Abstract - Army Aviation utilizes two distinct types of overhaul maintenance schedules on its rotary wing aircraft, Phase Maintenance and Progressive Phase Maintenance. All but one aircraft, the OH-58D Kiowa Warrior, use Phase Maintenance. This aircraft has both the highest operational readiness rate and average flight hours in the Army’s rotary wing fleet. The Army values uniformity in maintenance procedures across its fleets; however this inconsistency has existed for two decades. This study models the value and tradeoffs of one method versus the other using discrete event simulation. Progressive Phase Maintenance offers more efficiency in terms of time available for missions and may be applicable other airframes. Using the airframe specific Aeronautical Equipment Maintenance Management Policies and Procedures Training Manual and a operational data set from a deployed aviation unit, this study compares the two overhaul maintenance schedules in terms of operational readiness. The effectiveness of each method is measured in the amount of time each airframe is for missions.

INTRODUCTION
Perhaps one of the most crucial missions of the United States Army is equipment maintenance, and its aircraft are no exception. Army Aviation “provide[s] combat support and combat service support” through “coordinated operations as an integral member of the combine arms team” [1]. Supporting operations requires high levels of readiness enabled by aircraft maintenance.

The Army uses a wide variety of aircraft, most of which are built on four common airframes with varying levels of retrofitting. Each aircraft has a distinct mission set.

AH-64D: a twin engine aircraft that conducts distributed operations; precision strikes against re-locatable targets; armed helicopter reconnaissance, and security when required in day, night, obscured battlefield, and adverse weather conditions [2].

The CH-47D/F: a tandem rotor, twin engine aircraft that transports personnel, internal cargo, and equipment under VMC and IMC conditions. It also performs external transport of cargo and equipment, including aircraft recovery [2].

The UH-60A/L/M: a twin engine aircraft that transports personnel, cargo, and equipment; performs command and control; performs medical evacuation, and air ambulance service under VMC and IMC conditions [2].

HH-60L/M: a twin engine aircraft responsible for conducting medical evacuation and air ambulance under visual meteorological conditions (VMC) and instrument meteorological conditions (IMC) while providing increased situational and battlefield awareness [2].

The OH-58D: a single engine aircraft that conducts day and night reconnaissance and light attack as well as provides armed helicopter escort in combat zones [2].

The OH-58D Kiowa Warrior leads the Army’s fleet in operations readiness at approximately 85% of its aircraft [3]. In recent conflicts, the Kiowa Warrior also boasts the most flight hours at an average of 85hrs/aircraft/month [3]. The Kiowa Warrior is used as an armed reconnaissance helicopter to provide air observation and light ground troop support. The OH-58D is unique in several ways, in particular its maintenance schedule. It utilizes Progressive Phase Maintenance (PPM) opposed to Phase Maintenance (PM); presumably because of its variable uses and single engine. The question then must be asked, why don’t all aircraft uses Progressive Phase Maintenance if its most employed aircraft yields the highest operational readiness rate?

This study narrows its focus down to two aircraft: the OH-58D and the UH-60M. The OH-58D is the obvious choice to represent Progressive Phase Maintenance; however, in the study the UH-60M serves as the representative airframe for Phase Maintenance.

BACKGROUND
The Army uses three types of maintenance that effect the aircraft’s flexibility and usage: Progressive Phase Maintenance, Phase Maintenance and Combat Phase Maintenance. In order to determine why all aircraft don’t use the same maintenance, the differences in maintenance types must be determined.

I. Progressive Phase Maintenance (PPM)

Progressive Phase Maintenance is a scheduled maintenance system that consolidates and replaces daily, phase, and special inspections. Its purpose is to minimize inspection requirements for increased mission flexibility and aircraft availability. Aircraft checklist inspection requirements are distributed into equalized checklist
sections, which together constitute a complete PPM cycle. Specifics of checklist use, completion, and disposition are in the applicable aircraft maintenance training manuals. An automated aircraft maintenance management system complements the effectiveness of PPM [4].

Part 1 is the Inspection Checklist. A series of progressive inspection checklists are sequentially numbered and must be performed in sequence [5]. Inspections are due after an appointed number of flying hours or are due at the same time regardless of whether or not the previous inspection was performed early or late [5]. This is determined at the start of the progressive inspection cycle. The aircraft is typically not taken out of service, but allowed to continue with the inspection checklist when available [5]. This means the checklist requirements can be performed all at once or in pieces. Only if the aircraft does not complete the checklist before the next checklist begins, is it not operationally ready. This offers much more flexibility compared to Phase Maintenance because you only commit the aircraft to a small break down of parts at a time of your choosing.

Part 2 is the Preventative Maintenance Service. The PPM-PMS checklist both reduces the overall size of the PPM manual by listing items that are common, but also requires that the aircraft be inspected at regular intervals.

II. Phase Maintenance (PM)

Part 1 of Phase Maintenance is the Phase Maintenance Inspection. The PM inspection is a thorough inspection, which includes partial disassembly of the aircraft. Each phase inspection is a part of a total phase cycle, and each phase maintenance inspection cycle is a major scheduled maintenance service. During each PM cycle, all parts and systems of the aircraft requiring evaluation are inspected at least once. This is a complete tear down of the aircraft and all parts are removed from the airframe. This involves a huge commitment of the aircraft to the maintenance unit. Once the aircraft enters this inspection, it is impossible to use it for a mission until it is complete. When all numbered phase inspections are done a cycle is completed and the sequence is repeated [4].

Part 2 is the Preventative Maintenance Daily/Preventative Maintenance Service. The PMD is a daily inspection, which ensures continued safe operation of aircraft through visual and operational checks. The crew chief makes the inspection after the last flight of the mission day or before the first flight of the next mission day [8]. A PMS inspection is similar to a PMD inspection. Instead of being due after the last flight of the mission day, this inspection is due when a specified number of flight hours or calendar days elapses [4].

III. Combat Phase Maintenance or Combat Periodic Inspection (CPM)

During combat operations, the unit commander has the option of completing a CPM or CPE inspection instead of a standard PM/PE inspection. The combat phase maintenance inspection requirements are considered the minimum requirements to ensure continued safe combat operation [4]. However, CPM is rarely used, if ever. It is considered a last resort option because an aircraft is needed immediately. This event is made even rarer due to the large budget and high availability of parts and service to aircraft in combat.

Both the UH-60M and OH-58D have Maintenance Allocation Charts. These charts assign certain maintenance functions to respective levels of Maintenance based on historical data that indicated their intensity [6]. Often times, the average time to complete the maintenance function will be listed as well. This chart provides two key pieces of information: the expected service time and server required to perform the function.

The Army uses three levels of maintenance depending on the needs of repair, inspection and retrofit: Aviation Unit Maintenance, Aviation Intermediate Maintenance and Depot level maintenance. Understanding what services require certain levels of maintenance is important to determining why all Army aircraft don’t use the same type of maintenance. Aviation Unit Maintenance (AVUM) is at the platoon or company level. This level of maintenance is limited in its capabilities, but provides quick turnaround through the repair, replacement, adjustment, cleaning, lubricating and serving of aircraft [4]. AVUM is conducted by crew chiefs that perform daily servicing and inspections. This typically consists of remove-and–replace-type parts [4]. Aviation Intermediate Maintenance (AVIM) provides intermediate and limited backup AVUM support [4]. AVIMs are either divisional or non-divisional [4]. This is usually either a company or battalion. Depot level maintenance provides the ability to overhaul, repair, modify, retrofit, and modernize aircraft systems [4]. This takes place at Corpus Christi Army Depot, and provides worldwide support through maintenance support teams [4]. They are also responsible for design and development of aircraft.

The Army uses several designations to mark which status of readiness their equipment is in. There are two main designations: Mission Capable and Non Mission Capable. Mission Capable (MC) is when a piece of equipment is either Fully Mission Capable or Partially Mission Capable [2]. Non Mission Capable (NMC) is when a piece of equipment is not capable of performing its designed mission [2]. Mission Capable can be divided into two categories: Fully Mission Capable or Partially Mission Capable. Fully Mission Capable (FMC) is when a piece of equipment is fully operationally, safe and configured properly [6]. Partially Mission Capable (PMC) is when a piece of equipment can perfume one or more, but not all of its designed mission tasks [2]. Both PMC and NMC can be a result of supply or maintenance issues (PMCS, PMCM, NMCS and NMCM) [2].
FIGURE I
AIRCRAFT READINESS

The Army sets its readiness goals as FMC equals 75%, MC equals 80%, NMCS equals 10%, NMCM equals 10% and PMC equals 5%, where FMC, PMCS, PMCM, NMCS and NMCM must sum to equal 1 [2].

Aircraft maintenance can be modeled as a queue. Queuing theory is the science of lines. Entities, in this case aircraft, arrive and wait in a queue to be serviced. They are then processed through a server, and depart fully serviced. The population for aircraft is called the calling population [7]. They can be processed through several different queuing disciplines: first-in, first-out; last-in, first-out; priority; and others [7]. Queuing systems may also have capacities but don’t have to. For instance, you may only be able to fit so many aircraft in a hangar for servicing.

Several characteristics of the queue must be known to determine performance measure of the system: the arrival rate (λ) and the service rate (μ) [7]. Additionally, the mean inter-arrival time is 1/λ, the mean service time is 1/μ, and the traffic intensity factor (ρ) is λ/μ [7]. Queues can be modeled using these measures if the queue fits any of the closed form solutions common in the study of queuing. However, most real life queues such as the one in this study do not fall into any of these solutions and must use simulations to gather statistics from. Any system containing a queue can be modeled using a general understanding of the systems structure, the inter-arrival rate and the service rate.

APPROACH

In order to model both types of maintenance overhaul methods, this study uses a discrete event simulator called ProModel. Discrete event simulation was chosen because changes to the aircraft’s status occur at discrete moments and do not morph into one status from the other.

I. Assumptions, Constraints, and Data

Several assumptions needed to be made in order to create this model. First, the time it takes to travel from one location to the other is instantaneous. Although not true in the real world, there is no data that could represent this. It could be assumed that the travel time on the runway could be included in the time it takes to service an aircraft. The second assumption is that the time spent on the runway is negligible as well, and that the aircraft moves to the runway just to be queued for the mission.

This simulation uses fixed random streams to generate the random samples. An important facet of this model was determining the amount of time an aircraft would spend either receiving maintenance or waiting on supply. In order to do this, real deployment data was used. This data set contained real deployment data from 10th Combat Aviation Brigade which included the number of aircraft, the total amount of hours flown by those aircraft, and the hours broken down by aircraft status. Data sets for the months of May through September were used. For each month’s data, the average amount of time spent by each aircraft conducting either supply or maintenance per day was calculated. From this, the overall average of the average time and standard deviations were calculated. Since this study only had a sample size of 5, creating a distribution from the data was not possible. Instead, it was assumed that a normal distribution would be used.

In order to represent the amount of time an aircraft would spend flying a mission; this study uses the hours flown per day per aircraft. These estimates also came from the combat data provided by 10th Combat Aviation Brigade.

The model was run over a time span of 24 hours, one day. This was done because the deployment data was broken down into month long spans and only a per diem service time could be derived. The simulation was then run a total of 30 times, to represent a month’s worth of maintenance.

II. Modeling Structure

The conceptual model has the following components: locations, entities, arrivals and processing/routing. It reflects the common practice used to create a discrete event simulation using ProModel software. The simulation can be represented graphically in the Entity Flow Diagram below, and is the basis for all modeling decisions.

A. Locations

Each model uses three locations: the hangar, the runway and the mission area. The Hangar is where aircraft that are not FMC (PMC or NMC) are queued for maintenance and/or supply in order to return to FMC status. The Runway is where aircraft that are waiting to go on a mission are held. An aircraft can only sit on the runway if it is FMC. Finally, the Mission area is where an aircraft flies to conduct a mission. It leaves from the Runway, and can either return to the Runway or go back to the Hangar depending on its status.

B. Entities
This study’s simulation uses two different entities: the OH-58D and the UH-60M. Both entities correspond to their respective data provided by the 10th Combat Aviation Brigade.

C. Arrivals

Each entity arrives at the Hangar at time zero to represent starting the day with all aircraft present. 30 UH-60Ms and 28 OH-58Ds arrive at the Hangar. Upon arrival, two attributes are assigned: aircraft status and aircraft type. The aircraft status corresponds with the aircraft readiness provided in the operational readiness report of the 10th Combat Aviation Brigade on deployment. However, each aircraft starts FMC to represent starting the deployment with all fully operating aircraft. Each airframe has a different status and is pulled from a distribution stored inside the model (1=FMC, 2=PMCS, 3=PMCM, 4=NMCS, 5=NMCM). The aircraft type corresponds with the type of airframe (8=UH60M and 9=OH58D).

D. Processes/Routing

This study’s simulation processes and routing are based off of Figure 1. Since all of the aircraft receive an aircraft status of 1 (FMC), they will immediately proceed to the Runway. However, if they were to have a status other than 1 (PMCS, PMCM, NMCS or NMCM), then they would be required to wait at the Hangar based on a certain distribution of wait times corresponding to their status and airframe. This is to simulate receiving the needed part or maintenance. These distributions are stored in an array within the simulation, which is imported from the excel table below [8].

Once a new status is given to the aircraft, it can proceed in one of two directions. If the aircraft received a status of 1 (FMC), then it will proceed through route 1 which will take it back to the Runway. However, if the aircraft receives any other status indication; it will proceed back to the Hangar.

E. Validation and Verification

The model was verified throughout its development to ensure that it was designed correctly based on the conceptually model. In order to do this, entities were traced through each step of the model to ensure that they were acting as intended.

The model was validated based on the amount of uptime each aircraft averaged per mission. This metric was chosen because it could be compared to the aircraft’s respective endurances. An aircraft’s endurance is the amount of time that it can remain in the air based on its fuel capacity and consumption rate. In order to ensure that this model accurately represented reality, the uptime per mission should be less than an aircraft’s endurance. The UH-60M has an endurance of 2.5 hours or 5 hours with external fuel tanks [9]. The OH-58D has an endurance of 2 hours [10]. The simulation produced results that are realistic. The uptime per mission for the UH-60M was on average 2.66 hours with negligible variation. Although this number is slightly larger than the endurance without the external fuel tanks; it is indicative of the aircrafts mission. UH-60Ms typically conduct missions that involve transportation to and from a location. Therefore, it is very possible that they could refuel at the intermediate location. However, the OH-58D’s mission requires it to remain on station; meaning that it remains in the air for a certain amount of time. Therefore, it is unlikely that it would refuel at some intermediate point, and its uptime per mission of 1.18 hours is accurate.

RESULTS

In order to compare maintenance methods, a 95% confidence interval was taken of the uptime per aircraft for each respective aircraft. The results are shown below. Red confidence intervals denote those that are not in favor of the hypothesis, while those in green are. Black confidence intervals represent those that are statistically equal and neither disprove nor prove the hypothesis.

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### TABLE I

<table>
<thead>
<tr>
<th>Type of Parameter</th>
<th>UH-60M Parameters</th>
<th>OH-58D Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resupply Times (Hours)</td>
<td>N(20,26)</td>
<td>N(27,52,63)</td>
</tr>
<tr>
<td>Maintenance Times (Hours)</td>
<td>N(6,87,93)</td>
<td>N(6,24,24)</td>
</tr>
<tr>
<td>Mission Requirements (Hours)</td>
<td>N(6,67,36)</td>
<td>N(6,10,33)</td>
</tr>
</tbody>
</table>

### TABLE II

<table>
<thead>
<tr>
<th>User Distributions for Aircraft Status</th>
<th>UH-60M Status Probabilities (%)</th>
<th>OH-58D Status Probabilities (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMC</td>
<td>81.6</td>
<td>67.9</td>
</tr>
<tr>
<td>PMCS</td>
<td>0.29</td>
<td>1.25</td>
</tr>
<tr>
<td>PMCM</td>
<td>0.9</td>
<td>9.95</td>
</tr>
<tr>
<td>NMCS</td>
<td>0.56</td>
<td>9.96</td>
</tr>
<tr>
<td>NMCM</td>
<td>16.65</td>
<td>10.9</td>
</tr>
</tbody>
</table>

### TABLE III

<table>
<thead>
<tr>
<th>Results (Uptime per Aircraft)</th>
<th>UH-60M 95% CI</th>
<th>OH-58D 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Model</td>
<td>(16.37,16.90)</td>
<td>(10.67,11.16)</td>
</tr>
<tr>
<td>Equal Resupply Times</td>
<td>(16.54,17.08)</td>
<td>(11.77,12.29)</td>
</tr>
<tr>
<td>Switched Resupply Times</td>
<td>(16.51,16.98)</td>
<td>(11.67,12.26)</td>
</tr>
<tr>
<td>Equal Mission Requirements</td>
<td>(16.06,16.71)</td>
<td>(15.80,16.42)</td>
</tr>
<tr>
<td>Equal Mission Requirements and</td>
<td>(16.24,16.84)</td>
<td>(16.73,17.30)</td>
</tr>
<tr>
<td>Switched Resupply Times</td>
<td>(14.44,14.90)</td>
<td>(15.76,16.33)</td>
</tr>
</tbody>
</table>
Those results in which the confidence intervals do not overlap have a statistically significant difference in availability for missions at a 95% confidence level. Both the initial model and the model adjusted for resupply times have confidence intervals that do not overlap, therefore the UH-60M has a higher uptime in each of them. Only setting the mission requirements equal for each aircraft resulted in statistically equal uptimes with overlapping confidence intervals, regardless making the supply times equal. However, creating equal mission requirements and switching the resupply times resulted in the OH-58D having a statistically higher uptime per aircraft.

**DISCUSSION**

Empirical data from experienced Army pilots and maintenance officers indicates that Progressive Phase Maintenance has a larger amount of uptime based on the greater flexibility incorporated into its method. Yet, in the initial model, under all given conditions and parameters, the UH-60M has a statistically higher amount of uptime per aircraft. This thoroughly disproves my hypothesis given the operational data provided.

Situations may arise where Progressive Phase Maintenance yields larger uptimes than Phase Maintenance given a different set of scenarios. Particularly because the parameters used in the model represented one specific aviation unit in one specific situation, deployed in Afghanistan. One unit is not representative of all combat situations, and certainly not situations that are encountered by an aviation unit at its home base. In order to represent a wide range of realistic situations, three changes were made to the models parameters.

The first change made to the models parameters was to its resupply times. The operational data provided shows a longer resupply time for the OH-58D. This could be for several reasons, but all contribute to the same outcome which is a limited amount of OH-58D supplies. It is very reasonable to create a situation in which the OH-58D has the same amount of resupply time as the UH-60M, especially considering a nearly unlimited war-time budget. To represent this change in the model, the parameters of the resupply times (PMCS and NMCS status) were set equal for the OH-58D and the UH-60M. However, the UH-60M still had a significantly larger uptime per aircraft.

The second change was switching the parameters of the supply time to represent a scenario in which the OH-58D had more readily available supplies than the UH-60M. This change did little; and in fact, there was no statistical change to the uptime per aircraft for either aircraft. Therefore, it can be concluded that realistic changes to the availability of supplies has almost no effect on the uptime of the aircraft due to the small amount of time each aircraft spends in a PMCS or NMCS status.

The third change made to the model was the mission requirements of each aircraft. The parameters for the demand both the OH-58D and the UH-60M were required to spend on a mission was set to equal each other. Changing these parameters resulted in statistically equal uptimes per aircraft. However, the assumption that the OH-58D had the same endurance or mission requirements as the UH-60M has to be made. This assumption is not only infeasible, but would not likely occur naturally.

The results points to the recurring theme that resupply time is negligible compared to the overall time spent flying missions. This is most likely due to the abundance of resources in combat. Therefore the differences in the way maintainers resupply and fix aircraft are not emphasized.

In order to create an outcome in which the OH-58D has a statistically larger amount of uptime, the requirements for the mission had to be set equal to each other, and the resupply times had to be switched. However, creating a situation in which the resupply times and the mission requirements were equal did result in the OH-58D having more uptime, although the amount was marginally larger and couldn’t be considered statistically greater. This means that in a situation where the only difference between two aircraft was the maintenance schedule that they used, the one using PPM had more uptime, just not statistically greater uptime.

**CONCLUSION**

Since neither the original parameters, nor the realistic changes to the parameters resulted in a greater uptime per aircraft in favor of the OH-58D; the original hypothesis that Progressive Phase Maintenance offers a more effective overhaul maintenance schedule is disproved.

In the future, modeling that is based on the resources and timing required in each maintenance method may yield a much different result. This model in its current state is heavily focused on operational (combat) data. However, this inherently is driven by a surplus of funding and availability of parts and maintainers. This factor cannot be underestimated. For instance, imaging the level of productivity a person could have if they only needed to sleep one hour a night. However, with the army retrograding out of Afghanistan and the availability of parts and labor shrinking on the home front; more emphasis will be placed on resource availability. Progressive Phase Maintenance might then offer the higher amounts of uptime suspected by those in the industry.

**ACKNOWLEDGMENT**

The primary author would like to thank the following individuals: LTC Edward Teague, Ph.D., professor at the United States Military Academy Department of Systems Engineering, for his continual support; CW5 William Butler, 10th Combat Aviation Brigade, for providing the data in which the model was derived.

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