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AN ANALYSIS OF HOW THE U.S. GOVERNMENT CAN EFFECTIVELY TACKLE SUPPLY CHAIN BARRIERS TO SCALE UP THE LOW COST UNMANNED AERIAL VEHICLE (UAV) SWARMING TECHNOLOGY (LOCUST) PROGRAM

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

JOINT APPLIED PROJECT REPORT

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September 2019

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The LOCUST program is a scalable system of inexpensive swarming unmanned aerial vehicles to provide disruptive capability in contested environments against anti-area access denial defenses, enabling manned strike operations and localized landing site superiority with reduced cost, risk, and operator launch and workload. Our research and analysis will emphasize the challenges of moving from a U.S. Special Operations Command (USSOCOM) effort to a large program of record. Specific supply chain concerns that will be addressed include: 1) DoD organizational structure; 2) service-specific objectives and currently operating platforms; 3) requirements generation and related procurements to include production and quality challenges; 4) safety and quality assurance standards; 5) lead times, inventory plans, and throughput to include supplier base considerations and consolidations; and 6) latest evolving technologies and continuous improvement principles. Our team will utilize the Define, Measure, Analyze, Improve, Control (DMAIC) evaluative methodology that focuses on data-driven improvement cycles to better optimize process, design and results. Our results and recommendations highlighted multiple strategies that the Office of Naval Research (ONR) must focus on when developing the LOCUST supply chain. These conclusions and findings address both current supply chain development opportunities for the LOCUST program, as well as where the program must focus its efforts in the future.

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ABSTRACT

The LOCUST program is a scalable system of inexpensive swarming unmanned aerial vehicles to provide disruptive capability in contested environments against anti-area access denial defenses, enabling manned strike operations and localized landing site superiority with reduced cost, risk, and operator launch and workload. Our research and analysis will emphasize the challenges of moving from a U.S. Special Operations Command (USSOCOM) effort to a large program of record. Specific supply chain concerns that will be addressed include: 1) DoD organizational structure; 2) service-specific objectives and currently operating platforms; 3) requirements generation and related procurements to include production and quality challenges; 4) safety and quality assurance standards; 5) lead times, inventory plans, and throughput to include supplier base considerations and consolidations; and 6) latest evolving technologies and continuous improvement principles. Our team will utilize the Define, Measure, Analyze, Improve, Control (DMAIC) evaluative methodology that focuses on data-driven improvement cycles to better optimize process, design and results. Our results and recommendations highlighted multiple strategies that the Office of Naval Research (ONR) must focus on when developing the LOCUST supply chain. These conclusions and findings address both current supply chain development opportunities for the LOCUST program, as well as where the program must focus its efforts in the future.

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LIST OF ACRONYMS AND ABBREVIATIONS

AFRL	Air Force Research Laboratory
AoA	Analysis of Alternatives
A2 / AD	Anti-Access Area Denial
CAPE	Cost Assessment and Program Evaluation
CAS	Close Air Support
CNAS	Center for a New American Security
DARPA	Defense Advanced Research Projects Agency
DEPSECDEF	Deputy Secretary of Defense
DFMA	Design for Manufacture and Assembly
DMAIC	Define, Measure, Analyze, Inform and Control
DoD	Department of Defense
DOT&E	Director, Operational Test and Evaluation
EW	Electronic Warfare
IG	Inspector General
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
ISR	Intelligence, Surveillance and Reconnaissance
LOCUST	Low Cost Unmanned Aerial Vehicle Swarming Technology
LRIP	Low Rate Initial Production
MILCON	Military Construction
NDAA	National Defense Authorization Act
NDS	National Defense Strategy
NMS	National Military Strategy
NSS	National Security Strategy
OCO	Overseas Contingency Operations
ONR	Office of Naval Research
PEO	Program Executive Office
QDR	Quadrennial Defense Review
RDAT&E	Research, Development, Test, Acquisition & Evaluation
SAC	Systems and Analyses Center

S&T	Science and Technology
SECDEF	Secretary of Defense
SME	Subject Matter Expert
SOW	Statement of Work
TQM	Total Quality Management
UAV	Unmanned Aerial Vehicle
USSOCOM	U.S. Special Operations Command
VSM	Value Stream Mapping

EXECUTIVE SUMMARY

The Low Cost Unmanned Aerial Vehicle (UAV) Swarming Technology (LOCUST) Program is a scaleable system of low cost swarming UAVs. The goal of LOCUST is to operate within contested environments against anti area-access denial (A2 / AD) defenses. Our research and analysis will emphasize the challenges of moving from a U.S. Special Operations Command (SOCOM) effort to a large program of record. Specific supply chain concerns that will be addressed include DoD organizational structure, service specific objectives and currently operating platforms, requirements generation and related procurement to include production and quality challenges, safety and quality assurance standards, LOCUST lead times, inventory plans, and throughput to include supplier base considerations and consolidations, and evolving technology including continuous improvement principles. Our team utilized the DMAIC (Define, Measure, Analyze, Improve and Control) evaluative methodology that focuses on data driven improvement cycles to better optimize process, design and results.

Our analytical methodology outlines how each of the supply chain barriers has a significant potential to delay and interrupt LOCUST development and cross service integration. Each of these barriers has its own set of LOCUST target rich areas for identification, focus, specific improvement and monitoring. Our recommendations explain how these barriers require an investment of both human resource, time and funding. It is our opinion that LOCUST effort and focus must understand these implications, devote adequate resources to posit themselves at an advantage, and ultimately develop a high performing supply chain that is responsive and resilient.

Our analysis and subsequent results and conclusions support the following recommendations for the LOCUST program to be successful regarding supply chain and related scaleability concerns. This will also answer our final research question regarding viable solutions and/or alternatives for the LOCUST program going forward. Within DoD, scaleability of a major program of record is inherently linked to many factors, as previously stated, one of which is effective and efficient supply chain management. First, LOCUST supply chain must operate effectively in the face of minor or major supply disruptions.

Second, the supply chain must be resilient and able to recover and continue to operate from disruptions. The LOCUST program and larger DoD / service satisfaction must be supported by a multi-faceted supply chain that is able to operate in favorable or adverse conditions, thus requiring a thoughtful and strategized concept. The LOCUST program must develop supply chain risk assessment that not only addresses risk, but also likelihood and probability of disruption occurrence, and potential loss from disruptions, including interruptions to scheduled technological readiness assessments.

The following recommended LOCUST specific supply chain strategies will certainly facilitate program success and scaleability. First, commonality / modularity of design and capabilities to reduce never ending service specific variability. This would delay product differentiation, and allow the services to take the generic platform and modify it later on with their specific capabilities to meet warfighter goals and objectives. Second, incorporation of strategic stock "just in time" principles into supply chain management logistics to ensure critical components are available regarding uninterrupted program performance (e.g., additive manufacturing, 3D printing). Depending on LOCUST success and performance targets, suggest domestic strategic supply partner identification for the basic / modular LOCUST frame to minimize overhead and cost. Third, develop and retain an immediate flexible supply base to get the LOCUST program to a major program of record, adequately performing, and then reduce as needed in conformance with "just in time" principles. Fourth, encourage and develop "make and buy" principles into the LOCUST supply chain regarding existing capabilities for other successful DoD programs. This would provide LOCUST flexibility and resiliency should a supply chain disruption occur. Fifth, LOCUST should leverage larger DoD resources to provide economic incentives to grow specific suppliers, e.g., existing supply contracts supporting successful large programs of record. Sixth, encourage a diverse supply chain transportation network where necessary, e.g., multi-modal, multi-carrier, multiple routes, etc. Finally, LOCUST supply chain development must be requirements generation focused, without getting lost in product maturation deviation, or other service requirement dilution.

LOCUST must invest in a risk assessment program using a variety of methodologies to assess requirements, ranging from quantitative models to informal qualitative plans that support contingency planning. Whatever the methodology (e.g., stochastic process), a solid probabilistic estimate must be utilized to accurately characterize disruption / occurrence probabilities and related supply chain impacts. If this is not solidly calculable, then an estimate must be made in support of larger impact characterizations. This would facilitate an understanding of the probability distribution of supply chain interruption / loss resulting from disruptions, e.g., cost / benefit analysis. This assessment program would inevitably lead into a risk reduction program. The LOCUST program could certainly take advantage of initiatives for improving supply chain / freight security, and contingency suppliers or additional inventories that would overcome disruption occurrences. Additionally, suggest the LOCUST program utilize a supply chain specific Total Quality Management (TQM) program that would certainly add value. Going forward, all of these recommendations are applicable whether LOCUST parts are sourced domestically or internationally. Implementation of above would certainly facilitate uninterrupted LOCUST sourcing and operations retaining a high performing / robust supply chain in the face of disruptions.

LOCUST must create and work within a supply alliance network that is conducive to its technological maturation and overall program development. A strategic supply alliance (e.g., contract availability, hardware and software manufacturers and logistical providers) would support a less vulnerable supply chain that would operate both domestically and internationally. Creating a larger "safety net" for each individual piece, and provide the requisite redundancy to ensure ongoing high performance in the face of adversity. Would also facilitate reduced lead-time and associated risk exposure, and might require a re-focus of supply chain components to a more domestic focus that is more readily manageable and accessible. Finally, incorporation of an enterprise wide supply chain system would support a more holistic collaborative system that would provide supply chain visibility to inventories, component stock levels and shipments. A huge benefit to the enterprise system would be the capability of the supply chain components to coordinate their actions in a more efficient manner, thereby supporting a larger synergistically performing system. Would certainly facilitate repairs and fixes to the system, and support the proactive development of a system wide recovery plan.

LOCUST must weigh the costs and benefits associated with a proactive investment in their supply chain investment strategy. Obviously, a disrupted or ineffective supply chain has tremendous implications to scaleability to becoming a major program of record. Investing in a robust strategy will provide a myriad of benefits, covering multiple unforeseen contingencies. The cost and benefit of LOCUST specific supply chain management must be valued and incorporated into their overall strategy. It must be a strategic fit with proactive execution to support scaleability for LOCUST in not only becoming a major program of record, but also staying proactive in succeeding in becoming a foundational program in the DoD world.

It is no doubt the LOCUST program and its drone swarming technological capability underpinnings, will continue to mature into a major program of record, and be in demand for a variety of both DoD and non-DoD applications. It is for this very reason, that it is critical LOCUST take heed of developing a high performing supply chain, so physical assets are available when needed upon completing various milestones and technological readiness assessments, developments and capabilities. Will certainly require leading edge continuous improvement and innovation (exploitation and exploration). LOCUST must lead the way in innovative supply chain concepts, leveraging not only private sector technological improvements, but also out of the box typical DoD thought paradigms.

I. INTRODUCTION

A. PURPOSE / BENEFIT – WHY IS THIS RESEARCH IMPORTANT?

During a recent keynote address to the U.S. Naval War College, Chief of Naval Operations Admiral John Richardson opined that due to tremendous advances in technology, competitive advantages in military competition have been marginalized. In order for the U.S. military to regain and maintain that advantage, it must embrace and lead efforts to develop and control the overall technological advantage. Richardson stated that the U.S. military machine is well poised to develop and ultimately own this challenge, remarking, "I hope I have instilled in you that the character of the game has changed. … I hope I have instilled in you that we have to capture this changing character and get moving with a sense of urgency, a sense of immediacy; this is not something that can wait until 2040 to get going. We've got to make these moves now; we've got to make them boldly" (Thornton, 2017, para. 1 & 18).

This research is important as unmanned drone military technology is a key underpinning in the Department of Defense (DoD) Research, Development, Acquisition, Test & Evaluation (RDAT&E) landscape as future requirements become clearer. Drone technology has radically evolved over the last couple of decades, and continues to do so at an ever-increasing rate. The development of drone swarm technology is an example of this forward movement in further refining this particular technological capability. The Low Cost Unmanned Aerial Vehicle (UAV) Swarming Technology (LOCUST) program incorporates metaheuristic principles, utilizing algorithms to calculate best solutions in contested and congested environments where background information may be incomplete at best. Individual drone download includes baseline information regarding flight velocities, avoidance collisions via set distance parameters and centralized control via intra cognitive communications that address the overall landscape/challenges in achieving the mission goal. What the overall swarm understands and "sees" is much greater than what any one drone contributes to this puzzle (Longo, 2016).

A key tactical advantage of LOCUST swarming technology is the decentralized control via intra cognitive communications, where individual drones constitute low value. As opposing forces utilize surface to air missiles and the like to take out the "lead" drone that does not negate the ability of other LOCUST drones to continue to work towards the mission goal set. This will quickly exhaust and frustrate opposing forces in trying to defeat LOCUST. It leaves them no choice but to take out all drones, which could potentially number in the dozens. LOCUST drones would be considered expendable in both function and cost while conducting mission sets. Critical to the swarming concept is the ability of LOCUST to continue with the mission set regardless of individual drone loss due to enemy fire, mechanical failure, or other means of loss. The individual cost of a LOCUST drone to a piloted drone is minimally comparable. A LOCUST drone can be in excess of 1/100th the cost of a piloted drone, and will be much less of an operational security concern if brought down by opposing forces over enemy controlled terrain (Longo, 2016). Of course, this depends on the amount of technology and offensive / defensive capability with which each type drone is equipped.

For many decades, the DoD has used offset strategies to compensate for disadvantages and to better posture itself for successful engagements. Most recently, the DoD announced the Third Offset strategy in 2014 with the focus addressing the disadvantage DoD faced regarding particular technologies and warfighting domains in both anti-access and area-denial environments. This effort supported several high-level advanced research type projects, one of which was the concept of drone swarming technology (Mcleary, 2017, para. 1 & 2). The LOCUST program has reached a point of criticality considering program successes and the forthcoming challenges to scaling-up as a major program of record across the DoD services. As the importance of the research has highlighted, drone-swarming technology is the next frontier of UAV scaleable systems employing new offensive and defensive tactics against a range of environments with reduced cost, risk, and operator launch and workload. The following section on research benefit will clarify the specifics of supply chain issues as the LOCUST program scales up going forward.

B. PURPOSE / BENEFIT – RESEARCH BENEFITS?

The LOCUST program is an example of a cost-effective, intelligent capability that has reached successful milestones, but will certainly face scale-up challenges in the supply chain realm. A complete and detailed understanding of these challenges will assist in their identification, analysis and solution. If the LOCUST program is able to grow to a program of record within DoD, supply chain issues will be a concern for not only all the services, but also the private sector industries supporting this type of unmanned drone military technology production and sustainment.

The overarching primary research question is how can the U.S. government most effectively tackle supply chain barriers to scale-up of the LOCUST program? In answering this question, it becomes necessary to answer the secondary research questions specific to supply chain barriers to scale up of the LOCUST program: 1) What are the overarching DoD requirements needs, purchase / production needs and traceability? 2) What are the safety standards for scale-up operations and quality assurance concerns? 3) What are the lead times, inventory plans and throughput? 4) What are the supplier base considerations and consolidations? 5) What are the access and adaptability concerns to the latest evolving technologies and continuous improvement principles? In answering these questions, our team will utilize the Define, Measure, Analyze, Inform and Control (DMAIC) evaluative methodology. The DMAIC methodology focuses on data driven improvement cycles to better optimize process, design and results that will prove invaluable in answering the aforementioned questions.

Once these supply chain barriers have been further clarified and explained, the LOCUST program will be better positioned to move forward regarding the supply chain paradigm. One of the key outputs of our research will be our thoughts of the significance and importance of these issues. While they may be LOCUST supply chain specific, there will certainly be a greater theme in play, which other acquisition efforts may be able to pull information from to use in their specific endeavor / instance. The following section on the research plan summary will explain the activities, resources and deliverables expected because of this effort.

C. RESEARCH PLAN SUMMARY

(1) Thesis / Problem Statement

As previously stated, research will analyze how the U.S. government can most effectively tackle supply chain barriers to scale-up of the LOCUST program. Research and analysis will emphasize the challenges of moving from the current state of the LOCUST program to a large program of record. Specific supply chain concerns beginning with overarching DoD requirements through safety and quality assurance concerns, inventory plans and throughput, supplier base considerations and concluding with latest evolving technologies and continuous improvement principles utilizing DMAIC evaluative methodology. Analyzing these supply chain issues are certainly not LOCUST specific, and lessons learned can potentially be incorporated elsewhere. This project will require a thorough literary review of supply chain issues regarding the scale-up of the LOCUST program via published articles and online resources. Additionally, we will be researching relevant Special Operations Command (SOCOM) programs and conferring with the LOCUST program data library at the Office of Naval Research (ONR).

(2) Research Questions

- Primary Question

How can the U.S. government most effectively tackle supply chain barriers to scale-up of the LOCUST program? The answer involves defining and examining supply chain issues or concerns relative to LOCUST program scale-up and determining how these supply chain issues can be defined and analyzed. This information will be used to generate relative viable solutions and/or alternatives with the help of a well-defined Analysis of Alternatives (AOA) methodology. Relevant data and information has been sourced from credible technical advisors and subject matter experts (SMEs). Historical programmatic timelines for similarly related commodity areas and their scale-up processes will be annotated and supply chain barriers identified for like commodity areas and/or programs.

- Secondary Questions

How will LOCUST scale up be impacted by overarching DoD requirements needs, purchase and production needs, and traceability? Answering this question involves identifying the supply chain issues relative to the LOCUST program and scale-up operations and overarching DoD requirements needs. Additionally, production and quality challenges must be identified and analyzed, including design for manufacture and assembly. Required lead times, inventory plans, and throughput will also be analyzed.

How will increased safety standards and quality assurance concerns affect the LOCUST program scale up operations? Additionally, how will scale up be impacted by the LOCUST program lead times, inventory plans, and throughput? Answering these questions will involve the DMAIC process during which issues will be defined, evaluated, measured, analyzed, solutions implemented, and outcomes controlled. Current standards for safety, quality and production including ISO 9001, Design for Manufacture and Assembly – DFMA, Quality Functional Deployment – QFD, lean, 6 sigma will be assessed. Supplier base information and consolidation information will also be an integral part of this discussion.

What supplier base considerations and consolidations will need to be evaluated to improve scale up procedures and ensure program success? How will access and adaptability to the latest evolving technologies and continuous improvement principles affect the LOCUST program, specifically the scale up of the program? These questions will be answered with a thorough analysis of the current supply chain processes of the LOCUST program to determine how current supply channels are comprised and how capable and competent current supply partners are at supply chain operations management and effectively managing supplier relationships and performance. Evaluating this information will help determine capability and feasibility of LOCUST scale up. Lastly, what are the relative viable solutions and/or alternatives to the LOCUST program? Based on the analysis of the aforementioned questions, potential solutions and alternatives will be presented based on the relativity, feasibility, and sustainability of the solution or alternative.

D. OVERVIEW OF CHAPTERS TO COME

Throughout the remainder of this joint applied project, we discuss and analyze the LOCUST program's history. We will review its inception through its current state of Low Rate Initial Production (LRIP) while also discussing the supply chain hurdles throughout the program's current life cycle. We will focus on specific areas to help answer the questions surrounding the best approaches the U.S. government has to tackle supply chain barriers to scale-up of the LOCUST program. The goal is to provide the government with recommendations to solve these scale-up hurdles.

Chapter II will discuss an extensive background of the LOCUST program. We will introduce LOCUST subject matter expert (SME) information and discuss where the program currently sits. Chapter III will focus on a literature review to include RAND, IDA, GAO, IG, NDAA, service plans, and DoD roadmaps. This chapter will further discuss background research used to define the problem, identify key stakeholders, examine other interested parties, and view point regarding the LOCUST program. We will then move forward to methodology and analysis with Chapter IV. In this section, we will focus of identifying the problem, describe the DMAIC methodology, how it applies to the LOCUST program, as well as introduce and discuss the specific supply chain barriers affecting the program. We will focus on the content and issues surrounding the program before continuing the section with the presentation and explanation of the data and conclude with the analysis of the LOCUST data. In Chapter V, we will present our findings and results while providing a summary and recommendations for further studies. These determinations will be based on our data analysis of the LOCUST program.

II. LOCUST BACKGROUND

The LOCUST program evolved from previous UAV technologies dating back to the 1800s. Continuous improvement of these technologies over the years have allowed militaries across the world to build UAV capabilities. This evolution coupled with global military requirements, serves as the underpinning for the LOCUST program and swarming capabilities. In order to provide an in-depth background of the LOCUST program, we must first start with the history of UAVs. This will include how they have morphed and adapted to changing military requirements throughout history.

The first recorded use of UAVs dates back to 1849 with Austria using unmanned balloons to attack Venice. These balloons were loaded with explosives and dropped from the Venice skies (O'Donnell, 2017). In 1915, British forces during the Battle of Nueve Chappelle developed UAVs to conduct strategic aerial photoreconnaissance. They were able to capture more than 1500 maps showing aerial views of German trench fortifications in the region (O'Donnell, 2017). The first U.S. military UAV came about during World War I in 1916, through the development of the first pilotless aircraft.

Post World War 1, UAV technologies started to increase and provide substantial military support. In the 1930s, the U.S. military improved their technology by "experimenting with radio-controlled aircraft resulting in the creation of the Curtiss N2C-2 drone in 1937… further improvements came during WWII when Reginald Denny created the first remote-controlled aircraft the Radioplane OQ-2. This was the first mass produced UAV product in the U.S. and was considered a breakthrough in manufacturing and drone capability for the U.S military" (O'Donnell, 2017). Over the ensuing decades, UAV technologies continued to improve; however, they were seen as unreliable and expensive and used primarily as an alternate means for military operations.

The 1980s brought about new technologies and a recognized plan and need for increased military drone applications. In 1982, Israeli forces defeated the Syrian Air force using both UAVs and manned aircraft. The Israeli forces were able to destroy twelve Syrian aircraft with minimal causalities. During this time, the U.S. military was improving their

UAV technologies with the creation of the Pioneer UAV. This was an inexpensive, unmanned aircraft to support fleet operations. Israel and the U.S. teamed up to create a medium sized drone called the RQ2 Pioneer in 1986.

The mid to late 1980s saw tremendous growth and improvements in UAV technology. This technical maturation led to the complete transformation of UAVs and drones that are known today. The 1990s brought the introduction of miniature and micro UAVs; and the early 2000s brought about the Predator drone with capabilities never before realized. It was the Predator drone capability the U.S. used to search and locate Osama Bin Laden (O'Donnell, 2017). These cumulative technical capabilities, and recognized need for warfighter standoff from the enemy regarding survivability and lethality, culminated in significant drone capability investment.

This investment required a holistic examination of what current requirements could possibly be addressed using drone technologies. It was quickly recognized that UAVs must come in a variety of sizes and shapes with distinct payload and survivability / lethality capabilities. The U.S. military recognized that drones must be used by all services in one form or another, and must operate in all conditions to include supporting ground troops, vehicles and ships in domestic and contingency settings. Drone technology and capabilities were recognized as being critical in answering global modern warfare requirements, coupled with an ever-increasing enemy counter measures capabilities. The larger government background setting during this time focused on DoD modernization and readiness to be prepared and relevant in future battles (Scharre, 2014). All of this required the U.S military to embrace UAV technological capabilities resulting in the LOCUST program. The remainder of this chapter will focus on swarming technology and the LOCUST program. Information from SMEs will be introduced and various fiscal and supply chain concerns will be examined.

The LOCUST program was created in 2014 by the Office of Naval Research (ONR). As stated previously in chapter one, the LOCUST program incorporates metaheuristic principles, utilizing algorithms to calculate best solutions in contested and congested environments where background information may be incomplete at best. Individual drone download includes baseline information regarding flight velocities, avoidance collisions via set distance parameters and decentralized control via intra cognitive communications that address the overall landscape/challenges in achieving the mission goal. What the overall swarm understands and "sees" is much greater than what any one drone contributes to this puzzle (Longo, 2016). According to the ONR, "LOCUST was established as a scalable system of inexpensive, commoditized, swarming UAVs to provide disruptive capabilities in contested urban environments against A2 / AD defenses allowing for manned strike operations and localized landing site superiority with reduced cost, risk and operator/launch workload to the warfighter" (ONR, 2018).

The overall objective of LOCUST is to support rapidly available and remotely replenished swarms of small heterogeneous UAVs in direct support of ground Close Air Support (CAS) missions in congested urban environments (ONR, 2018). To fulfill this objective the overall program has five focus areas including mission effectiveness, automatic optimization of UAV behaviors, supervised autonomy and mission planning, replenishment, and connectivity (ONR, 2018). All five of these focus areas support the need for artificial intelligence and the underlying LOCUST capability and centralized control via intra cognitive communications. The ability of LOCUST to act as a natural, evolving swarm, make decisions real time, is at the very heart of the artificial intelligence and related technical maturation and development.

Mission Effectiveness – LOCUST must carry out Intelligence, Surveillance, and Reconnaissance (ISR) missions, target designation, kinetic, and electronic warfare (EW) strikes against threats as they arise or as identified by ground forces while conducting their missions (ONR, 2018).

Automatic Optimization of UAV Behaviors – LOCUST must optimize multiple variables to include resource allocation, navigation, obstacle avoidance, pose, multi-platform operations, and endurance against mission goals. UAVs must organize, adapt and travel in the ideal formation(s) to perform missions in obstacle rich environments, e.g., autonomously adapt and change course as obstacles change (ONR, 2018).

Supervised Autonomy and Mission Planning – LOCUST must operate with minimal operator involvement and workload. Operators will receive and interact with mission information and mission tasking through transportable interfaces to include smart phones, tablets and laptops. The goal is to have zero operator control once LOCUST is airborne as mission level interface is intent driven, e.g., adaptation and maneuver is real time via the swarm technology (ONR, 2018).

Replenishment – LOCUST must be replenished with support from either sea, air or ground launching platforms dependent on mission set. Overall replenishment will be based on utilization rates and operational tempo. The replenishment schedule will be tailored based on quantity and types of UAVs in each swarm to support each effort (ONR, 2018).

Connectivity – LOCUST must have extended range connectivity support. This will be accomplished through enhanced communication and reach back support with home base communication channels via air, sea or land connection points. LOCUST has the ability to interact and communicate with various channels for ideal connectivity and mission success (ONR, 2018).

A critical underpinning of LOCUST capability and success is the swarm concept. Swarming by definition are "large numbers of dispersed individuals or small groups coordinating together and fighting as a coherent whole" (Scharre, 2014). Bees, ants and termites, as well as other insects, operate in natural swarms. Simple rules govern their behavior for scouting, foraging, flocking, constructing as well as most other aspects of their daily existence. The ONR is trying to replicate these natural swarms by utilizing emerging technologies that will allow DoD to fight as a swarm with greater mass, coordination, intelligence and speed compared to the current networked forces. LOCUST will support this once scaled up and mass-produced / deployed to overwhelm enemy defenses. One of the most important "differences between natural and robotic swarms is that robot swarms are designed while natural swarms evolve" (Scharre, 2014). Replicating that natural / heuristic evolution is impossible but can be better achieved through continual research, understanding, and test and evaluation.

According to Scharre, "swarming combines the highly decentralized nature of a traditional melee combat tactic with the mobility of maneuver combat and a high technical degree of organization and cohesiveness to allow for large numbers of UAVs to fight as a collective unit. Compared to traditional maneuver warfare, swarming relies on higher organization and communication requirements due to the larger number of simultaneously maneuvering and fighting individual elements. Swarming requires sophisticated levels of command and control structures as well social and information organization" (Scharre, 2014). True swarm capability will be a total integration and fusion of sensor data across flight controller, ground controllers, radio, data transmitters, camera/payload and gimbals. Once LOCUST becomes fully autonomous, the warfighter will not need a controller, nor have an active role in the LOCUST mission set, (e.g., not actively controlling).

LOCUST onboard processing must be powerful enough and coupled with the correct software for each individual aircraft to accomplish its mission set and still report in a collaborative fashion with other swarm components. Tactical and theater requirements in many instances negate the possibility of drone recovery. A successful swarm must be a low price point with a one-way mission set with no need to recover (e.g., worst-case scenario involving A2 / AD scenarios), with high performance capability. LOCUST swarming will significantly alter how battles are fought and won through several advantages including dynamic self-healing networks, coordinated attack and defense, disaggregated functionality for low cost diverse solutions, distributed sensing and attack, deception, swarm intelligence and speed (ONR, 2018).

LOCUST swarm technology SMEs are enthusiastic about this technology and what swarming means for the future of warfare. There are multiple LOCUST like swarm technological capability demonstrations and development occurring across all services. This has created different swarm capabilities and extents depending on what requirement exists and what ultimate capability is developed. True swarming is much more than a small army of drones putting on a fancy pre-programmed light show. The principle underpinning in true swarming is the heuristic capability of true onboard task / auction-based algorithms that allow 4, 8, 16, 100 plus air vehicles to collectively organize and execute a mission in an operational environment. All of this while multiple simultaneous changes reoccurring with computer vision and processing, obstacle avoidance, flight / endurance optimization, mission set change due to weather or enemy, or flight routes in urban or rural terrain.

Therein lies the primary challenge, demonstrating a high technological readiness level in consideration of all these factors (SME, 2019).

The LOCUST swarming SME community leans toward this technology going the way of the "mosaic" in order to be self-aware and perform real time. This would require a group of dissimilar drones all networked together, e.g., fixed wing drones working with quad-copters where certain platforms fly over cities, fly between buildings, enter buildings, etc. The communications architecture and network to share what each air vehicle sees will enable real time optimization to solve problems. All factors regarding this mosaic concept and associated supply chain must be identified, invested in, and government funded / planned. A current example of this is what Amazon is currently doing with 5G networks using a "data pipe" for civilian drones to network and share information. An additional example are current changes to the national airspace system regarding how autonomous drone technology will navigate and operate. All of these sub-component / sub-platforms actions are a result from drone swarming technology development, but also will build the baseline operating systems and supply chain requirements of swarming technology (SME, 2019).

LOCUST program development was based from a phased approach for each mission set. The phases differ slightly depending on the particular mission set / constraints, (e.g., fixed and moving targets, Intelligence Surveillance and Reconnaissance (ISR), ground cued strikes). The following example is how the phases are visualized against a fixed target. Phase one would be target cuing, specific targets cued in on with the support of either space, air or ground assets. Phase two would include launch and ingress to target coordinates. Phase three is the relay phase where communications relay signals to LOCUST signaling autonomous positioning to the most advantageous location. Finally, phase four is the strike phase (ONR, 2018). Depending on the particular mission set, these phases would differ based on the target, where the strike originates from, and what other ground, air or sea assets are included in the mission set.

The missions that include more involvement and partnerships with multiple modes of support would have additional phases and the phases regarding relay and striking may be duplicated several times during a given mission. Regardless of the particular mission set, a critical component to LOCUST success is the launcher (e.g., the swarm cannot operate without being airborne). The launcher needs to be able to support multiple UAV launches with extreme speed and launch in rapid succession. The launcher must be able to support operations whether based from land, sea, or air. There are currently prototypes in the works for each scenario.

The LOCUST program has evolved and adapted since its inception in 2015. The program is currently moving forward with Raytheon BBN Technologies, an American research and development company, working with the Defense Advanced Research Projects Agency (DARPA) since 2015 to develop technologies for direct control swarms of small autonomous air and ground vehicles under their Offensive Swarm-Enabled Tactics program. In 2016, Raytheon successfully demonstrated netting together 30 UAVs in a swarm as part of the LOCUST program. Based on these initial successful tests, Raytheon BBN was awarded a $30 million dollar contract for continued development of LOCUST in 2018 (Naval Today, 2018). LOCUST will continue to have a place in DoD with how modern warfare is changing, evolution of enemy tactics, and the overall unpredictability of what current warfare strategies exist. Aside from the obvious benefits of LOCUST capabilities, there will continue to be an increased focus on warfighter survivability while reducing budgetary costs. The following chapter will examine the associated literature from various government and independent think tank sources related to the LOCUST program.

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III. LITERATURE REVIEW

> "The Budget … continues to prioritize the necessary long-term investments in early-stage science and technology at $12.5 billion to fund future technologies to reshape the battlespace, such as hypersonics, unmanned, and autonomous systems."
>
> — White House FY2017 Budget (Department of Defense, 2017).

The DoD global landscape on all fronts has recently been, and will continue to change, at an ever- increasing pace. This has been facilitated by an increase in globalization of organizations and people, access to technology, proliferation of non-traditional / non-State actors, and a decrease in traditional warfare practices towards newer asymmetrical warfare. In response to this, the U.S. and DoD balance its resources and risk management by prevailing in defense activities (e.g., warfighting, and preventing / deterring conflict in a wide range of contingency environments) (Department of Defense [DoD], 2014). These activities have required a hard look at where exactly DoD is winning, where it can do better, and where it has to do things differently. This has required a heavier emphasis on leading in the technological frontier, while realizing decreased budgets and personnel force size.

A key area to continue improving upon is unmanned systems that have the potential to utilize heuristic characteristics to act autonomously based on shared information (e.g., LOCUST). The DoD has recognized this technology has the potential to revolutionize conflict, and better position itself to manage the aforementioned growing unpredictable global landscape. The larger National Security Strategy (NSS), which will be discussed later, clearly recognizes the potential for LOCUST technology to be used in virtually every area of national and homeland security. According to the Modern War Institute, concepts are being researched and developed where drone swarms search the oceans for adversary submarines, search large areas to identify and eliminate hostile missile defenses, serve as sacrificial defense for incoming missile threats, equipped with chemical, biological, radiological, and nuclear detectors (Kallenborn, 2018, para. 1). While LOCUST does represent a major technological advancement, realizing its full potential will require an ongoing commitment and resource funding from the DoD to lead the way.

RAND - The RAND Corporation through the National Defense Research Institute has provided thoughtful and detailed information regarding the evolution of warfare from early on to the current era. They have classed this information into an "evolution of military organization and doctrine through four paradigms that have emerged throughout the ages: 1) the melee; 2) massing; 3) maneuvering and 4) swarming. Each builds from the previous using information and communication advances though information processing capabilities and embedded structural information. Swarming specifically has been enabled and fueled by the latest information revolution" (Arquilla, 2000). Rand does point out that swarming military doctrine will occur in the coming years, as LOCUST type technologies are refined, defeated, refined and so forth.

RAND astutely points out that in order for LOCUST type technologies to mature will require an "unfettered information flow and communication via internetted units, organized, capable information-processing systems, collectively identify targets and launch attacks (identify friend or foe), and proactive coordinate operations" (Arquilla, 2000). The individual pieces of the drone swarming to be effective must contain the following characteristics of "autonomy with shared direction, seemingly amorphous (but coordinated) assault from all directions, multiple small / dispersed units, integrated surveillance / sensors, stand-off or close-in capabilities, and attacks designed to disrupt adversary cohesion" (Arquilla, 2000). Differing degrees and types of warfare swarming have been in play for hundreds of years, whether it be during Roman times, to the British and Zulu skirmishes in Africa, or more recently in Vietnam, swarming will continue to be better understood and perfected utilizing LOCUST like technology. According to RAND, future warfare requirements will demand and define LOCUST doctrinal development (Arquilla, 2000).

Institute for Defense Analyses (IDA) has a tremendous amount of ongoing research, analysis and predictive studies regarding the larger UAS community and service specific requests. These requests cover the UAS spectrum from adjustments to existing platforms, combat loading, increased ISR optics and sensors. In reviewing IDAs LOCUST type specific research, it does not appear that the technology has matured enough; LOCUST is still within the technology demonstration phase. The services pursuing LOCUST technology have not asked for their assistance in problem solving / issue analysis yet.

In a broader sense and within the IDAs Systems and Analyses Center (SAC), they have a portfolio focused on strategic Intelligence, Surveillance, and Reconnaissance (ISR) reviews. This portfolio has been supporting investment decisions at the request of the Deputy Secretary of Defense. The DEPSECDEF has requested the Director of Cost Assessment and Program Evaluation (CAPE) and the Under SECDEF for Intelligence to co-lead an ISR strategic portfolio review. This review detailed UAS system usage and program costs over the past decade, and identified that overall UAS technical capabilities are losing their edge to deal with current threats, and not being adjusted quickly enough to stay effectively relevant. The CAPE asked the SAC to look critically in two areas regarding future UAS platform utility: 1) how proposed technologies can reduce labor requirements, and 2) UAS inter-operability of existing platforms.

The study findings are pending; however, there seem to be initial questions regarding technical maturation, and overall benefit when compared to investment requirements going forward (Institute for Defense Analyses [IDA], 2019). It is expected the study findings will result in a future analysis of alternatives that will include LOCUST type technologies that more quickly and cost effectively address evolving threats as explained in the background research section. Additionally, IDA is working towards an update of the 2014 ISR roadmap, which was initially developed as a comprehensive summary of ISR capabilities and support IRS capabilities integration regarding future operational needs (IDA, 2019).

The GAO has issued multiple reports about UAS technologies and how DoD can best posture itself going forward. The GAO authored a report in October 2018 titled, Weapons Systems (UAS) Cybersecurity – DoD Just Beginning to Grapple with Scale of Vulnerabilities, which was addressed to the Committee on Armed Services, U.S. Senate. The GAO highlights the state of UAS systems cybersecurity highlighting "factors that contribute to the current state of deficient cybersecurity, vulnerabilities in UAS / weapons that are under development and steps DoD is taking to develop more cyber resilient systems" (Government Accountability Office [GAO], 2018). It goes on to state that the "DoD plans to spend about $1.66 trillion to develop its current portfolio of systems including UAS. All of this is due to our potential adversaries that have developed advanced cyber-espionage and cyber-attack capabilities that target DoD UAS systems" (GAO, 2018). The report recognizes that DoD's systems are

> increasingly dependent on software and information technology to achieve intended performance. Software content in today's UAVs has increased within technologically complex subsystems. DoD UAS programs lack of cybersecurity requirements have also contributed to challenges with incorporating cybersecurity into systems testing. Specifically, DOT&E and service test agencies indicate that prior to 2014, program offices tried to avoid undergoing cybersecurity assessments, as they were oftentimes not definitively clear and thus not completely evaluated. Test officials indicated that many within DoD did not believe cybersecurity applied to weapons and UAVs systems. As a result, fewer cybersecurity assessments were conducted at that time in comparison to recent years.

By not incorporating cybersecurity into "key aspects of the requirements and acquisition processes, DoD missed an opportunity to give cybersecurity a more prominent role in key acquisition decisions" (Chaplain, 2018). Based in part on "GAO guidance since 2014, DoD has issued or updated at least fifteen policies, guidance documents, and memorandums intended to promote more cyber secure systems" (GAO, 2018).

Inspector General (IG) – Due to the technical maturation of the LOCUST program and the supporting software and platform development, there are not any specific (IG) reports regarding ONR's LOCUST program. There are multiple more general IG reports about how DoD and certain services can do business better and smarter. Specifically, the DoD IGs report FY2019 Top DoD Management Challenges articulates DODs top ten management and performance challenges. Many of these challenges are geo-political in nature, with specific DoD targets and actions; however, three of these challenges are certainly applicable to the LOCUST program: 1) implementing DoD reform initiatives; 2) improving cyber security and cyber capabilities; and 3) improving DoD readiness.

Regarding DoD reform initiatives, as a supplement to the National Defense Strategy, the FY 2018 – FY 2022 National Defense Business Operations Plan, issued by the Chief Management Officer, presents three strategic reform goals: (1) re-establish heightened readiness for increased lethality; 2) focus alliances and program cross-service interoperability; and 3) reform DoD business segments for greater performance and affordability. These are all large over-arching goals, but are certainly supportive of LOCUST development. One of the lesser stated LOCUST goals is to “free up” the warfighter to focus on other human centric activities, and these reform initiatives will certainly support that goal. Regarding improvements to cyber security and capabilities, the report clearly outlines the very real threats to internetted and interconnected DoD systems. As previously discussed, this will continue to be a significant challenge to the LOCUST program as the very heart of its success is bounded in metaheuristics based on the DoD Information Network (Department of Defense [DoD], 2019). Finally, improving DoD readiness is about as pie in the sky as you can get. Its applicability to LOCUST lies in the true necessity to realize and maximize technical opportunities rooted in human machine collaboration to maximize the warfighter’s abilities, time and effectiveness. This especially rings true when considering shrinking overall budgets, and maximizing warfighter lethality.

The various National Defense Authorization Acts (NDAAs) over the years are pushed and pulled by many internal and external factors. As discussed throughout this chapter, many UAV cyber threats to the LOCUST program have been identified, and the larger DoD has been making strides to address these issues for all unmanned systems. An example of this is the FY16 NDAA, “Section 1647 that requires the SECDEF to evaluate cyber vulnerabilities of each DoD weapon system by the end of FY2019 and develop strategies to mitigate risks stemming from those vulnerabilities. In response to this direction and the DoD Cyber Strategy, DoD is taking steps to better understand systems vulnerabilities, determine how to mitigate risks from those vulnerabilities, and inform future development of more secure systems. The Office of the Under SECDEF for Acquisition and Sustainment is leading this initiative in collaboration with Director, Operational Test and Evaluation (DOTE)” (Chaplain, 2018).

More importantly, the current NDAA focuses around the “New” Trump Strategy. According to the NDAA primer, there is a resurgence in the great power competition with revisionist powers such as China and Russia, and with regional dictators like Iran and North Korea. Current NDAA sections have applicability to LOCUST in the research and engineering section. Specifically: 1) critical emerging technology areas in artificial intelligence and information technologies; 2) improve DoD access to innovative high tech small businesses via better contracting processes; and 3) require Under Secretary of Defense (SECDEF) for Research and Engineering to develop interaction between DoD and the commercial technology industry and academia with unique national security applications like LOCUST (Cordesman, 2019). The 2019 NDAA Science and Technology (S&T) section includes several initiatives for the LOCUST program and related supporting technologies. According to Cordesman, specifically: "1) sustain a robust basic research program of 2.3 billion; 2) fund DARPA at 3.4 billion to continue developing technologies for revolutionary, high payoff military capabilities; and 3) continue to leverage research and development to provide leading edge capabilities for DoD, with emphasis on non-traditional technology companies to focus on DoD-specific challenges" (Cordesman, 2019).

Service Plans – The services have all been accelerating their operational plans and budgets in accommodating UAS, albeit at different speeds and urgencies. Enhanced loiter "UAS such as the Predator and Reaper have proven invaluable for ISR activities in contested areas, enhancing situational awareness, protecting DoD forces, and assisting in targeting enemy fighters… DoD continues its commitment to enhance ISR effectiveness of its fleet by developing innovative sensor technologies, support infrastructures, and operating concepts" (Department of Defense [DoD], 2010). In 2018, DARPA "announced the next phase of its offensive swarm-enabled tactics program, which seeks to improve force protection, firepower, precision effects, and ISR capabilities. DoD has already tested self-governing robotic fleets like LOCUST in trying to expand their capabilities. DARPA's swarm sprint competition, with the goal to utilize a diverse swarm of 50 air and ground robots to isolate an urban objective within an area of two city blocks over a mission duration of 15 to 30 minutes" (Day, 2018, para. 1 & 2).

Army – The Army is expanding all classes of UASs, e.g., the Raven, Puma, Black Hornet, Shadow, Gray Eagle, and accelerating the production of the Predator-class

Extended Range Multi-Purpose UAS. According to an April 29, 2019 statement from PEO Aviation, "the Army decided to collaborate with the PEO's project manager for UAS, the Defense Innovation Unit and the Maneuver Center of Excellence, to identify and prototype new capabilities with commercial companies that specialize in on-demand, eye-in-the-sky technologies" (Judson, 2019, 29 April, para, 1 & 2). Additionally, the Army is looking to increase LOCUST type technologies into its inexpensive, rucksack portable options for warfighter support (Judson, 2019, 29 April, para. 1 & 2). The Army is trying to balance its current obligations with its desire to expand its S&T demonstrations and capabilities. The Army is currently concentrating on "future vertical lift efforts for two future manned helicopter procurement programs, according to the acting director of the U.S. Army Combat Capabilities Development Command's, Aviation & Missile Center's Aviation Development Directorate" (Judson, 2019, April 18, para. 1 & 2).

According to Judson, "major efforts underway to build and field an attack reconnaissance aircraft and a future long-range assault aircraft, pursuing additional major acquisition programs is not being undertaken. Regarding S&T capabilities, the current plan is to focus on war-gaming efforts to flesh out concepts of advanced teaming between manned and unmanned aircraft… ultimately be added to the Army's Futures Command tasked with modernization efforts focused on the multi-domain operations doctrine including the Future Tactical UAS platforms" (Judson, 2019, April 18, para. 1, 3 & 4). Currently, "under an urgent operational need, the U.S. Army is now procuring Coyote as a near-term solution to eliminate enemy unmanned aircraft" (Raytheon, 2018).

Navy / Marines – The Department of the Navy is pushing ahead aggressively with all types of UAS. Specific to LOCUST, the ONR has awarded a twenty nine million dollar contract to Raytheon subsidiary BBN Technologies, to continue developing refinements to the existing LOCUST innovative naval prototype. This contract continues the development of the internetted, autonomous LOCUST goal of overwhelming adversaries. In 2016, the company carried out "demonstrations that successfully netted together 30 UAVs in a swarm, as part of the LOCUST program" (Naval Today, 2018). The current contract with BBN Technologies is part of the technology development program under the aforementioned DARPA's Offensive Swarm-Enabled Tactics program, "the UAV swarming system includes a tube-based launcher that can send UAVs into the air in rapid succession… technology then utilizes information sharing between the UAVs, enabling autonomous collaborative behavior in either defensive or offensive missions... Raytheon is expected to complete work on the ONR contract by January 2020" (Naval Today, 2018). Besides the ONR effort, as mentioned with the Army, Raytheon is providing Coyote to the U.S. Marine Corps for proof of initial concept testing (Raytheon, 2018).

Air Force – The Air Force's Research Laboratory (AFRL) has been, and is continuing to work on its artificial intelligence autonomous drone technology effort. The previous effort was called Project Maven and was developed in collaboration with Google and focused on image and pattern recognition. That effort has morphed into the current autonomous technology demonstration program called Skyborg. Besides the technology demonstration aspect, Skyborg intends to prove "mission-planning tools that emphasize modularity and openness" (Mitchell, 2019). As with the Army, Navy and Marine Corps, Raytheon has provided "Coyote to the AFRL for research, technology demonstrations and platform integration efforts" (Raytheon, 2018).

DoD Roadmaps – DoD roadmaps are inextricably linked to multiple planning documents (e.g., the Quadrennial Defense Review (QDR)). The 2010 QDR focused on wartime strategy regarding short-term efforts to prevail in Iraq and Afghanistan, with long-term strategies to prevent and deter conflict. The 2014 QDR evolved from the 2012 Defense Strategic Guidance, described 21st century DoD priorities, and supported the transition from ongoing wars to preparing for future challenges (while simultaneously dealing with Budget Control Act cuts). This transition recognized the need for not only significant technological improvements, but also the need for evolutionary acquisition regarding warfighter support (DoD, 2014). These technological improvements had many fronts cross service, including LOCUST through the ONR.

The February 2010 and March 2014 QDRs highlight two general overarching objectives: 1) rebalance and evolve DoD capabilities in consideration of current threats; and 2) build realistic and effective DoD capabilities required to defeat these threats. They go on to explain required DoD transformation in supplying the warfighter with effective technology specifically suited towards an increasing complex battlespace landscape. The

QDR explains how globalization has increased access to "technological innovation while lowering entry barriers for a variety of non-State actors using advanced military technology and sophisticated information and operations in employing unconventional technologies" (DoD, 2010). Trends that exacerbate this situation include: 1) resource demand; 2) urbanization of littoral regions; 3) climate change effects; and 4) geopolitical trends including regional cultural and demographic tensions. The QDRs explain that "in order for the U.S. DoD to continue to project and sustain large-scale operations over extended distances, it must transform its resources and strategies" (DoD, 2010).

The QDRs state that in order for the DoD to "succeed in counterinsurgency, stability, and counterterrorism operations; it must improve its capability to conduct ongoing counterinsurgency, stability, and counterterrorism operations in a wide range of environments" (DoD, 2010). Specific QDR initiatives specific to LOCUST technologies include the expansion and robustness of UASs for command, control, communications, computers and intelligence, surveillance, and reconnaissance through sustained loiter, which is considered a key enabling assets for USSOCOM. Additionally, "DoD must prepare for possible future adversaries likely to possess and employ some degree of technologically advanced anti-access and area-denial capabilities—the ability to blunt or deny U.S. power projection—across all domains" (DoD, 2010). The QDRs also state that future adversaries "will likely possess sophisticated capabilities designed to contest or deny command of the air, sea, space, and cyberspace domains… without dominant U.S. capabilities to project power, the integrity of U.S. alliances and security partnerships could be called into question, reducing U.S. security and influence and increasing the possibility of conflict" (DoD, 2010).

The QDRs were replaced in 2018 with the National Defense Strategy (NDS) planning document. In order to understand the NDS, it is critical to understand where it fits within the overarching national security planning documents. There are three distinct national security documents that all support the DoD; each with its own function. These documents include the "National Security Strategy (NSS), the National Defense Strategy (NDS), and the National Military Strategy (NMS)" (Carter, 2018, paragraphs 2 and 5). Additionally, the "NSS sets the broad principles and objectives for U.S. national security, which informs the NDS. In turn, the NDS provides the basis for the NMS" (Carter, 2018, paragraphs 2 and 5). This order of influence supports overarching top level down to service specific targets involving UAVs using LOCUST tactics / doctrine / technology.

The 2018 NDS speaks to DoD's approach regarding both current and emerging national security challenges, but also explains the strategic rationale for programs and related priorities contained within the FY2019-23 budget requests. The NDS highlights that the global strategic environment has changed significantly through an erosion of rules-based international order, thus requiring a new degree of strategic complexity (McInnes, 2018, para. 1). The 2018 NDS report outlines the DoD strategic approach based on "building a more lethal force through modernization of key capabilities, evolution of innovative operational concepts, developing a lethal, agile, and resilient force posture and cultivating workforce development" (Carter, 2018, para. 2 & 5). DoD must strengthen alliances with increased inter-operational depth. Finally, it must pursue reform that supports innovation, and streamlines rapid, iterative approaches from development to fielding (Carter, 2018, Paragraphs 2 and 5). The strategic support items all support LOCUST scaling to major programs of record cross service.

The DoD developed Unmanned Systems Integrated Roadmap 2017 – 2042 clearly baselines what capabilities DoD has, where it needs to expand, and specifically outlines service specific challenges. The roadmap highlights "four critical challenges in moving forward including interoperability regarding open and shared / common architectures, autonomy regarding increased efficiency and effectiveness, network security to ensure efficient spectrum access, and human-machine collaboration where machines will be valued as critical teammates" (DoD, 2017). The roadmap outlines the DoD strategic vision to collaborate with industry in developing low cost UASs within the entire DoD and joint force structures to further necessary technological advancements and achieve the paradigm shift in addressing the aforementioned challenges. DoD "continues to invest in Research & Development, Procurement, and Operations and Maintenance of unmanned systems across the Future Year Defense Programs… FY2017 funding requested in the Base and Overseas Contingency Operations (OCO) budgets as well as the FY2017 request for additional appropriations for all unmanned systems development, procurement and associated military construction (MILCON)" (DoD, 2017).

A. KEY STAKEHOLDERS

LOCUST technologies will provide new disruptive tactics against a range of environments with reduced cost, risk, and operator/launch workload. Stakeholders invested in the LOCUST development include resource sponsors, PEOs, warfighter commands, mission partners, DARPA, and performing industry partners such as Raytheon, GTRI, and Progeny (ONR, 2018). The Center for New American Security (CNAS) published a 2015 report titled, The Coming Swarm: The Quality of Quantity. The CNAS explained, "the heightened vulnerability of assets to vessels and aircraft has prompted DoD to invest miniaturized innovations such as emerging robotic technologies that can fight as a swarm… a huge business opportunity for companies that supply and integrate robots and unmanned systems in the defense industry" (Prakash, 2018). Around the same time, the "Strategic Capabilities Office, a discreet Pentagon division, tested micro-drones; 3D-printed UAVs that launched from a canister and were instructed to find one another in the air" (Prakash, 2018). Prakash further explains that DARPA

> approved the development of drones called "Gremlins," named after the creatures British pilots viewed as good luck charms during WWII… DARPA tapped four companies to develop those UAVs: Composite Engineering, Dynetics, General Atomics Aeronautical Systems and Lockheed Martin. The Gremlins design was multiple use (up to 20 times) and Lockheed Martin had developed adequate control mechanisms. (Prakash, 2018).

In April 2015, the ONR released "a video showcasing the U.S. Navy's latest technology for conducting autonomous warfare: LOCUST, or the Low Cost Unmanned Aerial Vehicle Swarming Technology program … the Pentagon's Defense Advanced Research Projects Agency (DARPA) has also been working on swarmbots for a while now with its Collaborative Operations in Denied Environment (CODE) program, although in comparison to the prototype tube-launched LOCUST UAV, no public demonstration has been given so far" (Gady, 2015). Raytheon's "small, tube-launched Coyote UAS has its own special software that enables several of them to fly as a swarm… Raytheon demonstrated this ability for the ONR in a Low-Cost UAV Swarm Technology, or LOCUST a few years ago" (Raytheon, 2018). According to Pete Mangelsdorf, director of Unmanned Air Systems at Raytheon's Missile Systems business, "I would say they performed flawlessly… it's a breakthrough technology that uses information sharing between UAVs, which enables autonomous, collaborative behavior" (Raytheon, 2018). Besides the ONR, Raytheon is providing the Coyote to the U.S. Marine Corps and U.S. AFRL, "If the U.S. government approves it, the company could someday offer Coyote to allied nations. … Raytheon is responding to the growing demand by expanding its UAS factory to build more of the versatile Coyote" (Raytheon, 2018).

B. TAKEAWAYS

In reviewing information from policy groups, think tanks, and strategic / planning documents, it is clear that there are four specific scaling and supply chain issues specific to LOCUST. First, the bounds of current and available technology must be recognized, and not pushed to the limits of being marginal resulting in chronic schedule and cost overruns. Second, effective oversight through detailed and qualified acquisition personnel to support LOCUST requirements regarding development and deployment schedules. Third, recognize resource constrained environment, require realistic requirements and capability developments that are not overly optimistic, demand performance, cost, and schedule realism. Finally, ensure LOCUST is adequately supported by high performing logistics and trained operators (e.g., joint force, multi-national, interagency). It is also critical to examine LOCUST technical risk by conducting comprehensive reviews, and technology readiness assessments to ensure the technologies utilized are sufficiently mature prior to final phases of engineering and manufacturing development. These issues must be addressed in order for LOCUST to not only be successful, but also be successful at an acceptable cost and in a timely manner.

Analogous to LOCUST development, the DoD has been developing wireless multi-media sensor and communication networks to surveil battlefield conditions (e.g., video and audio streams, still images, scalar sensor data). It has long been recognized that multiple sensors and communication networks have a significant synergistic advantage over single point locations. The wireless media networks rely on multiple receiving units, and can spontaneously formulate environmental / physical conditions and personnel presence. This is parallel to and supportive of LOCUST in that the use of artificial intelligence, with minimal human operator interface, relies on the same ability to self-recognize and make decisions real time (Liu, 2012).

DoD has illustrated to the entire world what drones are capable of, with media coverage of wartime accomplishments. This has provided significant interest from non-governmental parties to pursue their own drone specific applications including journalism, insurance, agriculture, shipping, 3D mapping, inspections, delivery, video collection. Private sector service requests will drive UAV platforms and related hardware to become commoditized and ubiquitous. This will more than likely drive consolidation (to a point) of private sector and military application UAV airframes with generic capabilities. Within the private sector algorithm, driven autonomous drones will certainly become commonplace, using predictive or more so prescriptive analytics (entertainment purposes include drone-based light shows during the Olympics and Super Bowl) (Castellano, 2018, para. 1, 2 and 4). This is certainly similar, but not the same situation DoD currently faces, regarding unpredictable situations caused by an unpredictable enemy. This is why DoD is taking LOCUST to that very specific level, to take what it can from the private sector where applicable, and then continue the artificial intelligence piece, to address the multitude of potential battlefield scenarios.

LOCUST technologies must be developed (scaled) and supported (supply chain) through robust efforts to ensure they are not only dominant, but also to ensure they do not materialize through opposing forces against DoD. Evolutionary acquisition to ensure successful LOCUST platform deployments revolve around the following: 1) clear and identifiable requirements linked to realistic schedules and post deployment logistics; 2) adequate resources that are programmed and budgeted for; and 3) effective acquisition through alternative considerations and solution decision / execution. The DoD must ensure that resources are planned and available to support LOCUST fielding in consideration of the Department’s Planning, Programming, Budgeting and Execution System (PPBES) cycle (DoD, 2014).

As discussed in the background chapter, we covered the history and evolution of UAVs. Their subsequent integration into military programs, and related changes based on immediate and pending global military requirements. As stated, this has led to increased focus on metaheuristic based, artificial intelligence platforms like LOCUST. The next two chapters will focus on methodology and analysis utilizing the DMAIC evaluative process, and discuss specific supply chain barriers affecting the program. Finally, we will conclude with Chapter V that will present our findings and results while providing a summary and recommendations for further studies.

IV. METHODOLOGY AND ANALYSIS

A. METHODOLOGY

Our methodology and analysis will support identification of the specific scale up and supply chain issues affecting the LOCUST program. Our methodology strategy is to utilize an evaluative process known as Define, Measure, Analyze, Improve and Control (DMAIC). The DMAIC methodology focuses on data driven improvement cycles to better optimize process, design and results that will prove invaluable in answering our research questions. Our analysis will take the DMAIC results and provide specific data analysis with supporting conclusions and recommendations.

Our overarching primary research question is how can the U.S. government most effectively tackle supply chain barriers to scale-up of the LOCUST program? This answer involves defining and examining supply chain issues relative to LOCUST program scale-up and determining how these supply chain issues can be defined and analyzed. In order to answer this question, we must answer a secondary research question: How will LOCUST scale up be impacted by overarching DoD requirements needs, purchase and production needs, and requirements traceability? Answering this question involves identifying the supply chain issues relative to the LOCUST program and scale-up operations and overarching DoD requirements needs. Production and quality challenges must be identified and analyzed, including design for manufacture and assembly. Required lead times, inventory plans, and throughput will also be analyzed.

In answering the second question, we must also answer a related question sub-set. First, how will increased safety standards and quality assurance concerns affect the LOCUST program scale up operations? Second, how will scale up be impacted by the LOCUST program lead times, inventory plans, and throughput? Third, what supplier base considerations and consolidations will need to be evaluated to improve scale up procedures and ensure program success? Fourth, how will access and adaptability to the latest evolving technologies and continuous improvement principles influence the LOCUST program, specifically the scale up of the program? Finally, what are the relative viable solutions and/or alternatives to the LOCUST program? Once we have answered these questions, the supporting information will be utilized to answer the broader two overarching research questions.

DMAIC methodology "utilizes a data-driven quality strategy used to improve processes. It is an integral part of lean, Six Sigma initiatives, etc., but can also be implemented solely as a quality improvement procedure" (American Society for Quality [ASQ], 2019). The five phases of the DMAIC methodology make up the overall evaluative process. It is critical to "define the problem, improvement activity, opportunity for improvement, or project goals in establishing a baseline for focus, scope, direction, and problem solving motivation" (ASQ, 2019). This step will be critical in answering our research questions specific to supply chain issues affecting scale up of the LOCUST program. We will provide a Value Stream Map (VSM) analysis to provide an overview of the entire process, supporting analyses, etc. The measurement of process performance will include a capability analysis to assess the probability of meeting LOCUST supply chain barriers and scale up challenges. Issue analysis will determine root causes of variation, and poor performance. The improvement portion of DMAIC will focus on "process performance by addressing and eliminating the root causes of variation and poor performance" (ASQ, 2019). We will focus on identifying problems and processes that are adversely affecting supply chain performance. Lastly, the control piece will identify improved processes, and a control plan to document what is required to retain improved process.

B. ANALYSIS

There are multiple supply chain barriers affecting LOCUST program scale up. With the drone market projected to be a $100 billion market opportunity between 2016 and 2020 (military $70 billion, consumer $17 billion, and commercial / civil $13 billion), there are many internal and external competing interests that either directly or indirectly affect LOCUST (Evans, 2018, para. 1). There are six supply chain barriers currently affecting LOCUST. Table 1 illustrates the specific barriers.

Table 1. LOCUST Supply Chain Barriers

Supply Chain Barrier	Description
#1	DoD organizational structure
#2	Service specific objectives and currently operating platforms
#3	Requirements generation, related procurement, to include production and quality challenges
#4	Safety and quality assurance challenges
#5	Lead times, inventory plans and throughput to include supplier base considerations and consolidations
#6	Evolving technology and continuous improvement principles

Barrier #1 – DoD organizational supply chain challenges must align and adapt its UAS platforms to enable a smooth and efficient supply chain strategy that overcomes organizational challenges of disconnectedness. This requires a well-planned approach that considers the past that leads to the various platforms currently, and where the current platforms need to be developed and funded to meet future goals and objectives. Cross coordination between services, Commands, and various sub-units makes managing the LOCUST supply chain very challenging. In terms of defining and measuring potential barriers (problems), changing DoD requirements needs, including increasing purchasing patterns, available funding, production capacities, and expedited delivery schedules, are certainly affecting LOCUST supply chain performance and related scaleability. This will ensure a more homogeneous understanding of what the requirements are for existing UAS platforms, what the requirements will look like for future UAS platforms, and what the supply base and chain needs to be in order to be efficient and support program scaleability.

Barrier #2 – Service specific objectives and currently operating platforms must be well researched, documented and understood that all the DoD services (including non-DoD agencies) have a current need for LOCUST type capabilities. With the ONR being the lead LOCUST developer, it is critical the program manager understand the greater implications of successful program milestones and technological readiness assessments / achievements. The drone swarming technology inherent in the LOCUST program has applicability far greater than the ONR and Department of the Navy. Overcoming these barriers and resistant forces, integrating vertically and horizontally, will be critical in expanding the LOCUST program throughout DoD, and thereby realizing gains in efficient supply chain management (e.g., speed, availability, control, accessibility and non-direct supply chain costs, such as inventory holding).

Barrier #3 – LOCUST supply chain requirements generation and related procurement must recognize and define the importance of collaboration, innovation and digital integration in its supply chain. This will require defining and measuring specific sustainment metrics and a detailed end-to-end supply chain approach that supports LOCUST performance and readiness. This will also require web-based tools designed to join with industry partners (cross-team functioning) and collectively expedite material to LOCUST through visualization and increased speed of learning. Realized improvements would likely include a reduction in back-ordered components and systems, including critical items, increased visibility of predictive spares requirements, a reduction in supply over-dues, and a reduction in customer wait times for repairable items (Office of the Secretary of Defense [OSD], 2018).

A good cost reduction effort is eliminating or greatly reducing the costs of poor, low-quality deliverables. The LOCUST program must demand the appropriate level of production quality relevant to the planned use of the LOCUST platform, one time sacrificial use, or planned multiple deployments. In analyzing and implementing sound practices to achieving this goal, a team mind-set is critical – the LOCUST program should rely heavily on the use of well-constructed integrated product teams (IPTs), integrated product, and process development (IPPD). Paraphrasing from DODD 5000.1, "Defense acquisition, requirements, and financial communities must work to maintain continuous and effective communications with one another and with all stakeholders to include operation end-users with IPTs. Effective teaming among warfighters, users, developers, acquirers, technologists, industry, testers, budgeters, and sustainers must begin during requirements definition." Open discussions regarding LOCUST quality standards and system expectations should be discussed openly among the selected IPT members from each of the services vested in LOCUST capabilities without reservation. Reasoned disagreement regarding acceptable quality standards should be raised and resolved early on and consistent, success-oriented participation must be encouraged by the lead program managers to ensure that IPT members feel empowered. As defined in the 1998 DoD Integrated Product and Process Development Handbook,

> Integrated Product and Process Development (IPPD) is the DoD management technique that simultaneously integrates all essential acquisition activities through the use of IPTs to optimize design, manufacturing, and supportability processes. IPPD facilitates meeting cost and performance objectives from product concept through production, including field support. It evolved in industry as an outgrowth of efforts such as Concurrent Engineering to improve customer satisfaction and competitiveness in a global economy.

IPPD will help proactively identify risks, like quality risk, and development processes and procedures for managing the risks specific to the LOCUST program. By implementing an IPT framework approach, LOCUST stakeholders, to include system and component designers, manufacturers, distributors, testers, and users, can collaborate to refine quality requirements and make certain LOCUST products adequately satisfy DoD needs. In particular, "the DoD endorses a risk management concept that is forward-looking, structured, informative, and continuous. The key to successful LOCUST quality risk management is early planning and aggressive execution. IPPD is key to an organized, comprehensive, and iterative approach for identifying and analyzing cost, technical, and schedule risks and instituting risk-handling options to control these critical risk areas" (Department of Defense, 1998).

Each program within the services has user organizations that advocate for quality and innovation. As such, uncertainty might exist regarding which warfighting community "owns" and "drives" UAS capabilities. Accordingly,

> If the U.S. military is to keep pace with the unfolding robotics revolution, it will need to adopt an aggressive strategy of targeted research and development, experimentation and concept and doctrine development. This will require not only increased resources, but also better institutional processes. Existing acquisition processes are too sluggish to keep pace with rapid technological change and pose a strategic risk to the United States. If they cannot be reformed, then DoD leaders will increasingly have to operate outside the traditional processes in order to rapidly adapt to emerging needs, as they repeatedly did when adapting to urgent needs for Iraq and Afghanistan. (Scharre, 2014, page 13)

It is important to ensure the user base understand the costs associated with larger-scale LOCUST production and quality. Again, these parameters are wholly contingent on the planned life for the LOCUST platform. In particular, “supply chain problems need to be quickly understood, so a planned resolution can be implemented before the problems grow and create related ripple effects. Strong supply chain discipline is critical to ensure team cooperation and anticipation of requirements and associated changes” (Piatt, 2018, para. 1 – 5).

In measuring and analyzing issues related to integration, LOCUST must integrate Design for Manufacture and Assembly (DFMA) into its engineering and design principles. Explicitly, “DFMA requires product design considerations to facilitate expedited manufacturing with reduced cost, easy transition into production, expedited assembly and testing, retain the targeted level of reliability and quality, and ultimately – satisfy warfighter requirements” (Bayoumi, 2007, para. 1 & 2). A particular DFMA applicability to LOCUST is the usage of standardized parts that would facilitate the building block (modularity of the platform) and accommodate other service and non-DoD plug and play scenarios (e.g., establish an initial, broad target line, which allows for the insertion of advanced technology in later increments). A solid strategy is to divide specific LOCUST systems into smaller components by

> disaggregate modernization across time, building modular platforms with incremental improvements in each procurement “block” over time. With only marginal changes between each “block,” this approach reduces technology risk and, as a consequence, cost. Another approach would be to disaggregate a system spatially into many components, adopting a family-of-systems approach. This would consist of a number of single-mission systems working together to accomplish a task, rather than a single exquisite multi-mission system. Because single-mission systems would be less complex than multi-mission systems, they could be produced with lower technology risk and at lower cost. (Scharre, 2014, pp. 44–45)

Furthermore, real-time information sharing from multiple sources would render entire data sets accessible to all LOCUST team members, resulting in elimination of data silos, enhanced communication and strong performance in planning, predictive analytics and supplier education and performance, and overall LOCUST effort alignment.

Barrier #4 – Safety concerns and quality assurance standards regarding DoD operational theater programs, LOCUST does not need to maintain compliance with traditional DoD standards or Non-DoD UAS compliance.

> Since 2006, the DoD has had very specific and stringent guidance on the domestic use of DoD UAS. On occasion, DoD operates UAS domestically in support of a request from Federal or State civilian authorities. DoD only conducts these operations with the approval of the Secretary of Defense. In 2018, SECDEF delegated the approval of the use of smaller UAS to the Secretaries of the Military Departments, or the Geographic Combatant Commander where smaller UAS use supports Force Protection and Defense Support of Civil Authorities. This policy direction is set out in the Secretary of Defense Policy Memorandum titled Guidance for the Domestic Use of Unmanned Aircraft Systems in U.S. National Airspace. This guidance also states that armed DoD UAS may not be used in the United States except for training, exercises, and testing purposes. (U.S. Department of Defense, 2019)

In addition, U.S. Army Regulation 95-23 "establishes local procedures, rules, and assigns responsibilities governing unmanned aircraft system (UAS) operations" (Department of the Army, 2018). The FAA requires "Non-DoD and commercial applications are regulated by The Federal Aviation Administration (FAA) rules for small UAS operations other than model aircraft – Part 107 of FAA regulations – which covers a broad spectrum of commercial and government uses for drones" (Federal Aviation Administration, 2018). Given that LOCUST operations are altogether different, production, quality and safety parameters need to be kept at the appropriate threshold to ensure the program is not encumbered, while ensuring warfighter safety. DoD organizational safety and quality assurance standards needs to be kept to an appropriate minimum when considering the LOCUST mission set, "these should be limited to flight safety, safety management system, and internal evaluation programs with all revolving around an operational risk management basis" (Federal Aviation Administration [FAA], 2013).

ISO 9001 is the international standard that specifies requirements for a Quality Management System (QMS). The LOCUST program and specifically the supply chain must use this standard to "provide top performing functionality, e.g., process refinement / improvement, process efficiency, and mechanisms and performance indicators for continuous improvement" (American Society for Quality [ASQ], 2018). Specifically, the LOCUST supply chain QMS should plan and determine process interactions, clearly and effectively manage resources, realize product processes from design to delivery, and continually improve its QMS through internal audits focused on corrective and preventative actions. Specifically,

> the importance for standard compliance is more crucial now than ever, with the current state of global and Government geopolitics, influx of innovative business growth, and climate change furtherance; coupled with a growing consumer concern for business transparency. Category, quality and sustainability program managers alike seek collaborations with suppliers that can display ISO compliance. The attractiveness of working with suppliers that are ISO compliant and certified is simple; compliance is attractive; however, the ramifications of obtaining and maintaining ISO certification are further reaching than just an attractiveness for collaboration. ISO certified business practices build a standard on its own, much larger than just business standards. (Kodiak Rating Community, 2019).

One example, Platform Aerospace, Inc., adheres to ISO regulations and The Aerospace Quality Management System Standards, AS9100D specific to the industry. The company's framework is

> recognized internationally for best practices, addressing the unique needs of manufacturers, maintenance and repair operations and distributors by providing multiple benefits to companies who chose to adopt the standards' requirements. These standards were developed to produce a harmonized platform to ensure that all operations in the supply chain are adhering to best practices. They include all the existing elements of ISO 9001 and a variety of aerospace sector-specific requirements. The Aerospace standards seek to improve customer satisfaction, quality & safety, reduce costs, and adapt to customer-unique requirements. The standards ultimately reduce the variation caused by multiple expectations and streamline audits conducted along the aerospace supply chain. (Platform Aerospace, 2019)

Barrier #5 – LOCUST lead times, inventory plans, and throughput exist multiple methods in order to reduce manufacturing / delivery lead times and related inventory requirements. The current ONR plan for LOCUST revolves around ISR and the ability to overwhelm an adversary's attack ability. This more refined mission set allows a succinct analysis of where the LOCUST program can take advantage of manufacturing efficiencies and lead time reduction. Specifically, LOCUST can use a

> domestic supplier with a proven record, with minimal international sub-contract pieces. Second, baseline and accurately project order frequency and usage statistics. Third, use standardized and modular components whenever possible. Fourth, consolidate the supply base as much as possible, and encourage the use of kitting services. Fifth, utilize contractual incentives that supports optimal performance. Finally, communicate and stay on top of issues with the supply base, using key performance indicators. (MCL Manufacturing, 2017)

Supplier base considerations and consolidations – Supply chain optimization requires a sustainable position, working from a rational, strategic plan to leverage a reduced number of suppliers, while fostering a more close relationship focused on high performance. These supply partners must not only be capable, but also function at a manageable size to ensure high performance, and rapid resolution to any issues. This would also accommodate lean principles of pursuing system wide efficiencies and elimination of wasteful products and processes. LOCUST must develop a supplier development program that would support the performance of lean supply chain initiatives. Specific targeted actions include an analysis of supplier capabilities and performance, (e.g., a spend analysis rooted in total annual spend, spend by quarter, spend by category, supplier plant address, current inventory, monthly usage, lead time, and supply performance ratings). Second, create a LOCUST specific supply plan, e.g., budget, timeline, cross functionality performance, etc. Third, construct an effective "A" level supply chain, avoiding "B" and "C" level sub-contractors. Finally, rate supply chain performance again a LOCUST "specific supply performance program (optimization plan) with measureable metrics that support high performing supply chain collaboration" (Crane, 2017, para. 1–5).

Barrier #6 – Evolving technology and continuous improvement principles – As the LOCUST program evolves, it is imperative to not only focus on the traditional aspects of lean and six sigma's dedication to reduction of waste and error, but to embrace leading edge continuous improvement and innovation (exploitation and exploration). New age continuous improvement principles are necessary for LOCUST to ensure the requirement does not die. This will require dedicated and knowledgeable supply chain experts solely supporting LOCUST. Focus on parallel and serial wins that support high performing supply chain management. Recognize how small wins affect the overall puzzle, and ensure these are in alignment with the overall picture of evolving, high performing supply chain management: "Technology and information support must be harnessed in a way that supports and evolves. … The usage of "probe and learn" and beta testing are integral towards both technology and continuous improvement, and not detracting from it in the form of missed opportunities" (Cole, n.d.).

Mr. Joe Wlad is a product and services director at Verocel, one of the industry leaders in providing tools and services for software or system verification across the aerospace industry. He notes that "with over 30 years of experience in aircraft, systems, and software certification, Joe believes that virtually every UAS developer today is enabled by agile development, low barriers to entry, new methods of design, and short time to market; however, they have limited experience in designing innovative, safety-critical systems. In contrast, most conventional military and commercial UAV equipment designers are driven by a methodical development processes, high barriers to entry and sustainment, conventional tooling for increasingly advanced systems, long lead times, and a wealth of experience in complying with ever-changing regulations" (Wlad, 2019).

Value Stream Mapping (VSM) is a powerful tool that is certainly applicable and beneficial to LOCUST scale-up. The mapping involves the manufacturing and supply chain and logistical pieces. Incorporating lean methodology, VSM highlights via illustration, analyses, and identifies process improvements for LOCUST supply chain management. Specific to the manufacturing piece, VSM identifies material handling and information flow. The supply chain and logistical piece will look to eliminate waste and costly delays (time, money or both) at points along the supply chain. Figure 1 illustrates LOCUST process flow.

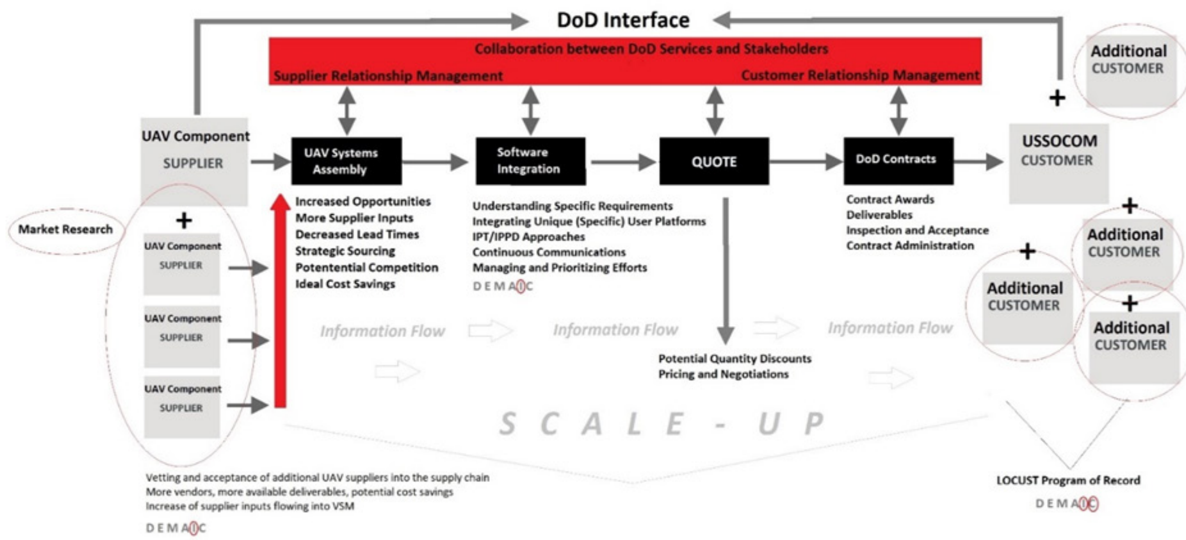

Figure 1. LOCUST Process Flow

LOCUST process flow as illustrated in Figure 1, explains how LOCUST would be utilized by USSOCOM. In this example, a typical USSOCOM task force team may require 30–50 systems for one set of mission operations. As LOCUST capability scales-up and gravitates toward a program of record, additional DoD customers will emerge. Additional DoD customers have been added and circled on the right-hand side of the process map. An increasing customer base will result in increased demand for LOCUST systems. Instead of standalone requirements for a single customer for 30–50 LOCUST systems, demand may increase to 150–250 LOCUST systems. These requirements will flow through to the supplier base on the left-hand side of the process map.

As previously annotated, process optimization requires a sustainable position and strategic plans to leverage a reduced number of suppliers, while fostering a closer relationship focused on high performance. Additional UAV suppliers (left) must be identified through extensive market research to meet the increase in customer demand. The limited number of supplier(s) currently providing UAV capabilities to commands require as much as 90–150 days for delivery. It is evident that to meet rising demand, additional sources must be sought to increase output capacities while decreasing lead times.

Additionally, the government must be cognizant of cost efficiencies and the current lack thereof given a limited U.S. supply base.

The Federal Acquisition Regulation (FAR) Part 25 prescribes the regulations and policies surrounding foreign acquisitions. Specifically, 41 U.S.C. chapter 83 describes the applicability of the "Buy American Act, which restricts the purchase of supplies that are not domestic end products for use within the United States… foreign end product may be purchased if the contracting officer determines that the price of the lowest domestic offer is unreasonable or if another exception applies" (Foreign Acquisition, 2019). Because many of the electronic components, chips, processors, and sensors used in UAV/LOCUST systems could be sourced from outside the U.S. in greater quantities for lower costs, the government should consider some of the exceptions available under FAR 25.103. Furthermore, the heads of contracting activities may make a determination that UAV supplies cannot be "produced or manufactured in the U.S in sufficient and reasonably available quantities of a satisfactory quality to support LOCUST scale-up... documenting unreasonable and unsustainable cost, that the scalability costs would be unreasonable, in accordance with FAR 25.105 and Subpart 25.5" (Foreign Acquisition, 2019).

The vetting and acceptance of additional UAV suppliers (foreign and domestic) into the supply chain would equate to a higher available of UAV component and system deliverables and potentially result in considerable cost savings. The influx of additional supplier inputs into the value stream resulting from strategic sourcing would also decrease lead times for components and deliverables. Figure 2, projected LOCUST Value Stream Map, depicts the aforementioned scenario—increasing DoD requirements flowing to the supplier base. Scale-up results in increased frequency and volume of LOCUST orders and components. The value added from an increased supplier base is an expedited material flow process, from component sourcing through UAV systems assembly and software integration.

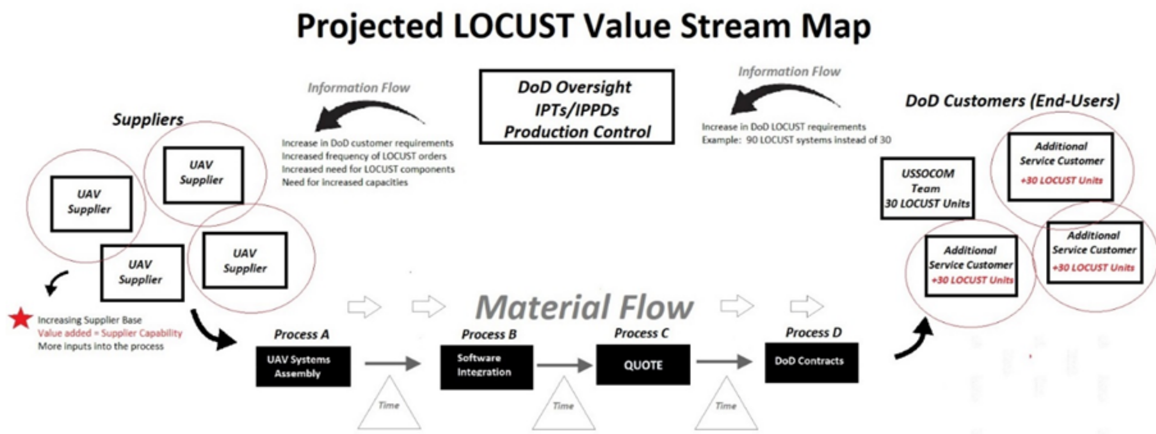

Figure 2. Depiction of Increased DoD Requirements Flowing to
the Supplier Base.

Selecting outsourcing suppliers and manufacturers for LOCUST scale-up requires important preliminary steps. Defining the LOCUST salient characteristics and statement(s) of work (SOWs) which actually describe what needs to be done in terms of performance outcomes is the key, not dictating the details of the processes by which these outcomes must be developed and achieved. DoD must recognize that suppliers have their own processes, which could prove valuable. If LOCUST insists on unique processes of its own, it forces "expanding suppliers to recreate individuality, resulting in a lack of scale, leaving LOCUST applicability uncompetitive or low-scale performing in the first place" (Rogers, 2009). Vetting potential suppliers for LOCUST scale-up prior to entering into agreements is critical and requires careful planning: "validating supplier credentials, testing and verifying capabilities, and levering industry-specific consultants in the outsourcing field can be time consuming, so evaluation must be performed early on in the process because most complex outsourcing deals are very expensive for suppliers to bid. The Government must not waste supplier time and money if suppliers are really are not an option" (Rogers, 2009).

As Rogers annotates, an "unexpected result of the evaluation process can be a hollowing-out of upstream knowledge so that up-tier innovations start coming only through tier-one suppliers (the outsourcing prime contractor). If contract manufacturers or supply chain management contractors filter the Government's contact with sources of market differentiation, the government may lose the ability to see breakthrough innovations because the outsourcing provider (contractor) does not see the full business situation. This can compound when providers are more interested in selling to the industry (commercial applications) than tailoring for particular Government customers" (Rogers, 2009).

Capacity-building spanning a multitude of LOCUST-specific management tasks is a component of innovation. If analysis and evaluation of capacity management processes have not been tested during the initial stages of LOCUST fielding and development, "major attention needs to be directed towards it at the stage of developing a scaling-up strategy. The need for additional testing and product demonstration, focused on building capacity needed to introduce large-scale innovation may be required" (World Health Organization [WHO], 2019). For example,

> if during scaling-up, supplier and subcontractor innovation is found to be weak in the area of supervision, efforts to improve supervision in routine programs could be tested as part of the initial scale-up strategy. If Government users and contractor organizations feel completely constrained by limited resources, it is tempting to conclude that nothing else can be done to scale-up innovation. In fact, experience shows that even resource-constrained systems provide opportunities to mobilize financial and human resources and to benefit from economies of scale. It is helpful to be on the lookout for these opportunities. In addition, it is important to identify and evaluate champions or policy entrepreneurs who are advocates for change. (WHO, 2010)

As the LOCUST program matures, maintaining cognizance over the following topics will maintain a high performing supply chain and related scale up front and center. The development and retention of clear technological readiness requirements is imperative. Understanding that as scale-up into a major program of record occurs; the supply chain must become flexible and adaptable for LOCUST scale-up to be sustainable. Building a network of program supporters and champions who are open to collaboration and information-sharing opportunities, especially between the services, is paramount. Finally, ensuring that ongoing supply chain situational awareness is clearly linked to current and effective decision-making (WHO, 2010).

In order for the LOCUST program to develop and rely on a productive and efficient supply chain, it must overcome resistant, engrained, bureaucratic processes: "the supply chain must have cross-service functionality, adequate measurement and performance indicators, and high performing information system support. This will require a constant adjustments and innovation initiatives to maintain and posture for a strategic and successful supply chain" (Fawcett, 2008). As previously mentioned, this will require LOCUST and people empowerment, information integration, and supportive organizational structure. Controlling both internal and external supply chain forces will be critical for the LOCUST program to succeed. The internal forces are entirely within DoD's and DON's ability to improve and manage through increased inventory turnover, cost reduction, and more timely LOCUST platform support. DoD and DON must set direction and performance expectations. The external forces such as technological improvement, private sector interaction, and gaming the competitive marketplace are all in support of LOCUST growing and scaling to a major program of record.

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V. RESULTS, CONCLUSION AND RECOMMENDATIONS

Overarching Primary Research Question: How can the U.S. government most effectively tackle supply chain barriers to scale-up of the LOCUST program? The U.S. government can most effectively tackle supply chain barriers to scale-up of the LOCUST program by addressing supply chain concerns previously discussed: 1) DoD organizational structure; 2) service specific objectives for LOCUST and currently operating platforms; 3) analyzing the requirements generation processes and related procurement to include production and quality challenges; 4) addressing safety and quality assurance standards; 5) analyzing LOCUST lead times, inventory plans, and throughput to include supplier base considerations and consolidations; and 6) leveraging evolving technology including continuous improvement principles. As discussed in this thesis, the government should utilize the DMAIC (Define, Measure, Analyze, Improve and Control) evaluative methodology that focuses on data driven improvement cycles to better optimize process, design and results.

Secondary Research Question: How will LOCUST scale up be impacted by overarching DoD requirements needs, purchase and production needs, and requirements traceability? LOCUST scale-up will be impacted by overarching DoD requirements needs, purchase and production needs, and requirements traceability. A sound scale-up strategy must involve identifying and measuring supply chain issues relative to the LOCUST program and scale-up operations, including the overarching DoD requirements needs. Production and quality challenges must be identify and analyze utilizing the DMAIC methodology, including design for manufacture and assembly. Our analytical methodology outlined how each of the supply chain barriers to scale-up has a significant potential to delay and interrupt further LOCUST development and cross service integration. As discussed, each of these barriers has its own set of LOCUST target rich areas for identification, focus, specific improvement and monitoring.

Subset Question (Secondary Research Question): How will increased safety standards and quality assurance concerns affect the LOCUST program scale up operations? Increased safety standards and quality assurance concerns will affect the LOCUST program scale up operations. Given that LOCUST operations are altogether different, production, quality and safety parameters need to be kept at the appropriate threshold to ensure the program is not encumbered, while ensuring Warfighter safety. DoD organizational safety and quality assurance standards needs must be kept to an appropriate minimum when considering the LOCUST mission set, especially considering FAA requirements regarding flight safety and related safety management system (operational risk management basis).

Subset Question (Secondary Research Question): How will scale up be impacted by the LOCUST program lead times, inventory plans, and throughput? LOCUST scale-up will be impacted by program lead times, inventory plans, and throughput. As such, it is evident that to meet rising demand, additional sources must be sought to increase output capacities while decreasing lead times. Additionally, the government must be cognizant of cost efficiencies and the current lack thereof given a limited U.S. supply base. Process optimization will require a sustainable position and strategic plans to leverage the number of available suppliers while fostering close relationships focused on high performance and high quality. As LOCUST becomes more refined, the continuing mission will permit analyses of where and how the LOCUST program can take advantage of manufacturing efficiencies, increased capacities, and lead time reduction.

Subset Question (Secondary Research Question): What supplier base considerations and consolidations will need to be evaluated to improve scale up procedures and ensure program success? As we have discussed, supply chain optimization requires a sustainable position, working from a rational, strategic plan to leverage a reduced number of suppliers, while fostering a more close relationship focused on high performance. Supply partners must not only be capable, but also function at a manageable size to ensure high performance, and rapid resolution to any issues. LOCUST must develop a supplier development program that would support the performance of lean supply chain initiatives. Specific targeted actions include an analysis of supplier capabilities and performance (e.g., a spend analysis rooted in total annual spend, spend by quarter, spend by category, supplier plant address, current inventory, monthly usage, lead time, and supply performance ratings).

Additional UAV suppliers for LOCUST must be identified through extensive market research to meet the increase in customer demand. As annotated, the government must make “determinations as to whether or not cost-effective, sustainable levels . . . “produced and manufactured in the U.S. in sufficient and reasonably available quantities of a satisfactory quality” to support LOCUST scale-up (Foreign Acquisition, 2019). The vetting and acceptance of additional UAV suppliers into the supply chain would equate to a higher available of UAV component and system deliverables and potentially result in considerable cost savings. The influx of additional supplier inputs into the LOCUST value stream resulting from strategic sourcing would also decrease lead times for components and deliverables.

Subset Question (Secondary Research Question): How will access and adaptability to the latest evolving technologies and continuous improvement principles influence the LOCUST program, specifically the scale up of the program? As the LOCUST program evolves, it is imperative to not only focus on the traditional aspects of lean and six sigma’s dedication to reduction of waste and error, also to embrace leading edge continuous improvement and innovation. The Government must leverage dedicated, knowledgeable supply chain experts solely supporting LOCUST and utilize the DMAIC process to define and evaluate small wins for the LOCUST program, implementing the suggested guidance to complete the overall puzzle, ensuring high-performing supply chain processes.

Subset Question (Secondary Research Question): What are the relative viable solutions and/or alternatives to the LOCUST program? Looking to the future, it is evident that the era of swarming drone technology is upon us. LOCUST capabilities will drastically change the way U.S. forces conduct mission operations, and the capability will likely not be limited to aerial swarming capabilities. We believe the swarming drone capabilities will likely be utilized by the U.S. Navy and U.S. Marine Corps for under-water autonomous operations as well as the U.S. Space Command for low-earth orbit operations. Drones within swarms will likely play different roles for different services. For example, target and destroy drones (e.g., Predator) will carry out offensive operations while swarming reconnaissance drones will gather and compile information about environments around and above the world, effectively communicating with numerous other drones and relaying information back to remote users.

The future of swarming technology will likely see drones of different sizes, ranging from micro and nano drones designed to reduce U.S. signatures in operating territories to larger drone swarms with increased payloads capable of carrying EW platforms and computer network operations, designed to mitigate enemy jamming capabilities and advance U.S. counterintelligence operations. Deploying autonomous drone swarms in increasing numbers (50, 100, 200 individual systems) perfectly synchronized with each other in multiple capacities (land, sea, air, space) would certainly revolutionize military operational strategy going forward.

LIST OF REFERENCES

American Society for Quality. (2019). The define measure analyze improve control process. Retrieved from https://asq.org/quality-resources/dmaic

American Society for Quality. (2018). What is ISO 9001:2015 – Quality management systems? Retrieved from https://asq.org/quality-resources/iso-9001

Arquilla, J. and Ronfeldt, D. (2000). Swarming and the future of conflict. Retrieved from https://www.rand.org/pubs/documented_briefings/DB311.html

Bayoumi, A. (2007, 9 May). Design for manufacture and assembly (DFMA): concepts, benefits and applications. Retrieved from https://www.sciencedirect.com/science /article/pii/ B9780080437118500519

Carter, J. (2018, February 23). What you should know about the national defense strategy. Retrieved from https://providencemag.com/2018/02/know-national-defense-strategy/

Castellano, F. (2018). Commercial drones are revolutionizing business operations. Retrieved from https://www.toptal.com/finance/market-research-analysts/drone-market

Chaplain, C. (2018). Weapons systems cybersecurity – DoD just beginning to grapple with scale of vulnerabilities (GAO-19-128). Washington, DC: Government Accountability Office.

Cole, R. (n.d.). From continuous improvement to continuous innovation. Retrieved from http://rube.asq.org/pub/qmj/past/vol8_issue4/cole.html

Cordesman, A. (2019). The U.S. defense budget in FY2019: underlying trends. Retrieved from Center for Strategic and International Studies website: https://www.csis.org/analysis/us-defense-budget-fy2019-underlying-trends

Crane, W. (2017, 23 January). Supply chain for tomorrow's technology. Retrieved from https://www.industrystarsolutions.com/blog/2017/01/supply-base-optimization-4-steps-ensure-success/

Day, E. (2018, 6 April). The Pentagon is imagining an army of autonomous robot swarms; get ready for the next generation of drones. Retrieved from https://www.motherjones.com /politics/2018/04/darpa-drone-swarm-robots/

Department of the Army. (2018). *Aviation Unmanned Aircraft System Flight Regulation*. (95-23). Fort Sill, Oklahoma: Author. Retrieved from https://sill-www.army.mil/USAG/.../REGULATIONS/Fort_Sill_Reg_95-23

Department of Defense. (1998). *DoD Integrated Product and Process Development Handbook.* Office of Undersecretary of Defense, Acquisition and Technology, ID: Author. Retrieved from https://www.acq.osd.mil/se/docs/DoD-IPPD-Handbook-Aug98.pdf

Department of Defense. (2010). *Quadrennial Defense Review report*. Washington, DC; Government Printing Office. Retrieved from https://www.archive.defense.gov/qdr

Department of Defense. (2014). *Quadrennial Defense Review 2014*. Washington, DC; Government Printing Office. Retrieved from https://www.archive.defense.gov/qdr

Department of Defense. (2017). *Unmanned Systems Integrated Roadmap 2017 – 2042*. Retrieved from https://www.defensedaily.com/wp-content/uploads/post_ attachment /206477.pdf

Department of Defense. (2019). Inspector General FY2019 top DoD management challenges. Retrieved from https://www.oversight.gov/report/dod/fiscal-year-2019-top-dod-management-challenges

Evans, Nicholas. (2018, 11 September). Drones in the supply chain: the evolving drone landscape and ecosystem. Retrieved from https://www.cio.com /article/3304425/drones-in-the-supply-chain-the-evolving-drone-landscape-and-ecosystem.html

Fawcett, S., Magnan, G., and McCarter, M. (2008). Benefits, barriers, and bridges to effective supply chain management. Retrieved from ResearchGate website: https://www.researchgate.net/publication /235286687_Benefits_ Barriers_and_Bridges_ to_ Effective_Supply_Chain_Management

Federal Aviation Administration. (2013, 24 January). Safety and quality assurance group. Retrieved from https://www.faa.gov/air_traffic/flight_info/avn/safety/

Federal Aviation Administration. (2018, 23 July). Fact sheet – Small-unmanned aircraft regulations (Part 107). Retrieved from https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=22615

Foreign Acquisition, FAR 25. (2019). Retrieved from https://www.acquisition.gov/content/part-25-foreign-acquisition

Gady, F. (2015, April 23). Drone swarms: How the U.S. Navy plans to fight wars in 2016. Retrieved from https://thediplomat.com/2015/04/drone-swarms-how-the-us-navy-plans-to-fight-wars-in-2016/

Government Accountability Office (2018). *Report to the Committee on Armed Services, U.S. Senate, Weapon Systems Cybersecurity, DoD just beginning to grapple with scale of vulnerabilities* (GAO-19-128). Retrieved from https://www.gao. gov/products/GAO-19-128

Institute for Defense Analyses. (2019). Evaluating intelligence surveillance and reconnaissance, space intelligence and chemical biological radiological and nuclear issues. Retrieved from https://www.ida.org/ida-ffrdcs/systems-and-analyses-center/sac-capabilities/evaluating-isr-space-intelligence-and-cbrn-issues

Judson, J. (2019, April 18). U.S. Army postpones demo plans for next-gen unmanned aircraft. Retrieved from https://www.defensenews.com/digital-show-dailies/aaaa/2019/04/18/us-armys-next-gen-unmanned-aircraft-tech-demo-plans-on-hold/

Judson, J. (2019, 29 April). U.S. Army takes another stab at 'rucksack portable' drone. Retrieved from https://www.defensenews.com/land/2019/04/29/army-takes-another-stab-at-rucksack-portable-unmanned-aircraft/

Kallenborn, Z. (2018, Oct. 25). The era of the drone swarm is coming, and we need to be ready for it. Retrieved from https://mwi.usma.edu/era-drone-swarm-coming-need-ready/

Kodiak Rating Community. (2017, 3 March). Importance of ISO certification for supply chains, sustainability, and society at large. Retrieved from https://medium.com/@KodiakRating/importance-of-iso-certification-for-supply-chains-sustainability-and-society-at-large-16d6bdb12261

Liu, Donggang. (2012). Efficient and distributed access control for sensor networks. *Science Direct Journal,* https://www.sciencedirect.com/topics/computer-science/sensor-networks

Longo, Maria. (2016). *The advantage of autonomous swarming drones in the military.* Unpublished manuscript.

Mcleary, Paul. (2017, December 18). The Pentagon's Third Offset may be dead, but no one knows what comes next. Retrieved from https://foreignpolicy.com/2017 /12/18/the-pentagons-third-offset-may-be-dead-but-no-one-knows-what-comes-next

McInnes, K. (2018, Feb 5). *The 2018 National Defense Strategy*. Retrieved from https://fas.org/sgp/crs/natsec/IN10855.pdf

MCL Manufacturing (2017, 26 July). Eight ways to reduce supply chain lead times. Retrieved from https://www.mcl.bz/blog/ways-to-reduce-supply-chain-lead-times

Mitchell, B. (2019, 26 March). With Air Force's Skyborg, autonomous drones could be coming soon. Retrieved from https://www.fedscoop.com/skyborg-air-force-drones-rfi/

Naval Today. (2018, June 28). Raytheon gets $29M for work on the U.S. Navy LOCUST UAV prototype. Retrieved from https://navaltoday.com/2018/06/28/ raytheon-wins-contract-for-locus-inp/

O'Donnell, Shea (2017, June 16). A short history of unmanned aerial vehicles. Retrieved from https://consortiq.com/media-centre/blog/short-history-unmanned-aerial-vehicles-uavs

Office of Naval Research (2018). *TIA 2.0 LOCUST.* Unpublished briefing

Office of the Secretary of Defense. (2018). Office of the Assistant Secretary of Defense Sustainment, DoD award for supply chain operational excellence. Retrieved from https://www. acq.osd.mil/log/SCI/award_for_excellence.html

Piatt, J. (2018, 7 Oct). Five steps to improved manufacturing quality. Retrieved from https://www.industryweek.com/5-steps-quality

Platform Aerospace. (2019). Quality management. Retrieved from https://platformaerospace.com/quality-management

Raytheon. (2018, 29 June). Mind of the swarm, amazing new technology allows drones to flock together as they fly. Retrieved from https://www.raytheon.com/news/feature/mind-swarm

Rogers, S. C. (2009). Supply-based advantage: how to link suppliers to your organization's corporate strategy. Retrieved from https://ebookcentral.proquest.com

Scharre, Paul. (2014). Robotics on the battlefield part II, the coming of the storm. *Center for a New American Security.*10/2014, 7 – 10. https://www.files.ethz.ch/isn/.../CNAS_TheComingSwarm_Scharre.pdf

SME Interview. (2019, May 15). Interview with swarming subject-matter expert.

Thornton, David. (2017, June 15). CNO warns about changing character of military competition. Retrieved from https://federalnewsradio.com/defense-news/2017/06/cno-warns-about-changing-character-of-military-competition/

United States Department of Defense. (2019). Unmanned aircraft systems (UAS) DoD purpose and operational use. Retrieved from https://dod.defense.gov/UAS/

Wlad, Joe. (2019). Certification initiatives ongoing for unmanned aircraft systems. Retrieved from http://mil-embedded.com/articles/certification-ongoing-unmanned-aircraft-systems/

World Health Organization. (2010). Nine steps for developing a scaling-up strategy. Retrieved from https://www.who.int/immunization/hpv/deliver /nine_steps_for_developing_a_scalingup_ strategy_who_2010.pdf

Under Secretary of Defense for Acquisition and Sustainment. (1998). *DoD integrated product and process handbook*. Retrieved from https://www.acq.osd.mil/se/docs/DoD-IPPD-Handbook-Aug98.pdf

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