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Optimizing UAS Mission Training Resource Allocation through Modeling and Cost Analysis

Christian Hess, James Kubisch, Jasmine Motupalli, Said Outlaw, and Anthony Williams

United States Military Academy, West Point, NY 10996, USA

Corresponding author's Email: christian.hess@usma.edu

Author Note: Cadets Hess, Kubisch, Outlaw, and Williams are seniors at the United States Military Academy. They will commission as Second Lieutenants in the United States Army in May of 2018. 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. The research team would like to thank Mr. Ken Davis, from the ProModel Corporation, who helped significantly with developing the discrete-event simulation model.

Abstract: A 2017 study of the Gray Eagle Unmanned Aircraft System (UAS), conducted by Bearden et al., found that there are inefficiencies concerning the use of operational UAS within the maintenance training program (2017). The current program uses operational aircraft to certify Soldiers in maintenance tasks, while the operational Army suffers from a shortage of Gray Eagle platforms. This research built upon the findings of a previous study to assess the feasibility of entirely replacing aircraft with partial-task trainers (PTTs) for maintenance task certification. Further, this study conducted a comprehensive assessment using discrete-event simulation and cost estimation, which resulted in a decision support tool for the UAS Project Management Office (PM UAS). This project will enable stakeholders to reduce current training program costs, increase the number of Gray Eagles in the operational Army while maintaining an adequate training throughput, and predict the optimal resource allocation given mission training needs.

Keywords: Discrete-event Simulation, Optimization, Unmanned Aircraft System, Cost Analysis, Resource Allocation

1. Introduction

The Gray Eagle maintainer's Advanced Individual Training (AIT) program requires the reallocation of multiple fully operational unmanned aircraft systems (UAS). The UAS Project Management Office (PM UAS) believes that investing in partial-task trainers (PTTs) will reduce the number of Gray Eagles taken from the operational Army without sacrificing achievement of critical training objectives. This study sought to build on research performed in fiscal year (FY) 17 by conducting a comprehensive assessment on the feasibility, costs, and benefits of replacing Gray Eagle aircraft with PTTs in the training program. Specifically, this study refined a discrete-event simulation model and produced a decision support tool for future assessments.

2. Background

The Army's MQ1-C Gray Eagle is currently the Army's primary Unmanned Aircraft System (UAS). The US Army contracted Lockheed Missiles and Space Company (LMSC) to develop unmanned aircraft in 1975 (Blom, 2010). UAS have exponentially grown in the 21st century (Blom, 2010). The Department of Defense's (DOD) budget for UAS in 2000 was only $284 million; however, by 2010 the budget had increased to $6.1 billion (Rostker, et al., 2015). The growing demand for Gray Eagles required an increase for personnel to repair Gray Eagles, resulting in the creation of 15E military occupational specialty (MOS). The refined Gray Eagle maintenance training program is illustrated in Figure 1.

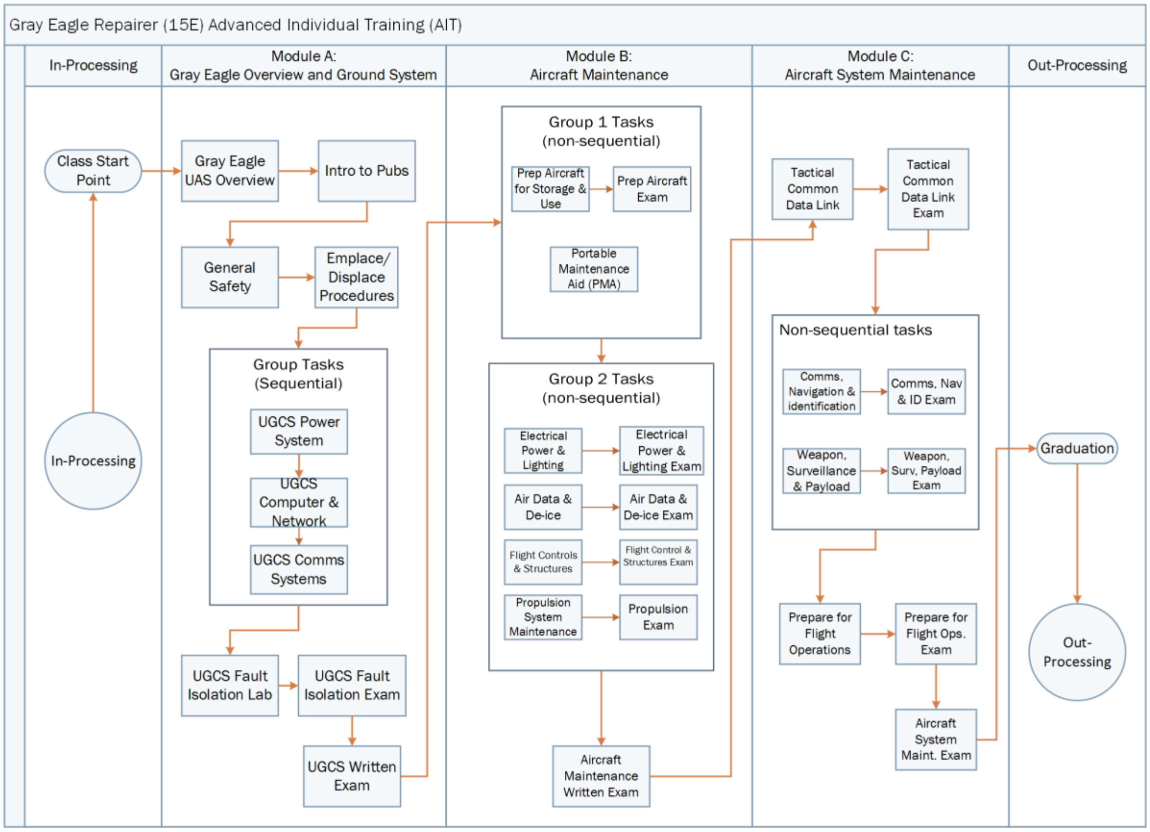

Figure 1. Gray Eagle Maintenance Training Program

3. Literature Review

A literature review and background research are provided in the following section to further clarify certain components of this study that are not intuitive. The topics included in this review are Discrete Event Simulation (DES), Multiple Unified Simulation Environment (MUSE), and Partial-task Trainers (PTTs). This study produced a model using discrete event simulation logic to model the Gray Eagle Training Program. MUSE is a simulation program that is prevalent in the Maintenance Training Program, which presented a key constraint for this study. PTTs have the potential to replace operational aircraft in the maintenance training program with minimal impact on critical training requirements.

3.1 Discrete-Event Simulation

The Gray Eagle Maintenance Training Program was modeled by Bearden, et al. using discrete event simulation (DES). Analysts commonly use this method to model and evaluate complex systems. Specifically, DES is a technique used for the study of systems, whose state changes at discrete points in time (Liu, 2014). The significant advantages of DES are that it allows for the estimation of system performance under different operating conditions, it is cost-effective, safe, and can address stochastic system behaviors (Liu, 2014). The Department of Human Factors and Systems at Embry Riddle Aeronautical University used DES to determine the optimal resource allocation for their flight training program. The Embry Riddle team changed the resource allocations within their simulation to create different scenarios for their DES to simulate; this allowed the team at Embry Riddle to use statistical methods to evaluate the system. Similarly, this study used discrete event simulation to model and conduct analysis on the Gray Eagle Maintenance Trainer Program (Liu, 2014).

Bearden et al. developed a discrete-event simulation model of the Gray Eagle Maintenance Training Program. The study conducted a regression analysis to predict the successful throughput of soldiers through the program using the availability of resources as the predictor variables. This analysis revealed the following: (1) availability of aircraft and PTTs were not

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statistically significant to meeting throughput requirements, (2) the instructor to student ratio was statistically significant to meeting throughput requirements, and (3) PTTs were statistically more efficient with regards to resource utilization percentage of aircraft.

3.2 Multiple Unified Simulation Environment (MUSE)

The multiple unified simulation environment (MUSE) is the most common unmanned aircraft system (UAS) trainer for the Department of Defense and United States Army. The Joint Technology Center/Systems Integration Lab (JSIL) developed the system and has sold over 2,500 licenses across the Department of Defense (DoD) (Meta VR, 2016). This simulator was added to the training of the MQ-1C Gray Eagle and the RQ-7 Shadow UAS pilots as a cost-effective system for modeling and simulating the capabilities of the UAS in a notional training/operational environment. The MUSE works with the Virtual Reality Scene Generator (VRSG) and the UAS's Universal Ground Control System (UGCS) to receive entity data from distributed interactive simulations (DIS) to augment the GCS to believe that it is networked to a UAS that is actually flying, when in reality it is only simulated (Meta VR, 2016). The important aspect of the MUSE is it does not allow the Partial Task Trainers (PTTs) to work independently without the Gray Eagle.

3.3 Partial-task Trainers (PTTs)

According to a study conducted by Jack A. Adams and Lyle E. Hufford, dynamic flight simulators can provide aircraft whole-task practice for aerial training (1962). Commercial companies and the US military use task trainers to qualify their employees for flight. The Gray Eagle training program uses four types of task trainers: Remove & Replace (R&R), Virtual Training System (VTS), Avionics, Armaments, and & Electrical (AAE), and Engine Partial Task Trainer (EPTT). The Gray Eagle VTS is software that trainees use to study simple maintenance tasks, while the R&R is used for tasks that require hands-on practice without fault isolation. The AAE allows students to train on fault isolation and repair of the aircraft system and the EPTT facilitates soldier training on engine and propulsion tasks. Adams and Hufford concluded, "[f]light simulators are costly to build and use, but they still have training costs far less than aircraft and are justified by their capabilities for training pilots" (1962). The capabilities of task trainers extend beyond their ability to train; task trainers and simulators have the advantage of teaching responses such as emergency procedures that raise safety concerns if taught in the air. Another positive characteristic associated with simulators is their independence of inclement weather. Lastly, task trainers enable people to maintain proficiency in all necessary skills (Adams & Hufford, 1962). In summary, task trainers are more cost-effective than aircraft, allow for training on hazardous tasks, are independent of weather conditions, and create opportunities for people to maintain proficient skill levels.

4. Methodology

This study began with background research and stakeholder analysis to identify the desired objectives and defining the appropriate measures of effectiveness. The results of this phase identified a need to refine the simulation model to assess deficits. The research team modified the simulation to include the four specific categories of PTTs and significantly reduced the number of scenarios from 530 to 81. Further, the simulation logic was updated to reflect more realistic processes for resource gathering and routing logic. Data from the PM UAS staff enabled the research team to perform a cost estimation for each scenario. This study conducted a regression analysis of the simulation output data, which predicts the successful throughput percentage for a given fiscal year based on resource availability and throughput quota. This study used the consolidated results of this analysis to develop a decision support tool (DST) for future assessments. The DST is a web-based application that offers the user prediction tools and visual aids for key statistics, such as soldier throughput, cost analysis, and resource utilization.

4.1 Stakeholder Analysis and Refining the Simulation

This study began by conducting stakeholder analysis with various subject matter experts and extensive examination of the simulation model produced by the Bearden study. The initial assessment found that the current Gray Eagle maintenance PTT capability does not meet all requirements to support a full transition from operational aircraft. Specifically, the current PTT capability does not support the integration of ground system tasks. Additionally, the assessment discovered that the current partial-task trainers use tactical software rather than fully simulated software, which would be expensive to replace. This study refined the Bearden et al. simulation model by incorporating the four specific types of PTTs and reducing the number of scenarios from 530 to 81. The reduction in scenarios allowed for the addition of multiple replicates to assess variability.

Table 1. 3^4 Design of Experiments Framework

Input Factor (Resources)	*Type*	*Number of Levels*	*Description of Levels*	*Number on-hand for training (real-world)*
# AAE	Integer	3	2, 4, 6	1
# EPTT	Integer	3	2, 4, 6	5
# R&R	Integer	3	1, 2, 3	1
# Instructors	Integer	3	25, 50, 75	Varies
All other resources	Integer	1	Based on user input	Varies

4.2 Simulation Logic

The way that resources are gathered is key to understanding how the simulation pushes classes of soldiers through the simulated Gray Eagle Training Program. There are twenty-three distinct resources, categorized by facilities, personnel, and equipment. Reference Figure 2 for the resource acquisition process. If a simulated lesson does not have the required resources, it waits one hour for resources to become available before allowing soldiers to enter the class. This is a change from the last study, in which the class would continue to search for resources until finding the necessary resources. The previous process for resource gathering was inefficient with computer memory and the amount of time needed for the simulation run. The addition of this step resulted in a decrease of more than 60% in simulation run time. Furthermore, modules include non-sequential tasks, which allow classes to complete alternative tasks without having to be in any specific order. This means that soldiers can move on to a different portion of training until the necessary resources become available.

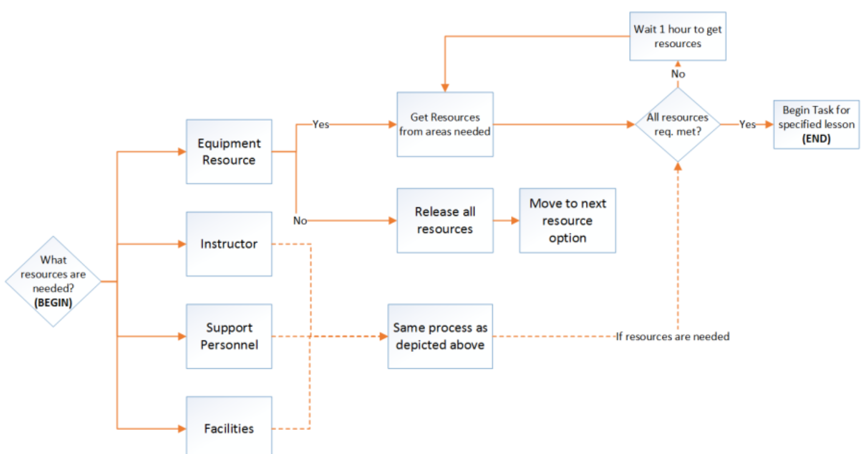

Figure 2. Simulation logic for general resource gathering

Additionally, the simulation incorporates feasible equipment substitutions for aircraft tasks within the program of instruction and assigns priorities for resource gathering accordingly. If all of the resources required for the task are not available, then the simulation will move on to the next non-sequential task and conduct the same process for finding the resources available to match the task resource standard. If all resources are in-use at the time a new class of soldiers comes through, then the soldiers wait in a queue until the resources become available.

4.3 Cost Estimation

The goal of this study was to find the optimal allocation of training resources to meet mission requirements while graduating the requisite number of students for each year. The research team developed a model to estimate the costs of the 81 scenarios and identify the most cost-effective alternatives. Equation (1) displays the cost estimation equation. C_i represents the cost to procure partial-task trainer i, $R_{Aircraft}$ represents the cost to repair an individual aircraft. The procurement and repair costs, obtained from the PM UAS costing team, are proprietary information and not published in this article (PM UAS Cost Team, 2017).

$$Total\ Cost = C_{AAE} * Max(X_{AAE} - 1, 0) + C_{EPTT} * Max(X_{EPTT} - 5, 0) + C_{R\&R} * Max(X_{R\&R} - 1, 0) + R_{Aircraft} * (6 - X_{MaxAC}) \quad (1)$$

5. Results and Analysis

The cost analysis on three replications of 81 scenarios resulted in the identification of six cost-effective scenarios, which cost an estimated $19,150,000 each. Table 2 contains the consolidated list of cost-effective scenarios. This analysis did not include the cost of employing instructors because the number of instructors is traditionally based on an instructor-to-student ratio to achieve the required soldier throughput for a given fiscal year. The results indicate that allocating two AAE PTTs and one R&R PTT are the least costly options. In general, the results of the cost analysis suggest that the least costly alternatives are those that minimize the need for fully operational aircraft systems.

Table 2. The most cost-effective resource allocation scenarios

Scenario Number	*AAE*	*EPTT*	*R&R*	*Instructor*
20	2	4	1	50
28	2	2	1	75
64	2	2	1	25
65	2	4	1	25
75	2	4	1	75
76	2	2	1	50

A regression analysis of the preliminary simulation model outputs resulted in a predictive model for the successful Soldier throughput based on the availability of R&R, AAE, EPTT, soldier throughput quota, and instructors. In equation (2), T_j represents the soldier throughput for fiscal year j, and x_{ij} represents the values of the five predictor variables outlined in Table 3.

$$T_j = -13.40 + 1.39x_{R\&R_j} + 0.22x_{AAE_j} + 0.22x_{Quota_j} + 0.05x_{Instr_j} \tag{2}$$

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

Predictor Variable	*Description*	$P - value$
$x_{R\&R_j}$	Number R&R available	< 2e-16
x_{AAE_j}	Number AAE available	0.00103
x_{EPTT_j}	Number EPTT available	1.0000
x_{Quota_j}	FY Quota	< 2e-16
x_{Instr_j}	Instructor	< 2e-16

Based on the emerging results of the regression analysis in Table 3 and using a 95% confidence level, the availability of the EPTT is not a significant predictor of a successful throughput percentage. Conversely, the availability of R&R, instructors, and Fiscal Year Quota are significant predictors. The Analysis of Variance (ANOVA) returned an F-statistic of 367.3 and a p-value of < 2.2e-16, indicating the model is significant in predicting throughput of trained Gray Eagle Repairers based on resource availability and fiscal year quota. The simulation model incorporates a substantial amount of variability concerning resource availability, which accounts for the 0.39 R^2 and 0.39 adjusted R^2 values. However, the R^2 and Adjusted R^2 values are similar, indicating the model does not include excessive variables. The low R^2 values are attributable to the randomness inherently in the model. Specifically, the Bearden study used random variates to mimic the non-availability of resources. Furthermore, the simulation logic, described in section 3 of this paper, aims to model real-world behavior for how the classes choose to flow through the system.

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6. Conclusions, Recommendations, and Future Work

Emerging results suggest replacing aircraft with PTT will result in substantial cost savings and return critical platforms to the operational force. The impacts of this study will allow PM UAS to effectively forecast resource needs and allow cost-effective allocation of critical resources across the Army. This study found that the current Gray Eagle partial-task training capability does not meet all mission training requirements, and therefore cannot entirely replace operational aircraft in the maintenance training program. To fully replace all aircraft with partial-task trainers, PM UAS would need to develop a PTT that supported ground system maintenance tasks. Specifically, this would require the development of a partial-task trainer with the capability to interface with the ground control station and ground data terminal.

Based on the PTT technology currently available and the cost estimation results, the research team recommends that the Gray Eagle Maintenance Trainer incorporate a total of two Armament, Avionics, and Electrical (AAE) PTTs, one Remove and Replace (R&R) PTT, and continue to base the instructor allotment on the 15E throughput quota for a given fiscal year. Further, the team recommends no change to the current allocation of engine partial-task trainers, given that the regression analysis indicated the allocation was not significant. Emerging results suggest that configurations that limit the number of aircraft systems necessary will be the most beneficial and the AAE PTT satisfies the greatest number of critical training tasks.

Further work must be done to improve the preliminary discrete event simulation to more accurately reflect the nuances of the Gray Eagle maintenance training program. Specifically, this study will refine the resource priority and resource gathering logic to more accurately mimic the real-world logic used by entities within the training program. Possibilities for the future application of this research include adapting this research methodology to similar Army programs, such as the Shadow UAS maintenance training program, to improve efficiency and cut down costs. Additionally, exploring the possibility of creating a PTT equivalent for the GCS has profound implications for the Gray Eagle Maintenance Training Program and the legitimacy of eliminating the need for fully-functioning Gray Eagle Aircraft in the Maintenance Training Program. Finally, the current PTTs use tactical software, which is inefficient and difficult to manipulate. The use of simulated software for future Gray Eagle maintenance training tasks has the potential to address redundancies and inefficiencies. The impacts of this study will allow PM UAS to identify resource deficits, estimate alternative costs, and predict the optimal resource allocation while meeting mission training needs.

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