Optimizing UAS Mission Training Needs Through Tradespace Analysis

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Author Note: Cadets Bearden, Scribbick, West, and Zapcic are seniors at the United States Military Academy. They will commission as Second Lieutenants in the United States Army in May 2017. MAJ Motupalli is an assistant professor in the Department of Systems Engineering and the advisor for this capstone project. The client for this project is the Unmanned Aircraft Systems Project Management Office (PM UAS) located in Huntsville, Alabama.

Abstract: The Gray Eagle unmanned aircraft systems (UAS) training program requires the reallocation of multiple fully operational UAS from the operational environment to facilitate training. The UAS Project Management Office (PM UAS) is concerned that this practice lacks efficiency. This study sought to: (1) conduct a comprehensive analysis for resource optimization with respect to achieving essential training tasks across multiple UAS, (2) conduct comprehensive cost-benefit analysis to assess the value of allocating a full-time and Gray Eagle platforms to accomplish training versus part-task trainers, and (3) define and quantify measures of performance and effectiveness. To achieve these objectives, this study implemented a tradespace analysis methodology to produce a discrete-event simulation model and a resource optimization tool. The impacts of this project will result in substantial cost savings per fiscal year, allow the client to forecast the resource needs of the organization effectively, and allow for the proper allocation of these resources.

Keywords: Unmanned Aircraft Systems, Training Resource Allocation, Optimization, Discrete-Event Simulation, Tradespace Analysis, Design of Experiments, Predictive Analytics

1. Introduction

Since the beginning of the 21st century, unmanned aircraft systems (UAS) have become a major asset for the U.S Department of Defense (DOD), primarily due to the ever-changing and dynamic operations that took place during recent campaigns, such as Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). Before the Global War on Terror, DOD held fewer than fifty UAS; by 2012, however, DOD had rapidly expanded their inventory to over 7,100 UAS (Rostker, et al., 2015). In contrast to manned aircraft, UAS provide a continuous intelligence, surveillance, and reconnaissance (ISR) capability to ground forces at the lowest echelons, while simultaneously mitigating the risk to the operator. Though there are multiple UAS platforms for the Army, this study focused on the Army's MQ-1C Gray Eagle. More specifically, this study examined the training program and resource allocation procedures used to produce repairers of the MQ-1C Gray Eagle and provided recommendations for improvement to the client, PM UAS.

1.1 Problem Definition

The center for UAS training, also referred to as the schoolhouse, currently uses 11 Gray Eagle platforms; however, PM UAS would like to utilize partial tasks trainers (PTT) at the schoolhouse and reallocate the Gray Eagle platforms to the operational Army. The operational force currently has a shortage of Gray Eagles due, in part, to recent operations tempo and maintenance issues. Furthermore, the repetition of training tasks at the schoolhouse causes deterioration of the fully functioning UAS. Moreover, the schoolhouse sometimes struggles to meet their throughput requirements because of resource availability. As illustrated in Figure 1, nearly 10% of the Gray Eagle platforms are at Fort Huachuca for Gray Eagle Training.

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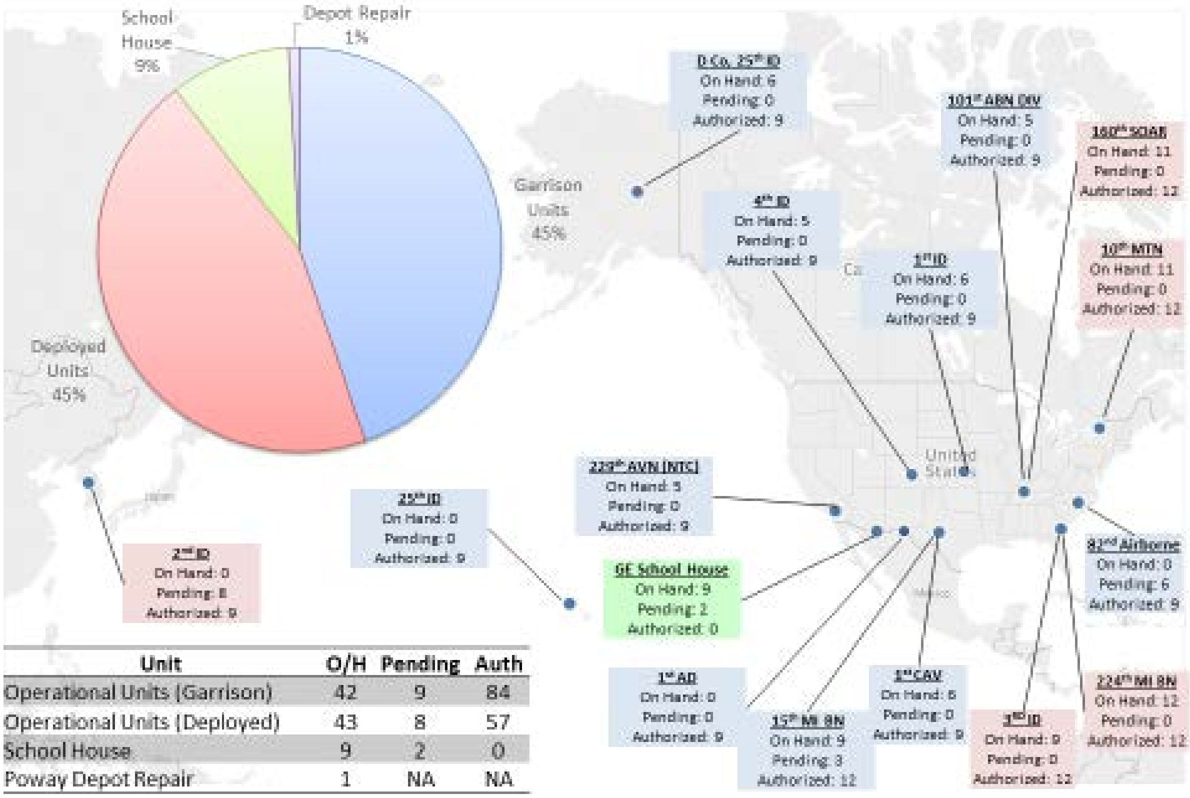

Unit	O/H	Pending	Auth
Operational Units (Garrison)	42	9	84
Operational Units (Deployed)	43	8	57
School House	9	2	0
Poway Depot Repair	1	NA	NA

Figure 1: Distribution of Gray Eagle Platforms

The impacts of this project will result in substantial cost savings per fiscal year, allow the client to forecast the resource needs of the organization effectively, and allow for the proper allocation of these resources. The resulting analysis will lead to redesigning UAS training to minimize the impact on scarce UAS platforms without compromising training effectiveness. The end state of this study was to define and quantify measures of performance and effectiveness and to conduct a comprehensive analysis for resource optimization with respect to achieving essential training tasks across multiple unmanned aircraft system types. Additionally, this study sought to assess the value of allocating a full-time and fully functioning Gray Eagle to accomplish training versus PTT. Finally, this study proposes an optimization tool for PM UAS to conduct future assessments independently.

2. Background

This study began with background research and a comprehensive analysis of the unmanned aircraft-training program at Fort Huachuca, AZ. Currently, 2-13th Aviation Battalion (AVN BN) has the responsibility for the development and administration of multiple programs of instruction, to include the certification of operators and repairers for the Shadow and Gray Eagle Systems. The training program requires the use of multiple fully functional UAS removed from the operational environment. PM UAS is concerned that this practice lacks efficiency and maybe unnecessary to achieve training objectives. As the study progressed, the focus of the research narrowed to the assessment of Gray Eagle repairers specifically.

2.1 Tradespace Analysis

Evaluating a training environment is a unique problem to try to solve due to the multiple variables, the volatility of the variables, and the lack of quantifiable answers. To account for the complexity of this system, this study employed a tradespace analysis technique to assess the effectiveness of Gray Eagle repairer training. Tradespace analysis "balance[s] functional performance, cost, risk, robustness, reliability, interoperability, growth margin, and other life cycle characteristics" (Witus & Bryzik, 2015). This methodology also allows analysts to examine and quantify the interactions of the parameters within a system. In *Tradespace Exploration for the Engineering of Resilient Systems*, Spero, et al. describes tradespace analysis as a methodology to aid stakeholders in identifying potential compromises and reveal opportunities to inform decisions that will have impacts throughout the lifecycle of the system (2014).

2.2 MQ-1C Gray Eagle Overview

The Gray Eagle UAS is a derivative of the Predator UAS platform, which had a high volume of military usage from 1995 to 2009 (Krock, 2002). The Gray Eagle has the capability to carry multiple payloads including but not limited to: Electro-optical/infrared (EO/IR) with laser designation, Synthetic Aperture Rader (SAR), communication relays, and four Hellfire missiles. The mission focus of the Gray Eagle includes "intelligence, surveillance, and reconnaissance (ISR), convoy protection, improvised explosive device (IED) detection and defeat, close air support, communications relay, and weapons delivery missions" (Gray Eagle UAS , 2016).

The United States Army designates the 15E military occupational specialty (MOS) with additional skill identifier U5 as unmanned aircraft repairers for the Gray Eagle, which requires a seventeen-week Advanced Individual Training (AIT) program. During AIT, repairers learn how to properly supervise, inspect, and perform maintenance functions of a UAS to ensure the aircraft are flight and mission ready. The repairs range from electrical and radio frequency to propulsion and mechanical systems. Additionally, the repairers must be able to maintain and repair the ground system of the UAS including the Ground Control Station and the Ground Data Terminal (Career & Jobs: Unmanned Aircraft Systems Repairer (15E), 2015). AIT for the Gray Eagle repairers consists of two administrative modules and three instructional training modules totaling 688 hours: (1) Gray Eagle Overview, (2) Aircraft System Training, and (3) Ground System Training. (602-ASIU5 (15E), 2015).

3. Methodology

Following extensive analysis of the programs of instruction for Gray Eagle repairers, this study focused on applying a tradespace analysis; a combination of "trade-off" and "play space" methodologies. By applying a tradespace analysis framework, this study was able to account for multiple objectives, resources, costs, and stakeholders associated with a complex system. According to Brantley, et al., the tradespace analysis began by setting the program and system parameters, attributes, and characteristics (2002), which enabled the team to establish a feasible region with a broad spectrum of results. In their journal article, Tradespace Exploration for Military Simulations, Hong, et al. classifies the range of results as the potential outcomes that span the system based on the parameters set in the beginning phases of the analysis (2012). Further, Hong, et al. asserts that the spectrum of results reveals a set of solutions for deeper consideration and allows for alternative solutions to the problem.

This study implemented the first part of the methodology by conducting background research and stakeholder analysis to identify the desired objectives and define the appropriate measures of effectiveness. Next, this study conducted further analysis of the system by deconstructing the programs of instruction and consulting subject matter experts from the training program to determine the operational capabilities of the system. The study then integrated the results of the analysis by developing a simulation model. The Integrated Computer Aided Manufacturing Definition (IDEF0) diagram (Figure 1) illustrates the factors that affect the training program, to include the system inputs, pertinent outputs, variables that control the system, and mechanisms that facilitate the functioning of the system.

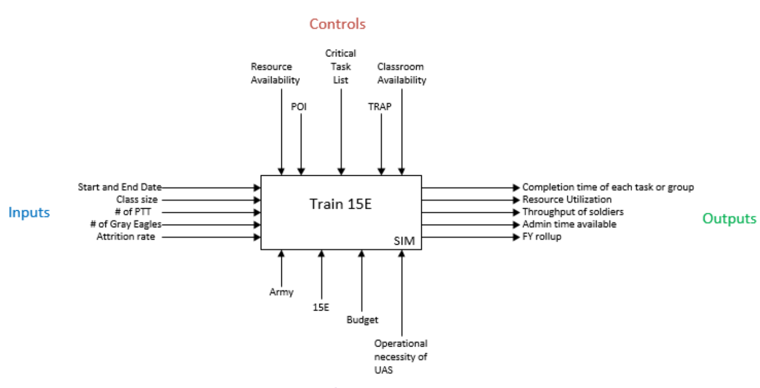

Figure 2. IDEF0 for the Gray Eagle repairers in AIT

Figure 3 illustrates the modeling and processing components for the discrete-event simulation. In the simulation, the soldiers arrive at the in-processing station located in the first column and join with a class. The user inputs, identified earlier by the IDEF0 in Figure 2, are the start date, end date, number of trainees, and estimated attrition rate for each class. The simulation collects the output data identified in the IDEF0, to include completion times, resource utilization, and the throughput of soldiers. Once a cohort of soldiers completes the training program, the simulation collects the total remaining administrative time, which serves to measure the efficiency of a given modeling scenario configuration.

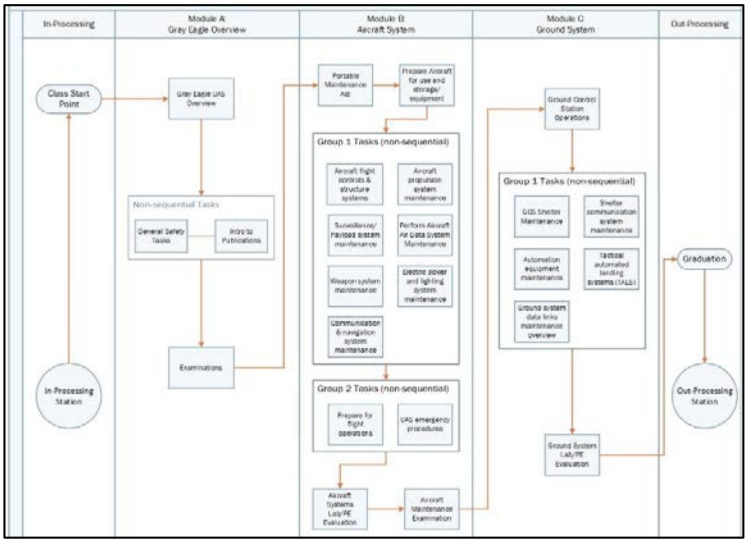

Figure 3. Gray Eagle Repairer Life Cycle at AIT

To account for the various resource configurations, this study integrated a statistical design of experiments (DOE) methodology into the simulation to identify the effects of resource allocation on the system outputs. For the DOE, this study implemented a $5^1 11^2$ full factorial design (Table 1) with the number of instructors available implemented at four levels, and the number of aircraft and partial task trainers available applied at 11 levels each. The number of aircraft systems dictated the number of ground control stations (GCS) available for a given scenario. Availability of all other resource factors, such as computers, ground crews, and test equipment remained constant based on user input. The full factorial design resulted in 605 scenarios. Next, the analysis team identified and removed all infeasible scenarios, which were scenarios that resulted in less than five combined partial task trainers and aircraft. The final design resulted in 530 scenarios for output data analysis. A simple linear regression analysis of the DOE outputs led to the development of a predictive model to forecast a given output, such as successful trainee throughput, based on resource availability. The predictive models will form the basis of objective functions for an optimization tool.

Table 1. $5^1 11^2$ Full Factorial Design of Experiments Framework

Input Factor (Resources)	*Type*	*Number of Levels*	*Description of Levels*
# Gray Eagle Aircraft	Integer	11	0 – 10
# PTT	Integer	11	0 – 10
# Instructors	Integer	5	10, 20, 30, 40, 50

This study used seven months of maintenance data from to incorporate resource non-availability of aircraft platforms, ground control stations, and ground data terminals into the discrete event simulation by fitting distributions Mean Time between Failure (MTBF) and Mean Time to Repair. The MTBF is the average time the resource is available before a breakdown, while the MTTR is the average time the resource takes to repair. The research team modeled non-availability of instructors by scraping a document provided by the 2-13th AVN BN that outlines the administrative instructor actions required for each lesson in the program of instruction. The research team determined the distributions of Mean Time between Non-availability (MTBN) and the Mean Time to become Available (MTTA). The MTBN is the average amount of time the instructor is available to

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students before needing to conduct an administrative action, while the MTTA is the average amount of time that instructors must spend conducting administrative actions. Table 2 outlines the equations (1 – 4) and distributions pertinent to incorporating resource non-availability.

Table 2. Resource Non-Availability Information

Measure	*Equation*		*Resource*	*Distribution*
Mean Time Between Failures (MTBF)	$MTBF = \frac{Total\ FMC\ Time}{\#\ of Breakdowns}$	(1)	Aircraft GCS / GDT	Power Function Triangular
Mean Time To Repair (MTTR)	$MTTR = \frac{Total\ NMC\ Time}{\#\ of Breakdowns}$	(2)	Aircraft GCS / GDT	Lognormal Triangular
Mean Time Between Non-availability (MTBN)	$MTBN = \frac{Total\ Instruction\ Time}{\#\ of\ Admin\ Tasks}$	(3)	Instructor	Chi-Squared
Mean Time To become Available (MTTA)	$MTTA = \frac{Total\ Admin\ Time}{\#\ of\ Admin\ Tasks}$	(4)	Instructor	LogLogistic

4. Results and Analysis

4.1 Throughput Analysis

A regression analysis of the simulation model outputs resulted in a predictive model for the percentage of Soldier throughput based on the availability of aircraft, partial task trainers, instructors, and the soldier throughput quota. In equation (5), T_j represents the percentage of soldier throughput for fiscal year j, and x_{ij} represents the four predictor variables outlined in Table 3.

$$T_j = -29.266 + 0.202x_{aircraft_j} - 0.027x_{PTT_j} + 2.770x_{Inst_j} + 0.186x_{Quota_j} - 0.015x_{Instr_j} * x_{Quota_j} \quad (5)$$

Table 3. Variable Descriptions and t-test p-value

Predictor Variable	*Description*	$P - value$
$x_{aircraft_j}$	Number aircraft available	0.405
x_{PTT_j}	Number PTT available	0.908
x_{Inst_j}	Number Instructors available	< 2e-16
x_{Quota_j}	FY Quota	2.86e-05
$x_{Instr_j} * x_{Quota_j}$	Instructor*FY Quota	< 2e-16

Based on the results of the regression analysis in Table 3 and using a 95% confidence level, the availability of aircraft and partial task trainers are not significant predictors for a successful throughput percentage. Conversely, the availability of instructors and the Fiscal Year Quota are significant predictors, to include a significant interaction effect. The Analysis of Variance (ANOVA) returned an F-statistic of 200.8 and a p-value of < 2e-16, indicating the model is significant with respect to predicting throughput of trained Gray Eagle Repairers based on resource availability and fiscal year quota. The simulation model incorporates a substantial amount of variability with respect to resource availability, which accounts for the 0.5829 R^2 and 0.5809 adjusted R^2 values. However, the R^2 and Adjusted R^2 values are similar, indicating the model does not include excessive variables.

4.2 Resource Utilization Analysis

As illustrated in Figure 4, spikes in utilization of partial task trainers correspond with significant decreases in utilization of aircraft. On average, each additional partial task trainer decreases aircraft utilization by 0.18%. Conversely, each additional aircraft only leads to a 0.02% decrease in aircraft utilization.

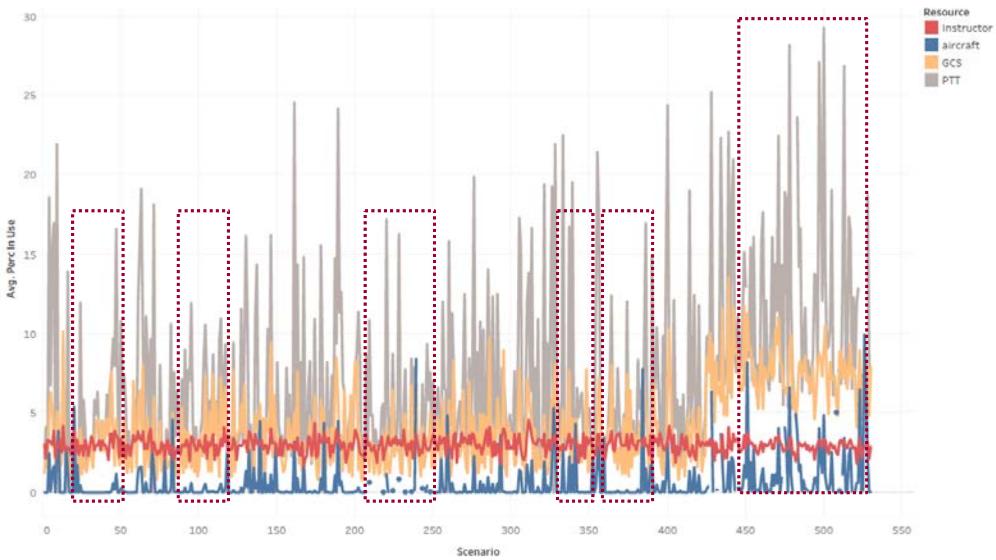

Figure 4: Average Resource Utilization by Scenario

5. Conclusion and Future Work

In the future, the study will apply the tradespace analysis methodology to other UAS training programs at Ft. Huachuca, to include the Gray Eagle operator-training program as well as the operator and repairer training programs for the Shadow UAS. Replacing aircraft with partial task trainers at the schoolhouse will result in substantial cost savings per fiscal year, allow PM UAS to effectively forecast resource needs, and allow for the proper allocation of these resources while minimizing the impact on the successful throughput of trained Gray Eagle repairers. Furthermore, incorporating partial task trainers will fill critical shortages of aircraft systems in the operation force.

6. Acknowledgement

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