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Fire Support Next: Achieving Air Freedom of Maneuver

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Author Note: Cadets Devon Hartsell, Alexander Lee, Zachary Lindsay, and William Webber at the United States Military Academy (USMA) worked on the Fire Support Next (FSN) Capstone Project through the Department of Systems Engineering. This is a multidisciplinary team comprised of a Systems Engineering Major, two Operations Research Majors, and an Engineering Management Major. Lieutenant Colonel Benjamin Morales is an Assistant Professor in the Systems Engineering Department that served as an advisor and mentor on the project. MITRE Corporation was our client and provided the guidance and resources to complete the project.

Abstract: Fire Support Next's mission is to improve the Find, Fix, Track, Target, Engage, Assess (F2T2EA) process on a Multi-Domain Battlefield. MITRE Corporation requested that a USMA capstone team research the capability of unmanned aerial vehicle swarm formations that can autonomously seek and destroy enemy air defense artillery (ADA) assets. This research team used Virtual Battle Space 3 as the simulation platform to simulate, assess, and provide insight on the offensive capability of unmanned aerial vehicles (UAVs) at the tactical level. The project team simulated deployment techniques in conjunction with current manned aerial platforms. It was found that a consort of ground deployed UAVs was the most effective strategy in destroying ADA assets.

Keywords: Unmanned Aerial Vehicles (UAV), Multi-Domain Operations (MDO), Air Defense Artillery (ADA), Virtual Battle Space 3 (VBS3)

1. Introduction

An interdisciplinary capstone team working closely with MITRE Corporation analyzed the offensive capability of UAV platforms. Since the operational environment has become more advanced, the U.S. Military must develop capabilities to defeat a peer threat on a multidomain battlefield. Currently, adversaries are deploying capabilities to fight the U.S. through multiple layers of stand-off in all domains – space, cyber, air, sea, and land (PAM 525-3-1, 2018). To compete in this battlespace, the military must reexamine current doctrine to eliminate any capability gaps that exist. MITRE Corporation efforts attempt to close the gap by using offensive employment of UAVs. MITRE manages federally funded research and development centers in support of agencies such as the DoD, DHS, and IRS (MITRE, 2020). MITRE requested that a USMA capstone team research, develop, and provide insight on the uses of UAVs to improve the current Find, Fix, Track, Target, Engage, and Assess (F2T2EA) process. The team used Virtual Battle Space 3 (VBS3) to program, code and simulate possible alternatives to provide insight on the tactical employment of unmanned aerial vehicles and swarm technology that may lead to an improvement to the F2T2EA process. These insights included the deployment distance from the target, number of platforms, altitude of flight, and the best attack strategy.

1.1 Problem Statement

Working closely with MITRE corporation, the capstone team formulated the following problem statement: Fire Support Next seeks to enhance the current F2T2EA process using multiple heterogeneous UAV platforms to neutralize enemy SA-15s/SA-19s and open a window of opportunity for follow-on forces on a multidomain battlefield (MDB).

1.2 Design Objectives

This project seeks to enhance the current F2T2EA process to contend with peer adversaries on an MDB. Currently, there are capability limitations to the process. Due to counter insurgency operations since 2002, a large capability gap formed between the U.S. and its peer adversaries (Cronk, 2018). These adversaries demonstrate asymmetric capabilities that deny our access to theaters, challenge the unity of coalitions, and negate freedom of action at the operational and tactical levels (PAM 525-3-1, 2010). The U.S. military is investing in developing capabilities to eliminate this gap. Specifically, the importance of a timely response of joint fires through the optimal allocation of assets is an area of improvement. Researching and developing offensive UAV capabilities is a method being explored to eliminate the gap and will allow U.S. forces to compete with existing technologies to penetrate highly contested airspace.

The design team's objective was to determine the best method of employing large and small heterogenous UAV platforms coupled with legacy platforms in the current and future operating environment to achieve the greatest effects on target. The desired effects were determined through stakeholder interaction to create We incorporated swarm technology to establish a methodology that uses a consort of UAVs to destroy, disrupt and degrade adversary's integrated air defense systems (IADS) on the multidomain battlefield. Thus, creating a window of opportunity for follow-on forces.

2. Background

2.1 F2T2EA Process

The F2T2EA process is a serial and process-oriented set of steps used to eliminate a target. All steps in the process have equal importance. The main motivation behind the process is to successfully create a collective understanding of targets and the target processing among joint operations (Annex 3-60: Targeting, 2019). There are multiple ways to define a target. It can be a graphical area or complex planned for destruction, intelligence usage, or an area designated for future firing (Annex 3-60: Targeting, 2019). For this project, the term target refers to an object planned for destruction.

The steps of this process include find, fix, track, target, engage, and assess. To find involves the detection of an emerging target. Fix refers to multiple assets used to positively identify an emerging target. Tracking a target involves the continuous monitoring of its position. Target represents the striking authority determining the desired effect and targeting solution. The engage phase occurs after a target has been positively identified as hostile and a predetermined weapon system is designated to carry out the strike (Annex 3-60: Targeting, 2019). Assess involves the predetermined assessment requirement that measures action taken to determine whether the engaging asset achieved the desired result. This project focused on the target, engage, and assess stages of the process because these predominantly occur at the tactical level.

2.2 UAV Platforms

Last summer, MITRE Corporation conducted experimentation on the use of Low Cost Unmanned Aerial Vehicle Swarming Technology (LOCUST) and the Skyborg, which is an autonomous platform, to determine their ability to enhance the F2T2EA process. Our project focused on simulating these capabilities in a tactical scenario to gain insight on their impact on a combat mission. Skyborg utilizes the Valkyrie XQ-58A platform, which is developed by Kratos Defense & Security Solutions. This is a unique platform because it incorporates a global position system (GPS) and pre-loaded flight-controlled software. These UASs send real-time information, gained with on-board sensors, to a ground station using a secure link during flight (Kratos Defense, 2020). The Skyborg asset can work in conjunction with a manned platform to serve as an autonomous wingman. The LOCUST Program uses large numbers of expendable drone swarms to allow U.S. forces to operate in areas that are highly contested by IADS which mitigates the risk of losing a manned aircraft.

2.3 Enemy ADA Formations and Assets

A multidomain battlefield has five domains which include air, land, sea, space, and cyber (PAM 525-3-1, 2018). The project's focus was the air domain. The scenarios in the simulations modeled a near-peer adversary's integrated air defense. The goal was to neutralize this defense to provide a window of opportunity for follow on forces. Specifically, our scenario has SA-19s and SA-15s defending a specified airspace because doctrine suggests that these platforms will be contesting the airspace (Grau and Bartles, 2016). To create a large enough air corridor for follow on operations, our alternative must destroy three

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SA-15 and two SA-19, which should open a large enough area to support follow-on force of a mechanized rifle brigade (Grau and Bartles, 2016).

2.4 Description of VBS3

To gather the raw data for each alternative we used a Department of Defense approved training simulation. The simulation platform used was VBS3developed by Bohemia Interactive Simulations. Over 50 nations use VBS3 for mission rehearsal and training at the tactical or operational level (BISim, 2021). VBS3 is a deterministic modeling software, producing a set result each run. It contains a wide variety of military assets available for simulation, with hundreds more accessible from online repositories. Using script editing software in standard query language (SQL) code, we modified the code for each mission to control the characteristics and behavior of each entity to model each alternative and evaluate their overall value.

3. Methodology

3.1 Process

The team developed alternatives through a value focused lens which emphasizes the values of the stakeholders to create alternatives (Parnell et al., 2011). The team determined that the focus must concentrate on the F2T2EA process. This insight came from interaction with stakeholders to identify the most critical part of FSN. Thus, identifying a fundamental objective nested with the F2T2EA process was imperative. Specifically, the project team focused on the tactical elements of the process (fix, track, engage, assess). Figure 1 depicts the mapping of system's functions to the process to assure the fundamental objective was met. After establishing the functions, we determined objectives and value measures used to evaluate each alternative. We created the alternatives through a design of experiments. Once we established the alternatives, we used the VBS3 simulation to analyze the alternatives and gather data. Using the value measures established and simulation results with sensitivity analysis, we provided a recommendation on future employment of Skyborg and LOCUST platforms.

3.2 Value Modeling Process

The value modeling process provides the systems engineering team an initial methodology for evaluating candidate solutions. The qualitative value model reflects the key stakeholder values regarding the system (Parnell et al). After creating and simulating the alternatives, the team evaluated the alternatives by using the value measures illustrated in Figure 2.

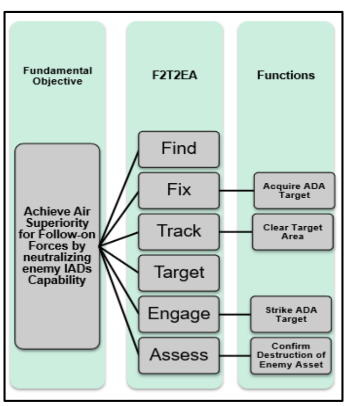

Figure 1. F2T2EA Mapping

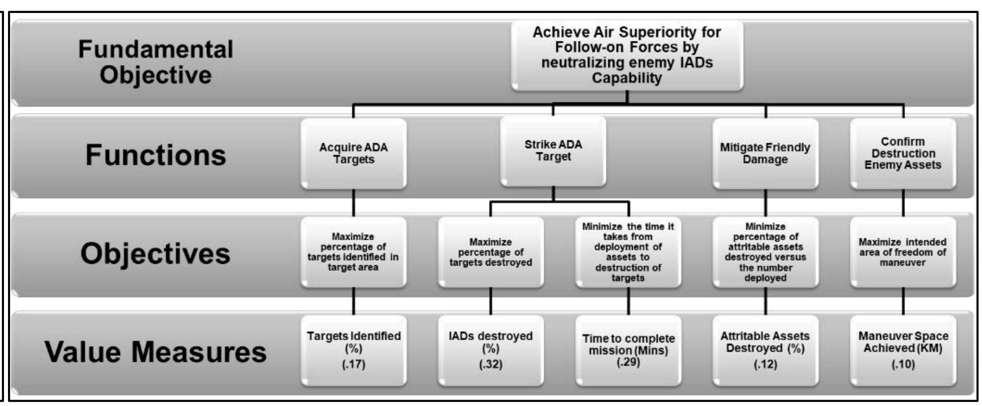

Figure 2. FSN Value Hierarchy

3.2.1 Value Hierarchy

The FSN Functional Hierarchy (Figure 2) represents the value hierarchy of the system. At the top of the figure is the fundamental objective, the end state that FSN is working to achieve. For this system, the fundamental objective is to achieve air superiority for follow-on forces by neutralizing enemy ADA capabilities. The second level indicates the functions of the system. These functions must be executed to achieve the fundamental objective. The third level depicts the objectives, which are statements of preference (Parnell et al., 2011). For example, in this system, we must maximize the percentage of the targets destroyed for the function of striking an ADA asset. Each objective has an associated value measure to determines how well each alternative achieves the objective. In short, they are measures of effectiveness (MOE). These values tell us how well a candidate solution attains an objective (Parnell et al., 2011). The last row in Figure 2 represents the value measures used to assess the performance of each alternative with their respective weights. By extension, it allowed the design team to determine the alternative that best achieved the project objective.

3.2.2 Value Weights and Value Functions

Determining the weight for each value measure and creating value functions were critical when scoring alternatives. All stakeholders played a pivital role in creating these elements. The weights associated with the value measures are seen in the last row of Figure 2. The value measures indicate the importance of each measure. For example, the most important value measure when assessing a candidate solution is the percent of IADs destroyed with a weight of .32. The team created value functions for each measure to convert the raw data to a score. Figure 3 illustrates one of a value functions used to convert raw data to score. The x-axis is the range of the raw data for that respective measure, and the y-axis is the corresponding score. It was necessary to create one for each MOE. Once the team converted the raw data for each measure to a score, each value measure score was multiplied by the weight to get a weighted value score for that that respective measure. Once all the raw data measures were converted to score and weighted, they were combined to establish an overall score for an alternative.

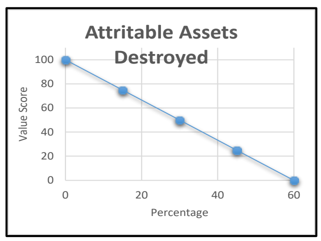

Figure 3: Value Function

3.3 Alternatives

Using the parameters based on the teams understanding of the current attack strategy of the F16, Zwick's morphological box was used to aid in creating alternatives. The team created multiple alternatives to penetrate highly contested airspace through simulation and scored each on value measures established by the stakeholder. The alternatives generated had a mix of F16s or F22s working in concert with either LOCUST and/or Skyborg assets. Based on our current doctrine and guidance from our stakeholders, the team established the base case to be six F16s attacking four SA-15s and two SA-19s defending an island. We had another alternative with six F22s and a third with six Skyborg assets. The F22, F16, and Skyborg deployed from a pre-established airbase, approximately 10 kilometers away from adversarial anti-air assets. Once the friendly assets reach the enemy airspace, they targeted two ADA assets at a time. We also formulated alternatives that utilize LOCUST swarms. Thirty LOCUST UAVs spawned in the simulation to simulate a ground and aerial deployment. Two swarms were deployed consisting of fifteen assets in each and each swarm targeted one asset. The design team created, simulated, and assessed eight different alternatives that combined F16s, F22s, Skyborg and LOCUST Swarms attacking enemy ADA assets.

3.4 Simulation Concept

Many modeling assumptions were made when creating the simulation to model the alternatives. There were two critical assumptions made to help accurately simulate the alternatives. The first assumption was the calculation to estimate the total strikes needed to destroy an enemy ADA asset. Below outlines the equation used (R. Murphy, personal communication, November 19, 2020):

$$p_t = 1 - (1 - p_k)m \tag{1}$$

P_t = probability of target surviving the strike.
P_k = probability of killing the target.
m = number of weapon strikes.

For the simulation we calculated m to determine how many elements in the LOCUST swarm needed to engage and destroy a target. We calculated that there needs to be two strikes to kill either a SA-15 or SA-19. The second assumption was

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the air deployed LOCUST swarm must be deployed outside of ADA range, which is approximately 10 kilometers. Once we were complete with the model, we conducted analysis to determine whether the assumptions were sensitive, which will be discussed in our sensitivity analysis section.

In the simulation, the defending force consisted of four SA-15s and two SA-19s defending an airstrip, see Figure 4. The attacking force had a heterogeneous mix of low cost autonomous manned and unmanned platforms operating in concert. The LOCUST swarms had two methods of deployment. The first method of deployment was air. The LOCUST deployed from an F22 for the movement to the objective. Once the LOCUST swarms acquired an enemy asset, they engaged. For the ground deployment, the team wrote SQL code to spawn the swarm at a location simulating a ground deployment. Once deployed, the swarm would navigate to destroy the ADA assets in the objective area. Figure 4 illustrates the map-view of the ground-deployed and air-deployed simulations in VBS3. The team chose each deployment location to facilitate safe deployment.

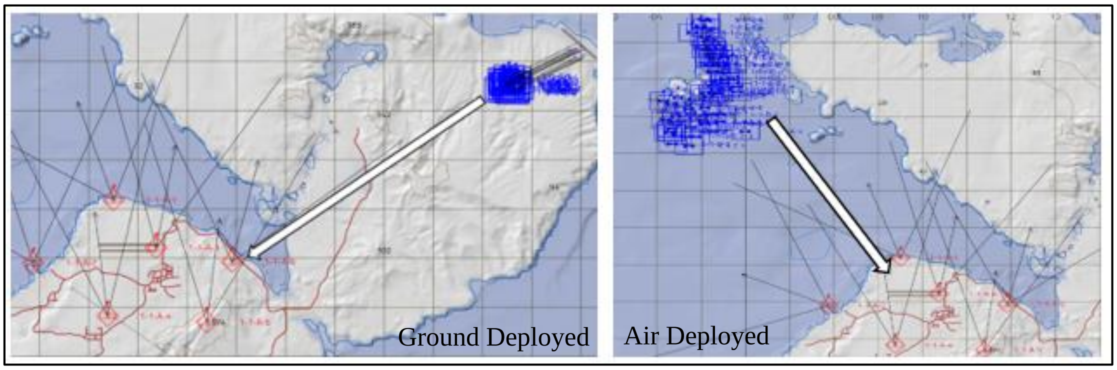

Figure 4. VBS3 Model of Ground-Based and Air-Based UAV Alternatives

4. Model Results

4.1 Alternative Scoring

4.1.1 Value Scoring and Cost vs. Value

After converting the raw data to a score for each value measure, via the value functions and weighting the scores using the value weights outlined in section 3.2.2 and Figure 2, the team scored all alternatives. Figure 5 depicts the total value score for each alternative and it highlights the weighted score achieved at each value measure with a different color.

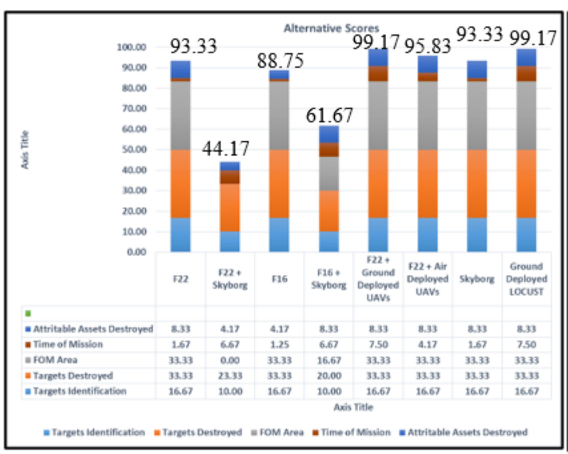

Figure 5. Stacked Bar Chart

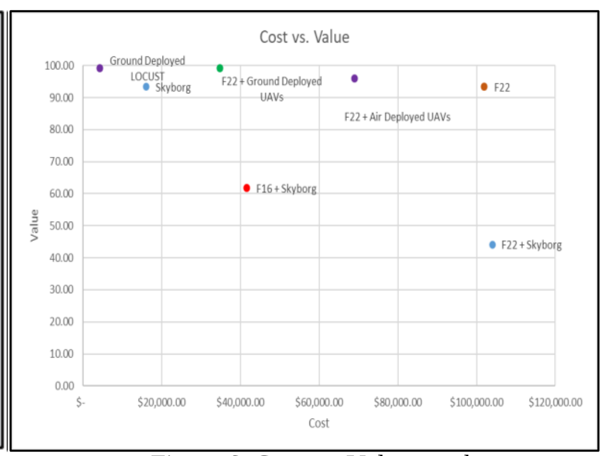

Figure 6. Cost vs. Value graph

Figure 5 illustrates that two alternatives had the highest value score of 99.17. In these alternatives, the attacking force destroyed all enemy ADA assets, while minimizing time with no assets lost. There are five alternatives that had a value score of over ninety. Therefore, the team conducted a cost vs. value analysis to determine the best alternative.

While value is important in finding the best alternative, cost should be considered. Instead of using life cycle cost, the stakeholders wanted us to minimize mission cost. Therefore, the cost of each alternative was determined by calculating the cost of fuel and any assets lost. The simulation data provided the information necessary to calculate the overall cost for each alternative. The cost vs. value graph (Figure 6) depicts the value of each alternative and its respective cost. Notably, the graph reveals the tradeoffs between value and cost and highlights the alternative with the greatest value and lowest cost. There were two alternatives that had equivalent value scores; however, the ground deployed LOCUST alternative had the lowest cost associated. This was due to the removal of the F22's cost of flight for the mission. After examining the trade space of the cost and value for each alternative, the ground deployed UAVs dominate all alternatives because it has the highest value with the lowest cost associated.

4.2 Sensitivity Analysis

Based on our observations while building the scenarios, it was apparent that there was further analysis needed on certain input variables. We conducted sensitivity analysis on the distance deployed from the target, and the number of UAVs needed to successfully eliminate all enemy ADA assets to determine whether they influenced the recommended alternative. Our focus was to analyze the effect of these assumptions not being accurate.

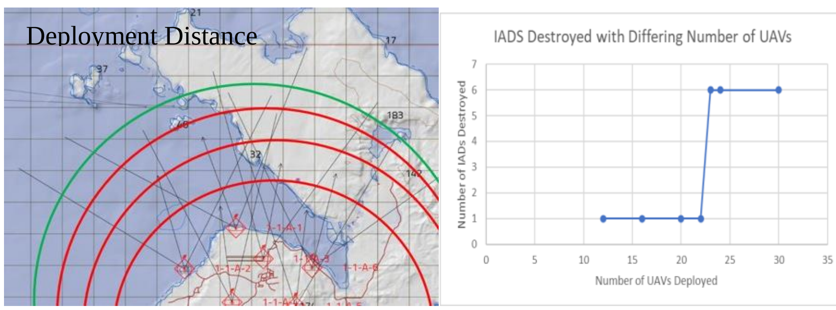

Figure 7. Sensitivity Analysis

When creating the scenario and conducting test runs, the team recognized that deployment distance may be a sensitive factor when air deploying the LOCUST assets. The goal was to get as close as possible to the objective, which would minimize time without getting the deployment vehicle destroyed before or after deploying the LOCUST. The analysis indicates that the optimal deployment distance is approximately seven kilometers away from the objective which is noted by a green ring in Figure 7, Deployment Distance. This confirmed the team's assumption that the UAVs must be deployed out of or near the effective ADA range and there was no change to the recommended alternative. Finally, we conducted analysis to determine the minimum number of LOCUST assets needed in a swarm to be successful. The analysis suggests it takes at least twenty-three assets in a swarm to complete the mission. Anything more than this number reduces the overall mission time (Figure 7, Number of Vehicles Deployed). This changed the team's initial assumption on the number of platforms needed for a successful mission. The initial assumption was two LOCUST per ADA; however, the sensitivity analysis proved that four were needed for mission success.

4.3 Recommendation

Based on the analysis of the simulation results, the highest scoring alternative is the ground deployed UAV assets. From the sensitivity analysis, we recommend a 4:1 UAV to ADA ratio, attacking at a low level to negate ADA capabilities, and deploying outside of ADA effective range, to successfully eliminate all enemy ADA assets. This ratio can be increased when time is of the essence because the benefit of increasing the swarm size decreases the overall mission time with a small associated cost. Therefore, there will be a tradeoff between urgency and cost.

5. Conclusions

The project team conducted an analysis on the Find, Fix, Track, Target, Engage, and Assess (F2T2EA) process to increase the U.S.'s capabilities on the Multi-Domain Battlefield. The team simulated the use of heterogeneous manned and unmanned aerial platforms, Skyborg and LOCUST, in VBS3 to determine the best course of action for destroying a near peer

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enemy IAD formation. Through the analysis, feasible alternatives were created to strike air defense assets and scored to find their overall value. The team determined that the ground deployed LOCUST assets was the alternative which performed the best. It completed the mission the fastest, destroyed every air defense asset, and cost the least in comparison to the other alternatives.

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