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Using discrete-event simulation to analyze personnel requirements for the Malaysian Army's new utility helicopter fleet

Mohamad Rais, Hasnan bin

Monterey, California: Naval Postgraduate School

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THESIS

USING DISCRETE-EVENT SIMULATION TO ANALYZE PERSONNEL REQUIREMENTS FOR THE MALAYSIAN ARMY'S NEW UTILITY HELICOPTER FLEET

by

Hasnan bin Mohamad Rais

June 2016

Thesis Advisor:	Dashi I. Singham
Co-Advisor:	Jeffrey B. House
Second Reader:	Connor McLemore

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Hasnan bin Mohamad Rais
Major, Malaysian Army
B.S., University Technology of Malaysia, 2000

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June 2016

Approved by: Dashi I. Singham
Thesis Advisor

Jeffrey B. House
Co-Advisor

Connor McLemore
Second Reader

Patricia Jacobs
Chair, Department of Operation Research
Graduate School of Operation and Information School

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ABSTRACT

This thesis describes the analysis used to determine personnel requirements for the Malaysian Army's S61A-4 utility helicopter fleet. We use discrete-event simulation to model maintenance activities in the Malaysian Army Aviation (MAA) fleet in order to evaluate the impact of maintenance crew resources on helicopter availability. Our model simulates the normal daily operating activities in the MAA environment and includes the size of the fleet, fleet flying operations, and maintenance activities including daily inspection, rectification, and scheduled maintenance. A ranking and selection method is used to select the best system or a subset that contains the best system design from the competing alternatives. The results of this paper provide the Malaysian Army Human Resource department an ability to allocate the appropriate number of personnel for the new fleet.

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LIST OF ACRONYMS AND ABBREVIATIONS

AeroTech	Aeromechanical Technician
AvioTech	Avionic Technician
Cx	Check
DES	Discrete-Event Simulation
DLM	Depot Level Maintenance
FLS	Flight Line Servicing
ILM	Intermediate Level Maintenance
LOH	Light Observation Helicopter
MA	Malaysian Army
MAA	Malaysian Army Aviation
OEM	Original Equipment Manufacturer
OLM	Organizational Level Maintenance
OpsRequest	Operation Request
RMAF	Royal Malaysian Air Force
R&S	Ranking and Selection
SME	Subject Matter Expert

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EXECUTIVE SUMMARY

The Royal Malaysian Air Force (RMAF) will deliver 12 Sikorsky S61 A-4 “Nuri” utility helicopters to the Malaysian Army (MA) that will enhance and widen MA operational capabilities. Prior to receiving the helicopters, MA is directed to make proper preparations in terms of its facilities, training, logistics, and most importantly, manning. This thesis uses discrete-event simulation (DES) to analyze Malaysian Army Aviation (MAA) maintenance personnel requirements for the new fleet. Avionic and aeromechanical technicians often perform maintenance in teams of five people, though some tasks require fewer people. The five-person teams consist of two avionic and two aeromechanical technicians, along with one technician from either type who serves as a senior tradesman. We wish to determine how many total technicians are needed to support maintenance requirements in these teams, which are formed and disbanded as needed for each major helicopter task. The simulation model described uses a ranking and selection (R&S) method to recommend the minimum number of personnel for a helicopter maintenance line to adequately support helicopter fleet operations.

The purpose of maintenance is to ensure the availability of helicopters to conduct assigned missions without jeopardizing helicopter airworthiness. This is achieved by conducting inspections, rectification, and scheduled maintenance with qualified avionic and aeromechanical trade technicians. The goal of this thesis is to come up with the appropriate number of technicians to allocate to a helicopter fleet with defined operational requirements for a given number of helicopters. The main challenge faced is limited access to confidential helicopter data, which we overcome by using estimates from subject matter experts.

The analysis examines trade-offs by varying the numbers of maintenance personnel and operational intensities to determine the number of missions likely to be accomplished within a given time period. We conduct our experiment by varying the number of personnel to find the minimum number needed to support the system. We conduct R&S to get the best configuration accounting for statistical uncertainty. We then use the selected subset and run the experiment with different arrival rates of the operation requests.

We confirm our result with 100 replications each run with 12 helicopters over a ten-year period, and determine that additional replications do not add any additional information. An output summary can be seen in Table 1.

Table 1. Comparing personnel levels and operations request rates.

Controls	**Average Responses**					
	20 AvioTechs			**30 AvioTechs**		
Ops Interarrival Dist: Exp(Hours)	Number Requests In Queue	Avio Utilization	Missions Complete	Number Requests In Queue	Avio Utilization	Missions Complete
Exp(12)	0.000492	11.1186	10164.5	0.000492	7.41286	10165.1
Exp(8)	5.11612	16.5998	15193.1	5.49073	11.0669	15218.5
Exp(6)	28.678	22.193	20296	30.1936	14.8263	20338.1
Exp(4)	231.501	33.2712	30433.9	239.538	22.2312	30486.3
Exp(3)	1340.93	41.603	38062.4	1360.21	27.7262	38078.2
Exp(2)	8199.92	42.455	38857.7	8198.85	28.3377	38883.5
Exp(1)	30120.4	42.5621	38857.7	30119.5	28.3252	38859.4
Exp(.75)	44686.9	42.5607	38857.7	44723.6	28.3402	38907
Exp(.5)	73898	42.5483	38918.2	73944.1	28.3546	38901.4
Exp(.25)	161615	42.5451	38935.5	161591	28.3431	38934.2

The "best possible" group is identified by the gray shading in the corresponding responses.

Because avionic and aeromechanical technicians are demanded in equal proportions throughout the model, we assume that we will hire equal numbers of each. Thus, the number of avionic technicians also refers to the number of aeromechanical technicians. We found that 20 technicians from each trade are needed to handle the maintenance in the new fleet. Hiring fewer maintenance personnel will be inadequate and could jeopardize the integrity and the airworthiness of the helicopters or result in missed operational requirements, while hiring more than the recommended number of maintenance personnel will almost certainly incur substantial additional costs without much performance improvement. Varying the rate of operations requests suggests that the system is robust to potential changes in the workload. The fleet should also consider not planning for more than five sorties per day as a sustainable long run average rate. Additional technicians (beyond 20 of each) will not help reduce the queue of sorties in this case. The size of the fleet and scheduled maintenance requirements are the limiting factors.

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I. INTRODUCTION

A. BACKGROUND

The Malaysian Army Aviation (MAA) was established in 1996 and provides tactical support to the MA through a Light Observation Helicopter (LOH) unit. The limited personnel and cargo capacity of the current model LOH, the Agusta A109 LOH (Figure 1), resulted in excessive MA reliance on the RMAF transportation fleet for servicing MA operational requirements; the RMAF transportation fleet is consistently requested for operations where the LOH's helicopter capacity is exceeded. To address this MAA shortfall, the Malaysian Government in 2012 approved the transfer of 12 heavier Sikorsky S61A-4 helicopters—also known as "Nuri" (Figure 2)—from the RMAF to the MA. These enhanced capacity helicopters will be used by MAA as Combat Utility Helicopters for cargo and personnel transport, air ambulance services, firefighting, and search and rescue.

Figure 1. Agusta A109 LOH

Source: A. Westland. Agusta A109LOH. Retrieved from http://www.helis.com/database/modelorg/319//. MAA A109 used for air observation, reconnaissance and tactical support to MA

Figure 2. Sikorsky S61A-4

Source: M. Zafriz, Sikorsky S61A-4. Retrieved from http://www.helis.com/database/model/763/. The Sikorsky S61A-4, or Nuri, has been used by RMAF since 1967 for various operations such as troop deployments, resupply, CASEVAC/MEDEVAC and Search and Rescue (SAR) missions.

To operate the new helicopter fleet, MAA is preparing a maintenance system that includes policies, processes, facilities, equipment, material, and manpower. There is no existing decision aid in the MAA inventory to assist in determining personnel requirements for new MAA helicopter assets. The current method, as per the MAA Engineering Instruction, Volumes 1 and 6, (1995) defines a helicopter-personnel team configuration as, two aeromechanical technicians, and two avionic technicians, with an additional technician of either type serving as the senior tradesman. This ratio is not valid for all maintenance aspects of the Nuri. Relative to the LOH, the Nuri has substantially more maintenance and operational requirements. The instruction does not account for any additional duties required of the tradesmen who are to maintain the Nuri, nor does it account for the Nuri's 24-hour operating tempo. Applying the instruction's manning direction would overload maintenance personnel, resulting in an inefficient maintenance tempo on these valuable and high-demand MAA assets. It is critical to identify the appropriate composition and number of maintenance personnel for the entire MAA helicopter fleet to sustain efficiently the expected operational workload while also minimizing excessive fatigue for maintenance personnel. Rather than fixing one team of technicians for each helicopter, we draw from a pool of avionic and aeromechanical technicians as needed. Major maintenance requires a full five person team (two avionic, two aeromechanical, and one more from either group) while other tasks require only one or two technicians from either group. This allows for flexibility across helicopters and tasks.

Simulation is a computational method used to evaluate a model numerically. Simulation is able to incorporate randomness through identified probability distributions based on real data, and is thus useful for studying the many interactions that occur in a complex helicopter maintenance system. We use discrete-event simulation (DES) because of its capability in modeling real world systems where state variables change at discrete points in time (Law, 2013). There are many advantages of using DES to make inferences about the real performance of the system and suggest changes if required. In this thesis, we perform a DES optimization experiment to determine the appropriate number of personnel for the maintenance crew of the new MAA helicopter fleet, while also considering personnel workloads. To model the maintenance of the utility fleet for MAA, our basic model's inputs include fleet size, maintenance procedures, helicopter operations, personnel work schedules and helicopter scheduled maintenance. The model is designed to answer the following questions:

- What is the initial number of personnel the Army Human Resources department should recruit for the new helicopter fleet?
- How does the maintenance system respond to changing rates of requests for helicopter operations?
- How can simulation optimization and R&S techniques be used to make these decisions given uncertainty in system performance?

B. LITERATURE REVIEW

Interest in simulation optimization is on the rise; previous military and civilian helicopter applications use a variety of simulation optimization techniques. For example, Mattila, Virtanen, and Raivio (2008) improve maintenance decisions in the Finnish Air Force through simulation. A study conducted by Marlow and Novak (2013) used DES to predict the size of a fleet of naval combat helicopters. An important goal of DES models is to compare and select the best design scenario from competing design alternatives without incurring any physical costs. To achieve this goal, ranking and selection (R&S) is applicable, given discrete input parameters and the small number of designs. R&S is a group of statistical techniques developed to address the optimization problem of selecting the best system or a subset that contains the best system design out of a set of competing alternatives.

Jacobson (2003) conducted a survey and concluded one of the important uses of DES models is its capability in comparing and contrasting various design alternatives without incurring extra costs, and that R&S is widely used as a statistical method for selecting the best design from sets of alternatives. Boesel, Nelson, and Kim (2003) used R&S to clean up the selection process after a simulation optimization experiment.

In this thesis, we focus on the development of a new method to calculate manning requirements for a MA unit, specifically the MAA fleet. We use R&S techniques to select the best system design.

C. OBJECTIVES

This research develops a decision aid that uses a DES for the Malaysian Army Human Resource Department to assist in determining the number of personnel to allocate to the maintenance group of the MAA's newest helicopter fleet, while simultaneously balancing maintenance personnel workloads.

D. SCOPE

The DES model is a tool the MA can use within the Malaysian defense environment. The distributions representing the maintenance activities are kept generic and can be adjusted based on helicopter type specifications. Other personnel groups required for the fleet, including operations and supporting personnel such as clerks and supply officers, will not be considered in this thesis.

E. LIMITATIONS

No reference data set from actual flight operations is used in this thesis due to its classified status. We use average values for several simulation parameters provided by MA subject matter experts (SMEs). Our current model does not differentiate some nuanced operational categories. As an example, we do not distinguish between operational and training flights or day and night flights. We do not believe the operational categories we have omitted would have any significant impact on our results. However, we do differentiate all important operational categories; for example, off-base flights will be treated differently than on-base flights because of the large resulting differences in flight times. Additionally, this paper is unable to account for *all* of the new helicopter specifications in this instance due to a lack of available technical data.

F. ASSUMPTIONS

We made the following assumptions in the simulation:

- The fleet is conducting maintenance under ideal conditions. There are no unanticipated spare parts shortages or maintenance equipment failures that prolong the time required to conduct maintenance on helicopters.

- No flight hour extensions are applied to any helicopter that has reached its scheduled maintenance flight hours limit. We selected the durations of the maintenance according to the contract to improve realism.

G. COURSE OF STUDY

The work flow applied in this thesis is as follows:

1. Understand the factors that need to be modeled. The model will simulate each helicopter’s activities, operational demands, and maintenance requirements.

2. Represent the factors of this problem in a DES model using the state-of-the-art Simio software.

3. Use simulation-optimization methodology to determine the best system configuration to manage tradeoffs between workload and personnel cost given uncertainty in helicopter serviceability status,

helicopter deployment/tasking, and maintenance personnel availability.

4. Run multiple scenarios to determine the best personnel configuration using R&S methods of simulation optimization. The variables considered are:

    - The number of personnel allocated to the maintenance line.

    - The arrival rate of operations requests in a day.

II. SYSTEM BACKGROUND

To facilitate a basic understanding of the simulated system, this chapter provides a detailed description of the helicopter fleet maintenance line flow in the MAA, including operations request rates and maintenance activities such as inspection, repair, and scheduled and unscheduled maintenance.

A. BACKGROUND

It is vital that MAA ensures the operational availability of the Nuri helicopter fleet is consistently high in order to support MA operational tasking. The Nuri helicopters are to be maintained by certified personnel with the correct training who are capable of using appropriate tools and equipment in accordance with MAA maintenance manuals. The maintenance crew is responsible for all aspects of maintenance support and logistics for helicopter readiness, and all helicopter subsystems through the servicing, inspection, rectifications and repair on the equipment. Systemic failures to meet the required standards would almost certainly degrade the ability of the fleet to perform its assigned tasks and could jeopardize MA operations.

The helicopter’s systems generally are divided into two groups; aeromechanical and avionic. Avionic systems include the electrical system, electronic system, air conditioning, navigation, communication, and helicopter radar. Aeromechanical systems include the engine system, rotor, hydraulics, mechanical flight control, and airframe.

B. HELICOPTER MAINTENANCE POLICY

The objective of MAA helicopter maintenance activities is to preserve helicopter safety and mission reliability to achieve the required level of helicopter availability, while utilizing available resources efficiently. The integrity of the helicopter is maintained through various types of servicing, and periodic maintenance checks are conducted based on flying hours. Flying hours accumulate from the time a helicopter becomes airborne until the time it touches down on the ground. After every flight, a helicopter's flying hours are recorded and stored. A helicopter's flight hours are used to determine when periodic servicing of the helicopter is due. Aircraft maintenance in the MAA is conducted at three levels:

1. Organizational Level Maintenance (OLM)

OLM covers all maintenance activities performed by the fleet maintenance crew. This includes tasks directly related to the preparation of the helicopter for flying and is known as Flight Line Servicing (FLS). OLM also encompasses scheduled maintenance, repairs and rectifications, and other associated maintenance work within the fleet maintenance capability. OLM tasks require a small range of support equipment and may involve the limited use of workshop facilities.

a. Flight Line Servicing (FLS)

FLS covers the final preparation of the helicopter for flight, turn around servicing as appropriate, and the subsequent servicing required after flight. FLS encompasses such tasks as the replenishment of consumable stores, and the examination of the helicopter for physical damage and defects, particularly of those items which are subjected to wear. It is divided into three parts as follows:

- **Before Flight Servicing (Check A)**. The servicing carried out to ensure that the helicopter is fit for its first flight of the day.
- **After Flight Servicing (Check B)**. Check B is carried out after the last flight of the day to replenish consumables as required and to replace covers to secure the helicopter for overnight parking.
- **Turn Around Check (Check C)**. Check C is the servicing performed when the helicopter is expected to fly again within 8 hours of landing.

b. Scheduled Maintenance

The OLM scheduled maintenance includes predetermined periodic maintenance that is within the capability of the maintenance crew. OLM requires basic facilities and tools, and can be done in the fleet. Check 1 and Check 2 are the names of the scheduled maintenance under this category.

2. Intermediate Level Maintenance (ILM)

ILM covers a wider scope of tasks than OLM that are beyond the capability of the fleet. It includes repair of complicated helicopter sub-assemblies and replacement, realignment, rectifications, modifications and major scheduled maintenance that requires a wider range of support equipment and facilities. Check 3 and Check 4 are the names of scheduled maintenance in this category.

3. Depot Level Maintenance (DLM)

This involves more complex maintenance activities beyond the capabilities of the fleet that require the facilities and services of overhaul agencies. These involve major repair, refurbishing, reconditioning, rebuilding, major stripping and components overhaul. Check 5 is the name of scheduled maintenance in this category.

4. Scheduled Maintenance Cycle

Description of a task as OLM, ILM or DLM provides no additional information about the form of maintenance involved. Maintenance processes are classified in this way to provide a convenient means of describing the general degree of difficulty to perform the associated tasks. The helicopter manufacturer has set the helicopter to undergo a thorough inspection after every 60 flying hours to ensure the integrity of the helicopter. Details about each type of scheduled maintenance are provided in Table 1.

Table 1. Scheduled maintenance for Sikorsky S61A-4 helicopters

MAINTENANCE TYPE	AIRFRAME HOURS	PERIOD (DAYS)	MAN HOURS	MAINT LEVEL
CHECK 1	60	2	40	OLM
CHECK 2	180	3	100	OLM
CHECK 3	540	21	1300	ILM
CHECK 4	1080	28	1500	ILM
CHECK 5	4320	135	7970	DLM

The maintenance of the helicopter is categorized into 3 levels with specific requirements.

C. FLEET MAINTENANCE CREW

The task of retaining a helicopter in serviceable condition requires many different maintenance processes to be performed by qualified and competent engineers and technicians adhering to procedures in the MAA *Technical Competency Instruction—Engineering* (1996). These highly trained technicians are divided into two trades, aeromechanical and avionic. The responsibilities of the avionic technician are to carry out routine scheduled maintenance involving maintenance and repairs on electrical systems, power generators, and wiring. Their job scope also involves maintenance, calibration, replacement and repair of electronic equipment including the radio compass, altimeter, pressurization systems, radar, and communication systems. Aeromechanical tradesmen undertake routine scheduled maintenance, inspection, maintenance and repair on all helicopter equipment related to the engine system, rotor, hydraulics, mechanical flight controls, and airframes. In maintenance activities where more than one trade is involved, the predominant trade is responsible for performing and certifying completion of the maintenance process.

Technicians are often unable to work at full capacity since additional duties, including other military duties, academic and technical courses, leave, or medical issues will frequently decrease manpower in the maintenance line. Additionally, because the Nuri helicopters will be required to fly at night, technicians will be required to work in shifts, and tradesmen should be divided accordingly. We are interested in modeling the utilization of the maintenance operation process to account for these issues to choose the correct number of technicians to work on the maintenance line.

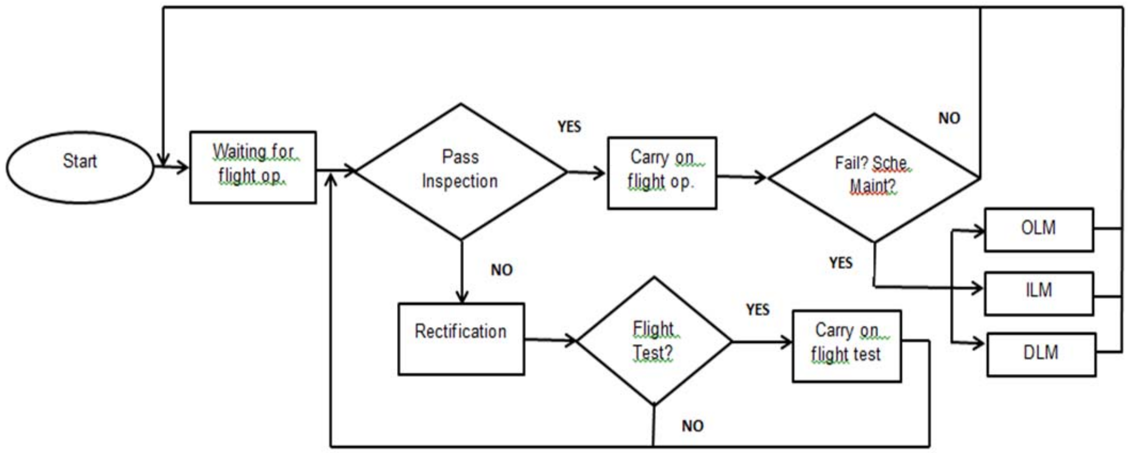
Rather than keep the teams in fixed groups of five, each time a maintenance task is ready to be performed on a helicopter, a team of five is formed from available mechanics. If not enough people are available, the helicopter will wait until a team is ready. Teams are disbanded after completion of work on a particular helicopter. This makes them available for working on different parts of the system, or on smaller tasks that only require one or two technicians.

D. MAINTENANCE OPERATION PROCESS FLOW

All maintenance at and under the OLM level will be conducted in the fleet and will be carried out by MAA maintenance crews. The number of maintenance personnel assigned to a maintenance server will be determined by the type and complexity of the given helicopter defect. Many relatively simple jobs, such as conducting a realignment or replenishing engine oil, require just one technician. However, many more severe defects such as those involving, for example, a helicopter main gear box removal or engine replacement, require several technicians. The complexity of the defect will also influence the time necessary to rectify the problem. We model this variability in every maintenance server. Since no data is available, we use a triangular distribution provided by a subject matter expert to model the rectification time. We denote the triangular distribution using Triangular(a,m,b), where a and b are the lower and upper limits of the distribution, and m is the mode of the distribution (the location of the peak). Law (2013) outlines properties of the triangular distribution.

The flow of the maintenance operation process, displayed in Figure 3, is initiated when the fleet operation room receives an operation request from the MA Headquarters, and ends when a helicopter finishes its flying for a given day.

Figure 3. Fleet maintenance flow



1. The Operation Request

The maintenance line in the fleet begins operations when the operations room issues the flight program or operation to be conducted to the maintenance line. We determine the number of operation requests from suitable distributions that will be discussed in later sections. An assigned sortie/tasking is cancelled if there is no helicopter available for 12 hours from the time a request is initiated and the model records the requested operation as incomplete in the output.

2. Hangar

Helicopters wait in the hangar until assigned to a flight operation. The number of serviceable helicopters dictates the number of sorties that can be conducted for the day. Helicopters that are being serviced are not considered available for operations until maintenance is completed.

3. Inspection

Helicopters are prepared by the fleet’s maintenance crew. A team consisting of technicians from both trades carries out the flight line servicing on the assigned helicopter to ensure the airworthiness of the helicopter before the helicopter is handed over to the air crew for flight operations. We include the possibility of aborting the operation because of a low probability defect.

4. Rectification

Probability distributions are used to model the probabilities of various helicopter defects occurring. Only one type of defect can occur at a time. The number and specialty of personnel assigned to the helicopter for the rectification depends on the nature of the fault. For example, defects on avionic systems require avionic technicians. Some of the defects require only minor adjustments to equipment and are solvable in a relatively short amount of time. However, some defects require substantial maintenance time and may even require a flight test to clear the defect. The time taken for the rectification process varies according to the complexity of the defect.

5. Flight Test

The flight tests are mostly conducted by air crews, though some defects do require at least one technician to be on board to collect system data. These following conditions require the helicopters to be flight tested:

- Intermediate Level and Depot Level servicing.
- Any adjustment likely to affect the flying characteristics of the helicopter.
- The replacement of major components, e.g engine and control systems.
- Any work where a flight test is required to test the functionality of the fitted equipment.

6. Flying Operations

There are two flying programs conducted in the fleet: training and operational flying. “Training flights” are any flights conducted by an aviator to maintain flying competency. “Operational flights” are normal MAA operations. This distinction is unimportant for the purposes of the model. However, it is important to distinguish whether flying is conducted “on-base” or “off-base”, because of the vastly different flight hour distributions that result. We determine the duration of each operation randomly using a symmetric triangular distribution based on the parameters given by a MAA subject matter expert.

7. Documentation

All flying hours recorded by the helicopter are documented in a special log-book used as the reference for calculating the periodic servicing of the helicopter and due time for its components.

8. Scheduled Maintenance

The cycle for each variety of scheduled maintenance commences from the time the servicing is complete until the same servicing is due again. Scheduled maintenance is performed on the basis of cumulative flight hours. Each type of scheduled maintenance is assigned to a specific facility according to its complexity.

E. DISTRIBUTION SELECTION AND PARAMETERS

Due to limited access to MA helicopter fleet classified data, we depend on subject matter experts and the author's extensive personal experience in the MAA operating environment to define model input data. We derive the parameter for the operations request interarrival time based on the author's fleet experience; we use an exponential distribution with a mean of 1 hour as a base case. This parameter is then varied in the simulation optimization experiments to test the system's sensitivity to the rate of requests.

We determine some other model parameters (e.g., flight duration, number of maintenance personnel assigned in each server, and scheduled maintenance interval and duration) using the opinions of a MAA SME.

Using a MAA SME, we estimate the following parameters:

- Interarrival times for the operation requests;
- Probability distribution for the times between failures;
- Number of crew participating in every event;

- Duration of flying activities.

As discussed in the assumptions, we do not consider delays due to material availability. For scheduled maintenance, since the scope of work is conducted per the manual and is straightforward, we do not consider durations longer than agreed in the manual/contract. Therefore, we use a symmetric triangular distribution for scheduled maintenance processing times (Mattila, Virtanen, and Raivio, 2008). No data is available on the mean times between failures or need for rectifications; therefore we select the occurrence probability based on expert opinion. For the maintenance crew, we determine the size based on the MAA Engineering Instruction mentioned earlier. Details for these processes are noted in Table 2.

Table 2. Maintenance processing distribution parameters

MAINTENANCE TYPE	LEVEL	CREW SIZE	DURATION DISTRIBUTIONS
Inspections (A,B,C)	OLM	5	Triangular(0.5,0.75,1.0) hrs
Rectification	OLM	2	Triangular(0.5,0.75,1.0) hrs
FlightTest	-	-	Triangular(1.0,1.5,2.0) hrs
InBaseFlying	-	-	Triangular(2.0,3.0,4.0) hrs
OffBaseFlying	-	-	Triangular(10,15,20) hrs
Check1	OLM	5	Triangular(2,3,4) days
Check2	OLM	5	Triangular(3,4,5) days
Check3	ILM	5	Triangular(21,23,24) days

Check4	ILM	5	Triangular(28,30,32) days
Check5	DLM	5	Random Triangular(135,140,142) days
Documentation	OLM	-	Random Triangular(10,20,30) mins

We determined the maintenance level and crew sizes as per instruction in MAA Engineering Instruction and the maintenance durations for scheduled maintenance based on expert opinion.

III. CONSTRUCTION OF THE SIMULATION MODEL

We build a simulation model of helicopter maintenance operations flow using the commercial software Simio (Kelton, Smith, & Sturrock, 2014). The helicopters and the operation requests are two different entities, produced from two different sources (“Operation” and “Hangar”), and are joined together in the model. The maintenance cells of the fleet are represented as servers processing the entities, while the maintenance personnel are the resources who perform all the related tasks at the servers.

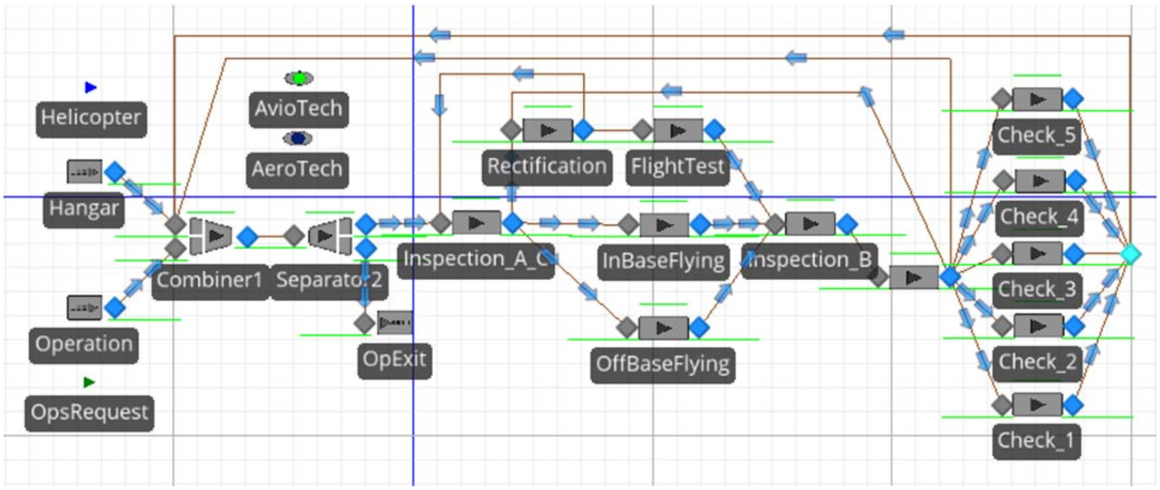
The model is initialized by the source called Operation that produces an entity called Operation Request (OpsRequest). This request then combines with an entity Helicopter created by the source called Hangar. This process produces combined entities that represent the helicopters being assigned to the specific tasking to be conducted by the fleet. Only a combined Helicopter-OpsRequest entity is processed through the system. A series of servers represent the various stations the helicopter goes through before and after flying. Each process in each server has its own processing time, according to an appropriate random distribution discussed earlier.

We note that whenever we refer to a team of five technicians, that team consists of two avionic and two aeromechanical technicians, with the fifth member drawn from either type who serves as a senior tradesman. The major servers require these five-person resource teams, while other tasks may require fewer technicians from either trade.

A. SYSTEM SETUP

To model the system as described previously, we place 2 Sources, a Combiner, 11 Servers, a Separator, and 1 Sink into the Facility Window as seen in Figure 4.

Figure 4. Fleet maintenance model in Simio



B. MODEL OBJECTS DESCRIPTION

These are the objects used in the model based on the description provided in Kelton, Smith, and Sturrock (2011):

1. **Entities:** Entities define a dynamic object that can be created or destroyed. It can carry data through a network of nodes, and enter/exit servers, queues, or through their associated nodes. There are two entities in the model.

    - Helicopter—Entity that represents a helicopter available in the fleet to operate on the particular day.

    - OpsRequest—Entity that represents an operation request to be fulfilled on the particular day.

2. **Source:** Sources generate specified entities with a given interarrival time distribution. There are two sources in the model.

    - Hangar—Source that generates serviceable helicopters in the fleet. It generates the entity Helicopter in the model.

- Operation—Source that generates helicopter operation requests represented by entity OpsRequest.

3. **Resources:** Resources provide the manpower that can be seized and released to process the entity at different servers. The number of these resources will be changed to optimize the model function and answer the key research question. Because we seek steady-state results, we run the simulation continuously across time without stopping the model at night when the technicians are not working.

    - Aeromechanical technician (AeroTech).
    - Avionic technician (AvioTech).

4. **Servers:** Servers represent capacitated processes that have processing times at each station. Servers seize resources to work on a particular entity, and then release those resources after the job is complete.

    - Inspection_A_C—Server that represents fleet's flight line servicing Check A and Check C inspections carried out by technicians of both trades in teams of five.
    - OnBaseFlying—Server that represents in-base operations conducted by the fleet based on the request received by the operation room.
    - OffBaseFlying—Server that represents off-base operations conducted by the fleet based on the request received by the operation room, and requires one technician of either trade.
    - Rectification—Server that represents action taken on a defective helicopter. The work is carried out by two technicians of either trade by random selection.
    - FlightTest—Some (corrected) defects need to be verified by flight test before a helicopter is certified as serviceable, and requires one technician.
    - Documentation—Server that records the aircraft flying hours for scheduled maintenance purposes.
    - Inspection_B—Server that performs fleet's flight line servicing Check B inspection, carried out by a team of five technicians.

- Check1—OLM scheduled maintenance carried out by technicians of both trades from the fleet, carried out by a team of five technicians.

- Check2—OLM scheduled maintenance carried out by technicians of both trades from the fleet, carried out by a team of five technicians.

- Check3—ILM scheduled maintenance carried out by contractors at their facility.

- Check4—ILM scheduled maintenance carried out by contractors at their facility.

- Check5—ILM scheduled maintenance carried out by contractors at their facility.

5. **Combiner:** Combiners are a process that combines the entities OpsRequest and Helicopter to determine the number of helicopters entering the maintenance system. The number of helicopters in the system shall not exceed the number of serviceable helicopters on the particular day. This ensures helicopters do not fly without a mission. The Combiner does not have a processing time.

6. **Separator:** The separator is an object that splits a batched group of entities processed by a combiner.

7. **Sink:** Sinks destroy entities that completed processing in the model.

   - OpExit**—**Entity OpsRequest exits through this sink and indicates the requested operation has been completed.

C. FLEET OPERATION FLOW

The activities of the fleet start with the source Hangar producing the entity type Helicopter. The number of helicopters produced by the source depends on available number of helicopters in the fleet. Once the model is running, the number of serviceable helicopters and the operations requests determine the number of helicopters entering the maintenance system on a particular day.

The source Operation generates the entity OpsRequest that represents a flying operation requirement. The operations requests arrive with an interarrival distribution and required flying hours for the sorties. If an operation request is made and a helicopter is available, then they will be joined in the Combiner to replicate the helicopter being assigned to a specific tasking or flying operation. The Separator removes the OpsRequest as the mission assignment is complete and then only the helicopter entity proceeds with the next steps. The combined entity goes through the server Inspection_A_C to conduct Check A by a team from the resource maintenance crew consisting of two aeromechanical tradesmen and two avionic tradesmen and the work will be verified by the senior technician of any trade. The total manpower for this team is five. Check C will only be conducted if the helicopter is meant to fly a subsequent sortie.

If the helicopter passes the daily inspections, it will proceed to the flying activities in OnBase or OffBase servers. The servicing time of this server represents the time taken for flying. However, if there is any defect found during the inspection, the helicopter goes to the Rectification server so the maintenance crew can repair the helicopter. There are two types of rectifications; avionic and aeromechanical. Minor defects such as pressure fluctuations or insufficient oil can be rectified easily in a short time. However, for the major defects that involve the helicopter's control system or vibrations, the helicopter requires more complicated maintenance and must go for a flight test before being certified serviceable. If the defects are not cleared after the flight test, the helicopter returns to the Rectification server. After any flying activities, the returned helicopter will be inspected again at the Inspection_B server and kept in the Hangar for later employment.

After all inspections, the flying hours are recorded at the Documentation server for maintenance purposes. Here, any faulty helicopter will be sent to the Rectification server if needed. For a serviceable returned helicopter, if there is a queue of requests to fly (OpsRequest), it will go through Check C at the Inspection_A_C server before proceeding to its next flying assignment. If the flying hours of the helicopter have reached the threshold of flying hours since the last maintenance, it will enter the appropriate server Check 1 to Check 5 to carry out scheduled maintenance. An add-on process in Simio is used to check the flying hours and past checks completed to determine what the next check would be. We exploit the pattern in the check process and use modulus mathematics to simplify the determination of which check server should be visited next. Check 1 and Check 2 are conducted by the fleet maintenance crew (each requiring a standard team of five technicians), while Check 3 and higher-level inspections are conducted by a certified contractor. These inspections do not require the fleet's manpower, so we only model the time spent and not the number of contractors needed.

D. EXPERIMENT DESIGN

We model our system to assess how different configurations or changes in our input data affect the simulation output through the responses. The scenario input data are based on the four different series of experiments using the described parameters. We study design of experiments methods by Montgomery (2001) for the simulation analysis. The experiments were split based on having different personnel configurations working in the maintenance line. In this first preliminary experiment to validate the model, one thousand replications of each scenario were run inside each experiment and the results were compared.

Table 3 shows the controls and responses in our experiments that we setup and ran for our model. Note that there is only one type of personnel, AvioTech, as we do not differentiate between the two trades or the type of helicopter failure, because the effect of both variables is similar. All other model specification parameters remain the same.

We also consider the intensity of operations requirements in terms of the interarrival time of the requests and the flight duration, but did not differentiate between operations and training flights because of the similarities between both types. The conduct of the operation depends on the availability of the helicopter that is determined by the maintenance activities requirement.

The model output consists of the number of conducted operations, queueing times and resource utilizations. Table 3 shows a sample experiment, though Chapter IV will outline the more extensive experiments in detail. The first control is the number of avionic technicians in the system. The number of aeromechanical technicians will also be equal to this value. The avionic and aeromechanical technicians will be combined to form the teams as needed. The second control is the mean time between the arrivals of operations requests in hours using the exponential distribution to simulate the time between arrivals. We denote the interarrival distribution using “Exp(x)” where x is the mean of the exponential distribution in hours. We purposely chose one slow rate of request arrivals for this experiment (average of one per day), and one fast rate (average of 12 per day) to observe if the model was working properly. For each row, the experiment was replicated a hundred times, with each replication having a run length of ten years. The responses for our experiments, averaged over the replications, deliver the mean number of helicopters in the queue (number in the hangar awaiting an operation), the mean number of operations requests in the queue (awaiting a helicopter), the average utilization of the avionic tradesmen (assuming all tradesman are available for work 100% of the time), and the average number of missions completed. All experiments are run with 12 helicopters.

Table 3. Controls and responses

Controls		**Average Responses**			
Number Avio Techs	OpsRequest Interarrival Dist: Exp(Hours)	Number Helicopters in Queue	Number of OpsRequests in Queue	AvioTech Utilization	Missions Completed
2	Exp(24)	0.4455	65.66	100	0
2	Exp(2)	0.001489	21882.6	100	0
5	Exp(24)	11.96	0	0.796	216.7
5	Exp(2)	0.003652	21864.7	99.9836	21.16
10	Exp(2)	0.012629	10877.4	82.2247	31159.3

E. MODEL VALIDATION

To validate the model, the inputs should at least affect output behavior in the same manner as real changes to the actual system would impact the fleet.

Because of the limited access to real data for the analysis, the parameters are determined by the author, who is considered a subject matter expert in the field.

The model is good for initial exploration of the problem if the simulation output behaves in the same way as the actual system is affected by the changes. We have chosen the mean occurrence that the helicopter receives scheduled maintenance to test the hypothesis that our model is a good representation of the real system in the fleet. In the design experiment, we change the parameters of our resources and left other simulation parameters (such as processing time distributions) as fixed to isolate the problem of deciding the number of technicians to employ in the maintenance system. The operation's interarrival time should have the biggest impact on the model because it dictates the maintenance work needed and the number of technicians needed, although the system is also constrained by having only 12 helicopters available to carry out missions. The final model represents the basics of the flight operation and the maintenance flow in the fleet, and can be improved for future use.

We can see from Table 3 that there are insufficient personnel in rows 1 and 2 to form a team, so maintenance processes cannot be carried out and the helicopters will be unable to carry out missions. For the minimum number of personnel to form a team (5), fewer missions were carried out for the rapid arrival of missions compared to the slower arrival rate. This is because of the bottleneck that occurs when only one maintenance crew is available. Little or no parallel processing of helicopters can occur. The number of completed missions increased tremendously after we added more personnel. Table 4 shows the result of our validation efforts to simulate the maintenance activities in the fleet.

Table 4. The simulated scheduled maintenance system of the fleet

Maintenance Type	**Level**	**Frequency**
Check 1	OLM	1655

Check 2	OLM	552
Check 3	ILM	138
Check 4	ILM	104
Check 5	DLM	29

We compared our simulated scheduled maintenance result from our model with the cycles from the OEM as per Table 4, which can be simplified as shown in Table 5. By reading each row from left to right, Table 5 lists the order that different scheduled maintenance events must occur. The maintenance order is divided into rows to reveal the patterns in the type of maintenance that must occur. We exploit these patterns in the model to quickly determine the next type of scheduled maintenance.

Table 5. Simplified S61A-4 scheduled maintenance cycle

Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 3
Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 4
Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 3
Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 4
Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 3
Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 4
Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 3
Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 2	Cx 1	Cx 1	Cx 5

Based on the cycle of the scheduled maintenance of the helicopter, the expected number of total scheduled maintenance tasks of each type should approximately match the number completed observed in the model. The minor discrepancies are shown in Table 6 and help validate the model.

Table 6. Comparison of the planned and modeled total scheduled

maintenance tasks completed

Object	**Planned Value**	**Percentage of checks**	**Simulated value**	**Percentage of checks**	**Discrepancy**
Cx 1	48	0.66667	1655	0.66787	0.12 %
Cx 2	16	0.22222	552	0.22276	0.05 %
Cx 3	4	0.05556	138	0.05569	0.01 %
Cx 4	3	0.04167	104	0.04197	0.03 %
Cx 5	1	0.01389	29	0.01170	0.22%

IV. ANALYSIS OF RESULTS USING RANKING AND SELECTION

A. INPUT CHOICES

The scenario inputs are a critical part of a valid simulation model, and we discussed in Chapter II how we chose the inputs. We run multiple scenarios of our model, each with different input values. In the first experiment, we simulated ten scenarios, each with 25 independent replications. Across scenarios, the numbers of AvioTech resources varied from two to 50, representing the amount of avionic technicians that were available to perform all required maintenance work when called by the maintenance servers. The number of AeroTech resources will always be the same as the number of AvioTech resources. Increasing the number of technicians enables more stations to conduct maintenance on the helicopters simultaneously. Each server requests the appropriate number of technicians of either type before service can begin on a helicopter. Because servers require varying numbers of technicians, we vary the total number of technicians in the system rather than the number of teams. We will increase the number of technicians and study the impact on the number of operations completed, helicopter availability, and utilization of the personnel. We want a large number of operations completed, and a high helicopter availability rate (measured by a high number of helicopters in the queue). We also want a large utilization of personnel, but must balance this against fatigue. The utilization should be less than 100% to allow for time to complete other administrative responsibilities, and to make sure the queues are stable. In the next experiment, we also examine the effect of different arrival rates for the operation requests in the fleet. Too high flight intensity can overcrowd our maintenance facilities, but too low will not satisfy MA mission requirements. Controlling the arrival rate of OpsRequests also represents our effort to manage the flying hours of all helicopters at a sustainable rate. It can also prevent too many helicopters being due for scheduled maintenance at the same time. To avoid the helicopters from being quickly exhausted by the rapid operations demands, equipment utilization is used to limit the number of flying hours allowed for each helicopter. For this specific helicopter the equipment utilization is 60 hours per month. With its average flying time around 5 hours per sortie, we can expect that each helicopter only flies 12 sorties per month. This is approximately modeled by a mean time between OpsRequests of five hours.

B. OUTPUT METRICS

This section explains various output metrics from the simulation. Simio is designed to automatically collect entity and resource information. Thus, the following responses were collected in Simio for analysis:

- Average number of helicopters queueing (waiting for operations). This is the average number of helicopters ready for an operation in the hangar and represents the readiness of the fleet.
- Average number of operations requests (waiting for helicopters). This represents the average number of operations at any given time that are waiting to be started because no helicopters are available.
- Utilization percentage of resources (personnel). This is the percent of time that the technicians are working (assigned to a helicopter) throughout the replication. This value is averaged across all technicians, so a value of 50% implies on average half the technicians are working at any given time.
- Average number of missions completed over a ten-year period.

These responses are the essential outputs of our simulation and the data needed for system design decisions in the fleet.

C. RANKING AND SELECTION

We implement R&S in Simio using the built-in function named Subset Selection Analyzer. This program uses the KN algorithm based on research by Kim and Nelson, (2001). This algorithm delivers a subset of systems that include the best system with a specified probability guarantee. We provide the experimental design, where each scenario has different inputs to the same model. The algorithm then runs the specified replications and compares all scenarios. The Subset Selection Analyzer determines the best subset of alternatives based on the variability in the mean response value across replications. This technique is suitable for our model because the input parameters in our study are discrete and we only need to try a small number of configurations. The user chooses whether they want to maximize or minimize the expected value of a given performance metric and then the algorithm gives the possible best subset of systems.

Subset selection is a statistical formulation designed to select a random sized subset that contains the best alternative with a specified probability based on inputs by our SME, and based on the estimation of each alternative's expected performance (Kiekhaefer, 2001). Simio segregates the output based on the responses into two groups: "Possible Best" and "Rejects" where the scenarios in "Possible Best" will be statistically better than the scenarios in the latter group. This takes into account the standard errors associated with the mean output. If the standard error is low relative to the difference in means, then the algorithm separates the "Possible Best" from the rest. In this experiment, we set ten different scenarios, each with 25 or 100 replications. Different systems require different numbers of replications depending on their variability, and their likelihood of being the best. We want to reduce the time the operations spend waiting in the queue for a helicopter to be available by having enough technicians to complete maintenance. Our preference (possible bests) will be scenarios with response values statistically better than the other group (rejects). In the first experiment, we vary the number of technicians when the operations request rate is high (the distribution between requests is exponential with a mean of two hours, denoted Exp(2) in the tables). For the second experiment, we vary the arrival rate of the OpsRequest to represent the intensity (or frequency) of the missions carried out by the fleet. While some operations cannot be controlled as they come from higher command, normal operations, such as training flights, are scheduled by the fleet. As these two factors directly dictate the flying activities in the fleet, it is important to get the correct configuration to optimize the fleet's operations.

D. SIMULATION RESULTS

We first vary the two inputs (number of technicians and operations request rate) separately to approximate the appropriate number of technicians and a reasonable range for the request rates. It is expected if the request rate is too high, then model performance is limited by the number of helicopters and thus additional technicians will not matter. The experiments at the end of this section will combine the two factors to determine the best number of technicians to employ under a reasonable request rate. Shaded results in the tables imply that the Ranking and Selection algorithm has selected that configuration as a "Possible Best," meaning that according to the given responses, that configuration is likely to have the best mean result given the variation across replications in each configuration. The R&S algorithm employs a 95% probability guarantee that the selected systems include the best configuration.

The first result shows the effect of personnel allocation to the maintenance servers and excludes the impact of different mean interarrival times of operations requests. We compare the results of running 25 replications (Table 7) with running 100 replications (Table 8). Each replication runs the system for a ten year period to obtain steady-state results and allows all the helicopters to circulate through the different maintenance levels. Here we simulate frequent requests (every two hours on average) to see how the system performs when there are not enough helicopters to meet the operational need.

Table 7. Result of 25 replications varying number of technicians

Controls		Average Responses			
Number Avio Techs	OpsRequest Interarrival Dist: Exp(Hours)	Number Helicopters in Queue	Number of Requests in Queue	AvioTech Utilization	Missions Completed
1	Exp(2)	0.001489	21882.6	100	0
2	Exp(2)	0.001489	21882.6	100	0
5	Exp(2)	0.003652	21864.7	99.9836	21.16
10	Exp(2)	0.012629	10877.4	82.2247	31159.3
15	Exp(2)	0.011258	8385.23	57.2669	38529
20	Exp(2)	0.010757	8240.63	42.4394	38829.9
25	Exp(2)	0.010422	8229.4	34.0276	38833.3
30	Exp(2)	0.010422	8187.59	28.3611	38881.1
35	Exp(2)	0.010422	8187.59	24.3095	38881.1
40	Exp(2)	0.010422	8187.59	21.2708	38881.1

The “possible best” group is identified by the gray shading in the corresponding responses.

Table 8. Result of 100 replications varying number of technicians

Controls		Average Responses			
Number Avio Techs	Ops Interarrival Dist: Exp(Hours)	Number Helicopters in Queue	Number of Requests in Queue	AvioTech Utilization	Missions Completed
1	Exp(2)	0.001613	21901	100	0
2	Exp(2)	0.001613	21901	100	0
5	Exp(2)	0.003414	21884.1	99.9854	20.6
10	Exp(2)	0.011699	10830.2	82.1982	31234
15	Exp(2)	0.011382	8327.98	57.2979	38562.6
20	Exp(2)	0.011721	8199.92	42.455	38857.7
25	Exp(2)	0.011630	8205.42	33.9862	38872.3
30	Exp(2)	0.011630	8198.85	28.3377	38883.5
35	Exp(2)	0.011630	8198.85	24.2894	38883.5
40	Exp(2)	0.011630	8198.85	21.2533	38883.5

The “possible best” group is identified by the gray shading in the corresponding responses.

As shown in Table 7, there are five “Possible Best” scenarios for reducing the average number of requests in the queue and increasing the average number of missions completed: the number of AvioTechs are 20, 25, 30, 35 and 40. Even when we increased the number of replications from 25 to 100 for all scenarios and use the Subset Selection Analyzer, the subgroup of “Best Selection” remains the same, indicating 25 replications may be sufficient for our experiments, (see Table 8). We observe the following from the results:

- No missions will be carried out if number of personnel is less than five people, which is the minimum requirement for a helicopter maintenance team in the following servers: Inspection_A_C, Inspection_B, and Check1 and Check2.

- As the number of technicians increases, the average number of requests in the queue becomes larger than 8,000. This implies that even though we have plenty of technicians, there are not enough helicopters to support this level of requests. The small number of helicopters in the queue implies that helicopters are constantly in use.

- More than 30 AvioTechs (60 total technicians) will not significantly improve effectiveness given that there are only 12 helicopters.

- The 30 AvioTech or 60 total technician configuration results in the maximum number of missions completed (38883), and the utilization of the personnel as greater than 30%. For 20 AvioTech (40 technicians total) the utilization was less than 45% and for 25 AvioTech (50 total) less than 35%.

Based on the number of completed operations, we recommend to the MA Human Resource Headquarters to employ no fewer than 40 technicians, consisting of 20 AvioTech and 20 AeroTech in the new fleet. These results make sense because there are only four servers in the fleet that require the technician to conduct daily servicing, namely the Inspections (Check A, Check B and Check C), and the Rectification servers. In addition, the requirement for helicopters to conduct scheduled maintenance is not as often as the daily servicing. With an intensity of one flight every two hours, 40 technicians (20 of each type) can ensure the best maintenance performance even though there are not enough helicopters to support the operational need. When the helicopters have to conduct scheduled maintenance, then the extra manpower is useful. From these results we can see there is a significant improvement in the number of helicopters served for 20 AvioTech (40 technicians total) but after 25 AvioTech (50 technicians) the marginal improvements were smaller. Adding more personnel above 30 AvioTech (60 in total) will not have much effect on the operations. Of course, the number of helicopters is limited to 12 so this will also provide an upper bound on the number of resources needed. Next, we explore the effect of changing the rate of operations requests.

If operations requests arrive with high frequency, it will influence many things in the fleet: maintenance activity increases, flying hours accumulate faster, and the probability of a faulty helicopter increases. Technicians may not be able to keep up with the maintenance workload. Tables 9 through 12 show the responses to different intensities of the mean interarrival of operations requests. We use these tables to show that the best configuration is 20 AvioTechs across different possible arrival rates. Figure 5 displays box plots comparing the average number of missions completed for different numbers of AvioTechs when the interarrival distributions for the request rate is Exp(2). The box displays the interquartile range, while the bars show 95% confidence intervals. We clearly see that hiring beyond 20 AvioTechs yields minimal improvement. Figure 5 is also a nice graphic representation of how R&S works: The confidence intervals for 20, 25, and 30 AvioTechs overlap, but are all distinguishable from the confidence intervals for 10 or 15 AvioTechs. This is how the "Possible Bests" are selected.

Table 9. Result of 100 replications with the operations request interarrival times distributed as Exp(2)

Controls	Average Responses			
Number Avio Techs	Number Helicopters in Queue	Number of OpsRequests in Queue	AvioTech Utilization	Missions Completed
10	0.01129	10902	82.2496	31124.2
15	0.01141	8048.63	59.0176	39352.4
20	0.01158	7818.36	43.7684	39975.4
25	0.01150	7822.43	34.9541	39963.1
30	0.01152	7798.51	29.1526	39967.6

The "possible best" group is identified by the gray shading.

Figure 5. Boxplot of average missions completed over ten years with the operations request interarrival times distributed as Exp(2)

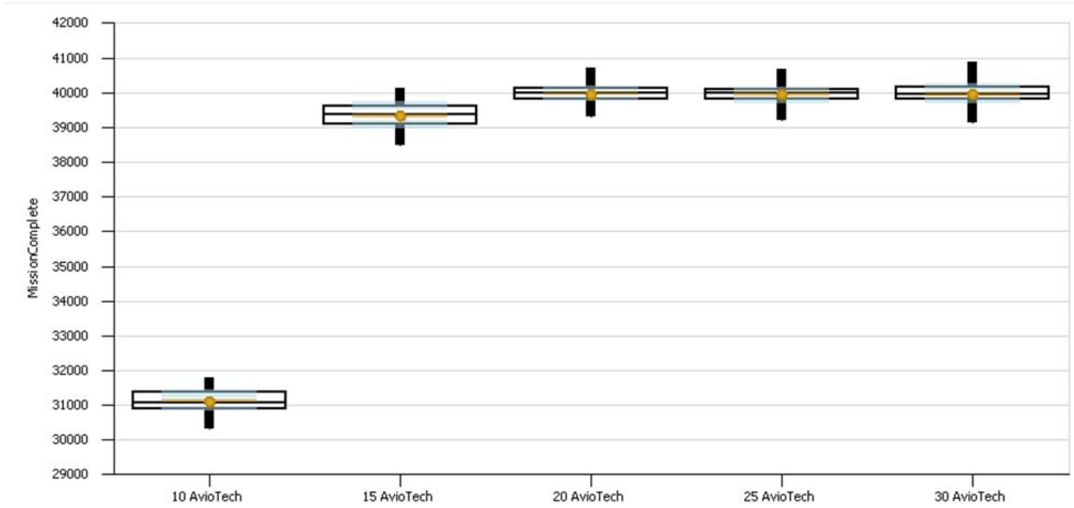


Table 10. Result of 100 replications with the operations request interarrival times distributed as Exp(3) hours

Controls	**Average Responses**			
Number Avio Techs	Number Helicopters in Queue	Number of Requests in Queue	AvioTech Utilization	Missions Completed
10	0.02492	3609.81	82.1435	31053.1
15	0.33334	1297.7	57.3778	38355.8
20	0.39259	1231.81	42.2776	38647.2
25	0.388994	1224.96	33.8334	38667.6
30	0.395113	1234.77	28.1804	38673.4

The “possible best” group is identified by the gray shading.

Table 11. Result of 100 replications with the operations request interarrival times distributed as Exp(4) hours

Controls	**Average Responses**			
Number Avio Techs	Number Helicopters in Queue	Number of Requests in Queue	AvioTech Utilization	Missions Completed
10	0.59951	524.143	78.3947	29898.5
15	2.57253	239.672	45.2442	30516.2
20	2.70491	219.68	33.2715	30464.8
25	2.6853	226.793	26.6583	30463.3
30	2.69641	224.019	22.1916	30454.4

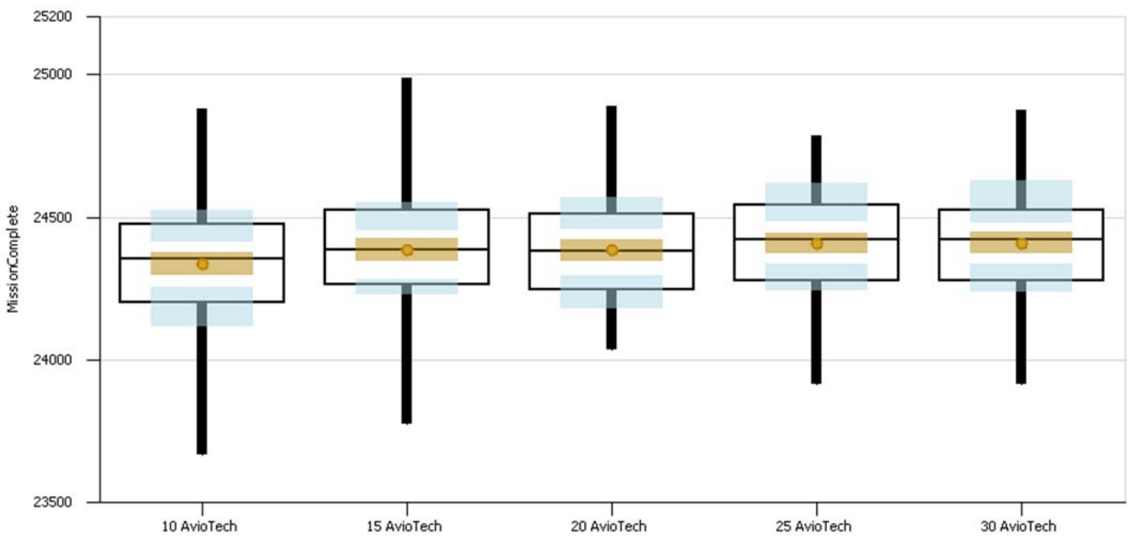
The “possible best” group is identified by the gray shading.

Table 12. Result of 100 replications with the operations request interarrival times distributed as Exp(5) hours

Controls	Average Responses			
Number Avio Techs	Number Helicopters in Queue	Number of Requests in Queue	AvioTech Utilization	Missions Completed
10	3.26509	94.6799	60.6983	24336.5
15	4.50946	79.1172	35.8055	24385.6
20	4.52737	77.2117	26.6942	24384.8
25	4.5299	78.2843	21.3518	24408.3
30	4.53275	77.7193	17.7896	24410.3

The "possible best" group is identified by the gray shading

Figure 6. Boxplot of average missions completed over ten years with the operations request interarrival times distributed as Exp(5) hours



Tables 9 through 12 have OpsRequests arriving with five different mean interarrival rates. Generally, additional techs beyond 20 of each will not significantly reduce the queue size and the utilization will become low, implying wasted personnel resources. As expected, when the number of operations requests increases, the number of missions completed also increases accordingly. However, the tradeoff is that the average number of operations waiting for the helicopter available also increases by almost double when more than one request arrives every two hours. Figure 6 shows parallel boxplots for the average number of completed missions for different numbers of AvioTechs. The boxplots show the relative variation in the results from the 100 replications.

We can see that for an arrival rate of OpsRequests higher than Exp(2) hours, or once every two hours, the average number of requests waiting for helicopters increases rapidly. When the arrival rate is high, additional numbers of personnel after 20 AvioTech (40 personnel total) does not have much effect because the total number of helicopters is fixed at 12. This confirms our first observation that 20 AvioTech is the best configuration, and hiring more people will only impose more costs to the government. Even though the number of waiting requests seems large and indicates system instability, this does not imply ineffectiveness of the maintenance crew.

Given the system is unstable with arrival rates faster than Exp(5), adding more than 20 AvioTech will not provide any additional benefit. We close by recommending that the fleet plan to accommodate no more than 5 sorties per day in the long run.

V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

As expected, the number of personnel and the intensity of the requests for operations play large roles in the maintenance operations of the fleet. Twenty AvioTech and AeroTech (40 technicians total) is the best manning configuration after analyzing the average number of operations requests in the queue, the utilization of the personnel resources, and the average number of missions accomplished. Employing fewer than the 40 technicians may result in fatigue and inability to meet mission requirements, while hiring more will not significantly affect the operational ability of the fleet and will induce additional costs. The fleet should also consider flying fewer than one sortie every five hours as a long run average rate, to avoid personnel fatigue and overuse of the helicopters. Furthermore, this thesis succeeds in displaying the capability of DES in assisting decision makers to determine possible configurations of the new fleet. The usage of Simio, based on built-in objects and processes, does not require deep knowledge in programming, and offers general capabilities for modeling any required system. The R&S method provides some statistical support for choosing a configuration and a probability guarantee that the subset chosen includes the best candidate.

B. RECOMMENDATIONS

We recommend the MAA assigns 40 technicians consisting of 20 from the avionic trade and 20 from the aeromechanical trade to support the maintenance operations of the new fleet. The fleet should also reduce the rate of flying operations to less than one sortie every five hours in the long run, given that the number of helicopters is fixed, to avoid instability as requests await helicopters. If headquarters need more flying activities, they should consider purchasing more helicopters, and can use the simulation model to decide how many further technicians to employ.

C. FUTURE WORK

In the future, this thesis can be a pilot study in simulation to determine optimal choices for some other decisions as follows:

- The number of helicopters needed to accommodate the typical operations request during day and night hours.
- The capacity of all the servers to process multiple helicopters at once.
- The appropriate work schedules for the personnel; shift or normal work schedules.
- The maintenance policy the MAA should practice on the helicopter; standard or extended. These policies have different scheduled maintenance periods and work scope.

To strengthen the analysis, we can require the helicopter maintenance policy to estimate the probability of defects to help calibrate the maintenance activity distributions. We further recommend that the MA promotes the application of simulation techniques not only in helicopter maintenance, but also in any other systems relying on a process flow in the MA environment. The model can also be expanded to a bigger system involving the higher-level command of the Army.

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