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Army Drone Swarms: An Emergent Capability in Multidomain Operations

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Abstract: Strategic Army doctrine emphasizes defeating anti-area and aerial denial (A2AD) systems in a multi-domain environment. These air defense systems pose a significant threat to friendly forces and severely restrict the air capabilities of a joint-task force. To this end, the Army seeks to understand how an autonomous drone swarm composition impacts joint-task force deep-strike mission success. Our goal is to enhance Army combat operations by evaluating the effectiveness of autonomous drone swarms. Using Virtual Battle Space Simulator 3 (VBS3), our team simulated missions against doctrinal Russian air defense assets with various drone swarm compositions. Our analysis shows that a drone swarm composition with an equal proportion of three drone types – kinetic, jamming, and decoy – performed best among our alternatives. This paper seeks to illustrate our methodology and relevant results.

1. Introduction

The United States Army has become increasingly focused on maintaining technological overmatch with peer adversaries (Congressional Research Service, 2022). United States Army Futures Command (AFC) is conducting research and development on autonomous drone swarms. In support of Army Futures Command and our primary stakeholder, System of Systems Enhanced Small Unit (SESU), we evaluated various autonomous drone swarm compositions. Our principal evaluation metric was the swarm's ability to enable a follow-on deep-strike asset (two F-22s) behind enemy lines. To this end, we implemented a series of stochastic simulations against enemy air defense assets in a modern battlefield environment using the Virtual Battlespace 3 software.

2. Background Research

In 2018, the Army published a new training pamphlet, *TP 525-3-1: The US Army in Multidomain Operations 2028*. This document describes threats and future challenges posed by Russia and China, focusing primarily on Russia. Additionally, it clarified how the Army, as a part of the joint force, will operate in competition and conflict against these adversaries.

TP 525-3-1 states that Russian "advanced mid-range radars and [surface to air missiles]" are a "significant threat to friendly air forces" (TRADOC, 2018, p.12). Consequently, *TP 525-3-1* states eliminating enemy air defense systems is paramount to successful penetration in conflict. The Army considers this a central military problem, asking "how does the Joint Force penetrate enemy anti-access and area denial systems [A2AD] throughout the depth of the support areas to enable strategic and operation maneuver?" (TRADOC, 2018, p. 16).

2.1 Window of Opportunity (WOO)

Our stakeholder's purpose is to render enemy air defense systems ineffective to establish a window of opportunity (WOO) for aviation assets to destroy key threat capabilities. Rendering enemy air defense capabilities ineffective opens aerial corridors for follow-on deep-strike operations. In prior simulations conducted by our stakeholder, F-16s and F-22s were used as the primary deep-strike platforms (Fefferman, 2022).

Our stakeholder defines a window of opportunity (WOO) as, "the condition existing physically, functionally, cognitively, or in some combination during a period when risk is sufficiently reduced to enable follow-on actions to achieve the desired outcome" (Maneuver Battle Lab, 2021). They also defined mission success and failure criteria.

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Mission success is defined as an opening of the WOO long enough for a deep-strike mission and survival of the deep-strike assets. However, if the WOO is opened but at least one deep-strike asset (i.e., F-22) is destroyed, then this constitutes mission failure.

2.2 The Kill Chain Process

The military's kill chain process is *Find, Fix, Track, Target, Engage, and Assess* (Air Land Sea Application Center, 2022, p. 15). Our scope falls within the "engage" phase of the kill chain. During the Engage phase, the drone swarm uses mission parameters transmitted via a command-and-control node to determine its area of engagement, then it acts autonomously to deliver its payload or inflict effects on enemy units (Air Land Sea Application Center, 2022, p. 53).

2.3 Low-Cost Unmanned Swarming Technology (LOCUST)

Low-cost drones, when employed en masse, become a LOCUST drone swarm. The low-cost Raytheon Coyote (Figure 1) used in our simulation has three variants: kinetic, jamming, and decoy. Kinetic drones carry a payload of 1.25 lbs of C-4 explosives and detonate on target (Bordes, 2022). Jamming drones use electronic signals to disrupt targeting capabilities, while decoy drones try to draw enemy fire by mimicking a larger asset on radar (they carry no payload) (Yount, 2021).

Figure 1: Raytheon Coyote Drone

The missions of LOCUST drone swarms differ from their larger counterparts as "a [single drone] would be unlikely… to pose a significant threat to a US F-35 [or other aviation assets], but hundreds of…autonomous drones…may potentially evade and overwhelm an adversary's sophisticated defense capabilities…" (Johnson, 2020). These cheap, low-flying drones are meant to overwhelm enemy weapon systems or serve as a decoy for a more destructive weapon to follow it up, such as an F-35 fighter jet (Smalley, 2015).

3. Methodology

We used the Systems Design Process throughout this project to progress through Problem Definition, Solution Design, and Decision Making (Parnell and Driscoll, 2010). The Solution Implementation phase was not within the scope of this work.

3.1 Problem Definition

To understand the scope of the problem, we conducted a stakeholder analysis through a series of in-person interviews and surveys tailored to each stakeholder. These stakeholders consisted of the project sponsor (MITRE) and Army Futures Command, and their subordinate unit focused on enhancing drone swarm technology (SESU). Our stakeholder analysis indicated that our work should focus on varying swarm compositions and evaluating their effectiveness on defeating enemy air defense assets – effectiveness being measured by the criteria of the window of opportunity (WOO, i.e., enabling follow-on deep-strike assets). In accordance with our stakeholder survey, we defined enemy air defense assets to be any vehicle-mounted anti-aircraft weapons (such as the Russian SA-19 Grison).

With stakeholder approval, we formulated the problem statement and scope as follows:

Problem Statement: To enhance the effectiveness of combat operations, we are analyzing the effects of drone swarm composition on opening a Window of Opportunity (WOO) against enemy air defense systems.

Problem Scope: We will simulate drone swarm missions against doctrinally appropriate air defense assets from a Russian Motorized Rifle Brigade. These missions will utilize drone swarms with the following capabilities: decoy, jamming, and kinetic.

3.2 Solution Design

Our baseline alternative was a swarm composed of 120 drones, whose composition was selected by our stakeholder. These drones were launched in 10 waves of 12 drones each. Each wave composition consisted of 41% kinetic, 17% jamming, and 42% decoy drones. In addition to this baseline alternative, we developed a set of 12 additional alternatives using Zwicky's Morphological Box with variance in size (120, 60, 36) and composition of the swarm (proportions of kinetic, decoy, or jamming; or prioritizing all three equally).

3.3 Decision Making

In addition to the mission success/failure criteria established by our stakeholder (Section 2.1), we used our stakeholder analysis and a visit to a simulation exercise conducted by our stakeholder to create evaluation criteria. These evaluation criteria measured the effectiveness of successful missions against doctrinal, brigade-sized Russian air defense elements (Figure 2). To calculate the weights of these criteria, we used rank weighting. We then used exponential value modeling to formulate the value curves.

Model Value Measures

Evaluation Criteria	Description	Global Weight
Percent of Enemy Assets Incapacitated (%)	The proportion of IAD(s) incapacitated by the drone swarm	0.3958
Percent of Distance Travelled by JTF (%)	The percent of distance to strike target travelled by the JTF before getting shot down	0.3334
Width of Window of Opportunity (km)	The width of the movement corridor that allows Joint Task Force strike assets to take advantage of the window of opportunity	0.2708

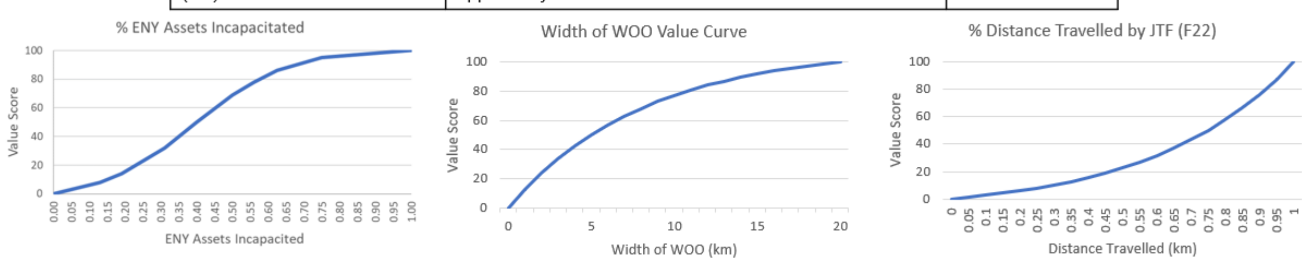

Figure 2: Model Evaluation Criterion Weights and Value Curves

4. Simulation Model

We used Virtual Battlespace 3 (VBS3) as our simulation tool. VBS3 is a virtual training environment that allows users to simulate military operations. It has been widely adopted for use in the United States Army. There, it is primarily used for tactical training exercises (Bohemia Interactive Solutions, 2020).

4.1 Assumptions

We made the followingd assumptions in our work (Table 1), which were supported by our stakeholder survey and simulation exercise visit.

Table 1: Key Simulation Assumptions

	Assumption	Justification
1	Enemy air defense asset locations are known prior to swarm launch.	Our work is focused on the 'engage' phase of the kill-chain process.
2	Individual jamming drone capabilities are: ▪ Range: 3 km ▪ Duration: 2 min ▪ Success rate: 25%	Actual technical specifications are classified. Subject-matter experts, in conversation, have stated these assumptions are functional.
3	Enemy air defense assets require a hit from two kinetic drones in order to be destroyed.	Given the payload of a kinetic drone and the ENY's armor specifications, our stakeholders deemed it necessary for a two-hit 'kill' condition.
4	The drone swarms are not recovered after being launched.	Friendly forces do not possess recovery and refit capabilities in the field.

4.2 Simulation Alternatives

To screen for feasibility, each alternative was tested three times. We defined the screening criteria as a greater than 40% mission success rate. Out of the 12 initial alternatives, five alternatives passed the feasibility screening and are shown in Table 2.

Table 2: Simulation Alternatives that passed feasibility screening

Name	Number of Kinetic Drones per Wave	Number of Jamming Drones per Wave	Number of Decoy Drones per Wave
Baseline	5	2	5
Heavy Kinetic	8	2	2
Heavy Jamming	2	8	2
Heavy Decoy	2	2	8
Equal Split	4	4	4

4.3 Enemy Situation Template

Each drone swarm alternative was simulated against four batteries of four SA-19 Grisons within a pseudo-Eastern European territory packaged with the VBS3 program (Grau, 2017). Each battery was emplaced in a position that offered good observation and fields of fire.

VBS3 is deterministic in nature (i.e., the same initial conditions always give the same result). By changing the spawn location for each run uniformly within a 0.25km radius, however, the simulation results were stochastic.

Drone waves were launched in succession (at 35 second intervals) and programmed to target the closest enemy threat to their current position and according to their individual capability (kinetic, jamming, or decoy). Once all the drones were destroyed or continuously loitering around a target, two F-22 fighter jets were launched upon a pre-determined path to destroy a key target behind enemy lines. The destruction of the target behind enemy lines and the survival of the F-22s resulted in mission success (section 2.1).

5. Results and Analysis

5.1 Results

5.1.1 Findings

The most effective alternative was Equal Split. This alternative resulted in mission success 70% of the time (Figure 3). The Equal Split alternative's performance exceeds the second-best performing alternative (Heavy Kinetic) by 20 percentage points. In addition, the Equal Split alternative has a cost exchange advantage – meaning that using swarms with this composition will do more damage to the enemy per dollar spent on the swarm itself. Additionally, it exhibits less variability in both cost ratio and value score than other alternatives. Consequently, the performance of an Equal Split swarm will be more predictable and mitigate the risk of mission failure.

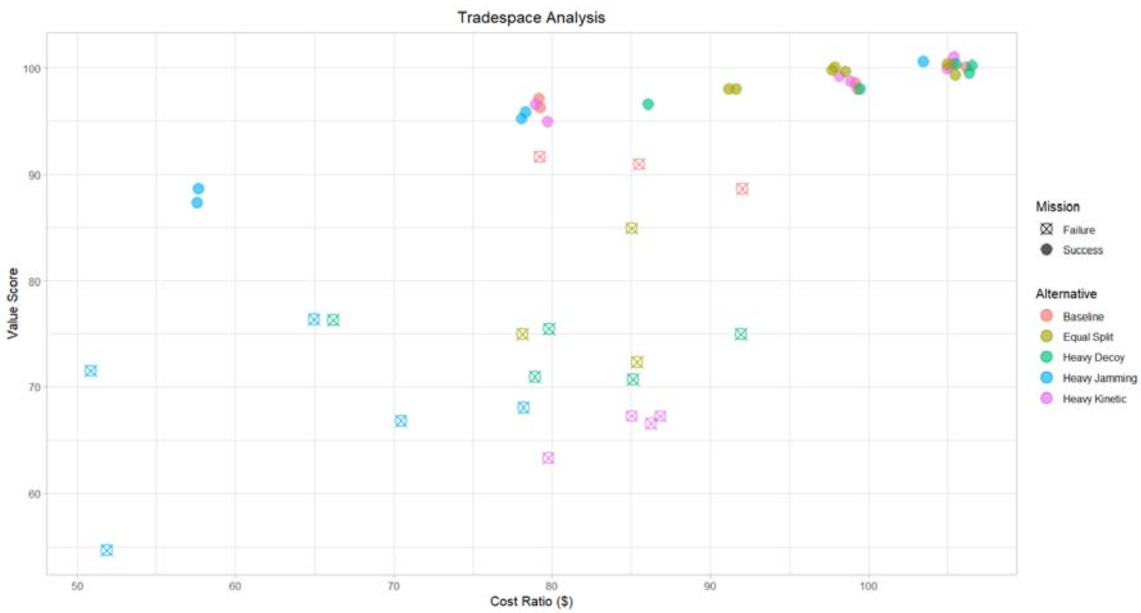

Figure 3: The Cost Ratio vs. Value Score of each iteration of alternative simulation. A failure is defined as one or more F-22s being downed by enemy air defense assets.

5.1.2 Sensitivity Analysis.

Our analysis showed that the value score of the Equal Split alternative is robust to changes in the value scoring weights. There were no alternatives whose value score was higher than Equal Split, even when applying different weighting. The most influential weighting factor was Width of the WOO. When weighted heavily, this criterion brought the value scores of four out of five alternatives to over 90. This sensitivity analysis excluded iterations which did not result in a successful deep-strike mission, as the value scores for unsuccessful missions may skew the alternative averages.

6. Conclusion

Our results showed that drone swarms with an equal proportion of capabilities (kinetic, jamming, and decoy) were the most effective at enabling a follow-on deep-strike mission. The Equal Split alternative was most successful (with a 70% success rate) and exceeded the next closest alternative (Heavy Kinetic) by 20 percentage points. We believe that the presence of all three variants in equal proportion allowed each wave to be robust to losses. In this manner, losing one or two drones would not result in a loss of capability for the wave (kinetic, jamming, or decoy), which would have significantly degraded their survivability “as a wave”. Other alternatives were more susceptible to losing a specific capability and relied upon the presence of future waves to regain that lost capability. Some limitations of our research included the VBS3 simulation software and its ability to generate more complex entity behavior for the swarm, as well as our assumption that each wave would be identical within each alternative. We believe future research should focus on developing simulation models at scale for drone swarms, and explore dynamic wave composition, where successive waves are adapted to the situation on the ground.

7. References

Air Land Sea Application Center (2022). Multi-Service Tactics, Techniques, and Procedures for Dynamic Targeting [Army Techniques Publication (ATP) 3-60.1] Department of the Army. https://armypubs.army.mil/ProductMaps/PubForm/Details.aspx?PUB_ID=1024232.

Bohemia Interactive Solutions. (2020, June). VBS 3 Virtual Desktop Training and Simulation. Bisimulations.com. Retrieved October 25, 2021, from https://bisimulations.com/sites/default/files/data_sheets/bisim_product_flyers_june2020_vbs3.pdf.

Bordes, J. Doody, K. Feeney, J. Hamrock, K. Riechman, C. (2022, April 10). *Fires Support Next.* United States Military Academy.

Congressional Research Service. (2022, November 21). Defense Primer: Army Multi-Domain Operations (MDO).
https://sgp.fas.org/crs/natsec/IF11409.pdf.

Fefferman. K. (Initial Capstone Brief, 2022).

Grau, L. W., & Bartles, C. K. (2017). *The Russian Way of War: Force Structure, Tactics, and Modernization of the Russian Ground Forces.* Foreign Military Studies Office. https://www.armyupress.army.mil/portals/7/hot%20spots/documents/russia/2017-07-the-russian-way-of-war-grau-bartles.pdf.

Johnson, J. (2020, April 16). *Artificial Intelligence, Drone Swarming and Escalation Risks in Future Warfare* Taylor & Francis Online; RSUI Journal. https://www.tandfonline.com/doi/full/10.1080/03071847.2020.1752026?scroll=top&needAccess=true

Parnell, G. S., Driscoll, P. J., & Henderson, D. L. (2011). *Decision making in systems engineering and management*. Wiley.

Smalley, D. (2015, April 14) *LOCUST: Autonomous, swarming UAVs fly into the future | Office of Naval Research*. (2022, March 18). Office of Naval Research. https://www.nre.navy.mil/media-center/news-releases/locust-autonomous-swarming-uavs-fly-future.

Training and Doctrine Command (TRADOC). (2018). The US Army in Multidomain Operations 2028 [TRADOC Pamphlet 525-3-1] Department of the Army. https://adminpubs.tradoc.army.mil/pamphlets/TP525-3-1.pdf.

Yount, D. (2021, July 16). *SOF Swarm: Special Operations Air Assets and Autonomous Systems > Air University (AU) > Wild Blue Yonder*. https://www.airuniversity.af.edu/Wild-Blue-Yonder/Article-Display/Article/2695823/sof-swarm-special-operations-air-assets-and-autonomous-systems/#:~:text=As%20compared%20to%20the%20cost.

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