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ALLOCATING FLIGHT HOURS TO ARMY HELICOPTERS

by

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Army helicopter battalions, consisting of 24 helicopters valued from $206.4 million (UH-60 Blackhawk battalion) to $432 million (AH-64 Apache battalion), allocate flight hours to helicopters using manual techniques that have caused an unnecessary decrease in battalion deployability. This thesis models the battalion's flight hour allocation problem using optimization; it develops both a mixed integer linear program and a quadratic program. The 2nd Battalion, 4th Aviation Regiment of 4th Mechanized Division currently uses a spreadsheet implementation of the quadratic program developed by the author called QFHAM (Quadratic Flight Hour Allocation Model), that is available to other battalions for use with existing software and computer resources. The mixed integer linear program, called FHAM (Flight Hour Allocation Model) more appropriately models the problem, but requires additional software. This thesis validates the two models using actual flight hour data from a UH-60 battalion under both typical training and contingency scenarios. The models provide a monthly flight hour allocation for the battalion's aircraft that results in a steady-state sequencing of aircraft into phase maintenance, thus eliminating phase maintenance backlog and providing a fixed number of aircraft available for deployment. This thesis also addresses the negative impact of current helicopter battalion readiness measures on deployment and offers alternatives.

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ALLOCATING FLIGHT HOURS TO ARMY HELICOPTERS

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ABSTRACT

Army helicopter battalions, consisting of 24 helicopters valued from \$206.4 million (UH-60 Blackhawk battalion) to \$432 million (AH-64 Apache battalion), allocate flight hours to helicopters using manual techniques that have caused an unnecessary decrease in battalion deployability. This thesis models the battalion's flight hour allocation problem using optimization; it develops both a mixed integer linear program and a quadratic program. The 2nd Battalion, 4th Aviation Regiment of 4th Mechanized Division currently uses a spreadsheet implementation of the quadratic program developed by the author called QFHAM (Quadratic Flight Hour Allocation Model), that is available to other battalions for use with existing software and computer resources. The mixed integer linear program, called FHAM (Flight Hour Allocation Model) more appropriately models the problem, but requires additional software. This thesis validates the two models using actual flight hour data from a UH-60 battalion under both typical training and contingency scenarios. The models provide a monthly flight hour allocation for the battalion's aircraft that results in a steady-state sequencing of aircraft into phase maintenance, thus eliminating phase maintenance backlog and providing a fixed number of aircraft available for deployment. This thesis also addresses the negative impact of current helicopter battalion readiness measures on deployment and offers alternatives.

DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort was made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

Army helicopter battalions, consisting of 24 helicopters valued from $206.4 million (UH-60 Blackhawk battalion) to $432 million (AH-64 Apache battalion), allocate flight hours to helicopters using manual techniques that have caused an unnecessary decrease in battalion deployability.

The 1^{st} Armored Division (AD), currently assigned in Germany, provides an example where the lack of individual aircraft flight hour allocation management resulted in a non-deployable helicopter battalion. During the Dayton Peace Accord arbitration process, prior to the U.S. implementation force (IFOR) deployment to Bosnia, 1^{st} Armored Division's UH-60 Blackhawk battalion reported 89% fully mission capable (FMC). Given the Army standard of 75% FMC, all reportable indications showed a battalion ready for deployment. However, the 1^{st} AD trained extensively for its impending deployment, and when the Dayton Peace Accords were signed in late November 1995 and 1^{st} AD was ordered to deploy, it immediately "sent up a red flag." The aviation brigade commander directed that aircraft with less than 75 flight hours remaining until phase maintenance, or nine of the battalion's 24 UH-60 Blackhawks would not deploy. This problem was previously unnoticed above the brigade level and was directly attributable to a lack of flight hour allocation management within the battalion.

This thesis models the battalion's flight hour allocation problem using optimization; it develops both a mixed integer linear program and a quadratic program. The 2^{nd} Battalion, 4^{th} Aviation Regiment of 4^{th} Mechanized Division currently uses a

spreadsheet implementation of the quadratic program developed by the author called QFHAM (Quadratic Flight Hour Allocation Model), that is available to other battalions for use with existing software and computer resources. The mixed integer linear program, called FHAM (Flight Hour Allocation Model) more appropriately models the problem, but requires additional software. This thesis validates the two models using actual flight hour data from a UH-60 battalion under both typical training and contingency scenarios. The result is a steady-state sequencing of aircraft into phase maintenance that eliminates phase maintenance backlog and provides a fixed number of aircraft available for deployment. This thesis also addresses the negative impact of current helicopter battalion readiness measures on deployability and offers alternatives.

QFHAM brings immediate results to a helicopter battalion. QFHAM would increase the number of deployable aircraft for 1st AD's UH-60 battalion by 20.8 % (83.3% vs. 62.5%) in the scenario discussed above. The initial model set-up is simple and requires a battalion less than an hour. The output provides flight company commanders a by-aircraft flight hour allocation for a planning cycle.

The allocation process takes less than 15 minutes and can be adjusted easily during the planning cycle if major changes occur. The aircraft flight hour allocation planning process that previously has either been ignored or estimated using time-consuming manual techniques can now easily be accomplished with an automated process.

The percent FMC measures the battalion's ability to maintain helicopters operationally ready, but it provides very little indication of a battalion's deployability. An aircraft is deployable if it is both FMC and has a minimum number of hours until phase maintenance. Furthermore, striving to maintain a high percent FMC can discourage proactive phase maintenance procedures. The additional readiness measure recommended in this thesis is a tiered reporting of the percentage of aircraft above 25, 50, and 75 hours. This report gives an immediate indication of the actual number of deployable aircraft, in terms of phase maintenance scheduling, for the battalion.

The bottom line: Optimization models such as QFHAM improve Army helicopter battalion deployability.

I. INTRODUCTION

Army helicopter battalions allocate flight hours to helicopters using manual techniques that have caused an unnecessary decrease in battalion deployability. This thesis models the battalion's flight hour allocation problem using optimization; it develops both a mixed integer linear program and a quadratic program. The 2nd Battalion, 4th Aviation Regiment of 4th Mechanized Division currently uses a spreadsheet implementation of the quadratic program developed by the author called QFHAM (Quadratic Flight Hour Allocation Model), that is available to other battalions for use with existing software and computer resources. The mixed integer linear program, called FHAM (Flight Hour Allocation Model) more appropriately models the problem, but requires additional software. This thesis contrasts both programs and shows that both provide helicopter battalions with a valuable planning tool for allocating flight hours.

A. BATTALION ORGANIZATION AND MAINTENANCE BACKGROUND

Under the Aviation Restructuring Initiative (ARI) the Army is reorganizing helicopter battalions (Robinson, 1998). The new organization consists of five companies: a headquarters company, three flight companies, and a maintenance company. The headquarters company performs the battalion's administrative activities and maintains the battalion's ground vehicles. Each of the three flight companies operates its eight aircraft and performs scheduled maintenance. The maintenance company coordinates all maintenance activities for the battalion's fleet of 24 aircraft valued at approximately $206.4 million for a UH-60 Blackhawk battalion and $432 million for an AH-64 Apache battalion (Jackson, 1997).

The Department of the Army (DA) schedules maintenance requirements for helicopters on a phase maintenance scheduling program (DA, 1995) where aircraft undergo extensive maintenance procedures after a fixed number of flight hours. For the UH-60 Blackhawk, AH-64 Apache, and CH-47 Chinook, the primary helicopters of the Army fleet, phase maintenance occurs every 500 hours (DA, 1996), 250 hours (DA, 1998), and 300 hours (DA, 1989) respectively. Phase maintenance is time and manpower intensive requiring anywhere from 30 to 300 days. The length of the phase maintenance can translate into lack of deployability with no quick fix for battalions that do not properly manage their aircraft.

DA (1995) advocates using the "Sliding Scale Method" to help manage the flow of aircraft into phase maintenance. The sliding scale method has battalions sequentially plot the aircraft's remaining flight hours until phase maintenance from most hours remaining to least hours remaining (Figure 1). They then compare this plot versus the Army goal, referred to as the DA goal line, a line drawn from zero to the maximum hours remaining until phase maintenance.

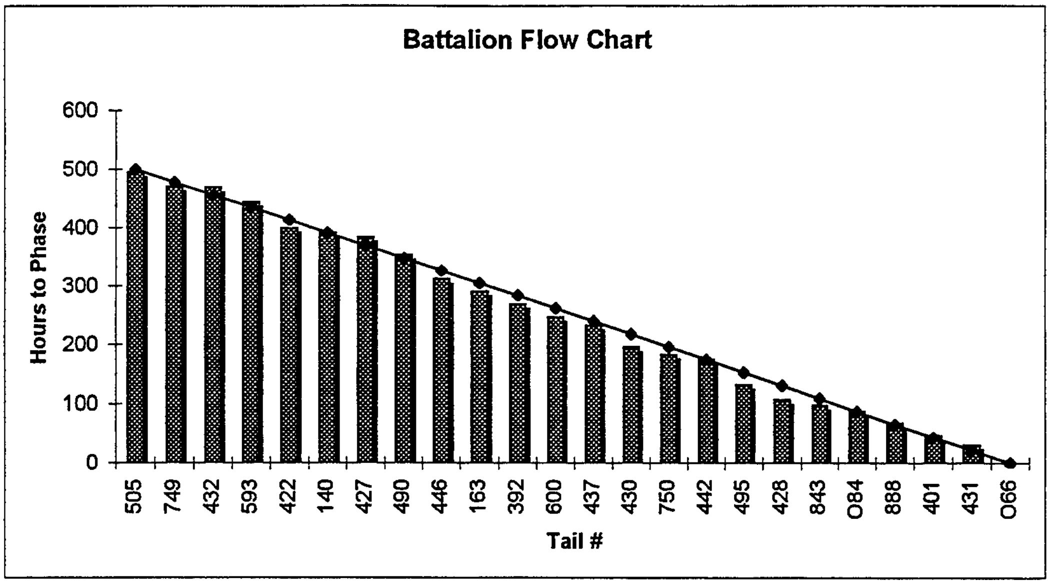

Figure 1 – Sample Battalion Flow Chart for a UH-60 Battalion. The graph shows the relationship between flight hours for sequentially sorted aircraft and the DA goal (shown as line). The DA goal line establishes a steady-state flow of aircraft into phase maintenance.

When flight hours remaining until phase maintenance are kept on the DA goal line, the times between the aircraft phase maintenance due dates are equal between the aircraft. For instance, if the next aircraft due phase maintenance has 30 hours remaining, and the unit's operational tempo (OPTEMPO) averages 15 flight hours/per aircraft/per month, then the next phase maintenance begins in about 2 months (60 days). By keeping the aircraft on the DA goal line (or parallel to it) the sequencing of aircraft into phase maintenance is equal. This prevents a backlog of aircraft waiting for phase maintenance.

Many battalions ignore DA guidance and do not manage their aircraft flow since current helicopter battalion measures of effectiveness (MOEs) do not require reporting of individual aircraft flight hour (time remaining until phase maintenance). The primary MOE for a helicopter battalion is the percentage of aircraft that are Fully Mission Capable (FMC) with a DA goal of 75% FMC. FMC is the percentage of time within the previous month that an aircraft is able to perform its full wartime mission (DA, 1992). The battalions must report percent FMC to higher headquarters on the 15th of each month.

The percent FMC measures the battalion's ability to maintain helicopters operationally ready, but it provides very little indication of a battalion's deployability. An aircraft is deployable if it is both FMC and has a minimum number of hours until phase maintenance. It is easy to see that a battalion could report 90% FMC for a given month and have several aircraft with only a few flight hours remaining until phase maintenance. As long as those aircraft are operational, they are reported as FMC, however, they are not considered deployable until phase maintenance is complete. This situation would not be visible on the battalion's monthly report.

Battalions that do manage aircraft flow tend to do so on a daily basis, with the battalion maintenance officer (maintenance company commander) dictating on a by-mission basis which aircraft to fly. This leads to reactive micro-management of the company's aircraft flight hours by the battalion rather than proactive management by the flight company commander.

B. HISTORIC CASE STUDY

The 1st Armored Division (AD), currently assigned in Germany, provides an example where the lack of individual aircraft flight hour allocation resulted in a non-deployable helicopter battalion. During the Dayton Peace Accord arbitration process, prior to the U.S. implementation force (IFOR) deployment to Bosnia, 1st AD's UH-60 Blackhawk battalion reported 89% FMC. Given the DA goal of 75%, all reportable indications showed the battalion was ready for deployment. Upon notification of its impending deployment, the 1st AD trained extensively for the mission. The Dayton

Peace Accords were signed in late November 1995, and 1st AD was ordered to deploy to the former Yugoslav Republic (Bosnia). Immediately the UH-60 Battalion "sent up a red flag." The aviation brigade commander directed that aircraft with less than 75 flight hours remaining until phase maintenance would not deploy. This affected nine of the battalion's 24 UH-60 Blackhawks. This problem was previously unnoticed above the brigade level and was directly attributable to a lack of flight hour allocation management within the battalion. The problem was further acerbated by the high OPTEMPO of the required training prior to their deployment. Figure 2 shows an example of this type of maintenance flow problem.

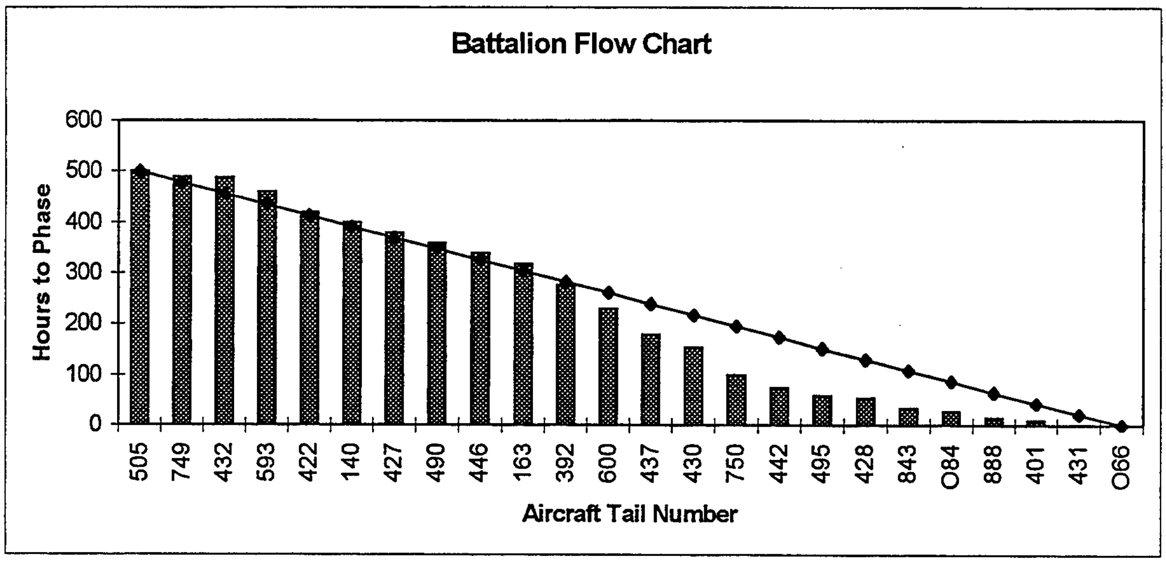

Figure 2 – Sample Battalion Flow for 1st AD prior to deployment to Bosnia (Based on authors recollection, actual data not available). All aircraft to the right of aircraft #442 are non-deployable and there is a backlog of four aircraft ready now for phase maintenance (hours remaining until phase <10 hours). It required several months for these four aircraft to complete phase maintenance and deploy.

The problem experienced by 1st AD is by no means exceptional. This problem can easily develop within any helicopter battalion.

Battalions must plan for unforeseen deployment scenarios by adhering to the DA goal line. Battalions should develop a maintenance program that ensures a fixed number of aircraft available for deployment at any time. With knowledge of impending deployments, battalions can achieve higher deployability by deviating from the DA goal line, however, for long term planning under conditions of uncertainty, the DA goal line provides the best solution for maximum deployability at any time. This thesis allocates flight hours to get as close to the DA goal line as possible. Chapter V addresses intentional deviation from the DA goal line for known deployments.

C. PROBLEM DEFINITION

An Army helicopter battalion must be prepared for missions that can vary daily. The Army organizes aviation maintenance activities to provide the battlefield commander with the maximum number of safe, mission-capable aircraft to meet its missions (DA, 1995). Given the vast array of mission profiles for the combat aviation unit, from direct, high intensity conflict to operations other than war, battalions can expect to deploy as either a battalion assigned to an aviation brigade level task force or as smaller sized (company and below) support packages. Therefore, the battalion must be prepared for any contingency. A large part of that preparation is a well-established battalion phase maintenance flow (DA, 1995).

In order to maintain an effective phase maintenance flow, the battalion commander must balance his operation and training requirements against his maintenance effort. The battalion staff and the flight company commanders are responsible for the operational and training aspects. The battalion maintenance officer is responsible for the maintenance effort. The battalion commander manages resources through flight hour allocation and maintenance management within a planning cycle (Planning cycles are typically monthly and this thesis uses only monthly planning cycles for computational studies, although FHAM and QFHAM are appropriate for any planning cycle length).

The battalion maintenance officer must recommend the flight hour allocation for each aircraft assigned to the battalion at the beginning of each planning cycle. Prior to making this recommendation, he must know the following information:

- Battalion commander's flight hour goal for planning cycle.
- Number of flight hours remaining until phase maintenance for each aircraft in the battalion.
- Minimum percentage of battalion flight hours each company receives.
- Most probable status of any on-going phase maintenance at the end of the planning cycle.
- Minimum and maximum flight hours each aircraft flies during the planning cycle.

The Army can benefit from an optimization program to help helicopter battalions allocate flight hours. Achieving and maintaining a steady-state flow of aircraft into phase maintenance guarantees a constant number of aircraft available for deployment without a phase maintenance backlog. QFHAM can help the battalion maintenance officer determine an optimal flight hour distribution between individual aircraft. The battalion maintenance officer applies current mission criteria and aircraft limitations while setting up the constraints within QFHAM. Having solved for the optimal flight hour allocation, the battalion maintenance officer then issues flight hour allocation goals for the flight company commanders for the planning cycle.

This thesis analyzes the stated optimization problem with FHAM and QFHAM. FHAM validates the exportable (to battalions) QFHAM. FHAM is a mixed integer linear program with penalties per hour deviation that increase as the flight hours from the desired DA goal line increase. The resulting aircraft flow should be as parallel as possible to the DA goal line and thereby provide a steady-state flow of aircraft into phase maintenance. QFHAM changes the methodology of the battalions from reactive micro-management to proactive management. Conducting the flight hour allocation on a periodic basis rather than managing on a mission-by-mission basis, gives the flight company commander the flexibility to manage his own aircraft assets within a planning cycle rather than having the choice of aircraft for missions dictated on a daily basis.

D. OUTLINE

Chapter II describes related research. Chapter III formulates both the mixed integer linear program and the quadratic program. Chapter IV provides results from both programs using data from a UH-60 battalion's annual flying hour program. Analysis includes both typical training and contingency scenarios. Chapter V discusses the implementation of QFHAM and the ramifications of current helicopter battalion MOE's and possible alternative MOE's.

II. RELATED RESEARCH

A literature review revealed several examples of similar work. However, previous models addressing issues of scheduled maintenance on repairable systems are not directly adaptable to the problem addressed by this thesis. The bulk of the work done for aircraft scheduling addresses mission assignment to specific aircraft with no consideration given to major scheduled maintenance procedures. In models addressing major scheduled maintenance procedures, systems are grouped by age of device with no consideration to individual systems (e.g., aircraft). The only model found that specifically addresses necessary issues contained in FHAM and QFHAM is developed by DA. The following contains a brief discussion of related models and their relevance to the problem addressed in this thesis.

DA prescribes a technique for establishing a steady-state flow of aircraft into phase maintenance called the sliding scale scheduling method (SSSM) (DA, 1995). Under the ARI organized battalions, the SSSM requires the battalion maintenance officer perform the following steps:

- Plot the actual flight hours and manually draw a linear approximation of this plot;
- Divide the number of flight hours available for the next planning cycle (given by battalion commander) by the number of aircraft assigned to the battalion;
- Subtract the average flight hours per aircraft from the Y-axis intercept of the linear approximation of the battalion's current aircraft flow; and

- Draw a line (adjusted goal line) parallel to the DA goal line such that it intercepts the Y-axis at the adjusted Y-intercept (Figure 3).

The battalion maintenance officer then determines the recommended flight hours by calculating the difference between actual flight hours and the adjusted goal line. If an aircraft is below the adjusted line, then that aircraft is not flown.

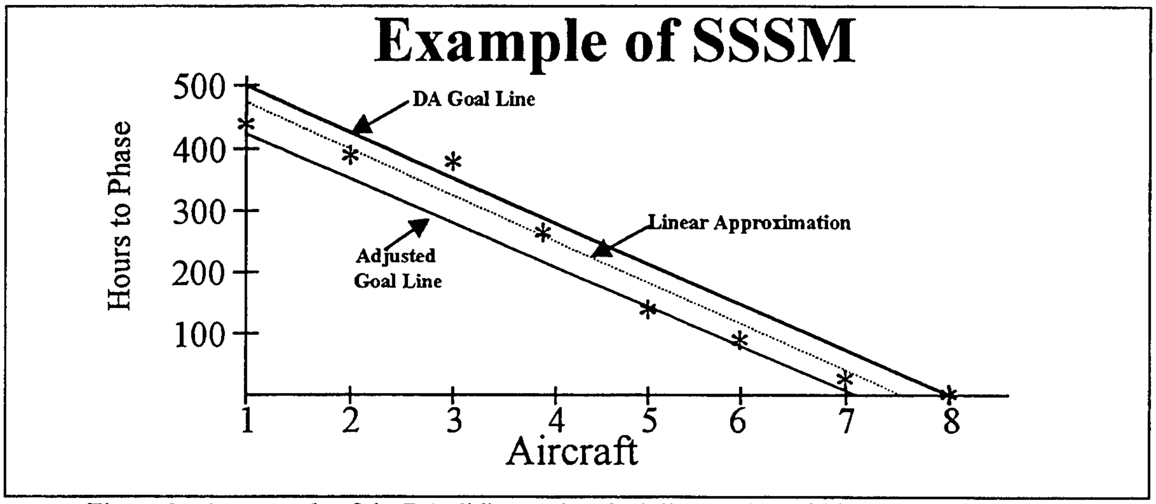

Figure 3 - An example of the DA sliding scale scheduling method (SSSM). For simplicity, SSSM is shown for a flight company. The DA goal line shows the desired position of the aircraft. The linear approximation shows the battalion maintenance officer's estimate of a linear fit to the actual flight hours. The adjusted goal line shows the line parallel to the DA goal line with a Y-intercept determined by subtracting the average number of flight hours for the aircraft for this planning cycle from the Y-intercept of the linear approximation. For example, aircraft 2 can fly 400 – 375 = 25 hours, while Aircraft 5 is allocated zero hours. The adjusted goal line is the desired end-state after the planning cycle.

Throughout a ten year aviation career, the author has never observed nor heard of any aviation battalion using SSSM. Whatever shortcomings kept SSSM from being used, it is less appropriate for today's ARI organized battalions as it is designed for use at a company level. Previous battalion organizations (pre-ARI) had much larger flight companies with their own maintenance sections allowing phase maintenance management at the company level. However, with restructuring of the battalion, all phase maintenance is now managed at the battalion level. At the battalion level, SSSM does not ensure any type of equitable distribution of flight time between the companies. Also, when aircraft fall below the adjusted goal line, then assigned flight hours fall below the allocated flight hours for the planning cycle. In general, the sliding scale scheduling method provides a generic planning tool, but its lack of flexibility and simplicity make it unusable at the battalion level.

Other more sophisticated methods were found in the literature. Bargeron (1995) addresses readiness issues from scheduling depot level maintenance of Marine Corps M1A1 main battle tanks. He develops a linear integer program with an imbedded multi-commodity network structure to solve the tank maintenance problem. Bargeron's linear integer program contained 36,284 variables and 12,705 constraints. The linear integer program solves in 674.29 CPU seconds on an IBM RS/6000 Model 590H computer. Bargeron's linear integer program has some similarities, such as scheduled maintenance based on usage and a time intensive maintenance procedure. However, there are some basic differences between his linear integer program and the problem addressed in this thesis: Bargeron groups tanks within a battalion based on age groups in order to avoid tracking individual tanks and his primary objective is to minimize the cost of a viable maintenance scheduling plan.

Sgaslik describes a decision support system designed to assist with maintenance planning and mission assignment for a German UH-1H (Huey) Helicopter Regiment (Sgaslik, 1994). In order to solve this problem, Sgaslik develops an elastic, mixed integer linear program. Sgaslik's mixed integer linear program contained 2,600 variables, 9,000 non-zero elements, and 1,200 constraints. The mixed integer linear program solves in less than 15 minutes on an IBM compatible 486/33 computer. Although this problem deals with scheduled maintenance issues, the primary objective is the assignment of missions to individual aircraft. In this situation, the missions and the mission length are known for each planning cycle.

Fabrycky and Blanchard (1984) address the issue of modeling repairable equipment population systems (REPS). The REPS model uses finite queuing theory to evaluate the costs as well as design of a service facility. Fabrycky and Blanchard track items based on a device age grouping and models parts requirements and repairs using nested Markov chains. This REPS model deals not only in scheduled maintenance, but also in the stochastic nature of unscheduled maintenance while this thesis does not address unscheduled maintenance. The REPS model groups systems of similar age characteristics while this thesis requires individual aircraft tracking.

A final model that deals with Army helicopters is the "Phoenix" model (Brown, Clemence, Teufert, and Wood, 1991). The Phoenix model schedules procurement and retirement for the Army's helicopter fleet. The model handles 16 different helicopter platforms spanning a planning cycle of 25 years. The modernization options considered in Phoenix model:

- Procuring new aircraft through completely new production campaigns;
- Procuring aircraft through block modification in which active production campaigns are altered to incorporate enhancements;
- Service life extension programs (SLEPs); and
- Retirement of obsolete aircraft.

Although Phoenix does not address issues involved with the problem addressed in this thesis, Phoenix shows Army Aviation willingness to use optimization planning systems.

III. OPTIMIZATION MODELING OF THE FLIGHT HOUR ALLOCATION PROBLEM

The mixed integer linear program (FHAM) and the quadratic program (QFHAM) use the following information:

- Battalion Commander's flight hour goal for the planning cycle expressed as the minimum and maximum number of hours.
- Number of flight hours remaining until phase maintenance for each aircraft in the battalion.
- Minimum flight hours for each company.
- Most probable status of any on-going phase maintenance at the end of the planning cycle.
- Minimum and maximum flight hours each aircraft flies during the planning cycle.

FHAM bases all penalties on a least squares approximation. This approximation thus penalizes more heavily for larger relative flight hour deviation from the DA goal line.

A. MIXED INTEGER LINEAR PROGRAM FORMULATION

This thesis uses a standard UH-60 Blackhawk Air Assault Battalion (500 flight hours between phase maintenance) for demonstration purposes: FHAM and QFHAM can also be easily adapted for AH-64 or CH-47 battalions. The total hours flown meets the constraint given by the battalion commander's flight hour goal. The distribution of flight hours between the flight companies is held equitable based on the desired allocation between the companies. Finally, the objective is to minimize the sum of the individual penalized flight hours from the DA goal line. The outputs from FHAM are the allocated flight hours per aircraft per planning cycle. The following shows FHAM's formulation in Naval Postgraduate School (NPS) format:

Indices:

i Interval from the DA goal line (e.g., 1,2,...,10);

p Position of aircraft on the battalion flow chart (e.g., 1^{st}, 2^{nd}, ..., 24^{th});

τ Aircraft tail number (e.g., 080, 254, ...); and

c Company (e.g., A, B, or C).

Sets:

$AIRCRAFT_c$ Set of all aircraft in Company c.

Given Data:

$\underline{BFH}$ Minimum flight hour allocation for the battalion during planning cycle (hours);

$\overline{BFH}$ Maximum flight hour allocation for the battalion during planning cycle (hours);

DAG_p DA goal for aircraft assigned position "p" on the DA goal line (hours);

HTP_τ Flight hours remaining until phase maintenance due for aircraft "τ" (hours);

$INTERVAL_{\tau,i}$ Allowed deviation within the i^{th} interval for aircraft "τ" (hours);

$MAXFLY_\tau$ Maximum flight hours for aircraft "τ" (hours);

$MINCO_c$ Minimum battalion flight hours for company "c" (hours);

$MINFLY_\tau$ Minimum flight hours for aircraft "τ" (hours);

$NEGPEN_{\tau,i}$ Penalty per flight hour below the DA goal line within the i^{th} interval for aircraft "τ" (e.g., 0,10,30,...,170) (penalty units / hour);

$POSPEN_{\tau,i}$ Penalty per flight hour above the DA goal line within the i^{th} interval for aircraft "τ" (e.g., 0,10,30, ...,170) (penalty units/hour); and

TAH_{τ} Total flight hours for aircraft "τ" (hours).

Decision Variables:

$devneg_{\tau,i}$ The flight hours aircraft "τ" is below the DA goal line within the "i^{th}" interval (hours);

$devpos_{\tau,i}$ The flight hours aircraft "τ" exceeds the DA goal line within the "i^{th}" interval (hours);

fly_{τ} Flight hours for aircraft "τ" during planning cycle (hours); and

$x_{\tau,p}$ One if aircraft "τ" is assigned to the "p^{th}" position, zero otherwise.

FORMULATION

Minimize the Objective Function...

$$\sum_{\tau}\sum_{i}\left[POSPEN_i * devpos_{\tau,i} + NEGPEN_i * devneg_{\tau,i}\right]$$ Objective

Subject to...

$$\left[HTP_\tau - fly_\tau - \sum_p DAG_p * x_{\tau,p}\right] \le \sum_i devpos_{\tau,i} \qquad \forall \tau$$ Constraint #1

$$-\left[HTP_\tau - fly_\tau - \sum_p DAG_p * x_{\tau,p}\right] \le \sum_i devneg_{\tau,i} \qquad \forall \tau$$ Constraint #2

$$\sum_\tau x_{\tau,p} = 1 \qquad \forall p$$ Constraint #3

$$\sum_p x_{\tau,p} = 1 \qquad \forall \tau$$ Constraint #4

$$\sum_{\tau \in AIRCRAFTc} fly_\tau \ge MINCO_c \qquad \forall c$$ Constraint #5

$$\underline{BFH} \le \sum_\tau fly_\tau \le \overline{BFH}$$ Constraint #6

$$MINFLY_\tau \le fly_\tau \le MIN\{HTP_\tau, MAXFLY_\tau\} \qquad \forall \tau$$ Constraint #7

$$0 \le devpos_{\tau,i} \le INTERVAL_{\tau,i} \qquad \forall \tau, i$$ Constraint #8

$$0 \le devneg_{\tau,i} \le INTERVAL_{\tau,i} \qquad \forall \tau, J$$ Constraint #9

$$x_{\tau,p} \in \{0,1\} \qquad \forall \tau, p$$

The objective function is the sum of the penalized flight hour deviation of the battalion's aircraft from the DA goal line. The flight hour deviation penalty per unit is different depending on the deviation interval. For example, assume aircraft #254 is assigned to the 5th position and is 23 hours above the DA goal line. Each interval allows only 10 hours ($INTERVAL_{254,i} = 10\ \forall i$) and the penalties for the first three intervals are: $POSPEN_{254,1} = 0$, $POSPEN_{254,2} = 10$, $POSPEN_{254,3}=30$. Then the penalty for this aircraft would be 0(10) + 10(10) + 30(3) = 190.

Constraint (1) measures flight hour deviation above the DA goal line for each aircraft τ. Constraint (2) measures flight hour deviation below the DA goal line for each aircraft τ. Constraint (3) ensures that each aircraft is only allocated one position within the battalion flow. Constraint (4) fills each position on the battalion flow chart with exactly one aircraft. Constraint (5) ensures equitable flight hour allocation between the flight companies. Constraint (6) ensures that the sum of the individual aircraft flight hours is within the upper and lower bounds of the battalion commander's goal of flight hours within the planning cycle. Constraint (7) ensures that individual aircraft fly the minimum required flight hours in a planning cycle and do not exceed maximum flight hours allowed or exceed the remaining flight hours until phase maintenance is due. Constraints (8) and (9) bound the hours above and below the DA goal line in each penalty interval.

B. QFHAM FORMULATION

QFHAM's objective function is the sum of the squared flight hours above or below the DA goal line,

$$Objective = Min\sum_{\tau}\left[HTP_{\tau} - fly_{\tau} - \sum_{p} DAG_{p} * x_{\tau,p}\right]^{2},$$

where positions of the aircraft within the battalion flow chart ($x_{\tau,p}$) are fixed. A pre-processing step fixes aircraft position based on current flight hours remaining until phase maintenance (HTP_{τ}) and the minimum flight hours for each aircraft during the planning cycle ($MINFLY_{\tau}$). A Visual Basic Macro (Excel, 1996) subtracts $MINFLY_{\tau}$ from HTP_{τ}, sorts the aircraft based on the result, and fixes the aircraft to their sorted order.

With the position fixed, there are only three constraints:

$$\sum_{\tau \in AIRCRAFTc} fly_{\tau} \geq MINCO_{c} \quad \forall c \qquad \text{Constraint \#5}$$

$$\underline{BFH} \leq \sum_{\tau} fly_{\tau} \leq \overline{BFH} \qquad \text{Constraint \#6}$$

$$MINFLY_{\tau} \leq fly_{\tau} \leq MIN\{HTP_{\tau}, MAXFLY_{\tau}\} \quad \forall \tau \qquad \text{Constraint \#7.}$$

QFHAM's objective function is minimize $\sum_{\tau}(C_{\tau} - fly_{\tau})^{2}$ where C_{τ} is the constant $\left(HTP_{\tau} - \sum_{p} DAG_{p} * x_{\tau,p}\right)$. This is a quadratic objective function of the form minimize $d'y + y'Iy$ that is convex since I is positive semidefinite (Bazaraa, Sherali, and Shetty, 1993, p. 232). Therefore, if the software finds a local minimum, it is guaranteed to be a global minimum.

IV. COMPUTATIONAL RESULTS

This chapter describes the validation of FHAM and QFHAM within both typical training and contingency planning scenarios. The validation determines the extent to which the system accurately represents the intended real world phenomenon from the perspective of the customer of the model (the aviation battalion) (DA, 1993).

FHAM contains 620 continuous variables, 115 discrete variables, 2,013 non-zero elements, and 630 equations. FHAM solves using GAMS, Release 2.25 (Brooke, Kendrick, Meeraus, 1996) on a 166 MHz PC within 62 seconds using the GAMS XA solver (Brooke, Kendrick, Meeraus, 1996). QFHAM is implemented using a Microsoft version 97 Excel spreadsheet. The basic Excel 97 solver limits any model to no more than 200 variables (Person, 1997), prohibiting solution of FHAM but not QFHAM's 24 continuous variable model. The run time for the Excel solver with QFHAM's quadratic objective function is approximately 8 seconds. Frontline Systems Inc. offers two upgrades for the Excel solver. The Premium Solver ($495) increases the variable capacity to 800. The Large Scale LP Solver for Microsoft Excel 97 ($1,495) also allows 800 variables, but decreases solution time significantly and simplifies sparse matrices input (only requires non-zero element input)(Frontline, 1998).

A. TYPICAL TRAINING SCENARIO

The data used for the typical training scenario are the flight hours flown by a Mechanized Infantry Division's UH-60 battalion (validation battalion) for calendar year 1997 (Based on actual flight hours for the 2nd Battalion, 4th Aviation Regiment as reported for their Annual Flying Hour Report). The author performed this analysis using a typical training scenario. For example, there were no aircraft deployed for high intensity missions. Battalions operate under this general scenario when basing out of their home station with no external support missions. The year consists of monthly planning cycles. FHAM uses the allocated total monthly hours for the purpose of analysis (Table 1) with an allowed deviation above ($\overline{BFH}$) or below ($\underline{BFH}$) of ten percent.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
471	427	234	236	389	177	502	267	273	282	226	458

Table 1: Actual hours flown per month for the validation battalion

The start point of the analysis is 15 January 1997. Table 2 and Figure 4 show the initial hours until phase maintenance for the battalion's aircraft.

Aircraft	Hours to Phase	Aircraft	Hours to Phase	Aircraft	Hours to Phase
A422	149	B401	254	C140	12
A427	494	B430	441	C163	443
A428	298	B490	0	C392	446
A431	200	B593	172	C432	153
A442	398	B750	436	C437	414
A446	492	B843	230	C495	306
A749	170	B888	198	C505	102
AO66	250	BO84	231	C600	500

Table 2:Initial state of the validation battalion. Shown are aircraft by company, tail number, and the hours remaining until phase maintenance. For example, aircraft B593 belongs to B Company and has 172 hours remaining until phase maintenance.

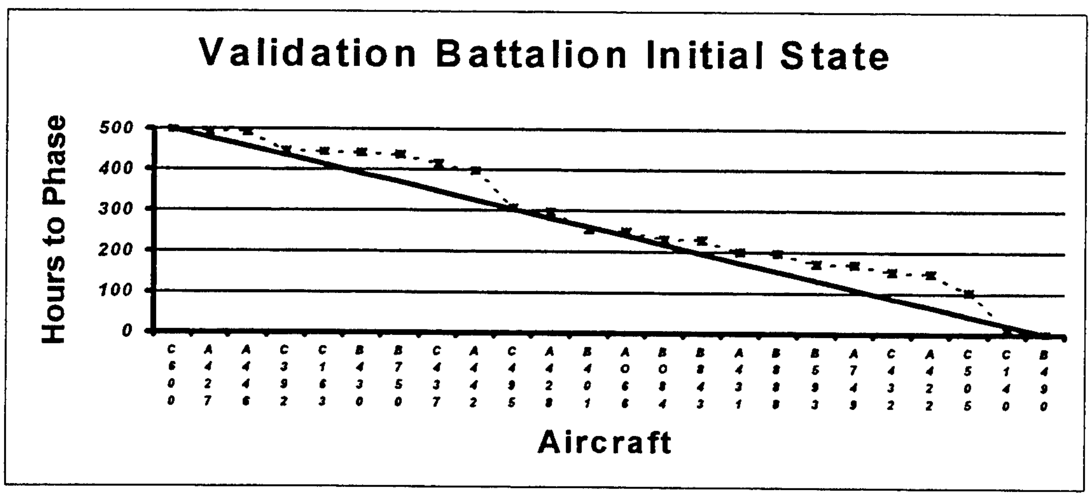

Figure 4: Initial state of validation battalion on 15 January 1997. Notice that the initial state shows very little adherence to the DA goal line. This is typical for Army helicopter battalions. Also note that the sequencing of aircraft into phase is not steady-state (parallel to DA goal line). This can lead to a backlog of aircraft awaiting phase maintenance.

FHAM fixes each aircraft's maximum monthly flight hours as the minimum of 30 or its flight hours remaining until phase. For instance, if an aircraft is due phase maintenance in 28 hours, the maximum allocated for that aircraft in a planning cycle is 28 hours. FHAM fixes an aircraft's minimum flight hours as the minimum of 3 or its flight hours remaining until phase. FHAM allocated each flight company at least 20% of the total flight time for the planning cycle.

FHAM analyzed each month based on the initial conditions of 15 January 1997, and the flight hours flown in each month.

B. OPTIMIZATION RESULTS FOR TYPICAL TRAINING SCENARIO

Figure 5 shows the results of the FHAM flight hour allocation as the battalion's phase maintenance flow approaches steady-state. FHAM uses the end condition of one month as the initial condition for the next month. Figures 6 and 7 show a comparison of FHAM results and the actual hours flown by the battalion after five months.

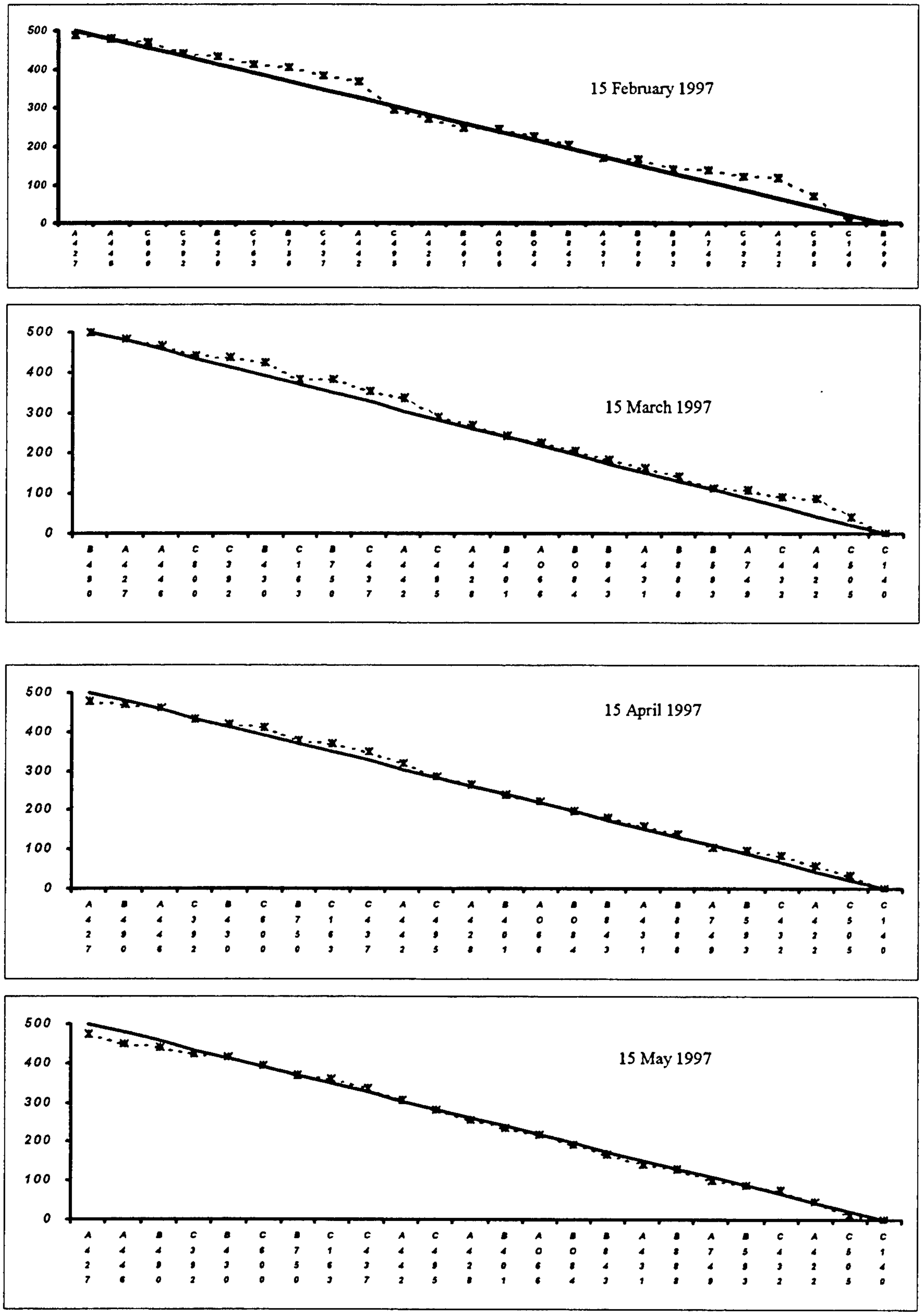

Figure 5:Shows the flow results of FHAM aircraft allocation on the validation battalion for February 15th – May 15th. The end condition of each planning cycle becomes the initial condition for the next month. FHAM quickly reaches adherence the DA goal line.

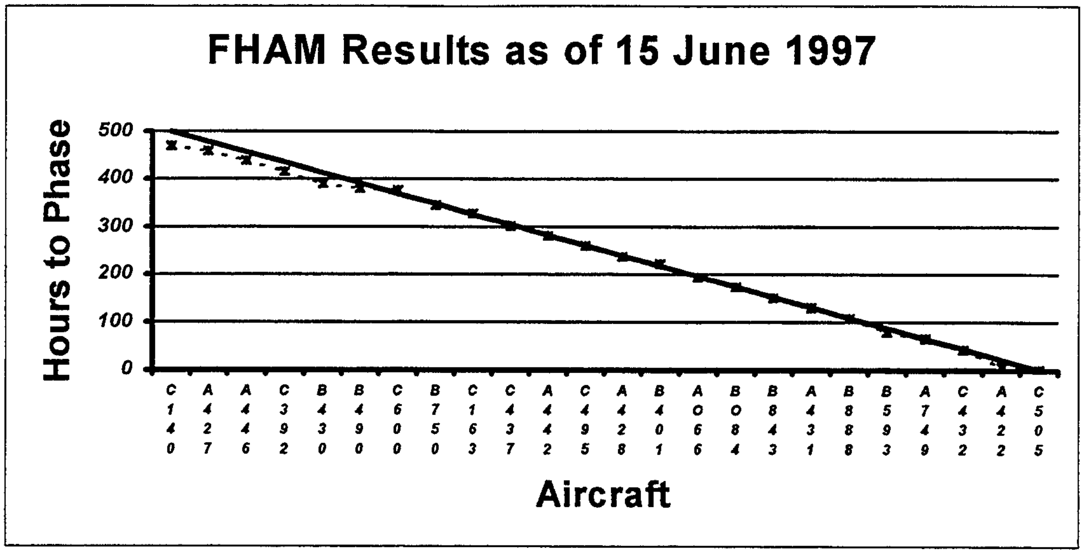

Figure 6: The resulting flow after 5 months of FHAM allocation. FHAM establishes a phase maintenance flow in adherence to the DA goal line.

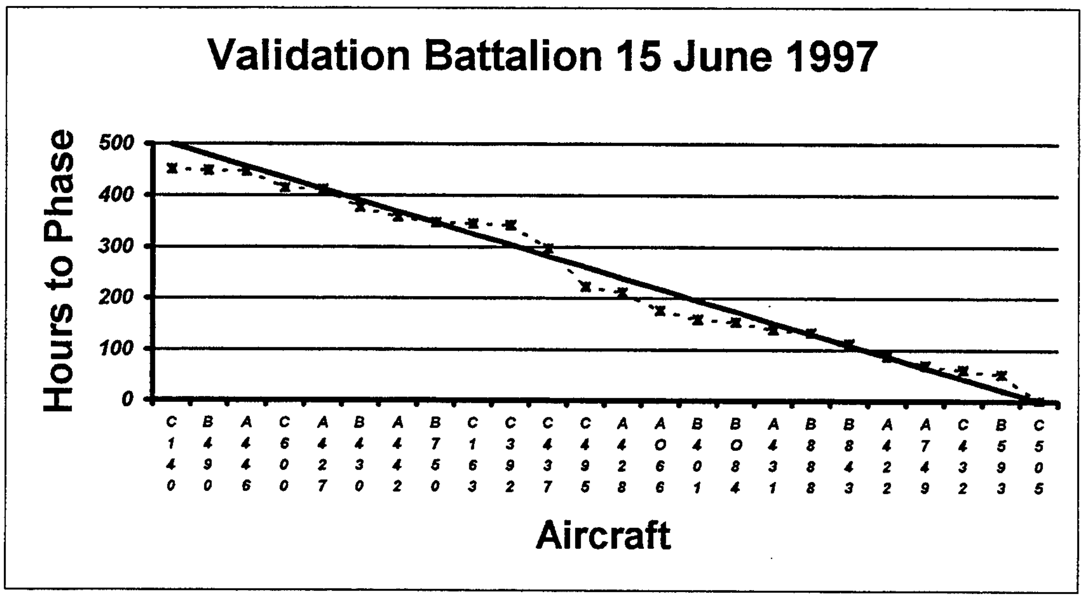

Figure 7: The actual flow for the battalion as of 15 June 1997. The battalion flow for the validation battalion is not as close to the DA goal line as the FHAM allocation.

FHAM's resulting flow of aircraft into phase maintenance now begins to parallel the DA goal line. The actual data from the validation battalion is not as close to the DA goal line as the FHAM results.

An essential problem handled by FHAM is the sequencing of low-time aircraft into phase maintenance. A key problem with the Army's current system of MOE reporting is that the only measure reported is FMC percentage. Leaders face a dilemma when aircraft approach phase maintenance. If an aircraft ready now for phase maintenance (e.g., less than 10 hours remaining until phase maintenance) is FMC, then the battalion's overall MOE is increased. If the battalion is barely making the DA standard (75% FMC) during a month, the battalion commander may delay bringing an aircraft to a non-mission capable status (NMC) for phase maintenance. This problem can easily manifest itself until there is a backlog of aircraft awaiting phase maintenance. Once a backlog develops, the OPTEMPO of the high-time aircraft increases since fewer aircraft are available to fly required missions. Eventually, battalions must conduct phase maintenance on multiple aircraft and risk not maintaining DA standards in FMC. This is a vicious cycle when careers are on the line.

Optimization as introduced here, avoids this cycle by providing a steady-state flow into phase maintenance. Depending on OPTEMPO, there is no need for more than one aircraft in phase maintenance at any given time, and overall readiness is higher as low-time aircraft enter phase maintenance on a schedule set by the OPTEMPO.

Figures 8 and 9 show how FHAM avoids the phase maintenance backlog dillemma while increasing deployability of a battalion. The annual flight data of the validation battalion shows that aircraft #C505 did not reach phase maintenance until July 1997. FHAM flight hour allocation results in C505 reaching phase maintenance in May 1997. The actual phase maintenance for C505 took 42 days to complete. Figure 8 shows the actual phase maintenance flow for the battalion in July 1997. Figure 9 shows what their phase maintenance flow would have been using allocations from FHAM.

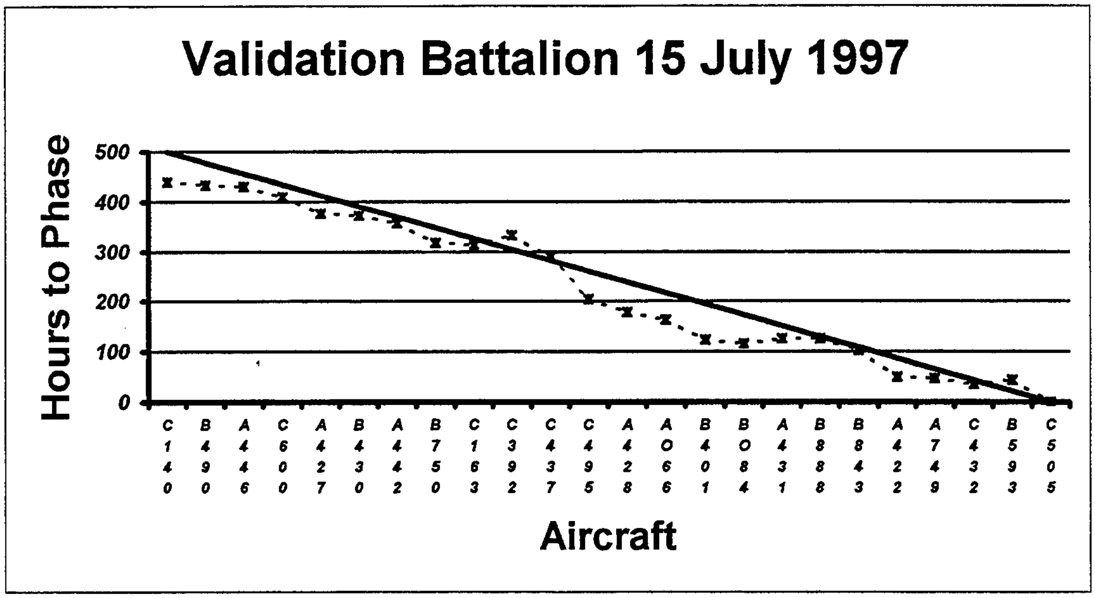

Figure 8: Shows the actual phase maintenance flow for the validation battalion on 15 July 1997. Note the bottom four aircraft above C505 are at approximately the same hour level and due phase maintenance at about the same time.

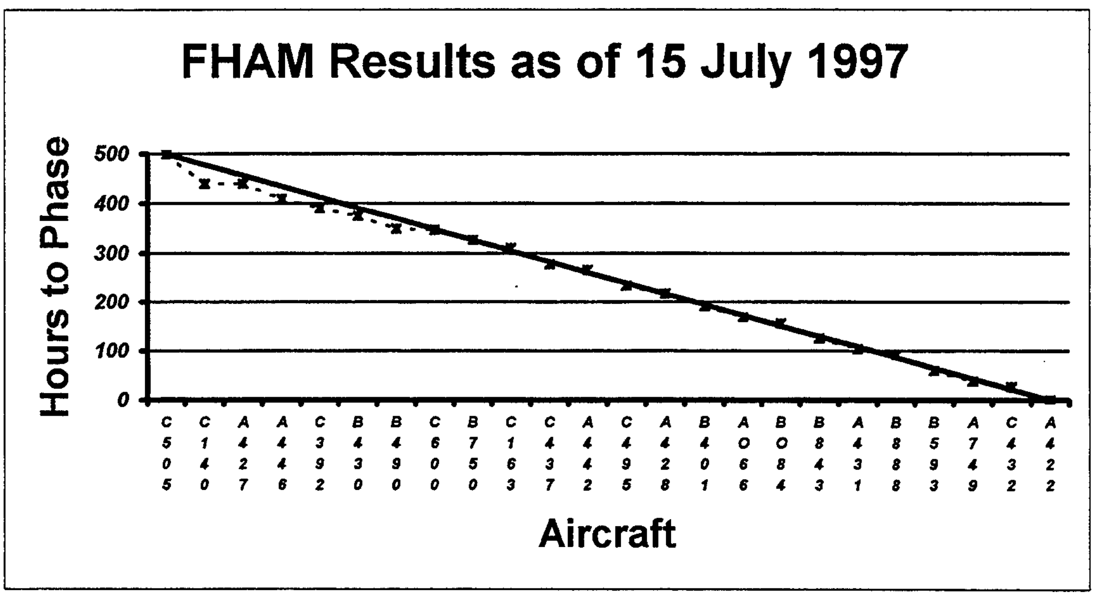

Figure 9: Shows the phase maintenance flow based on FHAM allocation on 15 July 1997. FHAM avoids the phase maintenance backlog shown in Figure 8 above by adhering to the DA goal line.

Figures 8 and 9 show the difference effective sequencing can make for a battalion's deployability. As aircraft C505 completes phase maintenance in July 1997, aircraft A422 enters phase maintenance (Figure 9). FHAM allocation results in an additional 500 flight hours available to the battalion with the completion of aircraft C505's phase maintenance. The historic data reveals that aircraft C505 was not actually phase maintenance complete until 10 September 1997. The backlog of aircraft awaiting phase maintenance grew during this time and the battalion was eventually required to perform phase maintenance on aircraft B593 and C432 simultaneously. During this time, aircraft A422 and A749 were awaiting phase maintenance with less than ten hours available. In essence, this backlog resulted in four aircraft completely non-deployable for a period of more than 90 days.

As a flight hour allocation tool, FHAM demonstrates the flexibility and capabilities necessary. Although not useable at the battalion level without supporting software, FHAM provides a baseline analysis for validation of QFHAM.

C. QFHAM OPTIMIZATION RESULTS FOR TYPICAL TRAINING SCENARIO

In order to validate the QFHAM, comparisons are made based on actual planning cycles for the validation battalion. The constraints are the same for both models (BFH, $MAXFLY_{\tau}$, $MINCO_{c}$,and $MINFLY_{\tau}$). Figures 10 and 11 show a comparison of QFHAM results and the actual hours flown by the battalion after five months (as of 15 June 97).

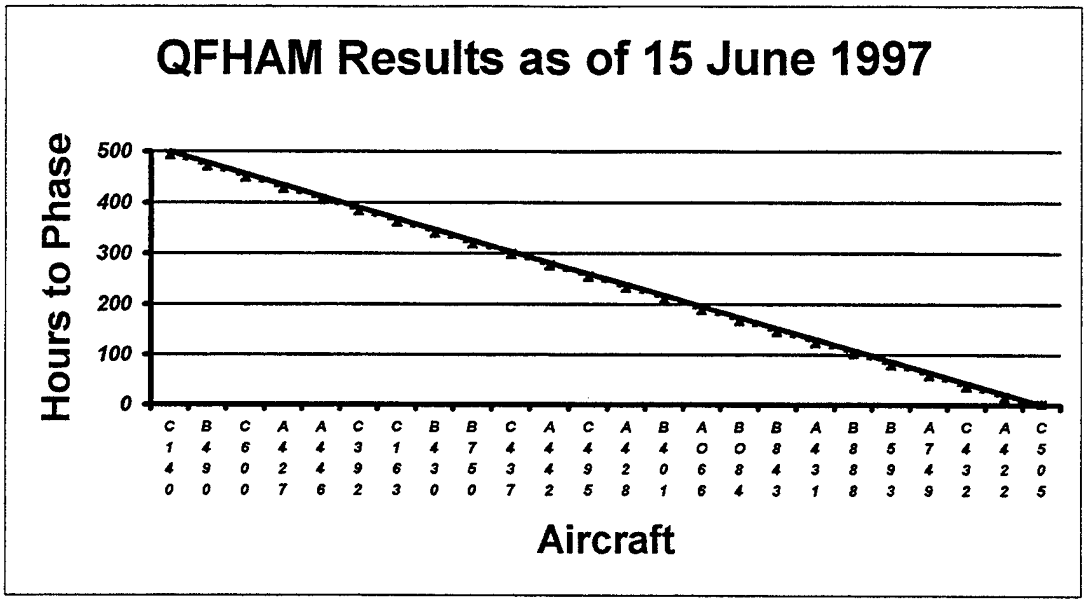

Figure 10:The resulting flow after 5 months of QFHAM allocation. QFHAM provides a battalion phase maintenance flow parallel to the DA goal line.

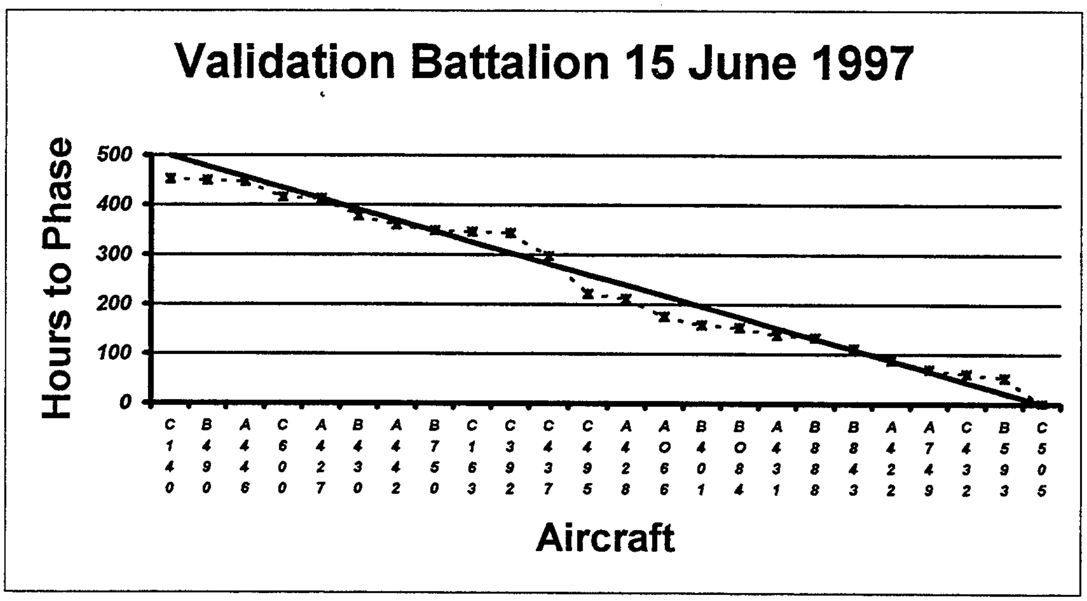

Figure 11:The actual flow for the battalion as of 15 June 1997. Note the deviation of the battalion's phase maintenance flow from the DA goal line.

As with FHAM, QFHAM corrects problems with the steady-state flow of aircraft along the DA goal line. Using the data from the validation battalion, QFHAM allocation reaches approximate steady-state after four planning cycles (months).

The resulting flow from QFHAM (Figure 10) is very similar to the flow achieved using FHAM (Figure 6). There are some differences in the aircraft order on the flow chart, a result of QFHAM's lack of binary variables. However, the results of the two models are very similar. FHAM's approximation of QFHAM's objective function is very close in all scenarios. Tables 3 and 4 show comparisons of flight hour allocations for FHAM and QFHAM.

Aircraft	QFHAM	FHAM	Aircraft	QFHAM	FHAM	Aircraft	QFHAM	FHAM
A422	30.00	30.00	*B401*	5.00	5.00	*C140*	5.00	5.00
A427	5.00	5.00	*B430*	24.03	6.92	*C163*	30.00	30.00
A428	11.46	15.19	*B490*	0.00	0.00	*C392*	7.29	5.00
A431	22.16	25.89	*B593*	30.00	30.00	*C432*	30.00	30.00
A442	30.00	30.00	*B750*	30.00	30.00	*C437*	30.00	30.00
A446	9.81	13.04	*B843*	30.00	30.00	*C495*	5.00	5.00
A749	30.00	30.00	*B888*	30.00	30.00	*C505*	30.00	30.00
AO66	6.94	11.07	*BO84*	9.68	13.40	*C600*	30.00	30.00

Table 3:Comparison of FHAM and QFHAM results from validation battalion's planning cycle of 15 Jan 97 – 15 Feb 97. Note that both models yield similar allocation results. Both models started with identical initial conditions.

Aircraft	QFHAM	FHAM	Aircraft	QFHAM	FHAM	Aircraft	QFHAM	FHAM
A422	30.00	30.00	*B401*	5.00	5.00	*C140*	0.00	2.10
A427	5.00	5.00	*B430*	5.00	5.00	*C163*	22.38	13.43
A428	5.00	5.00	*B490*	8.95	30.00	*C392*	5.00	5.00
A431	5.00	5.00	*B593*	12.86	13.90	*C432*	14.99	8.55
A442	20.86	18.00	*B750*	5.00	5.00	*C437*	15.12	5.00
A446	5.00	5.00	*B843*	5.00	5.00	*C495*	5.00	5.00
A749	5.00	5.00	*B888*	5.00	5.00	*C505*	8.85	11.66
AO66	5.00	5.00	*BO84*	5.00	9.10	*C600*	30.00	27.26

Table 4:Comparison of FHAM and QFHAM results from validation battalion's planning cycle of 15 April 97 – 15 May 97. Note that both models yield similar allocation results. Both models in this case used the FHAM results from the March-April planning cycle as initial conditions.

Although the individual aircraft allocations differ significantly in some cases, the overall result is the same for both models. Both models result in the establishment of a steady-state flow of aircraft into phase maintenance.

D. QFHAM OPTIMIZATION OF CONTINGENCY OPERATIONS

In order to analyze the capabilities of QFHAM to optimally allocate flight hours during contingency operations, an actual scenario is used from a Mechanized Infantry Division's UH-60 battalion. The 2nd Battalion of the 1st Aviation Regiment deployed a detachment (five UH-60's) to Bosnia in support of Operation Provide Comfort. The five aircraft deployed in support of the commander of forces in Bosnia. They flew a high OPTEMPO while geographically separated from their maintenance support facilities. No phase maintenance procedures were available in theater at the time, so high time aircraft were sent (at least 200 flight hours until phase maintenance). During this deployment, the battalion remaining in Germany began training to deploy to Bosnia six months later.

The battalion commander predicted a minimum flight hour requirement of 20 hours per month for the five aircraft deploying to Bosnia. The battalion commander tasked the non-deploying aircraft to fly a normal training OPTEMPO. Figure 12 shows an approximation of the battalion's aircraft flow on 20 December 1995 (Based on author's recollection as the battalion's maintenance officer, actual data not available).

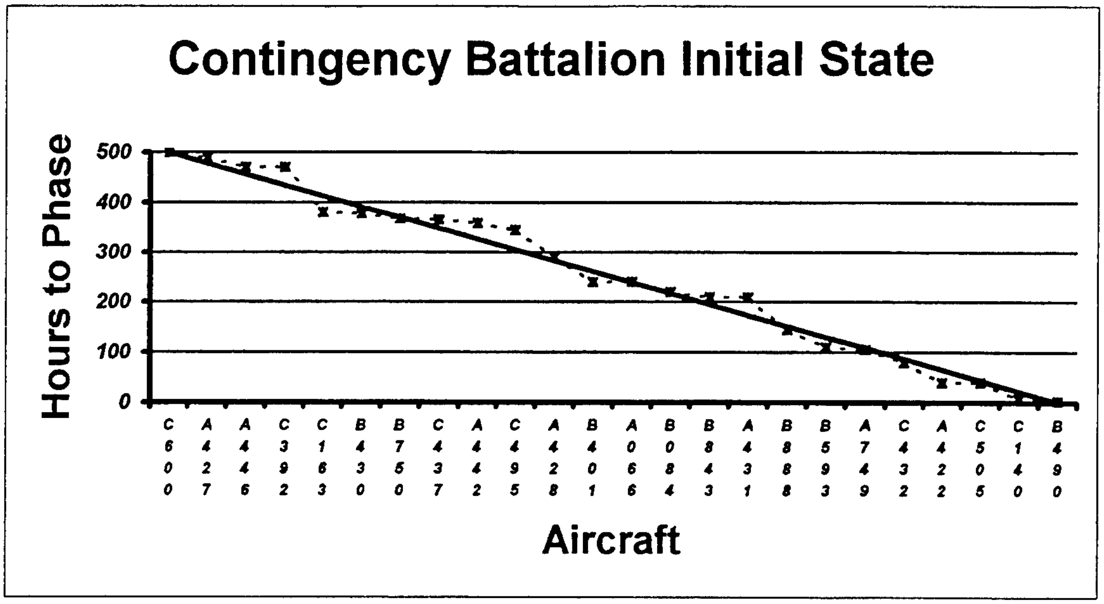

Figure 12:Initial status of Contingency Battalion's aircraft on 20 December 1995 prior to deployment to Bosnia.

The aircraft chosen for the deployment are C600, A446, C437, A066, and B843. The total battalion flight hours (BFH) for each planning cycle is given in Table 5.

	20 Dec - 15 Jan	16 Jan - 15 Feb	16 Feb - 15 Mar
BFH	425 hours	440 hours	425 hours

Table 5:Total flight hours allocated for the first three months of the contingency operations in Bosnia.

During these three months, the deployed aircraft planned a minimum OPTEMPO of 20, 30, and 30 aircraft flight hours per month respectively. In a situation such as this, manually optimizing the battalion's flight hour allocation is difficult. In this actual situation, the deployed battalion did not attempt to manage phase maintenance flow at all. Flight company commanders allocated missions to aircraft with no thought given to the resulting aircraft flow into phase maintenance.

This scenario is easily handled by QFHAM. Figure 13 shows the resulting aircraft flow after three months of operations. Note that aircraft B490 completed phase maintenance prior to March 15 and is shown as 500 flight hours until phase maintenance.

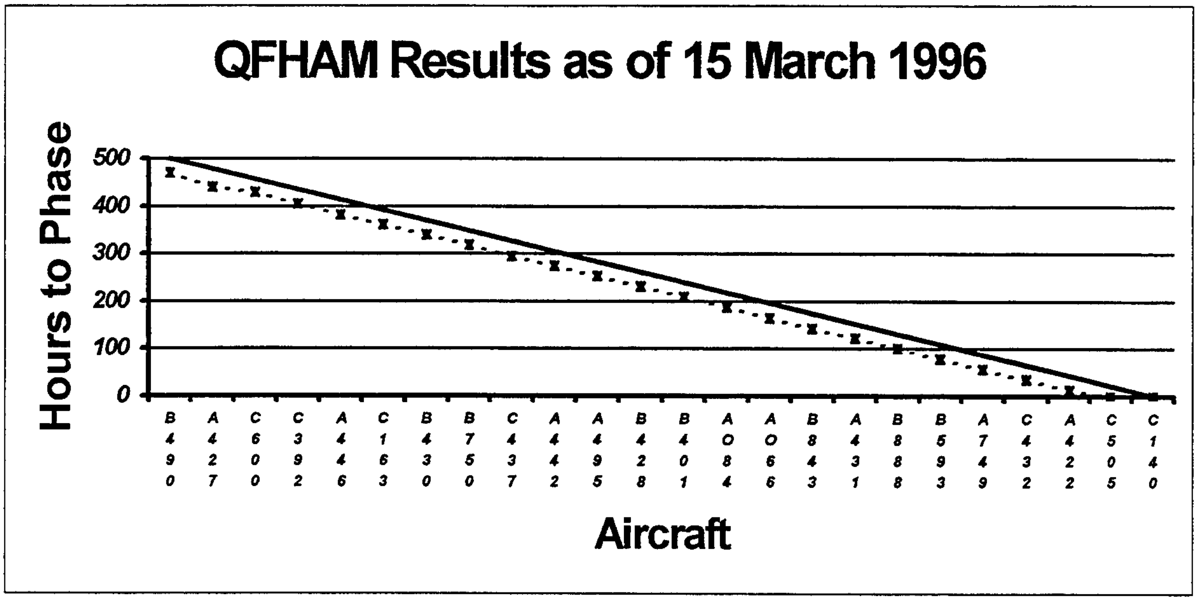

Figure 13:The resultant aircraft flow after three months of contingency operation using QFHAM aircraft hour allocation. The flow is parallel to the DA goal line. This is the desired state for a battalion as it ensures steady-state sequencing of the aircraft into phase maintenance.

The analysis required for each planning cycle takes the battalion maintenance officer less than 15 minutes. The resultant aircraft flow after only three months is exactly where it needs to be. The flow is parallel to the DA Goal line. Based on hour allocation, aircraft C140 would have entered phase maintenance in mid January. Thus, based on an average 45-day phase it would be available during the next planning cycle, and the flow line would shift up towards the DA goal line (Figure 14). Even in a contingency operation case, QFHAM ensured no phase maintenance backlog and provided a steady-state sequencing of aircraft into phase maintenance. The resulting flow using QFHAM allocation is ideal. Noteworthy, is the fact that QFHAM established steady-state after only three months of use under contingency operations. In actuality, the Contingency

Battalion discussed in this scenario deployed as a battalion to Bosnia in June 1996. QFHAM would have made a great difference in the overall deployability of the battalion.

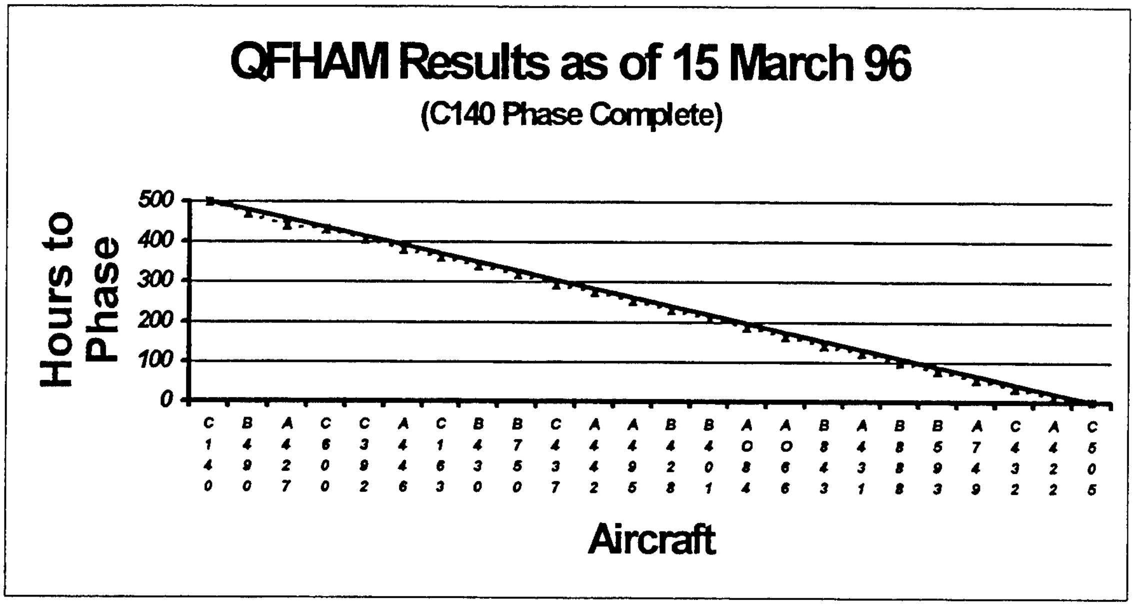

Figure 14: The resultant flow after three months of contingency operations using QFHAM aircraft hour allocation, with aircraft C140 phase maintenance complete.

E. DISCUSSION OF THE RESULTS

The results discussed in this chapter show that both FHAM and QFHAM have the capabilities and flexibility needed to help battalion commanders manage flight hour allocation. FHAM and QFHAM produce similar recommendations for flight hour allocation.

QFHAM, though simplified (no binary variables) to meet variable limits within Excel, still meets all operational requirements. Analysis conducted using actual historic flight data from operational battalions shows that battalions can correct most problems with aircraft flow within three or four months using QFHAM.

V. CONCLUSION AND RECOMMENDATIONS

Computational analysis shows that both FHAM and QFHAM offer helicopter battalions a decision support system that provides an optimal flight hour allocation. It is recommended that Army helicopter battalions use QFHAM since its spreadsheet implementation can be adopted without purchasing new software. The flight hour allocation planning process that previously has either been ignored or estimated using time-consuming manual techniques is easily handled by QFHAM. This thesis shows that QFHAM prevents phase maintenance backlog and provides a fixed number of aircraft available for deployment. QFHAM changes battalion flight hour allocation from reactive micro-management to proactive management at the flight company level.

A. READINESS IMPROVEMENT

This thesis addresses U.S. Army Helicopter deployability issues in terms of steady-state flow of aircraft into phase maintenance. What is a valid MOE for a helicopter battalion? Should it address historic performance or future readiness? Although an historic performance MOE (percent FMC) provides information concerning the battalion's maintenance program, a valid MOE should also address the future deployability of the battalion.

The effects on deployability of an achieved steady-state flow into phase maintenance vary depending on the battalion's actual flow. The historic case study offered in Chapter I gives an example of the negative effects of failing to maintain steady-state flow. The battalion discussed had nine of 24 aircraft non-deployable for operations in Bosnia (Figure 15) given the deployment criteria of 75 aircraft hours remaining until phase maintenance. Had the battalion maintained a steady-state flow (Figure 16), they would have reported only four aircraft non-deployable.

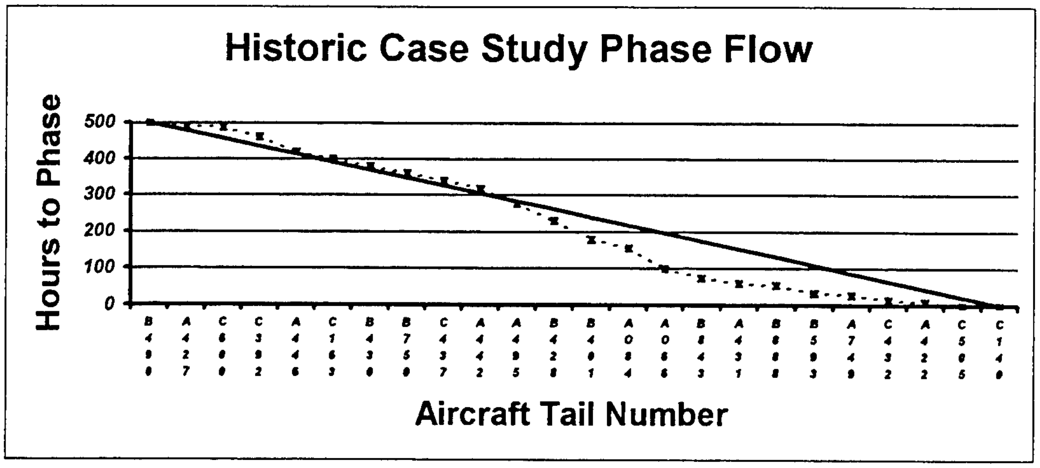

Figure 15:Historic case study's battalion phase maintenance flow upon receipt of orders to deploy to Bosnia. Note that nine of 24 aircraft fail to meet the deployment ceiling of not less than 75 aircraft hours remaining until phase maintenance.

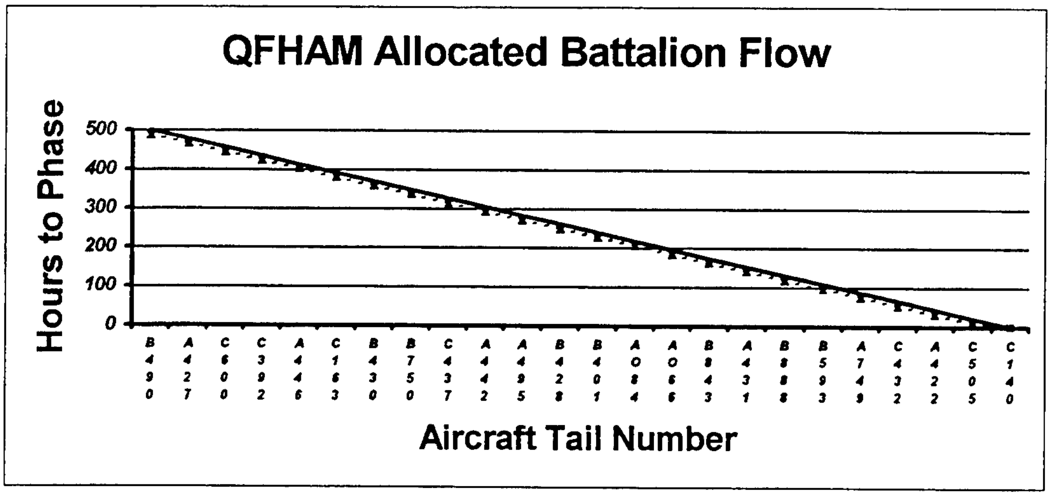

Figure 16: Approximation of QFHAM allocated phase maintenance flow for the historic case study. In this scenario, only four aircraft would have failed to meet the minimum deployment ceiling.

In this scenario, QFHAM offers a 20.8% increase in deployable aircraft (83.3% vs. 62.5%). For long-range maintenance planning, steady-state flow of aircraft into phase maintenance offers the highest deployability possibilities for a battalion. With advance warning of deployment, battalions can adjust flight hour allocation to keep aircraft above planned deployment criteria. QFHAM is flexible enough to handle the long-range and contingency planning scenarios.

B. RECOMMENDATIONS

The Army's MOE for helicopter battalions does not provide incentives conducive to effective phase maintenance flow. The FMC rate MOE actually discourages proactive phase maintenance procedures. In analyzing a system's performance, the Army looks at three categories: Reliability, Maintainability, and Availability (Department of Defense (DOD), 1982).

DOD defines reliability as the probability that an item performs its intended function for a specified interval under stated conditions (DOD, 1982). DOD defines maintainability as the probability that a system is retained in, or restored to a specified condition within a given period if prescribed procedures and resources are used (DOD, 1982).

The FMC rate MOE measures a combination of reliability and maintainability, but does not address future availability. DOD defines availability as a measure of the degree to which an item is in an operable and commitable state at the start of a mission when the mission is called for at a random point in time (DOD, 1982). A helicopter battalion's availability is their phase maintenance flow. As stated earlier, an aircraft with only one flight hour remaining until phase maintenance may be FMC, but it is not available.

The Army should incorporate a measure of availability as an additional helicopter battalion MOE on the monthly unit status report (USR). This gives visibility to deployability. The Army could accomplish this by requiring battalions to report the percentage of aircraft with more than *X* hours for tiered hour levels. An example for a UH-60 Blackhawk battalion is shown in Table 6.

Hours	# Aircraft Above	DA Standard
25	21	21
50	21	20
75	19	18

Table 6:Sample report from a battalion with a good aircraft phase maintenance flow. The first column shows the reported hour level. The second column shows the number of aircraft this battalion has above that hour level. The third column is the DA standard. In each reportable category, this battalion exceeds the DA standard, meaning this battalion does not have a phase maintenance backlog.

In the case outlined in the historic case study, the battalion would have reported as shown in Table 7.

Hours	# Aircraft Above	DA Standard
25	20	21
50	18	20
75	15	18

Table 7:Sample report from the historic case study battalion. Note that the battalion failed to meet the DA Standard in all three categories. This provides a "red flag" to higher headquarters that a deployability problem exists.

This report would alleviate the problem with phase maintenance backlog. The purpose of reporting different levels is to discourage commanders from "gaming" the report. If there is just one report at the 25 hour level, the tendency would be to push the backlog up to 25 hours instead of at zero hours. This tiered reporting alleviates the phase maintenance backlog problem. The Army could require additional reporting at higher flight hour levels, but 75 hours provides commanders sufficient time to space aircraft into phase maintenance. Given an OPTEMPO of 15 hours (per aircraft, per month), 75 hours is five months and based on computational analysis, QFHAM can reestablish a steady-state flow within five months. Battalions with aircraft requiring phase maintenance every 250 hours (AH-64 Apache) would report at the 12.5, 25, and 37.5 hour levels.

The Army should also deconflict the negative relationship between FMC rates and deployability. Battalions should not be penalized for phasing aircraft. The Army can accomplish this by not reporting aircraft in phase maintenance as non-mission capable for 30 days. This would encourage battalions to conduct phase maintenance without punishing their FMC MOE. The 30 day limit would ensure that battalions expedited the phase maintenance, as after the initial 30 days, their FMC MOE is affected. With these changes, battalions would become much more proactive in their maintenance execution.

C. QFHAM IMPLEMENTATION

QFHAM is a valuable for a helicopter battalion. The initial QFHAM set-up is simple and should require a battalion less than an hour. All procedures are command button driven using Visual Basic macros. The output provides flight company commanders a by-aircraft flight hour allocation for a planning cycle. The battalion commander issues these allocations as a goal, and as long as the company commanders get close to the recommendations, phase maintenance flow improves.

The monthly flight hour allocation process takes the battalion maintenance officer less than 15 minutes and can be adjusted easily during the cycle if major changes occur. The flight hour allocation planning process that previously has either been ignored or estimated using time-consuming manual techniques can now easily be accomplished with an automated process.

The bottom line: Optimization models such as QFHAM improve long-range deployability.

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