MODELING THE PAVE LOW HELICOPTER PILOT CAREER FIELD

THESIS

John C. McKoy
Captain USAF

AFIT/GOR/ENS/88D-14

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Wright-Patterson Air Force Base, Ohio
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THESIS

Presented to the Faculty of the School of Engineering of the Air Force Institute of Technology Air University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Operations Research

John C. McKoy, B.S. Captain USAF

December 1988

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Preface

I would like to thank the following individuals for their invaluable assistance:

My advisor, Major Kenneth Bauer, for his guidance, support and interest in both my welfare and my education.
My reader, Dr. James Chrissis, for his helpful editing.
My classmates for their help in getting me through the past year and a half.
My wife, [redacted] for having a good sense of humor about this whole thing.
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Abstract

This thesis presents a career model of the USAF Pave Low helicopter pilot force. A SLAM II computer simulation was developed to permit experimentation with key decision variables. Response surface methodology was used to produce two response equations which, in turn, became goals for a goal programming model. This model provided optimal values for the decision variables in order to achieve manning and experience-level goals.
MODELING THE PAVE LOW HELICOPTER PILOT CAREER FIELD

I. Introduction

The Issue

"Low-intensity conflict represents the most probable arena for the application of U.S. military force in the foreseeable future," according to Major Kenneth Page in his article, "US Air Force Special Operations: Charting a Course for the Future." As a result, Congress has directed the USAF to improve its special operations helicopter capability by building up its small force of MH-53 Pave Low helicopters. (Page, 1987:58,66)

However, at the same time, many other USAF helicopters are being phased out of service, resources which in the past have provided flying hours and experience for pilots who would later transition to the more sophisticated Pave Low. Therefore, there is concern that the Air Force may eventually be faced with the prospect of sending primarily new, less experienced pilots to the Pave Low, pilots who have not had the benefit of developing airmanship skills in a less complex helicopter.

Problem Statement

As the Air Force's pool of experienced helicopter pilots
shrinks, sustaining an experienced Pave Low pilot force will become more difficult. AFMPC does not have a model of the Pave Low pilot force to study force sustainment, so they are not able to predict how policies will affect the force.

Research Objective and Scope

The objective of this research is to develop and analyze a model of the 1025N (Pave Low pilot) career field as it will exist after the force reaches full strength in order to examine how to best sustain the pilot force in the future.

This investigation will be limited to Pave Low pilots and copilots, from the time they enter the Pave Low school until they stop flying the Pave Low permanently. It will include the time those individuals spend in career-broadening/staff assignments, assuming they return to the Pave Low cockpit. It will not include other helicopter pilots except as inputs to the Pave Low force.

Key Terms/Acronyms

AFMPC - Air Force Military Personnel Center
MAC - Military Airlift Command
PME - Professional Military Education
PQP - Prior Qualified Pilot
Rated Officer - a pilot or navigator
Rated Supplement - rated officers holding non-flying jobs in support career fields
UHT - Undergraduate Helicopter Training or a recent graduate
Outline of Subsequent Chapters

Chapter II provides a background to rated officer management and reviews modeling approaches used in the past to model personnel systems. Chapter III covers the modeling approach and output analysis used in this research. Chapter IV is the results of the analysis and Chapter V contains the conclusions drawn from that analysis.
II. Background and Literature Review

Introduction

This chapter describes how the Air Force manages rated officers and then gives brief descriptions of various methodologies that have been used to model personnel systems: in particular, military personnel systems. This review will help in the selection of the most appropriate modeling technique for the Pave Low system. The literature is reviewed in a topical order: rated officer management and personnel modeling approaches, which include both prescriptive and descriptive models.

Rated Officer Management

AFR 36-20 describes the gate system the Air Force uses to manage its rated officer force. Rated officers are required to complete six years of operational flying prior to being assigned to non-flying duties. Furthermore, "it is Air Force policy that as many members as possible perform at least 9 years of operational flying duty during the first 18 years of aviation service" (AFR 36-20:11).

Rated resource managers at AFMPC who manage the assignments of rated officers must balance these Air Force requirements with the need to provide officers the opportunity to broaden their careers in non-flying assignments such as staff duty, rated supplement, AFIT, and PME.
Additionally, the resource manager must consider what impact moving experienced personnel has on the flying organization. If a less-experienced replacement pilot must be absorbed into the unit, he must be allowed to fly to gain sufficient experience so he becomes an asset to the organization. Absorption capacity is "currently the most important factor" in determining the production rates of undergraduate flying training (Rated Management Document, 1987:6-1).

Davie (1988) said absorption could be a major problem for the Pave Low force as it expands and the pool of experienced helicopter pilots shrinks. Less-experienced pilots must have time to develop basic flying skills in addition to learning the Pave Low aircraft and mission. A linear programming model can be used to demonstrate how experience and stability requirements can severely restrict the number of inexperienced pilots (UHTs) the Pave Low force can absorb and still maintain its experience standard (Rated Management Document, 1987:6-3).

AFMPC recognizes that while a linear programming model can indicate an optimal mix of experienced and inexperienced pilots as inputs to the Pave Low force, that optimal mix will not necessarily reflect what is available for assignment (Rated Management Document, 1987:6-5). AFMPC needs a model of the force that will allow it to vary, among
other things, the mix of pilots to study the effects on force sustainment.

Personnel Modeling Approaches

Personnel models in the literature generally fall into one of two broad categories: prescriptive or descriptive. Prescriptive models prescribe an optimal solution for a given set of conditions. They generally involve some type of math programming such as linear programming (LP), goal programming, or network flow programming. Descriptive models are meant to imitate the systems and provide insight about that system. A common descriptive model is the simulation model (Olson, 1987:14,17).

Prescriptive Models

Linear Programming. A linear programming model is a set of linear equations that bounds a feasible region. An objective function is used to determine a point within that region that represents an optimal solution. The simplex method, developed by Dantzig (Hillier and Lieberman, 1986:4), can be used to solve a linear programming problem.

Kleinman and Goudreau (1977) used linear programming to determine the optimal number of Navy officer accessions from nine commissioning sources. Within the constraint to fill required slots, the model minimizes life cycle costs.

Aronson and Thomson (1985) applied forward simplex to the multi-period linear goal programming problems of Charnes, Cooper, and Niehaus (Charnes et al., 1972). They used
Markov transition probabilities between personnel grades to determine promotions from one period to the next.

TOPOPS (Akam and Nordhauser, 1974) is a USAF officer procurement program that determines the best combination of officer recruits from the various commissioning sources. It can be used to minimize costs or to maximize the quality of 20 officer types over a five year period. Charpie (1987) used both linear programming and simulation to study the USAF B-52 navigator career field. The linear program determined the optimal state of the force, including optimal accession and training rates for a given scenario. As a basis for his LP model, Charpie used a cross-sectional network model such as the one in figure 1.

<table>
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<tr>
<th>State</th>
<th>Time t</th>
<th>Time t+1</th>
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<td>0</td>
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Figure 1. Cross-Sectional Network Flows (Charpie, 1987)
This network represents positions or job types as nodes with the connecting arcs representing possible movement from one job (at time t) to another (at time t+1).

Charpie's LP model has five categories of constraints: 1) conservation of flow, 2) manning level requirements for the various jobs, 3) minimum and maximum flows from one position to another, 4) attrition, and 5) tour length. The objective function seeks to minimize a variety of variables including overall manning requirements, attrition, accessions, and upgrade training.

Charpie used the LP model to establish an optimal steady state condition for the navigator career field for a given scenario. The model, however, did have drawbacks. Charpie reported that the LP model could not incorporate as many different aspects of the career field as the simulation model could, it tended to ignore unrealistic personnel allocations, and finally, the solution was merely a "snapshot" in time and could not reflect, for example, attrition over a period of time.

**Goal Programming.** Goal Programming is an adaptation of linear programming that includes multiple goals in the objective function. Charnes, Cooper, and Niehaus (1968) developed several different personnel models for the US Navy using goal programming embedded with Markov processes.

Siverd and Thomson (1979) used ratio goal programming to assign personnel with various skill levels to jobs based on
a preferred mix of those skill levels. By doing so, they were able to maximize a measure of organizational effectiveness.

**Network Flow Programming.** Network models can be visualized as a set of nodes connected by arcs or paths. In a typical personnel network model, the nodes could represent jobs with individual workers flowing along the arcs, from node to node, as they change jobs. Thompson (1978) used a network transshipment model to approximate a linear programming model of a personnel system.

O’Conner (1982) developed an interactive computer program that used networks to model the Navy pilot force. The model was used to test the implications of various policy alternatives on Navy pilot requirements.

Liang and Thompson (1986) developed an assignment optimization model that uses a capacitated network to match Navy enlisted personnel to jobs according to Navy policy. People and jobs are both modeled as nodes with a connecting arc if an individual is eligible for that particular job.

Olson (1987) used a single-commodity network flow with side constraints to model the USAF rated officer force. The model balanced flying and non-flying assignments to ensure most rated officers met their flying gates.

Olson’s network is four-dimensional in the following parameters: 1) time period under examination, 2) duty assignment, 3) aviation service date (ASD) year group, and
4) accumulated flying gate credit. Each node represents time (in years), the first parameter, and an individual’s status, made up of the other three parameters. The arcs between the nodes represent assignments an officer could serve to get from one node/status to another node/status. Olson's network contains 975 nodes and 2374 allowable arcs.

The three dimensional network in figure 2 was taken directly from Olson's thesis. It illustrates how three of the four parameters interact. Arc 1 represents a one year assignment to duty type A, with a resulting increase in flying gate credit. Arc 2 represents a two year assignment to duty type B with no increase in flying gate credit.

The parameter not depicted in figure 2, ASD year group, increases directly with time. Thus the ASD year group for the individual at node B3/I is two years greater than it was when he was at node A1/I.

In addition to network flow constraints that prevent illogical assignments (such as AFIT followed by AFIT), Olson used side constraints to ensure that the model assigns sufficient personnel to each duty type without overmanning any of them. Side constraints were also used to ensure units are manned by sufficiently experienced personnel.

Olson used an optimization routine called NETSID to solve his formulation. NETSID is a simplex linear programming algorithm that can efficiently incorporate side constraints.
Olson defines a side constraint as any constraint that applies to flow across multiple arcs. The problem was formulated as:

Minimize \( cx \)

Subject to: \( Ax = r \)
\( Sx = b \)
\( 0 \leq x \leq u \)
A is a matrix with a 1 if the arc flows out of the node, -1 if the arc flows into the node, and 0 otherwise. S is a matrix of side constraints with b as the right hand side. An example of a side constraint would be one that required a minimum of 60 percent of all flying duty positions to be occupied by pilots in ASD year group six or higher. To determine which arcs are affected, the program must consider all arcs terminating at flying duty nodes with an ASD year group greater than or equal to six. The total of these flows would have to be greater than or equal to 60 percent of the total flow into all flying duty nodes.

The r vector represents the requirements at each node and u is the vector of upper bounds for the arc flows. The x vector is the solution vector. The objective function minimizes total costs associated with failing to allow pilots to meet their flying gates by the time they get to a given ASD year group. The cost vector, c, represents the costs along arcs that represents such failures. For example, any node with an ASD value of 12 years or more and a gate credit value of fewer than six years represents a failure to meet the first (six year) gate. Any arc terminating at such a node would have a penalty or cost associated with it.

Descriptive Models.

Simulation Models. Computer simulations of personnel systems generally model at either the individual (entity) or
the group (aggregate) level. Entity models provide more
detail, but can also require more input data and longer
computer run times (Clark and Lawson, 1984:42). Leupp
(1969) describes an entity simulation model the U.S. Navy
uses to project the number of SEABEE personnel needed in the
future. The model considers accessions, attrition,
promotions, and assignment rotations.

Looper (1979) describes a large-scale entity simulation
model called the Career Area Rotational Model (CAROM) that
uses Monte Carlo techniques to model the career progression
of airmen in the USAF. The model updates accessions,
promotions, assignment rotations, and attrition on a monthly
basis within a single career field for up to 30 years.

Percich (1987) simulated the career progression of USAF
strategic airlift pilots as a basis to study moving costs.
The model is a network and discrete-event simulation. He
built the network representation of the career field using
the SLAM II language (Pritsker, 1986). The entities that
flow through the system are the individual pilots, modeled
from the time they enter undergraduate pilot training (UPT)
until they leave the Air Force. As each pilot moves from
location to location with reassignments, the model collects
data on moving costs associated with each pilot.

While the network structure of SLAM II is adequate to
model the flow of pilots from one assignment to another,
Percich wrote separate subroutines to initialize the
network, set tour lengths, model attrition, make assignments, and collect moving costs.

Using the results of experimentation with the simulation model, Percich developed two response surfaces. He first group screened a total of 12 predictor variables or factors, divided into five homogeneous groups. Using linear regression, he was able to identify three significant groups containing a total of eight factors. He then screened those remaining eight factors down to four significant factors. Based on those four factors, he built both linear and quadratic metamodels, polynomials that are significantly easier and quicker to use than a simulation model.

Charpie (1987) developed a model of the B-52 navigator career field in the U.S. Air Force and used it to examine changes in policies affecting the crew force. He used a network representation in which nodes represent the various jobs that a navigator can hold with navigators as the entities. The arcs represent allowable assignments for individuals at each stage of their careers.

Litko and Travis (1982) developed a dynamic simulation model to examine the potential consolidation of four USAF career fields into one. The model used a combination of the network, discrete-event, and continuous flow capabilities of SLAM. The flow of personnel to and from overseas assignments was modeled as a continuous process, while the actual consolidation of the career field was modeled as a
network activity. The discrete-event portion of the model was used to subtract or add personnel to the career field as technical school classes enter and graduate. The school takes personnel out of the system for the duration of the school.

Percich (1987) reports the Integrated Simulation Evaluation Model (Prototype) (ISEM-P) is a large-scale aggregate simulation that AFMPC can use to model the entire USAF personnel system. Starting with a mission plan, it establishes manpower requirements and, after considering attrition, determines the necessary accessions to build the required inventory.

Forrester (1980) developed systems dynamics to incorporate closed feedback loops into simulation models in an effort to more realistically represent real world interactions. Knight (1978) used systems dynamics in a highly simplified, aggregate model of USAF pilots. He used the model to examine policies controlling the size of undergraduate pilot training classes and instructor to student ratios.

Lawson (1982) used an aggregate simulation model of enlisted force structures within A.F. Communications Command (AFCC) to experiment with policies regarding the flow and distribution of personnel. His model also employed the system dynamics approach.

Clark and Lawson (1984) used the systems dynamics approach to model a segment of the USAF enlisted force that
is often assigned overseas. They started with an influence
diagram that graphically showed both feedback structures and
cause and effect relationships. Their simulation model
required significantly less computer code and structure than
it would have if they had used an entity model.

The models described in this chapter provide a basis on
which to choose a methodology to model the Pave Low pilot
force. The next chapter describes that methodology.
III. Methodology

Introduction

The purpose of this chapter is to examine the data available to build a model and then to discuss the modeling approach and the model itself. Included are discussions of the model assumptions, verification, validation, and experimental design.

Data Availability

Because the steady state Pave Low personnel system to be modeled is not yet a reality, data on the system is scarce. The relatively new career field has tended to hold pilots in the cockpit longer than in other weapon systems due to the complex nature of the mission and equipment. Furthermore, there is currently only one assignment location, whereas there will eventually be multiple locations. Because this research is intended to examine a steady state environment, data on average assignment/tour lengths, number of tours, and flying hours taken from the current system would be misleading at best.

As a result, most of the numbers used in this research have been gleaned from discussions with individuals at AFMPC, MAC, and 23rd AF. They are educated guesses at what the steady state system will look like. The exception is the retention data (see appendix A), which is actual historical data reflecting the entire helicopter force for the year 1987.
**Model Assumptions**

For the purpose of this investigation, it will be assumed that the system (career field) to be modeled is in steady state. That is, all the Pave Low helicopters are operational and in place, the units are fully manned, and some percentage of the pilots are temporarily in non-flying assignments. Since this steady-state system does not yet exist, however, the model will use reasonable estimates for parameters such as average time to upgrade from one crew position to another.

A sustained pilot force will be defined as 100 fully qualified pilots (not including those in staff positions), 60% of whom must be experienced Pave Low pilots. An experienced Pave Low pilot is one with at least 850 total flying hours, 300 of which must be in the Pave Low helicopter (AFR 51-2). Finally, these 100 pilots are assumed to be distributed across the different crew positions and ranks as they would in a real world flying squadron.

As previously mentioned, retention data used is from historical data. This data remains constant throughout the simulation, although in reality these figures would change somewhat from year to year. In fact, all system parameters such as input rates into the system (INP), the mix of UHTs (UHT) versus PQPs, and tour lengths (TRL) are constant throughout the simulation. In the real world, these
necessarily fluctuate with changing requirements and policies.

Promotions to higher grades and upgrades to higher crew positions are not modeled. It is assumed these occur at normal rates and times. In reality, if it were perceived that promotions and upgrades lagged behind those in other career fields, retention rates would probably decline.

**Modeling Approach Selection**

The models discussed so far can be categorized as dynamic or static, stochastic or deterministic, aggregate or entity, and prescriptive (optimization) or descriptive (non-optimization). The relative advantages and disadvantages of these various approaches depend on the system to be modeled.

Personnel systems are by nature dynamic, that is, changing over time. Static models generally ignore the passage of time, instead taking a "snapshot" in time of that system. Litko (1982:33) says this method can be misleading when modeling a changing process such as a personnel career field. For this reason, a dynamic model seems to be appropriate for this research.

Similarly, real-world personnel systems have a degree of unpredictability about them. To treat a career field as deterministic suggests the ability to predict or predetermine factors such as tour lengths or individual career decisions. A stochastic model, on the other hand, uses random numbers to model the variability in such factors.
and will therefore be used.

Litko (1982:36) says the disadvantages of an entity model for large personnel systems are the need for an extensive data base and longer computer run times. The disadvantage of the aggregate approach is the potential loss of necessary detail and validity.

The Pave Low pilot data base is currently very small since it is a relatively new weapon system. Even when it reaches its projected peak, it will consist of just over 100 actively flying pilots with about that many in non-flying positions. With so few entities to model, the need for detail seems to outweigh the difficulty of dealing with a large data base. Furthermore, initial runs of a simple prototype entity simulation model suggest very short computer run times: only a few seconds actual CPU time.

The question of whether to use an optimization or non-optimization model should be tied to the type of questions to be answered with the model. The primary objective of this research is to provide AFMPC with a tool to study the impact (on the Pave Low pilot force) of policy decisions, particularly decisions concerning the allowable mix of UHTs versus PQPs as inputs to the Pave Low system. This research is intended to provide "an array of acceptable policies ... from which the planner can choose the one with the best tradeoff." (Jaquette et al., 1977:6). Furthermore, it should allow decision makers to ask "what if" questions and
evaluate tentative results without actually implementing any policies. A secondary objective is to determine, for a given set of circumstances, an optimal policy.

To meet the first objective, the modeling approach of choice will be a dynamic, stochastic, entity simulation (non-optimization) model. Response surface methodology will be applied to the simulation output to develop response equations that describe the responses in terms of policy variables. These equations will, in turn, be used as goals in a goal programming (optimization) model to determine an optimal policy, one that meets the manning and experience goals as closely as possible.

Model Overview

The Pave Low simulation model was fashioned after Percich's Strategic Airlift PCS cost simulation model (Percich, 1987). Percich modeled a rated career field, the strategic airlift pilots, in order to study permanent change of station (PCS) costs. His model is an entity simulation model written in SLAM II, a language which is also available for this research. Like that model, the Pave Low model breaks the pilot's career into three periods: one to six, seven to eleven, and twelve to seventeen years. The period from 18 years to retirement is modeled, but not considered for flying assignments.

The first period, from one to six years, consists of flight school for UHTs, Pave Low school (CCTS), and the
first flying assignment(s). Non-flying assignments are not allowed during this period in keeping with gate requirements. Subsequent periods include both flying and non-flying assignments. Figure 3 is a macro flow chart of the Pave Low Simulation Model.

**Intended Use of the Model**

The Pave Low simulation model is intended to provide decision makers a range of options to sustain the Pave Low force at required manning and experience levels. It allows decision makers to ask "what if" questions; that is, to change key parameters and see the potential impact a policy decision might have on the actual system.

**Pave Low Simulation Model**

The model itself is written in SLAM II. SLAM II is a FORTRAN based modeling language with the capability to incorporate both discrete-event and continuous modeling into a network model (Fritsker, 1984).

**SLAM II Network Code.** Entity attributes, values associated with particular entities, and global variables, which are not associated with any particular entity, are defined in table 1. A network diagram and the network computer code appear in appendices B and C. The first create node creates an entity whose sole purpose is to call subroutine CLEAR at 200 time units (months). Subroutine CLEAR clears all statistical arrays of transition period
Figure 3. Pave Low Model Flow Chart
data in order to eliminate bias created by the warm-up period prior to steady state.

The second create node creates an entity every XX(6) months that represents a CCTS class of two student pilots.

Table 1  SLAM II Attributes and Variables

<table>
<thead>
<tr>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  tour length</td>
</tr>
<tr>
<td>2  hours per tour</td>
</tr>
<tr>
<td>3  pilot type (UHT or PQP)</td>
</tr>
<tr>
<td>4  time in service</td>
</tr>
<tr>
<td>5  Pave Low flying hours</td>
</tr>
<tr>
<td>6  hours until experienced</td>
</tr>
<tr>
<td>7  separation indicator</td>
</tr>
<tr>
<td>8  CCTS class size</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Global Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  number of experienced pilots</td>
</tr>
<tr>
<td>2  number of actively flying pilots = TOT</td>
</tr>
<tr>
<td>3  hours required</td>
</tr>
<tr>
<td>4  XX(1)/XX(2) = EXP</td>
</tr>
<tr>
<td>5  excess hours</td>
</tr>
<tr>
<td>6  time between class creations</td>
</tr>
<tr>
<td>7  percent UHT</td>
</tr>
<tr>
<td>8  low side tour length distribution</td>
</tr>
<tr>
<td>9  mode of tour length distribution</td>
</tr>
<tr>
<td>10 high side tour length distribution</td>
</tr>
<tr>
<td>11 hours payback (PAY)</td>
</tr>
<tr>
<td>12 total number of blocked cockpit seats</td>
</tr>
</tbody>
</table>

XX(7) percent of those pilots are labeled UHTs and have a time-in-service of 12 months (for flight school and a PCS). The rest of the pilots are labeled PQPs and have a time in service drawn from a triangular distribution with low, mode, and high values of 42, 48, and 54 months respectively. In the absence of a known distribution, the triangular
distribution was used to provide a range of possible values with the mode being the most likely value. This represents approximately a year for flight school and a three year tour in another type of helicopter. All students are sent to CCTS for seven months (accumulating 80 Pave Low hours), at which time they are counted as part of the actively flying line force.

Next, the pilots are assigned a tour length drawn from a triangular distribution, again, since it is not a known distribution. The event node calls subroutine FLIER, which determines retention/separation status and updates applicable attributes, such as Pave Low flying hours. If a UHT needs more flying time in order to reach 850 hours, he is looped back for a second assignment.

The next section of the network determines, to the month, when each pilot becomes experienced and immediately updates the ratio of experienced to total active pilots. Pilots who separate before becoming experienced are collected at a different node from those who separate after becoming experienced.

Pilots who have not finished paying back for their Pave Low training are looped back for another flying assignment. The rest move on to the 7 to 11, or the 12 to 17 year group, as appropriate. From Queue3, XX(12)/2 pilots are blocked for flying assignments beginning sometime during the 7 to 11 year period. The same number, XX(12)/2 are blocked in the
12 to 18 year group. XX(12) is the total number of blocked cockpits, but these are divided between two career stages. After these slots are filled, the remainder of the pilots fill non-flying assignments. These non-flying pilots are subtracted from the force and the experience level is recalculated.

The 12 to 17 year group part of the network parallels the previous section. The 18 year to retirement section was only used for non-flying assignments for this research, but could be used to block cockpits for more senior pilots. The final section of the model is data collection nodes.

**FORTRAN Subroutines.** FORTRAN subroutines are located in appendix D. Subroutine INTLC is used to read in the parameter values from a coded design matrix. It then decodes the parameters into a form meaningful to the SLAM II network. The subroutine also holds the retention data table. Subroutine INTLC could be used to initialize or load the network to shorten the transition period to steady state.

Subroutine FLLIER rounds the time in service and pending tour length to whole years in order to apply the retention data. It then makes a draw from a uniform (0,1) distribution and compares that number to the applicable retention figures. If the random draw is greater than the retention figure for any year of the pending assignment, the tour length is shortened and attributes are updated.
accordingly. The entity is given a separation indicator that will cause it to leave the network. If the entity does not separate, flying hours and time-in-service are updated according to the originally assigned tour length.

Subroutine NONFLY is identical to subroutine FLIER, except flying hours are not updated.

Subroutine OUTPUT writes the six predictor variables and the two response variable values to a file. This file can then be read directly by a statistical package, such as SAS.

Verification

The network model and FORTRAN subroutines were verified as the model was being built. The SLAM II MONTR/TRACE option allows entities and attributes to be monitored all the way through each part of the network to ensure the model was operating as desired. Likewise, all input parameters were written to files to ensure that the output made sense for that input.

Validation

Because the real-world system being modeled has not yet reached anything close to steady state, it is difficult to compare the model output to actual data. And since the Pave Low system is so small and unique, it is not easy to make comparisons to another weapon system or to the helicopter system as a whole. However, as the Pave Low system approaches steady state, data will become available to help modify and validate the model.
**Experimentation**

**Experimental Design.** Examples of experimental designs are located in appendix E. The first portion of the analysis will consider a number of factors/variables that are suspected as being significant and screen out those which are insignificant. With a large pool of possibly significant factors, the first step is to group homogeneous factors and use regression analysis to screen out entire groups of insignificant factors. The remaining factors are ungrouped and individually screened for significance. The factors remaining after this two-stage screening process are then used to build the first-order metamodel. A metamodel is a model of a model. In this research, it is a polynomial equation that "captures" what the simulation model is doing. A lack of fit test reveals whether or not the response surface is a plane or is curved, the latter requiring a second-order metamodel. This process of building a response surface is pictured in figure 4.

In this particular research, group screening was not needed because only six factors were examined. The factor screening stage of the analysis screened the six predictor variables or factors to determine which have significant impacts on the two response variables.
Figure 4. Metamodel Building Process (Bauer, 1988)
The six predictor variables are:

1) **INP** (Input) - the average number of pilots who enter the Pave Low system each year, either directly from flight school (Undergraduate Helicopter Training) or by cross-training from another type of helicopter.

2) **UHT** - the percentage of "INP" who come directly from flight school, with no previous operational flying experience.

3) **TRL** (tour length) - the length, in months, of the average flying tour/assignment.

4) **BLK** (block) - the number of blocked cockpits. Blocked cockpits are flying positions reserved for previously qualified Pave Low pilots who are currently serving in the rated supplement, but who eventually return to the cockpit. The more blocked cockpits, the fewer new inputs can be brought into the system.

5) **PAY** (Payback) - the amount of time (in flying hours) a trained Pave Low pilot is expected to remain in the cockpit. The greater the payback requirement, the more experienced the pilot force will be.

6) **HRS** (hours) - the average number of flying hours each pilot flies each month. The more hours, the more experienced the force.

The two response variables are:

1) **TOT** - Total operational pilot force. This includes only line pilots in full-time, operational flying (excludes
staff, school instructors, etc.).

2) EXP - The percentage of "TOT" who are "experienced", meaning they have 850 total flying hours, 300 of which are in the Pave Low helicopter. The desired operating conditions for the model are defined in terms of TOT and EXP. The number of authorized line pilots is approximately 100, so TOT values that vary significantly from 100 suggest an over or under-manned organization. Likewise, the Pave Low experience level (EXP) should remain at or above 60% (AFR 51-2). The two response variables must be examined together. In other words, it is not acceptable to have an EXP of 70% if TOT is very low or very high.

A full factorial, two level experimental design \(2^6\) with replications was used. The Statistical Analysis System (SAS) will be used to create an Analysis of Variance (ANOVA) table for each response variable. The F statistic will then be used to determine model adequacy and significance of factor effects. Furthermore, assumptions regarding constant variance and normality of residuals will be examined using residual plots (Montgomery, 1984:85-93, 223-224).

From the regression analysis, a first-order metamodel will be developed. That model will be checked for lack of fit to determine if a second-order model is required. If so, an appropriate three-level design (depending on the number of significant linear factors) will be used to construct a second-order metamodel.
Goal Programming Model. Once reasonable response surface equations for the two response variables have been developed, those two equations will be set equal to constant values that reflect the goals of 100 pilots with a 60% experience level. These goals, with associated deviation variables, will become constraints in a mathematical programming problem. The objective function will seek to minimize deviations from the goals. Upper and lower bounds will be placed on the predictor variables to restrict them to the experimental region. The solution to the goal programming problem should provide optimal settings for the predictor variables in order to achieve, as closely as possible, the stated goals.

This chapter described the Pave Low model and the experimental design for the output analysis. The next chapter discusses the results of that output analysis.
IV. Analysis

Introduction

The purpose of this chapter is to describe the operation of the SLAM model and the analysis of the model output using response surface methodology and goal programming. The response surface methodology is used to build response equations that are then used as goals in the goal programming formulation. The goal programming model, in turn, determines optimal values for the decision variables.

SLAM II Model Operation

To estimate the length of the transient period, several model runs were conducted for time periods of 100 years. The time average of the experience level was then plotted (See appendix G). The plot indicates the model has a warm-up period of approximately 150 months before reaching a steady state condition. In subsequent runs, all statistical arrays were cleared after 200 months. The model was then allowed to run for another 700 months or about 60 years.

Output Analysis

Factor Screening. The model was run using ten replications of the six-factor, two-level full factorial design with the six predictor variables shown in table 2. These variables, along with the two response variables were analyzed using SAS procedures PROC REG and PROC STEPWISE.
Table 2. Factors and Settings

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>LOW</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>INT</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>UHT</td>
<td>0</td>
<td>.5</td>
</tr>
<tr>
<td>TRL</td>
<td>36</td>
<td>60</td>
</tr>
<tr>
<td>PAY</td>
<td>500</td>
<td>750</td>
</tr>
<tr>
<td>BLK</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>HRS</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

The residual plot from the second response variable, TOT, indicated a slightly increasing variance. A natural log transformation of the response corrected the problem (All residual plots and normality plots are in appendix F). The resulting ANOVA tables are in tables 3 and 4.

Table 3. ANOVA for EXP factor screening

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SUM OF SQUARES</th>
<th>MEAN SQUARE</th>
<th>F VALUE</th>
<th>PROB&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL</td>
<td>6</td>
<td>93673.59</td>
<td>15612.26</td>
<td>866.10</td>
<td>0.0001</td>
</tr>
<tr>
<td>INP</td>
<td>1</td>
<td>758.21</td>
<td>758.21</td>
<td>42.06</td>
<td>0.0001</td>
</tr>
<tr>
<td>UHT</td>
<td>1</td>
<td>65642.40</td>
<td>65642.40</td>
<td>3641.54</td>
<td>0.0001</td>
</tr>
<tr>
<td>TRL</td>
<td>1</td>
<td>3691.20</td>
<td>3691.20</td>
<td>204.77</td>
<td>0.0001</td>
</tr>
<tr>
<td>BLK</td>
<td>1</td>
<td>13987.60</td>
<td>13987.60</td>
<td>775.97</td>
<td>0.0001</td>
</tr>
<tr>
<td>PAY</td>
<td>1</td>
<td>6347.88</td>
<td>6347.88</td>
<td>352.15</td>
<td>0.0001</td>
</tr>
<tr>
<td>HRS</td>
<td>1</td>
<td>3246.30</td>
<td>3246.30</td>
<td>180.09</td>
<td>0.0001</td>
</tr>
<tr>
<td>ERROR</td>
<td>633</td>
<td>11410.45</td>
<td>18.028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>639</td>
<td>105084.04</td>
<td></td>
<td>ADJ R² = .89</td>
<td></td>
</tr>
</tbody>
</table>
Table 4. ANOVA for TOT factor screening

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SQUARES</th>
<th>MEAN SQUARE</th>
<th>F VALUE</th>
<th>PROB&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL</td>
<td>6</td>
<td>98.38</td>
<td>16.40</td>
<td>1006.49</td>
<td>0.0001</td>
</tr>
<tr>
<td>INP</td>
<td>1</td>
<td>60.89</td>
<td>60.89</td>
<td>3737.30</td>
<td>0.0001</td>
</tr>
<tr>
<td>UHT</td>
<td>1</td>
<td>6.64</td>
<td>6.64</td>
<td>407.53</td>
<td>0.0001</td>
</tr>
<tr>
<td>TRL</td>
<td>1</td>
<td>2.68</td>
<td>2.68</td>
<td>164.32</td>
<td>0.0001</td>
</tr>
<tr>
<td>BLK</td>
<td>1</td>
<td>11.34</td>
<td>11.34</td>
<td>695.92</td>
<td>0.0001</td>
</tr>
<tr>
<td>PAY</td>
<td>1</td>
<td>5.92</td>
<td>5.92</td>
<td>363.17</td>
<td>0.0001</td>
</tr>
<tr>
<td>HRS</td>
<td>1</td>
<td>10.93</td>
<td>10.93</td>
<td>670.72</td>
<td>0.0001</td>
</tr>
<tr>
<td>ERROR</td>
<td>633</td>
<td>10.31</td>
<td>.016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>639</td>
<td>108.70</td>
<td></td>
<td></td>
<td>ADJ R^2 = .90</td>
</tr>
</tbody>
</table>

The p values of 0.0001 for the six predictor variables indicate that all six are significant. It was noted, however, that UHT was, by far, the most significant factor to EXP, and INP was the most significant to TOT (based on significantly larger F values). To further simplify the linear metamodel, then, the remaining four factors were screened out.

First Order Metamodel. Ten replications of a three-level, two-factor full factorial experimental design were run. A two-level, two-factor design was used in a trial run and indicated that a second order model was needed. The four screened factors were set to constant, nominal values so they would not influence the results. Factor settings are shown in table 5.

The two-factor linear model residual plots were convex curves, indicating quadratic tendencies, which were confirmed by using SAS procedure PROC RSREG. This procedure breaks the regression or model sum of squares into linear,
Table 5. Factor Settings for First-Order Metamodel

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>LOW</th>
<th>MID</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>INF</td>
<td>12</td>
<td>16</td>
<td>24</td>
</tr>
<tr>
<td>UHT</td>
<td>0</td>
<td>.25</td>
<td>.50</td>
</tr>
<tr>
<td>TRL</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAY</td>
<td>680</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLK</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRS</td>
<td>12.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

quadratic, and cross-product components. Tables 6 and 7 show both significant quadratic and cross-product components. If a two-level design had been used instead of a three-level design, PROC RSREG’s lack of fit test would have indicated a lack-of-fit for a linear model. That was the case in the trial run.

Table 6. First-order lack-of-fit for EXP

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SUM OF SQUARES</th>
<th>MEAN SQUARE</th>
<th>F VALUE</th>
<th>PROB&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINEAR</td>
<td>2</td>
<td>13256.83</td>
<td>6628.41</td>
<td>18725.26</td>
<td>0.0001</td>
</tr>
<tr>
<td>QUADR</td>
<td>2</td>
<td>25.69</td>
<td>12.84</td>
<td>36.29</td>
<td>0.0001</td>
</tr>
<tr>
<td>CROSS</td>
<td>1</td>
<td>7.26</td>
<td>7.26</td>
<td>20.51</td>
<td>0.0001</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5</td>
<td>13289.78</td>
<td>2657.96</td>
<td>7508.72</td>
<td>0.0001</td>
</tr>
<tr>
<td>RESIDUAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.O.F.</td>
<td>3</td>
<td>2.65</td>
<td>0.88</td>
<td>2.57</td>
<td>0.0552</td>
</tr>
<tr>
<td>PURE E.</td>
<td>171</td>
<td>58.94</td>
<td>0.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>174</td>
<td>61.59</td>
<td>0.35</td>
<td>ADJ $R^2$ = .99</td>
<td></td>
</tr>
</tbody>
</table>

36
Table 7. First-order lack-of-fit for TOT

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SQUARES</th>
<th>MEAN SQUARE</th>
<th>F VALUE</th>
<th>PROB&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINEAR</td>
<td>2</td>
<td>165973.55</td>
<td>82986.78</td>
<td>62480.93</td>
<td>0.0001</td>
</tr>
<tr>
<td>QUADR</td>
<td>2</td>
<td>5739.51</td>
<td>2869.76</td>
<td>2160.64</td>
<td>0.0001</td>
</tr>
<tr>
<td>CROSS</td>
<td>1</td>
<td>753.38</td>
<td>753.38</td>
<td>567.22</td>
<td>0.0001</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5</td>
<td>172466.44</td>
<td>34493.29</td>
<td>25970.07</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

RESIDUAL

| L.O.F. | 3  | 18.70     | 6.23        | 5.02    | 0.0025 |
| PURE E. | 171 | 212.41   | 1.41        |         |        |
| TOTAL  | 174 | 231.11   | 1.33        | ADJ R² = .99 |        |

Second Order Metamodel. The residual plots for the second-order model based on the two factors, INP and UHT, indicate a non-constant, decreasing variance for response variable EXP and a non-constant, wave pattern for TOT. These could indicate the need for a transformation. Several transformations were tried, including natural log, arcsin, and square root functions of the response variable. Based on residual plots, the best transformations were ln(84-EXP) and ln(TOT). ANOVA tables are in tables 8 and 9.

Table 8. ANOVA for second-order metamodel (EXP)

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SQUARES</th>
<th>MEAN SQUARE</th>
<th>F VALUE</th>
<th>PROB&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL</td>
<td>5</td>
<td>71.48</td>
<td>14.30</td>
<td>8770.87</td>
<td>0.0001</td>
</tr>
<tr>
<td>INP</td>
<td>1</td>
<td>1.27</td>
<td>1.27</td>
<td>784.38</td>
<td>0.0001</td>
</tr>
<tr>
<td>UHT</td>
<td>1</td>
<td>66.33</td>
<td>66.33</td>
<td>40913.57</td>
<td>0.0001</td>
</tr>
<tr>
<td>UHT*UHT</td>
<td>1</td>
<td>3.63</td>
<td>3.63</td>
<td>2241.22</td>
<td>0.0001</td>
</tr>
<tr>
<td>INP*UHT</td>
<td>1</td>
<td>0.25</td>
<td>0.25</td>
<td>152.70</td>
<td>0.0001</td>
</tr>
<tr>
<td>ERROR</td>
<td>175</td>
<td>0.28</td>
<td>0.0016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>179</td>
<td>71.77</td>
<td></td>
<td>ADJ R² = .99</td>
<td></td>
</tr>
</tbody>
</table>
Table 9. ANOVA for second-order metamodel (TOT)

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SQUARES</th>
<th>MEAN SQUARE</th>
<th>F VALUE</th>
<th>PROB&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL</td>
<td>5</td>
<td>11.63</td>
<td>2.33</td>
<td>25580.85</td>
<td>0.0001</td>
</tr>
<tr>
<td>INP</td>
<td>1</td>
<td>10.87</td>
<td>10.87</td>
<td>12045.03</td>
<td>0.0001</td>
</tr>
<tr>
<td>UHT</td>
<td>1</td>
<td>0.63</td>
<td>0.63</td>
<td>6968.06</td>
<td>0.0001</td>
</tr>
<tr>
<td>INP*INP</td>
<td>1</td>
<td>0.13</td>
<td>0.13</td>
<td>1450.75</td>
<td>0.0001</td>
</tr>
<tr>
<td>INP*UHT</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>13.49</td>
<td>0.0003</td>
</tr>
<tr>
<td>ERROR</td>
<td>175</td>
<td>0.02</td>
<td>0.00009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>179</td>
<td>11.65</td>
<td></td>
<td>ADJ R²</td>
<td>.99</td>
</tr>
</tbody>
</table>

After decoding, the second order metamodel for response EXP was:

\[
\ln(84-\text{EXP}) = 1.3312 + 0.0265*\text{INP} + 6.0524*\text{UHT} \\
(0.007) (0.004) (0.004)
- 4.8224*\text{UHT}^2 - 0.0371*\text{INP*UHT} \\
(0.008) (0.005)
\]

The second-order metamodel for TOT was:

\[
\ln(\text{TOT}) = 4.2696 - 0.0078*\text{INP} + 0.2432*\text{UHT} \\
(0.002) (0.001) (0.001)
+ 0.0016*\text{INP}^2 + 0.0026*\text{INP*UHT} \\
(0.002) (0.001)
\]

Figure 4 shows both responses plotted in the INP/UHT plane. Since both response surfaces were second order, they are both paraboloids. The figure is a plot of the projection of the paraboloid contours in the INP/UHT plane. The contours are nearly straight lines because the region of interest is so far from the parabolas' vertices. This figure will vary with the values used for the other four decision variables (TRL, PAY, BLK, AND HRS). This
particular figure is based on the values listed previously in table 5.

Figure 5. Second-Order Metamodel Contours
Goal Programming. Goal programming is a form of mathematical programming that allows more than one objective to be achieved in the same problem. So rather than minimizing or maximizing one objective, goal programming minimizes deviations from one or more established goals. Goals can be prioritized and deviations can be weighted depending on the judgment of a decision maker or expert (Hillier and Lieberman, 1986: 242-246).

The two goals in this research are: 1) to maintain the force (TOT) at close to 100 pilots and 2) to maintain the force experience level (EXP) at a minimum of 60%. A linear goal programming problem was formulated as follows, using the six-factor linear metamodels in the goal equations:

Minimize: \( d_1^- + d_2^- + d_2^+ \)

Subject to:

1) \( 36.79 - 0.81\text{INP} - 40.52\text{UHT} + 0.2\text{TRL} + 0.03\text{PAY} + 0.31\text{BLK} + 0.90\text{HRS} + d_1^- - d_1^+ = 60 \)
2) \( -19.78 + 6.05\text{INP} + 45.36\text{UHT} + 0.64\text{TRL} + 0.09\text{PAY} + 0.92\text{BLK} - 6.20\text{HRS} + d_2^- - d_2^+ = 100 \)
3) \( 12 < \text{INP} < 24 \)
4) \( 0 < \text{UHT} < 0.5 \)
5) \( 36 < \text{TRL} < 60 \)
6) \( 500 < \text{PAY} < 750 \)
7) \( 0 < \text{BLK} < 30 \)
8) \( 10 < \text{HRS} < 15 \)

The "d" variables are the deviation variables for the two goals. Since the experience level can be allowed to go
above, but not below 60%, $d_1^+$ was left out of the objective function. The remaining three deviation variables are minimized. All the predictor variables have lower and upper bounds, to keep the solution set within the experimental region.

The goal programming model was run on LINDO (Schrage, 1986), a linear programming package. The results, after 13 iterations, were:

- \( \text{INP} = 17.92 \)
- \( \text{UHT} = 0.12 \)
- \( \text{TRL} = 36.0 \)
- \( \text{PAY} = 500.0 \)
- \( \text{BLK} = 0.0 \)
- \( \text{HRS} = 10.0 \)

Objective function value = 0.0
All deviation variables = 0.0

Thus, the goals were able to be met exactly by setting all but the first two predictor variables to their lower bound. These optimal values were run in the Pave Low simulation model and produced an EXP value of approximately 61 percent and a TOT value of 109. While not exactly on target, they are an indication the goal programming model accurately reflects the simulation model output.

In contrast, the second-order metamodels were used as goals in a non-linear goal programming problem. The optimal solution was to set INP to 14.2 and UHT to 42 percent. When this solution was run in the simulation model, it met the experience goal, but exceeded the manning (TOT) goal by about 22. The difference between the two metamodels (linear
vs quadratic) is the linear includes the four less significant decision variables. These four variables help provide a better reflection of the simulation in the metamodel equations.

The difficulty with any "optimal" solution is that it may not be practical. Although all the predictor variables are decision variables and can be controlled, some are more easily varied than others. Since INP and UHT are probably the easiest to change, the other predictor variables can be set to values that seem to most closely reflect reality and let the model solve for INP and UHT.

This chapter discussed the analysis of the simulation output. In light of this analysis, the next chapter will make policy recommendations as well as recommendations for further research.
V. Summary and Recommendations

Introduction

This chapter summarizes the research and its implications, and then provides recommendations for policy decisions and further research.

Summary of Research

The objective of this research was to model the Pave Low pilot career field and to examine how best to sustain an experienced pilot force. This was accomplished by developing a simulation model that permitted experimentation with key policy/decision variables. Response surface methodology was then used to screen out less important variables and to develop response equations which captured the simulation outcomes in simple polynomials. These polynomials were used to define goals within a goal programming model. That model produced optimal values for the policy variables in order to achieve the desired manning and experience levels for the Pave Low pilot force.

Implications

The value of this research is in developing a methodology both to describe the Pave Low pilot career field and to determine optimal policy decisions. As more complete data on the pilot force becomes available, the models used in this research can be easily modified to more accurately reflect reality.
Policy Recommendations

This research suggests two policy recommendations once the Pave Low pilot force is fully manned. First, only about ten percent of the pilots entering the Pave Low should be right out of Undergraduate Helicopter Training (UHT) to avoid causing the experience level to drop below 60 percent. Second, the input rate into the system will probably have to be reduced slightly from the current twenty pilots per year to prevent over-manning. The exact amount of reduction will depend on future retention rates.

Recommendation for Future Research

Future research should focus on the implications of overseas basing, such as how short overseas tours and the ratio of overseas to stateside assignments affects manning and experience levels.
### Appendix A: Retention Rates

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<tr>
<td>25</td>
<td>.500</td>
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</table>
Appendix B: SLAM II Network Diagram
Appendix C: SLAM II Code

GEN,MCKOY,PAVE1,6/15/1988,32,N,N,N,N,72;
LIMITS,5,8,750;
TIMST,XX(4),PERCENT EXPERIENCED,.20/0./.05;
TIMST,XX(1),NO OF EXP PILOTS;
TIMST,XX(2),NO OF ACTIVE PILOTS;
SEEDS,1145661099(1);
;RECORD, TNOW, TIME, P, 5.0;
;VAR, XX(4), PERCENT EXPERIENCED, 0.0, 1.0;
EQUIVALENCE/XX(1), EXPD/
       XX(2), ACCT/
       XX(3), REQD/
       XX(4), FRC/
       XX(5), EXCS;

NETWORK;
;CLEAR STATISTICAL ARRAYS AT TNOW=200
CREATE.,200;
CLEAR EVENT,3;
TERM;

;CREATE A CLASS OF 2 STUDENTS W/ T.B.C. OF XX(6)
CREATE,XX(6);
ASSIGN,ATRIB(8)=2,1;
UNBATCH,8,1;

QUE1 QUEUE(1);
       ACT(20);

;LABEL STUDENTS AS UHTS OR PQPS
GOON,1;
       ACT/1.,XX(7),UHT;UHTS
       ACT/2.,1-XX(7),PQP;PQPS

;UHT IS ASSIGNED TIME IN SERVICE OF 12 MONTHS
UHT ASSIGN,ATRIB(3)=0.,
        ATRIB(4)=12.,
        ATRIB(5)=0.,
        ATRIB(7)=0.,1;
       ACT,,G1;

;PQP IS ASSIGNED T.I.S. IAW TRIANGULAR DISTRIBUTION
PQP ASSIGN,ATRIB(3)=1.,
        ATRIB(4)=TRIAG(42.,48.,54.,1),
        ATRIB(5)=0.,
        ATRIB(7)=0.,1;

;CCTS TAKES 7 MONTHS, 80 FLYING HOURS
G1 GOON,1;
       ACT/3,7.;CCTS
ASSIGN, ATRIB(4) = ATRIB(4) + 7.,
ATRIB(5) = ATRIB(5) + 80.,
ACTV = ACTV + 1.,
PERC = EXPD/ACTV, 1;
; STUDENT IS NOW AN ACTIVE, THOUGH INEXPERIENCED PILOT

; PILOT GETS FIRST OPERATIONAL ASSIGNMENT
; TOUR LENGTH IAW TRIANGULAR DISTRIBUTION
QUE2
    QUEUE(2);
    ACT(100);
    ASSIGN, ATRIB(1) = TRIAG(XX(8), XX(9), XX(10), 1), 1;

; SEE FORTRAN CODE
E1
    EVENT, 1, 1;

; UHT GETS A 2ND TOUR TO GET 850 HRS
    ACT/4., ATRIB(3). EQ. 0.0 . AND. ATRIB(5). LT. 850., G2; GET
EXPER
    ; UHTS W/ 850 HRS
    ACT/6., ATRIB(3). EQ. 0., UHTX; EXP-UHT
    ; PQPS WHO ATTRIT FROM SYSTEM W/O GETTING 300 HRS
    ACT/8., ATRIB(5). LE. 300., LOSE; FIRST YR LOSS/PQP
    ; PQPS W/ 300 HRS
    ACT/10., ATRIB(3). EQ. 1., PQPX; EXP-PQP
G2
    GOON, 1;
    ACT/12, ATRIB(1), G3;

G3
    GOON, 1;
    ; UHTS WHO ATTRIT DURING FIRST TOUR
    ACT/14., ATRIB(7). EQ. 1.0, LOSE; SEPAR1
    ACT/16,,, QUE2;

; COMPUTES # OF MONTHS INTO TOUR THAT PILOT
; REACHES EXPERIENCED STATUS (850 HRS)
UHTX
    ASSIGN, EXCS=A TRIB(5)-850.,
    REQD=ATRIB(2)-EXCS,
    ATRIB(6)=REQD/15., 1;

; UHTS WHO ATTRIT DURING 2ND TOUR W/O REACHING 850 HRS
    ACT/18., ATRIB(6). GE. ATRIB(1), L0;
; UHTS W/ 850 HRS
    ACT/20, ATRIB(6), ATRIB(6). LT. ATRIB(1), CNTR; #EXP UHTS
L0
    GOON, 1;
    ACT/22, ATRIB(1), G4;

; COMPUTES # OF MONTHS INTO TOUR THAT PILOT
; REACHES EXPERIENCED STATUS (300 HRS)
PQPX
    ASSIGN, EXCS=A TRIB(5)-300.,
    REQD=ATRIB(2)-EXCS,
    ATRIB(6)=REQD/15., 1;
; PQPS WHO ATTRIT
   ACT/24, ATRIB(6) .GE. ATRIB(1), L1; PQP NEVER EXP
; PQPS W/ 300 HRS
   ACT/26, ATRIB(6), ATRIB(6) .LT. ATRIB(1), CNTR; #EXP PQPS

; COUNTS EXPERIENCED PILOTS, COMPUTES PERCENT EXP
CNTR ASSIGN, EXPD = EXPD + 1., PERC = EXPD / ACTV,
; COMPUTES TIME REMAINING IN TOUR
   ATRIB(1) = ATRIB(1) - ATRIB(6),
   ATRIB(6) = 0.0, 1;
   ACT/28, ATRIB(1), G4; TOTAL EXP

L1 GOON, 1;
   ACT/30, ATRIB(1), G4; PQP ONLY

G4 GOON, 1;
; EXPERIENCED PILOTS WHO ATTRIT
   ACT/32, ATRIB(7) .EQ. 1.0. AND. ATRIB(6) .EQ. 0.0, DEPT;
; NEVER EXPERIENCED PILOTS WHO ATTRIT
   ACT/34, ATRIB(7) .EQ. 1.0. AND. ATRIB(6) .NE. 0.0, LOSE;
; EXPERIENCED UHTS WHO OWE PAYBACK FOR TRAINING
   ACT/36, ATRIB(3) .EQ. 0.0. AND. ATRIB(5) .LT. 1000., PAY0;
; EXPERIENCED PQPS WHO OWE PAYBACK FOR TRAINING
   ACT/38, ATRIB(3) .EQ. 1.0. AND. ATRIB(5) .LT. XX(11), PAY1;
; PILOTS W/ MORE THAN 11 YRS SERVICE
   ACT/40, ATRIB(4) .GE. 132., QUE4; SKIP JOB3
; EVERYONE ELSE
   ACT/42, , QUE3; TO JOB2

; ASSIGN SUBSEQUENT FLYING TOUR LENGTHS TO UHTS
   PAY0 ASSIGN, ATRIB(1) = TRIAG(XX(8), XX(9), XX(10), 1), 1;
   EVENT, 1, 1;
   ACT, , L0;

; ASSIGN SUBSEQUENT FLYING TOUR LENGTHS TO PQPS
   PAY1 ASSIGN, ATRIB(1) = TRIAG(XX(8), XX(9), XX(10), 1), 1;
   EVENT, 1, 1;
   ACT, , L1;

; 7 TO 11 YEAR GROUP
   QUE3 QUEUE(3);
   ACT(100)/44; TO G5
G5 GOON, 1;
; # OF BLOCKED COCKPITS FOR 7-11 YR GROUP
   ACT, , NNACT(46) .LT. XX(12), FLY2;FLY2
; OTHERWISE TO NON-FLYING JOB
   ACT, , NOF2; NOFLY2

; FLYING ASSIGNMENTS FOR 7-11 YR GROUP
   FLY2 ASSIGN, ATRIB(1) = TRIAG(XX(8), XX(9), XX(10), 1), 1;
EVENT, 1, 1;
    ACT/46, ATRIB(1),, G6; FLY2

; NON-FLYING ASSIGNMENTS FOR 7-11 YR GROUP
NOF2 ASSIGN, ATRIB(1) = TRIAG(30., 36., 42., 1),
        ACTV = ACTV - 1.,
        EXPD = EXPD - 1.,
        PERC = EXPD / ACTV, 1;
EVENT, 2, 1;
    ACT/48, ATRIB(1); NOFLY2
ASSIGN, ACTV = ACTV + 1.,
        EXPD = EXPD + 1.,
        PERC = EXPD / ACTV, 1;

G6 GOON, 1;
; ATTRITION
    ACT/50, , ATRIB(7).EQ.1.0, DEPT; SEPAR3
; LESS THAN 11 YRS TIME IN SERVICE
    ACT/52, , ATRIB(4).LT.132., QUE3; <11YRS GATE TIME
; EVERYONE ELSE
    ACT/54; TO JOB 3

; 12-17 YR GROUP
QUE4 QUEUE(4);
    ACT(120)/56; TO G7
G7 GOON, 1;
; BLOCKED COCKPITS FOR 12-17 YR GROUP
    ACT, , NNACT(58) .LT. XX(12), FLY3; FLY3
    ACT, , NOF3; NOFLY3

FLY3 ASSIGN, ATRIB(1) = TRIAG(XX(8), XX(9), XX(10), 1), 1;
EVENT, 1, 1;
    ACT/58, ATRIB(1),, G8; FLY3

NOF3 ASSIGN, ATRIB(1) = TRIAG(30., 36., 42., 1),
        ACTV = ACTV - 1.,
        EXPD = EXPD - 1.,
        PERC = EXPD / ACTV, 1;
EVENT, 2, 1;
    ACT/60, ATRIB(1); NOFLY3
ASSIGN, ACTV = ACTV + 1.,
        EXPD = EXPD + 1.,
        PERC = EXPD / ACTV, 1;

G8 GOON, 1;
    ACT/62, , ATRIB(7).EQ.1.0, DEPT; SEPAR4
    ACT/64, , ATRIB(4).LT.204., QUE4; <17YRS
    ACT/66; LASTJOB
; 18-20+ YR GROUP
QUE5 QUEUE(5);
   ACT(150)/68; TO G9
G9 GOON,1;

;# BLOCKED COCKPITS FOR SENIOR OFFICERS
   ACT,,NNACT(70).LT.0,FLY4;FLY4
   ACT,,NOFLY4;NOFLY4

FLY4 ASSIGN,ATRIB(1)=TRIAG(18.,24.,30.,1),1;
   EVENT,1,1;
   ACT/70,ATRIB(1),,G10;FLY4

NOFLY4 ASSIGN,ATRIB(1)=TRIAG(30.,36.,42.,1),
   ACTV=ACTV-1.,
   EXPD=EXPD-1.,
   PERC=EXPD/ACTV,1;
   EVENT,2,1;
   ACT/72,ATRIB(1);NOFLY4
ASSIGN,ACTV=ACTV+1.,
   EXPD=EXPD+1.,
   PERC=EXPD/ACTV,1;

G10 GOON,1;
   ACT/74,,ATRIB(7).EQ.1.0.AND.ATRIB(4).LT.240.,DEPT;
   ACT/76,,ATRIB(4).LT.240.,QUE5;<20YRS

; RETIREES
   ACT/78:RETIRE
   ASSIGN,EXPD=EXPD-1.,
   ACTV=ACTV-1.,
   PERC=EXPD/ACTV,1;
   COLCT,ALL,RETIREES,,1;
   TERM;

; PILOTS LOST BEFORE BECOMING EXPERIENCED
LOSE ASSIGN,ACTV=ACTV-1.,
   PERC=EXPD/ACTV,1;
   ACT/60,,COLL; NEVER EXPD

; EXPERIENCED PILOTS WHO SEPARATE
DEPT ASSIGN,EXPD=EXPD-1.,
   ACTV=ACTV-1.,
   PERC=EXPD/ACTV,1;
COLL COLCT,ALL,SEPARATED,,1;
   TERM;
   END;

INIT,0,900;
SIMULATE;
; THIS IS JUST ONE LINE OF THE DESIGN MATRIX
   -1   -1   -1   -1   -1
FIN;
Appendix D: FORTRAN Code

```
DIMENSION NSET(20000)
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
1MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
2SSL(100),TNEXT,TNOW,XX(100)
COMMON QSET(20000)
COMMON/UOM1/RET(25)
EQUIVALENCE(NSET(1),QSET(1))
NNSET=20000
NCRDR=5
NPRNT=6
NTAPE=7
OPEN(11,STATUS='NEW',FILE='THEESIS.DAT',
1,FORM='FORMATTED')
OPEN(12,STATUS='NEW',FILE='SAS.DAT',
1,FORM='FORMATTED')
CALL SLAM
STOP
END

SUBROUTINE INTLC
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
1MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
2SSL(100),TNEXT,TNOW,XX(100)
COMMON QSET(20000)
COMMON/UOM1/RET(25),XINP,UHT,TRL,PAY,BLK,HRS
EQUIVALENCE (XX(1),EXPD),(XX(2),ACTV)
C READ AND INITIALIZE THE VARIABLES
C READ(NCRDR,*),XX(6),XX(7),XX(9),XX(11),XX(12)
C CODED VARIABLES
XINP=XX(6)
UHT=XX(7)
TRL=XX(9)
PAY=XX(11)
BLK=XX(12)
HRS=-1.
C UNCODED FOR SLAM
XX(6)=-.5*XX(6)+1.5
XX(7)=.25*XX(7)+.25
XX(9)=12.*XX(9)+48.
XX(8)=XX(9)-6.0
XX(10)=XX(9)+6.0
XX(11)=125.*XX(11)+625.
XX(12)=(15.*XX(12)+15.)/2.
XX(13)=10.
```

53
C SET UP RETENTION RATES FOR YEAR OF SERVICE 1-20
DATA
RET/1.0,.986,1.0,.958,.974,.971,.909,.963,.955
1,.977,.875,.886,.892,1.0,1.0,.983,1.0,.955,.906,.745,
2.521,.667,1.0,.778,.5/
RETURN
END

SUBROUTINE EVENT(I)
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II
1,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE
2,SS(100),SSL(100),TNEXT,TNOW,XX(100)
COMMON QSET(20000)
COMMON/UCOM1/RET(25),NE1,NB2,NB3
GO TO (1,2,3) I
C FOR FLYING ASSIGNMENTS
1 CALL FLIER
RETURN
C FOR NON-FLYING ASSIGNMENTS
2 CALL NONFLY
RETURN
C TO CLEAR STAT ARRAYS AFTER 200 MONTHS
3 CALL CLEAR
RETURN
END

SUBROUTINE FLIER
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II
1,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
2,SS(100),SSL(100),TNEXT,TNOW,XX(100)
COMMON QSET(20000)
COMMON/UCOM1/RET(25),NB1,NB2,NB3
C TIME IN SERVICE IN YEARS
ITIS=INT(ATRIB(4)/12.)
C ASSIGNED TOUR LENGTH IN YEARS
ITRL=INT(ATRIB(1)/12.)
C DRAW FROM UNIFORM DISTRIBUTION
PROB=UNFRM(0.0,1.0,1)
XRET=1.0
ATRIB(7)=0.0
C FOR AS MANY YEARS AS TOUR, CHECK RETENTION
DO 10 I=1,ITRL
54
**SUBROUTINE NONFLY**

```
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,
1I1,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE
2,SS(100),SSL(100),TNEXT,TNOW,XX(100)
COMMON/QSET(20000)
COMMON/UCOM1/RET(25),NB1,NB2,NB3

ITIS=INT(ATRIB(4)/12.)
ITRL=INT(ATRIB(4)/12.)
PROB=UNFRM(0.0,1.0,1)
XRET=1.0
ATRIB(7)=0.0
DO 10 I=1,ITRL
   XRET=RET(ITIS+I)
   TEMP=ITIS+I
   IF(TEMP.GT.25)XRET=RET(25)
   IF(PROB.GT.XRET) THEN
      ATRIB(1)=I*12.
      ATRIB(4)=ATRIB(4)+ATRIB(1)
      ATRIB(2)=10.*ATRIB(1)
      ATRIB(5)=ATRIB(5)+ATRIB(2)
      ATRIB(7)=1.0
      GO TO 3
   ENDIF
10 CONTINUE
ATRIB(4)=ATRIB(4)+ATRIB(1)
3 RETURN
END
```
SUBROUTINE OUTPUT
COMMON/SCOM1/ATTRIB(100),DD(100),DDL(100),DTNOW
1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE
2,SS(100),SSL(100),TNEXT,TNOW,XX(100)
COMMON QSET(20000)
COMMON/UCOM1/RET(25),XINP,UHT,TRL,PAY,BLK,HRS
EQUIVALENCE (XX(4),PERC),(XX(2),ACTV)
TEMP=100*TTAVG(1)
C WRITE UNCODED VARIABLES AND OUTPUT TO A FILE
WRITE(11,100)XX(6),XX(7),XX(9),XX(11),XX(12),XX(13)
1,TEMP,TTAVG(3)
C WRITE CODED VARIABLES AND OUTPUT TO A FILE
WRITE(12,200)XINP,UHT,TRL,PAY,BLK,HRS,TEMP,TTAVG(3)
100 FORMAT(8(1X,F6.2,1X))
200 FORMAT(6(2X,F5.2,1X) ,2(1X,F5.1,X))

RETURN
END
Appendix E: Experimental Designs

Factor Screen: 2^6 Full Factorial

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<th>INP</th>
<th>UHT</th>
<th>TRL</th>
<th>PAY</th>
<th>BLK</th>
<th>HRS</th>
<th>EXP</th>
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<td>-1.0</td>
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<td>-1.0</td>
<td>-1.0</td>
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<td>68.3</td>
<td>136.4</td>
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### 2³ Full-Factorial Design for Two-Factor Metamodels

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Appendix F: Graphs of ANOVA Assumptions

Factor Screen: EXP

Predicted Value
Normal Probability Plot: EXP

RESIDUALS
Factor Screen: TOT

Predicted Value

62
Factor Screen: \( \ln(\text{TOT}) \)

**PREDICTED VALUE**
Normal Probability Plot: ln(TOT)

---

RESIDUALS

-0.4  -0.2  0.0  0.2

64
First-Order Metamodell: EXP

\[ \text{EXP} \]

\[ \begin{align*}
2^+ & \quad * \\
1^+ & \quad * \\
R & \quad * * * \\
E & \quad * * * \\
S & \quad * \\
L & \quad * \\
-1 & \quad * \\
-2 & \quad * \\
-3 & \quad * \\
\end{align*} \]

55 60 65 70 75 80

PREDICTED VALUE

65
First-Order Metamodel: TOT

PREDICTED VALUE
Second-Order Metamodel: EXP

\[ \text{EXP} = I^2 + R^2 + K^2 + E^2 + D^2 + U^2 - A^2 - L^{-1} + S^2 \]

PREDICTED VALUE
Second-Order Metamodell: TOT

PREDICTED VALUE
Normal Probability Plot: \( \ln(84-\text{EXP}) \)

\[
\begin{align*}
N & + 2K * & F^1 + R^0 + R & 1 + A & B - 1 + L & E^* - 2 + K & S & I^* - 3 + U & A - 4
\end{align*}
\]

---

-0.100 -0.025 0.050 0.125

RESIDUALS
Second-Order Metamodel: ln(TOT)
Normal Probability Plot: \( \ln(\text{TOT}) \)
Appendix G: Steady-State Graph

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VITA

This thesis presents a career model of the USAF Pave Low helicopter pilot force. A SIM II computer simulation was developed to permit experimentation with key decision variables. Response surface methodology was used to produce two response equations which, in turn, became goals for a goal programming model. This model provided optimal values for the decision variables in order to achieve manning and experience-level goals. 

**Thesis Advisor:** Major Kenneth W. Bauer, PhD

Associate Professor of Operational Sciences

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**Abstract:***

Surface-Launched Air Missile (SLAM)