment, SwitchBlade	74	S	<a href="http://www.avinc.com">http://www.avinc.com</a>
AceCore Technologies, NEO	73	C	<a href="https://www.acecoretechnologies.com">https://www.acecoretechnologies.com</a>
AceCore Technologies, ZOE	73	C	<a href="https://www.acecoretechnologies.com">https://www.acecoretechnologies.com</a>
Leptron Avenger	73	B	<a href="http://www.leptron.com">http://www.leptron.com</a>
Pulse Aerospace, Vapor 55	73	B	<a href="http://www.pulseaero.com">http://www.pulseaero.com</a>
Silent Falcon UAS Tech, Silent Falcon	73	B	<a href="http://www.silentfalconuas.com">http://www.silentfalconuas.com</a>
Schiebel, CAMCOPTER® S-100	70	B	<a href="https://schiebel.net">https://schiebel.net</a>
Arcturus UAV, Jump 20	68	B	<a href="https://arcturus-uav.com">https://arcturus-uav.com</a>
Black Swift Technologies, LLC, S1	68	B	<a href="https://bst.aero">https://bst.aero</a>
Black Swift Technologies, LLC, S2	68	C	<a href="https://bst.aero">https://bst.aero</a>
Tekever, AR3 Net ray	68	B	<a href="http://airray.tekever.com">http://airray.tekever.com</a>
ElistAir, Orion	67	C	<a href="http://elistair.com">http://elistair.com</a>
Planck Aerosystems, Shearwater	65	C	<a href="http://planckaero.com">http://planckaero.com</a>
UAVOS, Borey-10	63	B	<a href="http://www.uavos.com">http://www.uavos.com</a>
UAVOS, UVH-29E	63	B	<a href="http://www.uavos.com">http://www.uavos.com</a>
Reference Technologies, Hummingbird XRP	61	C	<a href="http://www.referencetek.com">http://www.referencetek.com</a>
Unmanned Aerial Specialists, Nightingale Security	61	C	<a href="http://www.ua-sp.com">http://www.ua-sp.com</a>
Tekever, AR5 Life Ray	61	B	<a href="http://airray.tekever.com">http://airray.tekever.com</a>
Delair, DT26M	60	C	<a href="https://delair.aero">https://delair.aero</a>
Trident World Systems, SparrowHawk	60	S	<a href="http://www.tridentworldsystems.com">http://www.tridentworldsystems.com</a>
Leptron RDASS	60	C	<a href="http://www.leptron.com">http://www.leptron.com</a>
High Eye, HEF 32 VTOL	59	B	<a href="https://www.higheye.com">https://www.higheye.com</a>
ECA, Mini UAV (tethered)	58	C	<a href="https://www.ecagroup.com">https://www.ecagroup.com</a>
Elroy Air	58	B	<a href="http://www.elroyair.com">http://www.elroyair.com</a>
CyPhy, Persistent Aerial Reconnaissance and Communications (PARC)	58	C	<a href="https://www.cyphyworks.com">https://www.cyphyworks.com</a>
Black Peak Engineering, SA-200 Weasel	56	B	<a href="http://www.blackpeakengineering.com">http://www.blackpeakengineering.com</a>
4 Front Robotics, Navig8 Electric	55	B	<a href="https://www.4frontrobotics.com">https://www.4frontrobotics.com</a>
DroneTechUAV, VMX8 Pelican	53	B	<a href="http://www.dronetechuav.com">http://www.dronetechuav.com</a>
Advanced Aircraft Co, Hybrid Advanced Multi-Rotor (HAMR)	51	C	<a href="http://www.advancedaircraftcompany.com">http://www.advancedaircraftcompany.com</a>
SunBirds, SB4 Phoenix	51	C	<a href="https://www.sunbirds.aero">https://www.sunbirds.aero</a>
Latitude Engineering, HQ 10	50	C	<a href="https://latitudeengineering.com">https://latitudeengineering.com</a>
Latitude Engineering, HQ 40	50	B	<a href="https://latitudeengineering.com">https://latitudeengineering.com</a>
Latitude Engineering, HQ 55	50	B	<a href="https://latitudeengineering.com">https://latitudeengineering.com</a>
Latitude Engineering, HQ 90B	50	B	<a href="https://latitudeengineering.com">https://latitudeengineering.com</a>
C-Astral, Bramor PPX	50	C	<a href="http://www.c-astral.com">http://www.c-astral.com</a>
Novadem, NX110m	49	S	<a href="http://www.novadem.com">http://www.novadem.com</a>
Fotokite, Fotokite Pro	47	F	<a href="https://fotokite.com">https://fotokite.com</a>
XCRAFT, X2 Pro	47	S	<a href="https://xcraft.io">https://xcraft.io</a>
Unmanned Aerial Specialists, Freebird One	42	B	<a href="http://www.ua-sp.com">http://www.ua-sp.com</a>
Digital Aerolus, aertus 121	38	S	<a href="http://digitalaerolus.com">http://digitalaerolus.com</a>

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## APPENDIX B. SUMMARY OF RESULTS FOR UGVs

Company Name & Platform	Total Score	Nominal Information	Website/Link
Autonomous Solutions Inc, CHAOS	72	P	<a href="https://www.asirobots.com/platforms/chaos/">https://www.asirobots.com/platforms/chaos/</a>
AION Robotics, Model M	66	C	<a href="http://www.aionrobotics.com">www.aionrobotics.com</a>
Milrem Robotics, Tracked Hybrid Modular Infantry System (THeMIS)	56	C	<a href="https://milremrobotics.com/">https://milremrobotics.com/</a>
NXT Robotics, Scorpion	56	E	<a href="http://www.nxtrobotics.com/scorpion/">http://www.nxtrobotics.com/scorpion/</a>
Ghost Robotics, GR Vision	49	S	<a href="https://www.ghostrobotics.io/robots">https://www.ghostrobotics.io/robots</a>

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- Advanced Aircraft Company. (n.d.). HAMR. Retrieved June 1, 2018, from <https://www.advancedaircraftcompany.com/>
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