Proceedings of the Annual General Donald R. Keith Memorial Conference
West Point, New York, USA
April 28, 2022
A Regional Conference of the Society for Industrial and Systems Engineering

Fires Support Next

Jack Bordes, Kyle Doody, John Feeney, Kyle Hamrock, Collin Riechman, and Benjamin Morales

Department of Systems Engineering
United States Military Academy
West Point, NY 10996

Corresponding Author's Email: jack.bordes@westpoint.edu

Author Note: Jack Bordes, Kyle Doody, John Feeney, Kyle Hamrock, and Collin Riechman are Cadets at the United States Military Academy working on the Fires Support Next (FSN) Capstone through the Department of Systems Engineering. The team consists of students in the Systems Engineering Department. Colonel Benjamin Morales, a Faculty Advisor in the Systems Engineering Department at the United States Military Academy, serves as the faculty advisor for the project.

Abstract: The goal of the Fires Support Next project is to enhance the current Find, Fix, Track, Target, Engage, Assess (F2T2EA) process through modeling, simulation, and data analysis. Our Capstone group worked in conjunction with MITRE Corps to model the effectiveness of swarm technology of Unmanned Aerial Systems (UAS) against Anti-Air Defenses. MITRE Corps sponsors this research in conjunction with Army Futures Command, Air Force Special Operations Command, Air Force Research Laboratory, and the Office of Naval Research. Virtual Battle Space 3 (VBS3) was the simulation platform used to simulate models to allow the group to assess and provide insight on the offensive capability of unmanned aerial vehicles (UAVs) at the tactical level. This paper seeks to illustrate the methodology used to evaluate the alternatives.

1. Introduction

Our primary stakeholder's focus is to solve problems funded by the Federal Government and public-private partnerships to promote a safer world. Primarily, MITRE concentrates on problems that challenge the safety, stability, and well-being of the United States**Invalid source specified.**. Their primary client is Army Futures Command, but they have also partnered with Air Force Special Operations Command, Air Force Research Laboratory, and the Office of Naval Research. In this project, our priority is to improve the F2T2EA process by using UAS in an offensive role to neutralize an integrated anti-air defense (IADs) on a multidomain battlefield.

2. Background

2.1. F2T2EA Process

The F2T2EA process is a set of steps that include find, fix, track, target, engage, and assess where order matters. The first step is to find a potential target. Once found, fixing the target constitutes positively identifying the target. Following identification, continuous tracking of the potential target is imperative. Next is the targeting process where the striking authority determines the desired effect and weapons system to execute the strike. The engage phase is when the weapon system engages the identified target. After the target engagement, the assess phase determines whether the assets that conducted the strike achieved the desired effect (Annex 3-60: Targeting, 2019). The aim of this project is to analyze the effectiveness of attacking with swarms of UAS to maximize the lethality of this process.

2.2. Unmanned Platforms

Our research centered on UAS attacking in swarms; specifically analyzing the Coyote and the Altius-600 (Figure 1). The Coyote is a small UAS manufactured by Raytheon. The Coyote's size allows different deployment methods with a max endurance of 60 minutes, max air speed of 70 knots, and a cruising speed of 55 knots in altitudes 30,000 ft (about the cruising altitude of a commercial jet) or lower (Army Tech 2020). The Coyote's ability to traverse drastically diverse levels of altitude makes this UAS highly effective when engaging enemy IADS targets. Comparatively, the Altius is larger which decreases the number in each swarm due to increased lethality in comparison to the Coyote. The Altius-600 has a max endurance of 4+ hours or 276 miles (Area I 2020). These two platforms will use Low-Cost UAV Swarming Technology (LOCUST) created by the Office of Naval Research (ONR). These platforms are ideal in swarm technology since "the LOCUST program is truly maturing the algorithms to be able to maneuver individual vehicles in complete concert, single organism type of domain, and to be able to break off, go do something, engage, sense what have you, and come back" (Doubleday, 2016). Through stakeholder analysis, our task was to analyze these platforms using the LOCUST technology.

Figure 1. Coyote (left) ("Raytheon Coyote") and Altius 600 (right) (Centeno)

2.3. Design Process

The team used the Systems Design Process (SDP) to organize and develop solutions. The SDP consists of four phases: Problem Definition, Solution Design, Decision Making, and Solution Implementation (Parnell et al., 2011). Value focused thinking is the focal point for the SDP. This methodology strives to create alternatives that meet the needs, wants, and desires of the stakeholders by identifying value measures used to determine a solution. The Problem Definition phase ensures that the design team solves the right problem through research, stakeholder analysis, and value modeling. This phase ends when the team establishes a well-defined problem statement and value measures for the project. The Solution Design concentrates on creating alternatives to maximize the total value of the project. The outputs for the Solution Design phase are feasible candidate solutions. The third phase is Decision Making, where the design team evaluates candidate solutions and presents a recommended solution with an alternative that meets stakeholder's requirements. The final phase of the process is Solution Implementation phase which was beyond the team's scope.

3. Methodology

3.1. Define System

The primary tool used by the design team to understand the system was a systems boundary diagram. Our team evaluated the system by identifying the inputs, outputs, functions, and external factors. We placed these elements in a schematic illustrating how they interact. Figure 2 maps the system's architecture. Additionally, a dotted box in the middle of the image represents the system boundary. On the left of the image, lists the inputs of the system which include

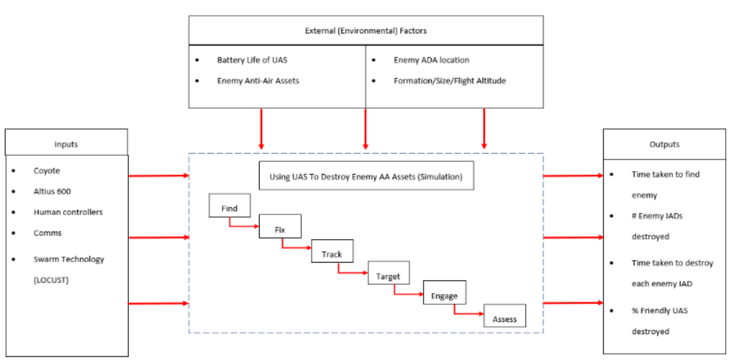

Figure 2. System Boundary Diagram

unmanned aerial systems, communications, swarm technology and human controllers. These inputs enter the system boundary indicated by the red arrows. Inside the system boundary are the sequential functions of the F2T2EA process. External environmental factors that influence the system are in the box above the system boundary. Finally, the outputs of the system are on the right side of the graphic. The systems boundary diagram was essential when creating our alternatives, collecting data on the alternatives, and evaluating their performance.

3.2. Value Focused Thinking

The qualitative model starts with defining a fundamental objective which is the goal the system strives to achieve. After defining the fundamental objective, the team established functions that achieve the fundamental objective and assigned each objective to a function. To measure the effectiveness of each alternative, the team established value measures for all the objectives. The client assigned each value measure a weight to illustrate importance. Prior to creating alternatives, we completed a qualitative value model. Figure 3 illustrates the qualitative value model. This model highlights the distinct functions of the model and associates each function's respective value measure.

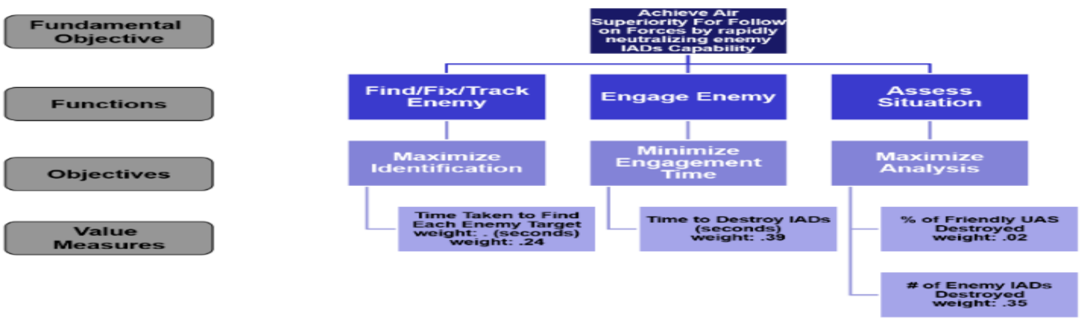

Figure 3. Qualitative Value Model (Functional Hierarchy)

3.3. Quantitative Value Model

To score an alternative we established value functions to convert raw data to a unitless value. The process of value measure scoring provides a method to compare alternatives on how well each alternative achieves the fundamental objective. Figure 4 illustrates the value functions constructed through client input for each value measure. The x-axis lists the possible raw data that an alternative produce where the y-axis shows the value score associated with each of the x-axis scores. The value functions associated with the value score allow the team to convert raw data gained from the simulation to a unitless score for each value measure.

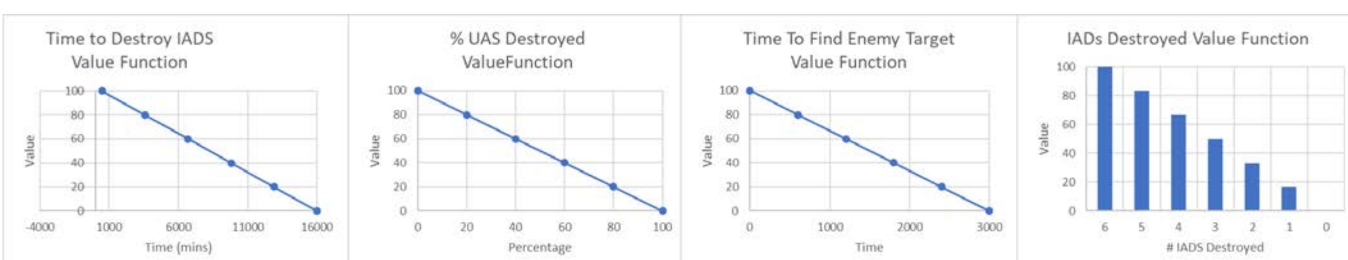

Figure 4. Value functions for each value measure

Once the team has the raw data for an alternative converted to value for each measure, the team calculated a weighted value score for each measure by multiplying the value measure score by its respective weight. The last step is to add the weighted value measure scores into a single score, yielding the overall value score. This process occurs for each alternative and these final value scores assist in the analysis of which alternatives are better.

ISBN: 97819384962-2-6

3.4. Redefined Problem Statement

At the end of problem definition, the team established a redefined problem statement. The capstone team and clients agreed that Fires Support Next seeks to enhance the current F2T2EA process by using a mix of heterogenous UAS platforms to neutralize an enemy integrated air defense using lethal and non-lethal UAS platforms. The aim of Fires Support Next is to enhance offensive capabilities of friendly forces.

3.5. Alternatives

Using the systems boundary diagram, the qualitative value model, and the redefined problem statement, our team established alternatives. There were hundreds of possible alternatives screened to twelve though stakeholder interaction. Our group created alternatives by constructing combinations that varied the type of LOCUST platform (Altius 600 or Coyote), number of assets in a swarm (20,40,80), and whether to use non-lethal swarms to neutralize an adversary’s air-defense threat. To completely understand the process used to evaluate an alternative, we will focus on explaining two alternatives. Alternative 1 (Altius 40): 40 Altius-600 drones attacking an enemy formation of 6 adversarial anti-air assets (SA-19s). Alternative 2 (Coyote 40): 40 Coyote drones attacking an enemy formation of 6 adversarial anti-air assets (SA-19s).

4. Simulation Model

4.1. Methodology to Evaluate Alternatives

To model each alternative, we used Virtual Battlespace 3 (VBS3) which is a desktop, virtual training environment that allows a user to simulate military operations. VBS3 has been in service for the past 15 years and consistently evolves with the modern operational environment (Bohemia Interactive Solutions, (n.d.)). Over fifty countries use VBS3 to evaluate military simulation, mostly to rehearse missions and examine their command plans (Bohemia Interactive Solutions, (n.d.)). The program has over 16,000 detailed entities displaying real life technologies (Bohemia Interactive Solutions, (n.d.)). VBS3 also has a vast content library of operational tools and data to make mission planning realistic in its scenarios. Running the simulation typically requires a human player interacting with the entities around the battlefield. To circumvent this behavior and to facilitate multiple iterations, the project team used video game script editing software to program commands in standard query language (SQL) code. We modified the code for each mission to allow the mission to run independently.

4.2. Concept of Simulation

The established scenario, which was the same for all alternatives, allowed us to compare the data gathered after a simulation run. Figure 5 depicts the 3-phase scenario which each alternative executed. The layout of 6 enemy SA-19s assets spawn in a 500-meter radius establishes an integrated air defense that the swarms engage. We constructed a base model in which enemy IADS were emplaced in locations in an interlocking defensive posture.

ISBN: 97819384962-2-6

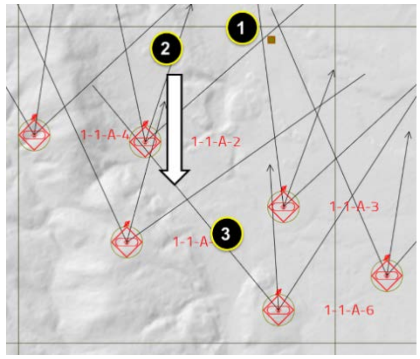

Figure 5. Concept of the Simulation

Phase I: Begins with surveillance and reconnaissance or decoy drones deployed and ends with deployment of UAS platforms.
Phase II: Begins with deployment of UAS platforms and ends with contact received from enemy anti-air assets.
Phase III: Begins with contact received from enemy air-defense and ends all anti-air defense assets destroyed or all UAS assets destroyed.

4.3. Example Simulation Output

In VBS3, simulations that have inputs with no element of variability or randomness always produce the same result. To transform the deterministic model into a stochastic model, we varied the location of the air-defense assets for each iteration. To model the variability of the IADS formation, we used tools in VBS3 to randomize IADS's location for each simulation run by having the air defense assets spawn within a 500-meter radius at the start of the simulation as opposed to a specific location. This helped ensure that enemy locations remained realistically in the formations of Russian doctrine, while altering the cover and concealment for each enemy air defense asset.

After running the simulations for the Altius 40 and the Coyote 40 alternatives, the project team formulated an output script that gathered data for each value measure listed in Figure 3 (Qualitative Value Model). Unfortunately, the time taken to run an individual simulation even in accelerated time was roughly 10 minutes. Given our time constraints, we found it infeasible to run over 1,000 simulations per alternative. Therefore, we ran approximately 30 iterations for each alterative and recorded the raw data for every value measure. Then we used distribution fit software to determine the best sample input distribution associated with that data. Figure 6 is an example of two input distributions for two of the four value measures for the Altius 40 alternative. The chart on the left is the value measure of the number of anti-air assets destroyed and the chart on the right illustrates the value measure for time to find enemy targets in seconds.

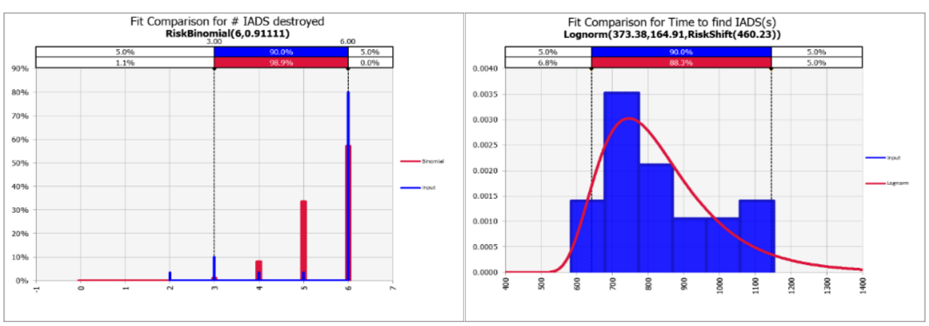

Figure 6. Altius 40 Alternative # IAS Destroyed Value Measure (Left) and Time to Find IADs Value Measure (Right)

In this case, the data suggests that the number of IADs destroyed is a 99.9% goodness of fit for a binomial distribution with parameters n = 6 and p = .911. Furthermore, the distribution associated with the time to find the enemy for this alternative is a 93.8% goodness of fit for a lognormal distribution with following parameters: mean of 373.4 and a standard deviation of 164.4. We conducted this analysis for all four value measures for every alternative. To use these distributions in a Monte Carlo simulation, we checked for correlation amongst the value measures to highlight any dependencies our value measures have on one another. A correlation matrix, generated in Excel, uses the value measure data the team extracted from our VBS3 simulation runs and compares them against every other value measure, calculating a correlation coefficient between value measures (Clemen, 518-519). The coefficient is then used when sampling the distributions for the Monte Carlo simulation to accurately reflect dependency between variables. Given the fact that the value measures interact differently in each alternative, this process occurred separately for each alternative.

4.4. Monte Carlo Simulation

Once the group established a distribution for each value measure, we generated additional data using the results for each alternative. To evaluate each alternative, we conducted a Monte Carlo simulation to do a repeated random sampling of the raw data to obtain scores for each alternative (See section 3.3 for scoring methodology). We ran a Monte Carlo simulation with 1,000 iterations. Since the data is a distribution, the overall value score will also be a distribution (Figure 7).

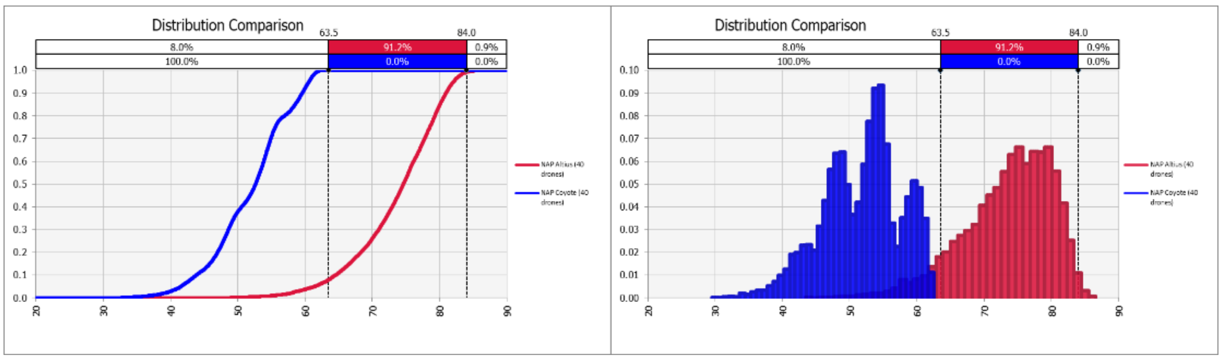

Figure 7. Altius 40 Alternative (Blue) and Coyote 40 Alternative (Red) Overall Score Distribution

The image on the right in Figure 7 illustrates the total value score distribution for the Altius 40 (Red) and Coyote 40 (Blue) alternatives. The x-axis is the value score, and the y-axis is the probability of receiving that score. The chart on the right is the probability density function (PDF) and it illustrates that there is over a 91% chance of having a higher value score with the Altius 40 alterative. The graph on the left is the cumulative distribution function (CDF) for each alternative which illustrates the proportion of values less than or equal to a given value (Clemen, 282). The CDF is used to determine stochastic and deterministic dominance. The goal for each alternative is to maximize value; therefore, the alternative CDF that lies entirely to the right of another achieves stochastic dominance (Clemen, 164). This graph illustrates that the Altius 40 stochastically dominates the Coyote 40 alternative. This means that no matter what outcome occurs (probability value chosen), the Altius 40 alternative will always yield a greater value than the Coyote 40 alternative (Clemen, 164).

5. Conclusion

To date, the team has followed the SDP methodology and is currently in the Decision-Making phase. From stakeholder analysis, creating value functions to model scores of our alternatives, coding the simulation, and formulating our alternatives, the team simulated and collected raw data. We used the raw data to create stochastic distributions for use in the Monte Carlo Simulation which produced statistical distributions of each alternative's value score. The team completed this analysis on 2 of 8 feasible alternatives which we included in this paper; however, the team will complete the analysis for the remaining alternatives in the future. Paired with the value scores, the team plans to conduct a cost analysis providing further insight into more cost-effective alternatives. In addition, our future work includes simulating the deployment of decoy drones to analyze the impact of deception against IADS and on the alternatives' value scores. Future simulations will also include legacy systems such as the F22 and Skyborg. Upon the completion of our simulations, we will conduct sensitivity analysis for each alternative to determine the minimal number of drones needed to complete the mission with a 95% success rate. Based on the interpretation of the value score distributions, cost analysis, and the results of the sensitivity analysis, the team will have the evidence required to provide a recommendation on the best alternative to our stakeholders.

ISBN: 97819384962-2-6

6. References

Area-I, Inc. *ALTIUS-600 | Area I.* (2020, October 21 https://areai.com/altius-600-2.
Centeno, G. (2021, April 6). *Em teste bem-sucedido, USAF lança um drone a partir de outro*. AEROFLAP. https://www.aeroflap.com.br/em-teste-bem-sucedido-usafa-lanca-um-drone-a-partir-de-outro/
Clemen, R. T., & Reilly, T. (2013). *Making hard decisions with DecisionTools*. Cengage Learning.
Corporate Overview. (2020, October 28). The MITRE Corporation. https://www.mitre.org/about/corporate-overview
Coyote Unmanned Aircraft System (UAS). (2022, April 19). Army Technology. https://www.army-technology.com/projects/coyote-unmanned-aircraft-system-uas/.
Doubleday, J. (2016). Office of Naval Research seeking payloads for drone swarm. *Inside the Navy*, 29(43), 7-7.
Parnell, G. S., Driscoll, P. J., & Henderson, D. L. (Eds.). (2011). *Decision making in systems engineering and management*. John Wiley & Sons.
United States Air Force. (2021) *Targeting* (Air Force Doctrine Publication 3-60). https://www.doctrine.af.mil/Portals/61/documents/AFDP_3-60/3-60-AFDP-TARGETING.pdf
VBS3 | BISim. (n.d.). Bohemia Interactive Simulations. https://bisimulations.com/products/vbs3
Wikipedia contributors. (2022, January 7). *Raytheon Coyote*. Wikipedia. https://en.wikipedia.org/w/index.php?title=Raytheon_Coyote&oldid=1064239026

ISBN: 97819384962-2-6