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THESIS

A MARKOV MODEL FOR FORECASTING INVENTORY LEVELS FOR U.S NAVY MEDICAL SERVICE CORPS HEALTHCARE ADMINISTRATORS

by

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March 2014

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13. ABSTRACT (maximum 200 words)

The United States Navy Medical Service Corps is a diverse group of healthcare professionals that functions as a support community, providing administrative and clinical services as an integral part of Navy Medicine. There are currently more than 3,000 active and reserve Medical Service Corps officers serving around the globe, approximately 40 percent of whom are healthcare administrators.

This thesis develops a Markov model to estimate the number of HCA accessions necessary to meet inventory requirements from FY14 to FY18. The general HCA model validation and analysis show that aggregate annual transition rates pass the stationary assumption required of Markov models. Models the study develops for some subspecialties perform better than others and are consistent and accurate. Consistency and accuracy are important because budget planners and recruiting command rely on manpower estimates during the fiscal year.

These results suggest that the Markov model is a useful tool for HCA community managers to forecast inventory levels across rank and subspecialties, and is effective for determining force structure.

Determining the end strength of HCA officers is an important part of the accession planning process for manpower planners to balance the force structure to effectively minimize deviation from target inventory levels that impact training and labor costs, as well as to manage career progression.

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	active component
AMD	Activity Manpower Document
BA	Billets Authorized
BSO	Budget Submitting Office
BUMIS	Bureau of Medicine Manpower Information System
CNA	Center of Naval Analysis
CCP	Clinical Care Providers
CNP/PERS-2	Chief of Naval Personnel
DMDC	Defense Manpower Data Center
DP	Direct Procurement
DOPMA	Defense Officer Personnel Management Act
FY	Fiscal Year
FYDP	Future Year Defense Plan
HCA	Healthcare Administration
HCS	Healthcare Sciences
HSCP	Health Professions Scholarship Program
IPP	In-Service Procurement Program
IST	Inter-Service Transfers
MedMACRE	Medical Manpower All Corps Requirements Estimator
MSC	Medical Service Corps
MFT	Mission, Functions and Tasks
NAVMAC	Navy Manpower Analysis Center
NPC	Navy Personnel Command
NC	Nurse Corps
OCM	Officer Community Managers
POE	Projected Operational Environment
POMI	Plans Operations Medical Intelligence
RC	Reserve Component
ROC	Required Operational Capabilities
SSN	Social Security Number

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I. INTRODUCTION

A. OBJECTIVES/PURPOSE

During the past few years, the Medical Service Corps (MSC) has undergone myriad changes. Most challenging to the MSC Healthcare Administration (HCA) community is the pressure to reduce end-strength, while the Navy tasks manpower planners with designing an appropriate force structure to support the fleet based on unclear future mission requirements. While the MSC currently utilizes the operationally focused Medical Manpower All Corps Requirements Estimator (MedMACRE) manpower planning tool to ensure that they can support operational and wartime requirements, it does not focus on peacetime requirements. The evolving process of personnel planning has to ensure that the proper number and mix of MSC officers are available. It is therefore imperative to examine the current state of personnel planning in the HCA community, and determine its most robust force structure.

This thesis evaluates the effectiveness of a Markov model to create a five-year forecast of MSC HCA inventory levels by rank and subspecialties. We employ the model to determine the number of HCA accessions required to meet inventory requirements over the next five years, to include classification targets for each subspecialty. Furthermore, this thesis examines current business practices used for personnel planning and forecasting in the MSC to meet its readiness and peacetime missions.

B. BACKGROUND

In recent years, the Navy has experienced a decrease in accession and retention of the MSC mainly due to the challenges of sequestration, the Navy's changing mission, and continued downsizing. In his 2011 Admiral's call, former Navy Surgeon General Vice Admiral Adam M. Robinson, Jr., stated

> I recently spoke at Navy Medicine's annual Leadership Symposium. This year's theme was "Total Force - Focusing on the Future." The Symposium's objectives are worth repeating because they really should be our focus as well in how we build our future force in the coming years: 1) Improve our readiness to fully support current and future operations; 2)

> attain agility in how we lead, how we communicate, and how we support our diverse staff; 3) strengthen our delivery of primary care; and 4) adapt to the changing environmental healthcare needs of our population…Over a year ago, we began an Enterprise-wide assessment of the size, specialty levels, and distribution of our Total Force billet requirements and personnel inventories. This yielded the development of several assessment tools. MedMACRE provides an analytical defense for sizing our force, especially for less than full mobilization scenarios and issues relating to Force Specialty Mix. Demand Based Staffing Tool is a regional and command level management tool that takes inputs from MedMACRE to help create uniform requirements. Fit-to-Fill Assessments help identify who is doing the work and where the work is being done. Lastly, Total Force Assessments provide more transparent assessments of force mix, distribution, and Military Training Facility workload, and are used in partnership with the Bureau of Medicine and Surgery, Regions, and Commands. Our Total Force Concept is about standardizing how we allocate, recruit, retain, educate, train and incentivize the right work force for the right mission across the Enterprise in order to eliminate gaps and overlaps, increase efficiencies through resource sharing, and integrate learning strategies. (Robinson, 2011, p. 4).

The MSC actively supports the Navy and Marine Corps team and Navy Medicine's readiness and health benefits missions with a community of active component (AC) and reserve component (RC) professionals. Health care accessions and recruiting remain a top priority, despite some critical wartime specialty shortages. At the end of Fiscal Years (FY) 2011 and 2012, AC Medical Service Corps manning was 97 percent of authorized levels and decreased to 95 percent in FY13 (Nathan, 2012).

Of the 10 HCA subspecialties examined, a staffing shortage exists for the patient administration specialty, manned at 45 percent, and education and training management, at 30 percent. This shortage is due to increased requirements and billet growth during the past three years. The Navy anticipates that these specialties will be fully manned by the end of FY2014 through increased accessions and incentive programs. Improvements in special pays have mitigated manning shortfalls; however, it will take several years until Navy Medicine is fully manned in several critical areas.

1. United States Navy Medical Service Corps

The United States Navy MSC is a diverse group of healthcare professionals that functions as a support community, providing administrative and clinical services as an integral part of Navy Medicine. Founded on 4 August 1947 with the passing of the Army-Navy Medical Service Corps Act, the MSC was originally called the Navy Hospital Corps in World War I ("Medical Service Corps," 2013). The MSC originally had four specialties: Supply and Administration, Medical Allied Sciences, Optometry, and Pharmacy. Today, the MSC comprises 31 subspecialties, organized under three major categories: Healthcare Administrators (HCA), Clinical Care Providers (CCP), and Healthcare Sciences (HCS). The HCA category further subdivides into ten subspecialties: General HCA, Patient Administration, Material Logistics Management, Health Facility Planning and Project, Plans Operations Medical Intelligence (POMI), Manpower and Personnel Management, Financial Management, Education and Training, Operations Research and Information Systems Management.

There are currently more than 3,000 active and reserve MSC officers serving around the globe, while the Navy HCA makes up approximately 40 percent of the MSCs. MSC officers come from varying educational backgrounds, and specialize in an array of fields to provide quality healthcare in support of Navy Medicine's primary mission of readiness and provision of healthcare benefits. They are entrusted with significant responsibilities that determine the direction of healthcare for U.S. service members and their families, ranging from managing the Navy healthcare system to providing direct patient care. With strong operational presence at sea and ashore, MSC officers serve in a variety of locations and situations, including deployments and humanitarian missions, aircraft carriers, joint commands, Navy hospitals and clinics worldwide. They also provide combat support to put Marines into the fight where they are needed.

To better understand the breakdown of the MSC subspecialties and differences in manning and inventory levels, Tables 1 and 2 illustrate the MSC manpower inventory. The inventory of MSC officers as of 30 September 2013 was 2,690, with 987 of them being HCAs. During this period, there were 2,796 total MSC billets authorized (BA), which put the overall MSC at 95% manning level further detailed in Table 2 by manning levels, inventories, and billets authorized by specialty for MSC officers. This research focuses on the HCA community as the subject of this study due to the homogeneous nature of the ten subspecialties and the fact that they make up a high proportion of the MSC.

Table 1. MSC Subspecialties and Inventory, September 2013 (after BUMED MSC report, 2013)

Health Care Admin			**Health Care Science**			**Clinical Care Provider**		
Subspecialty	*Total Inv*	*Inv %*	*Subspecialty*	*Total Inv*	*Inv %*	*Subspecialty*	*Total Inv*	*Inv %*
Gen. Health Care Admin	603	61%	Biochemistry	38	6%	Clinical Psych	179	17%
Patient Admin	31	3%	Microbiology	52	8%	Audiology	29	3%
Mat'l Logist Mgt	63	6%	Radiation Health	97	14%	Social Work	71	7%
Info Systems	33	3%	Physiology	16	2%	Physical Therapy	118	11%
Hlth Fac Pln & Proj	15	2%	Aerospace Physio	98	15%	Occupational Therapy	38	4%
Plans/Ops/Med Int	117	12%	Aerosp Exper Psych	30	4%	Clinical Dietetics	26	3%
Financial Mgt	78	8%	Research Psych	17	3%	Optometry	109	11%
MPT&E	31	3%	Entomology	39	6%	Pharmacy, General	136	13%
Educ & Trng Mgt	7	1%	Environmental Health	96	14%	Podiatry	26	3%
Operation Research	9	1%	Industrial Hygiene	112	17%	Physician Assistant	300	29%
			Medical Technology	76	11%			
Total	**987**	100%		**671**	100%		**1,032**	100%

Table 2. MSC Report as of 30 September 2013 (from BUMED MSC report, 2013)

SUBSPEC CODE #	SPECIALTY	INV	# ASSIGNED IN TRAINING	NET INV	F/S+AUTH BILLETS	2XXX	AUTH BILLETS	# OVER/UNDER MANNED	MANNING PERCENTAGE
1800	Health Care Adm	603	24 =	579	483	24 =	459	96	119.9%
1801	Patient Admin	31	0 =	31	70	1 =	69	-39	44.3%
1802 & 3121	Mat'l Logist Mgt	63	1 =	62	83	1 =	82	-21	74.7%
1803 & 6201	Info Systems	33	3 =	30	33	1 =	32	-3	90.9%
1804	Hlth Fac Pln & Proj	15	0 =	15	19	=	19	-4	78.9%
1805	Plans/Ops/Med Int	117	4 =	113	164	5 =	159	-51	68.9%
3110-3112	Financial Mgt	78	2 =	76	79	1 =	78	-3	96.2%
3130	MPTA	31	5 =	26	35	3 =	32	-9	74.3%
3150	Educ & Trng Mgt	7	1 =	6	19	=	19	-13	31.6%
3211	Operation Research	9	4 =	5	7	=	7	-2	71.4%
	HCA Subtotal	987	44 =	943	992	36 =	956	(49)	95.1%
1810	Biochemistry	38	0 =	38	35	=	35	3	108.6%
1815	Microbiology	52	1 =	51	46	2 =	44	5	110.9%
1825 & 1828	Radiation Health	97	6 =	91	85	1 =	84	6	107.1%
1835	Physiology	16	1 =	15	14	1 =	13	1	107.1%
1836	Aerospace Physio	98	12 =	86	88	5 =	83	-2	97.7%
1840-43	Clinical Psych	179	35 =	144	164	=	164	-20	87.8%
1844	Aerosp Exper Psych	30	3 =	27	29	=	29	-2	93.1%
1845	Research Psych	17	0 =	17	19	=	19	-2	89.5%
1850	Entomology	39	3 =	36	33	=	33	3	109.1%
1860	Environmental Health	96	1 =	95	94	=	94	1	101.1%
1861	Industrial Hygiene	112	4 =	108	120	1 =	119	-12	90.0%
1862	Audiology	29	0 =	29	32	=	32	-3	90.6%
1865	Medical Technology	76	3 =	73	71	=	71	2	102.8%
1870	Social Work	71	20 =	51	88	=	88	-37	58.0%
1873	Physical Therapy	118	7 =	111	115	1 =	114	-4	96.5%
1874	Occupation Therapy	38	0 =	38	37	1 =	36	1	102.7%
1876	Dietetics	26	0 =	26	33	=	33	-7	78.8%
1880	Optometry	109	2 =	107	109	3 =	106	-2	98.2%
1887	Pharmacy, General	136	3 =	133	127	3 =	124	6	104.7%
1892	Podiatry	26	2 =	24	27	=	27	-3	88.9%
1893	Physician Assistant	300	7 =	293	291	3 =	288	2	100.7%
	TRAINING BILLETS				147				
	TPPH Billets				40				
	HCA Subtotal	987	44 =	943	992	36 =	956	-49	95.1%
	HCS subtotal	1703	110 =	1593	1657	21 =	1636	-64	96.1%
Total MSC Officers w/o 2XXX		**2690**	154 =	2536	**2836**	57	*2739	**(146)**	**94.9%**
	2XXX billets						57		
	Total MSC Officers	**2690**					**2796**		

FOOTNOTES:
1. SUBSP inventory captures all MSC officers with reported primary subspecialty code regardless of assignment.
2. Certain SUBSP inventory has been combined within the overall primary subspecialty code.
3. 2XXX share as determined by BUPERS, PERS-N131M
* Total billets without 2XXX and TPPH (Includes (156) AD Training billets)

2. Navy Manpower Requirements and Authorizations Process

Understanding the manpower requirements and authorization processes is essential to examining MSC requirements. There are several important sub-processes by which the Navy executes manpower policy. Navy manpower requirements originate in the National Security Strategy (Hatch, 2013). The goal of manpower requirements is to establish the quantitative and qualitative military and civilian manpower necessary to execute missions assigned to ships, aircraft squadrons, and shore establishments that support deploying forces. The resource sponsor is tasked with identifying the aggregation of resources and desired level of manpower authorizations required to support the assigned missions and support functions. This request is submitted to Congress for approval as part of the budget and Military Personnel Navy (MPN) end strength request. Manpower authorization represents manpower requirements supported by approved funding and end strength for the current fiscal year and programmed through the Future Year Defense Plan (FYDP). Manpower authorizations are programmed in the Planning, Programming and Budget Execution System (PPBES) cycle, which are then submitted as part of the president's budget. The approved manpower authorization level or end strength is then sent back to the resource sponsor and Budget Submitting Office (BSO) for execution. The approved end strength is used as a guide by officer community managers (OCM) to develop and execute personnel inventories.

Manpower requirements are based on a naval activity's capabilities under which they are expected to operate afloat, referred to as Required Operational Capabilities (ROC) and the Projected Operational Environment (POE). Activities ashore operate under Mission, Functions and Tasks (MFT).

Based on each activity's ROC/POE, the Navy Manpower Analysis Center (NAVMAC) establishes a Ship Manpower Document (SMD) and Squadron Manpower Document (SQMD). The BSO develops the Statement of Manpower Requirements (SMR) for shore activities. These documents are the bases of the Activity Manpower Document (AMD). The AMD lists all the qualitative (billets) and quantitative manpower requirements necessary for a specific activity, and identifies which requirements are to be funded. The qualitative expression of manpower is depicted by the skill set of the officer as described by the subspecialty code.

3. Accession Planning

Navy Medicine uses personnel plans to meet future readiness and peacetime missions, ensuring that the quantity and quality of MSC officers are available. End strength, accession, and promotion are three personnel plans used by the MSC planners to ensure that the right number of officers are at the right grade and available at the right time.

The Chief of Naval Personnel (CNP/PERS-2) issues policy guidance in the execution of the Navy's personnel plans. This assists the MSC OCM and manpower analyst in the development of accession plans to target projected inventory levels and peacetime recruiting goals for future fiscal years. The MSC manpower analyst work closely with the specific OCM to determine the number and mix of officers they wish to recruit and to develop the most efficient and effective accession plan. With the manpower analyst located at BUMED, and the OCM located at Navy Personnel Command (NPC), there is the need for proper communication and accurate information to keep the accession planning process adaptable to required changes.

After the promotion plan is completed and promotion numbers determined by pay-grade, the accession plan is formulated. The results of the promotion plan enable the OCM and manpower analyst to identify gaps in pay-grades for the future year and target the expected number of new officers required by specialty. Thus, the accession plan is developed by examining the beginning inventory and current personnel inventory, in addition to expected gains minus expected losses. This identifies an accession figure. Once combined, the OCM and manpower analyst comprise the new fiscal year end strength targets. This calculation can be adjusted by increasing or decreasing to ensure that the targeted end strength figures are met.

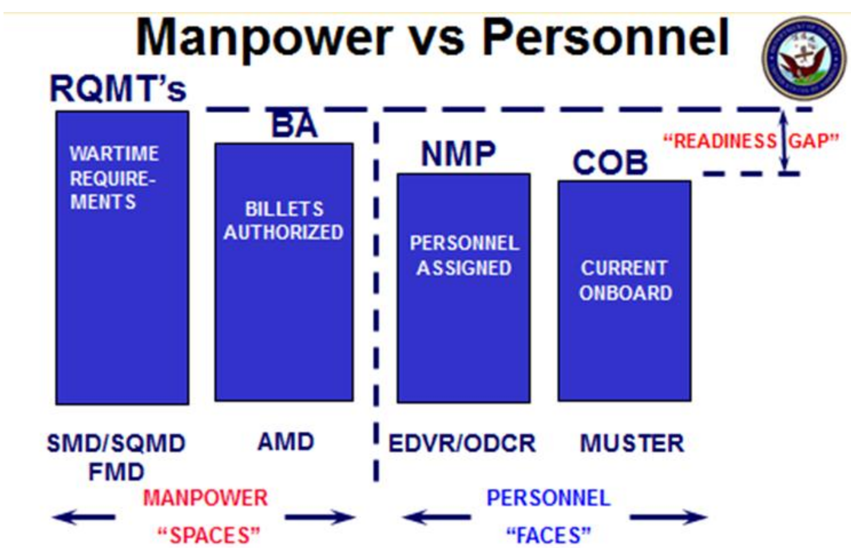

Figure 1. Navy Manpower Manning Process (from Hatch, 2013)

MSC accessions come from a variety of sources such as NROTC, recalls, and lateral transfers from other communities that apply to the MSC. The most common accession sources are the In-Service Procurement Program (IPP), the Health Services Collegiate Program (HSCP), the Health Professions Scholarship Program (HPSP) and Direct Procurement (DP).

The accession plan begins in July and is completed in December, two fiscal years ahead of time from the current year. After the CNP approves the accession plan, a mid-year review is conducted as changes may develop during the review process (Houser, 1996). Modifications to the accession plan must be approved by the OCM.

4. Officer Promotions

Promotion planning ensures the Navy meets its end strength requirements and is vacancy-driven. When gains and losses are calculated, promotion planners use end strength numbers to develop promotion rates. The promotion cycle begins when end strength figures are broken down by grade. The Defense Officer Personnel Management Act (DOPMA) of 1980, amended by Congress, establishes the control grades of lieutenant commander, commander and captain, which decisively affect promotion flow points, selection for promotion and promotion opportunities (Rostker et al., 1993). Unlike the Medical and Dental Corps, the MSC has a limited number of officers in these control grades as established by DOPMA. The promotion flow points as specified in DOPMA guidance is shown in Table 3.

Table 3. Promotion Flow Points (after Rostker et al., 1993)

Promotion To:	**Flow Point**
Captain	21 to 23 years
Commander	15 to 17 years
Lieutenant Commander	9 to 11 years
Lieutenant	4 years
Lieutenant (Junior Grade)	2 years
Ensign	N/A

Based on DOPMA guidance, all ensigns receive a statutory promotion to lieutenant junior grade after 18 months to two years of service. The last row indicates “N/A” because an individual cannot be “promoted to” ensign. The flow point column illustrates the overall view of the total time it takes to advance to the next grade. Advancement from lieutenant junior grade to lieutenant is similar to that of an ensign in that it is an automatic promotion as well. An annual promotion board is convened for selected officers from the ranks of lieutenant to captains eligible to promote. Officers above the grade of captain are appointed, not promoted, by the president of the United States to the admiral pay-grades.

C. MSC ACCESSIONS

The most common accession sources used to procure MSC officers are IPP, HSCP, HPSP, and DP. These programs will be discussed in detail in the following paragraphs. The others such as Inter-Service Transfers (IST), recalls and lateral transfers from other communities that apply to the MSC make up a very small percentage of MSC accessions.

Most HCA officers are recruited from the civilian sector (direct accession/procurement) or from enlisted status (in-service procurement). The HSCP and portion of the IPP are the only educational and training programs utilized to recruit officers to the MSC. Due to gaps in training, it is difficult to determine whether there could be losses. MSC manpower planners use direct accessioning to fill in these gaps in order to balance officer shortfalls and to make the necessary adjustments during the fiscal year. When officers are accessed through these programs, it is based on different pay-grades by education level. For example, a new MSC recruit with a bachelor's, master's or doctorate degree, will be given the rank of ensign, lieutenant junior grade, and lieutenant, respectively.

Table 4. FY2013 & FY2012 MSC HCA Accessioning Source Percentages (after BUMED MSC report, 2013)

Accession Sources	FY2013		FY2012	
	Number	Percentage	Number	Percentage
IPP	17	30%	20	36%
Direct	16	28%	18	32%
HSCP	24	42%	17	30%
HPSP	0	0%	1	2%
IST	0	0%	0	0%
Recall	0	0%	0	0%
Total	57	100%	56	100%

1. In-Service Procurement Program

The IPP is the most popular accession source in Navy Medicine. The majority of HCA officer accessions are commissioned with some type of previous military experience. Enlisted service members eligible to receive a commission have the opportunity to serve in most of the subspecialties depending on their level of education and degree program. The OPNAV instruction provides all specific qualifications for IPP. However, the instruction changes each year as the needs of the Navy change to support its mission. A selection board made up of senior MSC officers meets annually to review Navy or Marine Corps enlisted members, E-5 and above for selection into the program. While in the program, the enlisted member receives educational benefits and retains eligibility for enlisted promotion.

2. Health Services Collegiate Program

The HSCP is an accession source that is an educational pathway for individuals, with or without prior military service, entering an accredited graduate program to receive a commission as an MSC officer. This program provides a two or three-year scholarship, depending on whether it is a Master's or Doctorate program, for students to pursue an advance degree for a designated health profession. The program also provides students with E-3 pay and additional benefits.

3. Health Professions Scholarship Program

The HPSP primarily provides Optometrists with a full scholarship, monthly stipend and a commission as lieutenant upon graduation. They serve for a minimum of three years, after which they are promoted to the next pay-grade.

4. Direct Accession

Candidates for direct accession, usually with no prior military experience, apply to be commissioned after completing an accredited educational program in a chosen field.

D. CURRENT FORCE PLANNING TOOLS

BUMED currently uses the MedMACRE modeling tool, to size the force, assess specialty levels, distribute personnel inventories and determine the minimum manpower resources required to deliver quality health care to the fleet. MedMACRE is one such tool that provides an analytical defense for sizing our force, especially for less than full mobilization scenarios and issues relating to Force Specialty Mix.

However, the inventory of subspecialty training are not tracked or managed in any way. By only tracking current HCA inventory and accessions, manpower planners and OCM remain purely reactive and lack a holistic view of the community.

E. SCOPE AND METHODOLOGY

Of particular interest is exploration of the systematic behavior within the HCA community in terms of accession, transition and attrition to ensure that the MSC has on active duty the right number of HCA officers, at the right grade, at the right time. The scope of this thesis consists of Navy HCA officers from pay-grades O–1 through O–6, and their respective subspecialties from FY2010 to FY2013. The aggregate data from the Defense Manpower Data Center (DMDC) Master file for each officer populates the probabilistic representation of accession, transition, and attrition within the HCA community. The thesis concludes with recommendations and potential areas for further research.

F. ORGANIZATION OF STUDY

This chapter examines the overall objectives, purpose, scope and organization of the thesis. It also provides an overview of the Navy MSC and describes the background of the HCA community and its structure. Chapter II provides a detailed literature review and describes other studies of Markov modeling as it relates to civilian firms, the military, and more specifically, the MSC HCA accessioning process and manpower determination. Chapter III captures the specific data and methodology used to develop a Markov model of the behavior of the HCA community. This chapter also determines the best transition matrix for the Markov modeling. Chapter IV provides the implementation and validation of the Markov model and provides the limitations of the model as well. The final chapter summarizes the study and provides conclusions and recommendations for each of the research questions as well as recommendations for further research.

II. LITERATURE REVIEW

A. OVERVIEW

This chapter explores research on manpower planning and derives methodologies to assist in the current study. Manpower analysts tend to concentrate on topics in the civilian sector, but there are relatively few studies directly related to the MSC manpower and personnel. Furthermore, most military personnel planning models are deterministic—"they ignore the uncertainty implicit in personnel loss projections"—and most of them are steady-state—"they ignore current personnel inventory and its evolutionary possibilities" (Hall & Moore, 1982, p. v). Only two studies focus specifically on the behavior of MSC HCA officers. One of the studies describes attrition and retention in the HCA community. The other uses a steady-state analysis to determine the optimal number of MSC HCA officers the Navy must access each year in order to maintain a desired end strength. However, we find no research that develops new models which includes current personnel inventory that specifically focus on tracking and managing subspecialties. This thesis attempts to fill that gap.

B. BARTHOLOMEW, FORBES, AND MCCLEAN

In the second edition of their book, *Statistical Techniques for Manpower Planning*, Bartholomew, Forbes, and McClean include an account of most of the stochastic models researchers use in manpower planning and provide a systematic account of the technical aspects of manpower planning tools. Stochastic models on manpower planning have been developed and studied in the past by many well-known researchers like Bartholomew (1971), Smith (1970), Forbes(1971), Vajda (1975), and Grinold and Marshall (1977). We apply the basic concept, terminology and notations derived from Bartholomew et al. in this study.

The statistical approach to manpower planning has mainly been contributed by Bartholomew (1971) due to features of most manpower planning problems. The two main features are concerned with aggregates and uncertainty. Manpower systems can be explored through an examination of historical data. Data from the historical study aggregates to provide an extensive description of the system. The behavior patterns or probabilities are then used to represent these aggregates and reflect the uncertainties that generally arise from the highly unpredictable human behavior (Bartholomew et al., 1991).

Each model for a manpower system, according to Bartholomew et al., must be presented as a mathematical description of a succession process with a known scheme of successional transitions and their time characteristics which describe the flow within the system (Bartholomew et al., 1991). As stated in the previous chapter, billets and authorizations are limited. However, the system can generate more personnel than there are billets to bring manning levels to 100 percent. The manpower system describes the personnel flow in the model of the system and how the system is constrained by available resources. Despite these constraints, the system is able to control some behaviors such as promotion, which requires a board. Other behaviors such as voluntary retirement can be difficult to control. All manpower models have these common aspects of constraints and flows.

Bartholomew et al. highly recommend the use of transition models based on the theory of Markov chains when dealing with heterogeneous systems. Based on this theory, the MSC community can be referred to as a heterogeneous system, a system that classifies people to "such things as grades, age, or location" (Bartholomew et al., 1991). Markov chains play a vital role in the study of military systems in which personnel exist in each state of the model which are mutually exclusive, such as subspecialties and rank. According to Bartholomew et al., Markov chains are useful in determining the "ideal" manpower population and force structure (Bartholomew et al., 1991).

C. OTHER CIVILIAN STUDIES

During the past decade, Markov chains have received considerable attention in the literature. This is evident in the growing number of journal articles, literature, and proceedings of national and international conferences that deal with manpower planning methods. It has also received the support of civilian firms, military and governmental agencies, operations research, management science and a host of other entities interested in manpower systems.

The use of Markov models in civilian manpower planning varies widely in the populations studied compared to the military. Including Bartholomew, numerous researchers like Davies (1973 and 1981), Zanakis & Maret (1980), Sales (1971), Ugwuowo & McClean (2000) make appreciable contributions in the general application of Markov modeling in the areas of statistical manpower planning and control. Vassiliou (1997) and a host of other referenced authors in this thesis apply studies in other contexts such as non-homogeneous and semi-Markov manpower models to manpower planning and specific populations including patient care (Faddy & McClean, 2005), police force (Birge & Pollock, 1989), and medical decision making (Sonnenberg & Beck, 1993). Consequently, researchers and analysts use the processes of Markov modeling in a wide variety of applications in manpower planning.

D. ACCESSION AND ATTRITION BEHAVIOR PATTERNS

From 1983 through 1988, the Center of Naval Analysis (CNA) found a decrease in the accession and retention rate for the Medical Corps and the Nurse Corps. In 1989, Dolfinin conducted a study in an attempt to discover whether similar issues arose within the MSC community. The study examines accession and retention of MSC officers to determine whether there exists an actual manpower shortage.

Dolfinin uses the MSC continuation rate to examine accession and retention at the aggregate community level, and finds that from FY1984 to FY1988, the continuation rates for both aggregate and community levels are consistent at 90 percent or above. Additionally, it reveals disparities between HCA officers and HCS officers in regards to their continuation and retention rates. HCA officers are relatively stable for the first 10 years of commissioned service and then experience a downward trend thereafter. While HCS officers on the other hand, experience a different continuation pattern. They tend to make a long-term career decision to stay in the Navy, once they reach 10 years of commissioned service. HCS officers usually serve until the 20 year mark before the continuation rate drops. These different retention patterns between HCA and HCS officers are mostly attributed to the majority of the HCA officers who are prior-enlisted and have the ability to retire before 20 years of commissioned service.

The study recommends leadership in policy decision making, to increase the accessions or continuation rates, or both to solve the manpower shortage problem. Although the study does not provide recruiting strategies, it forecasts average continuation and maintenance rates for the future, as well as provides HCA and HCS personnel inventory levels during the study. It also recommends adjusting the accessioning process, which our thesis attempts to fulfill.

E. MILITARY APPLICATIONS OF MARKOV MODELS

Military personnel possess various attributes like rank and occupational specialty. They also transition to various ranks and specialties during the course of a career. Markov chains are adept at modeling the flow of personnel through such a system.

It is not possible to guarantee continued service or attrition for specific personnel in the military. Therefore, manpower analysts estimate attrition and retention behavior by using analytical judgment, prior experience, and most importantly historical personnel data. Historical data can include observable predictive variables such as rank and subspecialties, for each individual as of some specified point in time, and whether or not each individual continued service (and for how long) after that point in time. By applying these estimates to current personnel, analysts obtain a prediction of future behavior.

While some studies utilize logistic regression techniques, steady-state analysis, and survival analysis, our thesis takes a deterministic approach considering the current personnel inventory due to the data available.

1. Uncertainty in Personnel Force Modeling

Hall and Moore (1982) address the impact of uncertainties related to the recruiting shortfalls, stay/leave decisions, and accession and retention rate estimation of enlisted Air Force personnel. The project examines the impact of various types of uncertainties on projections of force structures using a Markov flow model of the first-term force.

Development of these specifications for an enlisted force management planning system replaces the Air Force's current system at the time known as TOPCAP (Total Objective Plan for Career Airman Personnel). Like most military studies, the TOPCAP consists of deterministic models. To develop new models, the researcher investigates the degree of uncertainty implicit in personnel flows and evaluates the need to incorporate uncertainty in these new models as well as alternative means of performing this task.

The study analyzes the impact of uncertainty on accession requirements, reenlistment requirements and personnel costs. Findings indicate that individual stay/leave decisions and the proportion of accession requirements are the largest contributors to uncertainty, while uncertainties regarding estimates of flow rates and the mix of people contribute less.

The study makes two recommendations. One advises the development of improved procedures such as including "environmental" data (e.g., occupational categories) for estimating probabilistic parameters in personnel flow models such as loss rate. The other recommends the revision and extension of recently-developed retention decision models to predict how the flow behaviors for various categories will change based on policy changes. Our thesis focuses on assisting in the second recommendation for HCA officers to improve procedures and methods to provide consistent, interpretable and cost effective sets of parameters for model estimations, flow rates, variables, and outcomes.

2. Steady-State Analysis and Logistic Regression

We review three studies that analyze the steady-state inventory of officers. The first and second studies are two NC theses that focus on predicting NC career progression. One of these theses provides an in-depth focus on regression analysis techniques to improve validity. The third study focuses on personnel progression within the MSC HCA community to determine the steady-state of HCA officers and compare them to the actual target end strength and accessioning numbers.

Deen and Buni (2004) use Markov modeling to provide the Navy NC with a tool to forecast recruiting goals. This NC thesis focuses on officers between grades O-1 and

O-3 categorized by time in service and rank based on 11-year data (FY1991 to FY2003), provided by BUMIS. The transition matrix depicts the personnel flow process of NC officers, where an officer remains at the current rank, promote to the next rank or attrite or leave the Navy. There are no demotions in this model. Additionally, to create the best transition matrix for the model, the study allows officers in pay-grades O-4 and O-5 to flow through the system. It also uses logistic regression to investigate and predict if any variables in the data set, especially accession sources, affect the probability of staying in the NC. The study merges NC cohort data files from FY1990 to FY1994 and FY1996 to FY1998 for analysis.

Findings from the logistic regression show that Recalls, Medical Enlisted Commissioning Program (MECP) and Nurse Candidate Program (NCP) are all correlated with increased probability of staying in the NC. They also show that males are more likely than females to stay in the NC. Furthermore, change in education levels decrease the probability of staying in the NC. By observing the Markov model function over the ten-year period, the thesis finds that officers in pay-grades O-1 and O-2 reach a steady state at the eight-year mark. Officers in pay-grade O-3 on the other hand, reach a steady state at the 17-year mark. Furthermore, findings indicate that at steady state, there are 521 ensigns, 530 lieutenants junior grade and 900 lieutenants. The thesis makes no changes to these values as long as NC number and rank of accession remains the same. When the study compares these values to target figures, it shows that O-1s are 220 over, O-2s are 63 under and O-3s are 220 under, which yields an overall shortage of 63 nurses. Therefore, the study finds that there is a severe shortage of O-3s and an overflow of O-1s when it compares the current accession plans to the NC goals.

Kinstler and Johnson (2005) complete a follow-on thesis which focuses on the accession challenges of the NC in determining the appropriate number of nurses manpower planners should access each year in order to maintain desired end strength. The study uses logistic regression to examine promotion and exit rates (leaving) at various pay-grades based on accession source. Given these dependent variables, the study uses logistic regression in an attempt to estimate the probability that a nurse would promote, stay in the Navy, or leave the service.

Results indicate that the accession source significantly impacts the probability of a person leaving. Although there does not appear to be a clear pattern, it is also shown to significantly impact promotion rates. The model includes officers in pay-grade O-4. The study merges data obtained from BUMIS and DMDC for analysis. Like the first NC thesis, the study develops a similar transition matrix. It compares the results from a two-year projection, 2006–2009, to the targeted end strength in the same period. It runs several scenarios to minimize overages and shortfalls in rank distribution, by changing both the distribution of accession sources and the distribution of recruited ranks. Optimal distribution of accession source and rank are dependent upon the degree of acceptable deviation from the targets set by the NC. However, due to unavailable information, the study does not provide a recommendation on the best mix of accession source and rank to meet current targets. Findings also show that two-year projection of current business practices of the NC optimizes accessions but would not produce large deviations in the near term. Greater efficiency, however, could be obtained in the out-years.

Vance (2006) uses a Markov model and steady-state analysis that specifically focuses on MSC HCA officers. The thesis adapts the methodologies used in the two prior NC theses above. The purpose of the thesis is to determine the optimal number of MSC HCA officers that the Navy must access each year in order to maintain a desired end strength. The study obtains data from BUMIS and DMDC, but the major contributor of data comes from DMDC. The study examines the flow of officers in pay-grades O-1 through O-4 using sixteen-year data (1988–2004) pulled using cohort files of all MSC officers including HCSs as well as HCAs. It develops the primary transition matrix by combining data over all the seventeen calendar years, and broken down by pay-grade and years of service within that pay-grade.

The study analyzes five scenarios to determine the most effective method to determine accession levels. One focuses on the historical averages of the past four accession plans. Conducting a four-year historical review helps identify that the current business practices will not allow for steady-states to be reached at each pay-grade. Results determine commissioning source to be significant and influences retention at the seven and ten year mark. There are three scenarios that focus on the junior officer ranks.

The study achieves optimization by changing with distribution of accessions sources and recruiting ranks. The final scenario applies a solver application to minimize “badness.” When it compares the force structure to the predicted value, the solver scenario provides the alternative with the least amount of shortfalls and overages.

Survival analysis identifies that IPP has a different survival function than other sources. Regression analysis addresses the retention of MSC HCA officers at certain year milestones. Findings show that single officers are less likely to be retained to seven years, when compared to married officers. It also shows that officers who are commissioned when older are less likely to be retained to seven years. Furthermore, HCA officers who enter the service through the IPP are more likely to be retained to seven years than officers entering through other programs. Results also indicate increased variations between the current force structure plan and the predicted Markov model outcomes. This suggests that greater efficiency could be obtained in future years. The study finds Markov model to be a useful tool for improving extended forecast for accessioning.

3. Survival Analysis

Military studies use survival analysis to analyze the survivability (stay/leave) patterns of personnel. It is one method of looking at retention behavior and is especially useful for observing differences across groups over time. We review two NPS theses in this section. The first thesis focuses specifically on MSC HCA officers, and the second is a review of survival analysis techniques which focuses specifically on the United States Marine Corps (USMC).

Farr (1994) utilizes data obtained from the Navy Officer Master File, Navy Officer Loss File, and Navy Personnel Research and Development Center’s Officer Fitness Report File, to estimate the factors that influence the effectiveness of accession through the IPP and direct procurement. The thesis uses multivariate analyses to compare officers by accession sources. It also uses various survival analysis techniques including proportional hazard models, ordinary least square models, and logit models. The thesis uses proportional “hazard” models to estimate the years of commissioned service the MSC HCA officers expect to serve before retiring or being voluntarily released from active duty. It uses the ordinary least square models to estimate the influence of accession source, education, and personnel demographics on separation behavior and fitness report performance. Lastly, it uses logit models to evaluate the probability of promotion and the probability of having above average fitness report performance values as a function of the accession source.

Results indicate that HCA officers with ten or more years of commissioned service are more likely to leave within a few years of becoming eligible to retire. The thesis also identifies a significant difference in education levels and early fitness report performance between officers who access through IPP and direct procurement. The thesis recommends a cost-benefit analysis to determine the optimal HCA accession policy.

Hoglin (2004) analyzes the determinants on the survival of prior and non-prior enlisted officers and to develop the methodology to optimize the accessions of these officers. The study obtains data from the Marine Corps Officer Accession Career (MCOAC) file. The study utilizes a Cox proportions hazards model to estimate the effects of commissioned officer characteristics on their survival in the USMC. Results indicate that prior enlisted officers have a better survival rate than non-prior enlisted officers. The study also uses a Markov model to determine the optimal percentage of prior and non-prior enlisted accessions for the USMC. Findings also show that officers who are married, commissioned through MECEP, graduate in the top third of their TBS class, and are assigned to a combat support MOS have a better survival rate than officers who are unmarried, commissioned through USNA, graduate in the middle third of their TBS class, and are assigned to either combat or combat service support MOS. Additionally, the optimum number of prior enlisted officer accessions is significantly lower than recent trends and differs across MOS. The study recommends a review of prior enlisted officer accession figures.

F. CHAPTER SUMMARY

This chapter establishes the use of the Markov chain as a manpower tool both in the civilian sector and within the military. While this review discusses and evaluates studies that deal directly with methodologies that could be applied to this thesis, Bartholomew et al. serve as the basis for applying a Markov chain to the MSC HCA community, and helps answer the primary research question of our study.

III. DATA AND METHODOLOGY

A. INTRODUCTION

This chapter introduces a Markov modeling method applied to this study to create a five-year forecast (FY2014 to FY2018) of MSC HCA personnel inventory levels by rank and subspecialties. To understand the type of information required to create this model, Chapter III describes the data we use for the study. As discussed in the previous chapter, personnel in the Markov model flow through the system either by staying at current rank, promoting to the next rank or leaving the system (attrite). The transition matrix developed for this model does not allow demotions. The ranks analyzed in the Markov model are ensigns though captains (O-1 through O-6).

B. DATA SOURCES

1. Descriptive Variables

This thesis obtains data from DMDC field office of Monterey, California, received as an Excel file. We pull the following descriptive variables from DMDC using cohort files of all active duty Navy MSC HCA officers over a four year period (FY2010 to FY2013). The data consist of three variables which we input into SAS to merge, code and clean. We then export the cleaned data into Microsoft Excel format to incorporate into the Markov model.

a. Social Security Number

Our model requires the use of Social Security Numbers (SSN) to provide a means of identifying personnel within the data. For privacy reasons, we replace SSNs with a unique identifier—a numeric string associated with identifying the individual in the system.

b. Rank

The data contain ranks from ensigns (O-1) through captains (O-6). The variable rank has only six possible values (O01 through O06 representing ensigns through captains).

c. Sub-specialty Codes

The sub-specialty code variable captures in numeric format the primary subspecialty of each HCA officer. These codes include all the 1800s, 3100s and 3200s. The data contain 10 possible subspecialties as shown in Table 2 (1800, 1801, 1802/3121, 1803/6201, 1804, 1805, 3110-3112, 3130, 3150, and 3211).

2. Descriptive Statistics

The sample size includes 56,621 observations. The observations consist of MSC HCA officers in the pay-grades O-1 to O-6 (Figure 2) and with subspecialty codes 1800 to 3211 as shown in Figure 3.

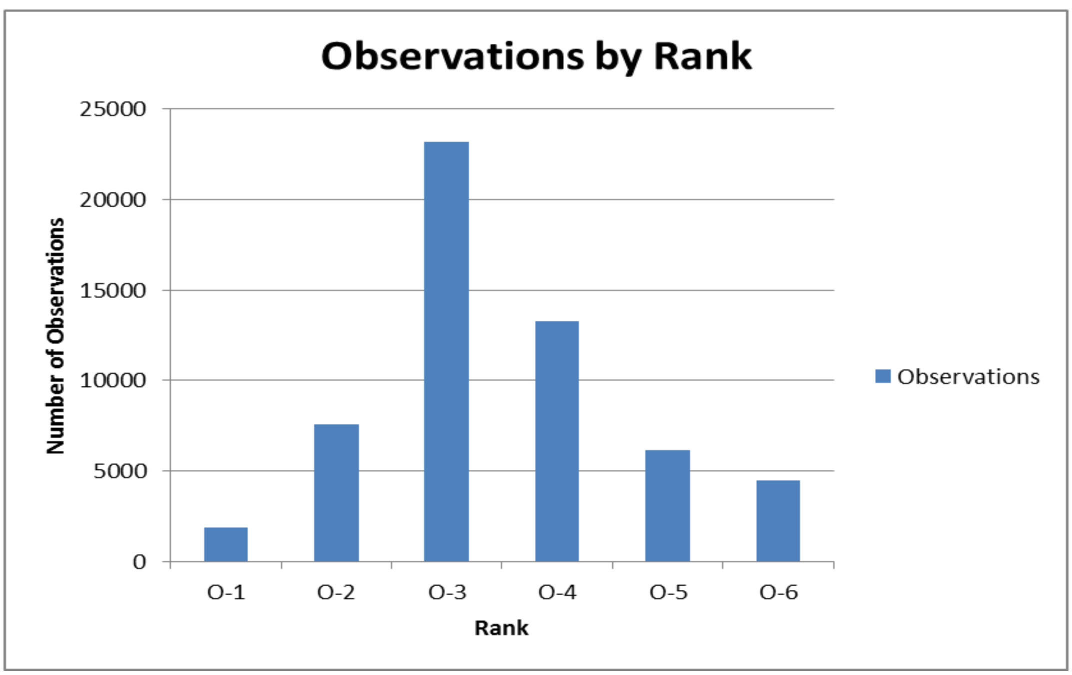

Figure 2. Observations by Rank

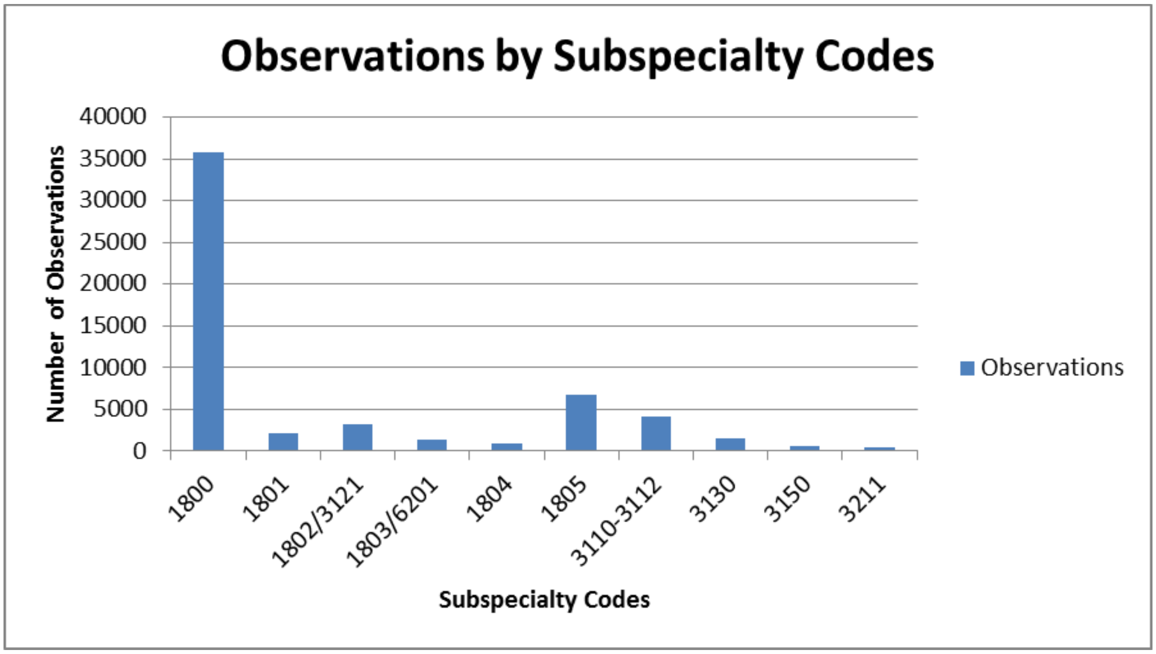

Figure 3. Observations by Subspecialty Codes

C. MARKOV MODEL THEORY

1. Markov Model Formulation

According to Zanakis and Maret (1980), "Personnel supply in an organization can be forecasted using Markov chains to model the flow of people through various "states" (usually skill or position levels, minority status, and sometimes years of service)" (p. 1095). We can further classify the HCA community into mutually exclusive states of rank and subspecialties. Given these characteristics, the systematic behavior of the HCA community allows the modeling application of a Markov chain.

a. Basic Markov Model Assumptions

Probabilistic models such as Markov models are extremely useful in manpower management applications and for predicting the aggregate behavior of the system, i.e. total end strength. Markov models require adherence to the following three fundamental assumptions: Finite State Space, Markovian Property, and Stationary Transition Probabilities.

States in the Markov chains in this thesis are countable, mutually exclusive, and exhaustive. An element of the Markov model may reside in a "state" for a period of time.

For our purposes, the states of the models we employ consist of grade-subspecialty code combinations. See figure 4 for an illustration of the conceptual model.

The Markovian Property is the property such that the probability that the system will transition to any particular state depends only upon the current state (Bartholomew, 1971). This means that the probability of promotion in rank, subspecialty code, or both depends only upon the current grade-subspecialty code combination. Because this study examines annual transitions, we look at what happens to each individual at each rank after one year. For instance, there are four possible outcomes for ensigns as seen in Figure 4: First, an O-1 might remain an O-1. Secondly, an O-1 might be promoted to O-2. Thirdly, an O-1 might make a lateral move to another subspecialty. Finally, an O-1 might attrite, or leave the Navy. The same idea applies to the other ranks. However, there is no "promotion" out of O-6. Individuals who promote to O-7 count as "attrites" because they are leaving the "system".

For transition probabilities to be stationary, then the following must be true for all values of t: $P(X_{t+1} = j \mid X_t = i) = P(X_1 = j \mid X_0 = i)$. Thus, the probability that the system transitions from state i to state j at time t, is the same as the probability that the system makes this same transition at time $t = 1$. In other words, the Markov chain should have transition probabilities which remain stationary over the life of the model (Sales, 1971). The predictive power of the model degrades if the transition probabilities change from one time period to the next.

D. METHODOLOGY

1. Conceptual Model

The Markov Model we develop for this thesis shows the flow of personnel through the manpower system. It consists of a transition matrix, an inventory vector, and a recruitment vector. The model calculates the annual officer strength by identifying the number of HCA officers in the system at each state and how likely they are to transition to the next state. Personnel can flow through the system either by advancing to the next state or by leaving the system (attrition). Figure 4 depicts the system from pay-grades O-1 to O-6.

A truncated depiction of the model of HCA officer manpower flow shows the system's annual transitions from O-1 to O-6. The transition probability, p_{11} is the probability that an O-1 with a subspecialty of 1800 might remain an O-1 with a subspecialty of 1800, and p_{12} is the probability that an O-1 with a subspecialty of 1800 might promote to O-2 with a subspecialty of 1800 in the next time step. If an officer leaves the system for any reason, he or she flows into the attrition state. The same idea applies to the other ranks.

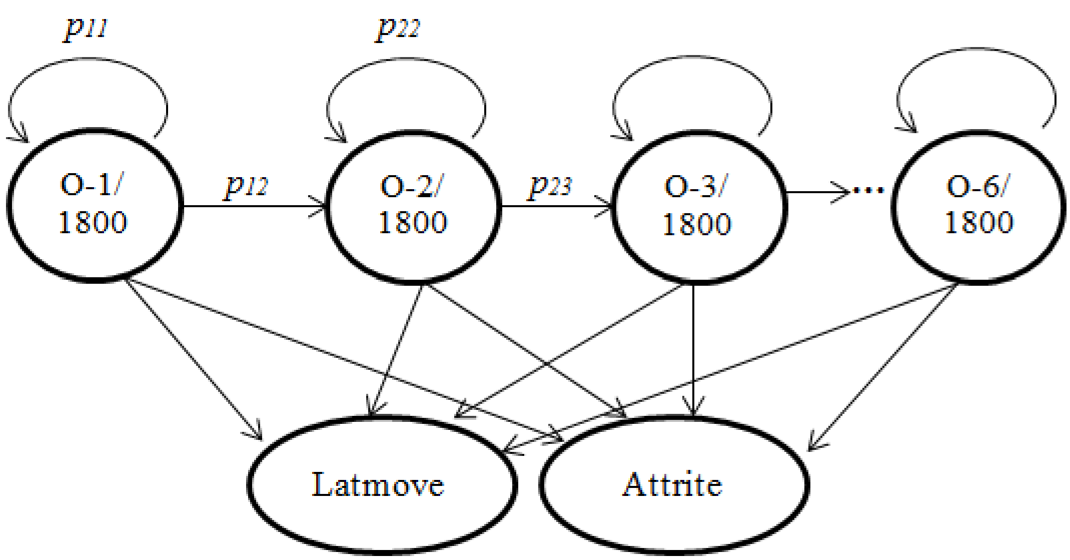

Figure 4. Truncated conceptual model (transition probabilities suppressed for clarity)

The purpose of this subsection of the thesis is to construct and illustrate the characteristics and capabilities of the fixed inventory and fixed recruiting models. The fixed inventory model of the Markov chain determines the number of personnel required to access to meet required end strength of the MSC HCA community. Alternatively, the fixed recruiting model determines the expected end strength generated by the given accession mission.

Table 5. Aggregated Flows from FY10 through FY13

	O-1	O-2	O-3	O-4	O-5	O-6	Attrite	Total
O-1	71	63					2	136
O-2		267	268				6	541
O-3			1255	203			104	1562
O-4				810	76		76	962
O-5					342	44	44	430
O-6						281	50	331

In order to determine the transition probability matrix **P**, we aggregate the flows between states for each time step using Microsoft Excel. In this case, we portray the flows from FY10 to FY11 as FY11 with a time step of one FY and so on. With data from FY10 through FY13, four years of flows remain which are aggregated together across all subspecialties combined (see Table 5).

We divide the flow for each transition by the total inventory from that state. For instance, the probability that an HCA officer who began as an ensign and continued within that same state is given as P(O-1| O-1) = 71 / 136 = 0.52. We conduct this process for each p_{ij} in the aggregated flows and in the individual time steps (see Table 6). The rows sum to 1 because we must account for each individual within the system.

Table 6. Aggregated Transition Probabilities Matrix **P** for FY10 through FY13

	O-1	O-2	O-3	O-4	O-5	O-6	Attrite	Total
O-1	0.52	0.46					0.01	1.00
O-2		0.49	0.50				0.01	1.00
O-3			0.80	0.13			0.07	1.00
O-4				0.84	0.08		0.08	1.00
O-5					0.80	0.10	0.10	1.00
O-6						0.85	0.15	1.00

2. Fixed Inventory and Fixed Recruiting Models

a. Equation

The equation for the fixed inventory model is exactly the same as the fixed recruiting model. We use the equation in the fixed inventory model to predict stock sizes in the different categories while controlling the number of people recruited during the forecasted period of time (Erhardt, 2012). The idea is to determine the number of accessions required to achieve desired inventory targets. Whereas, for the fixed recruiting model, the number of accessions are determined and we predict the resulting inventory levels through time.

$$\mathbf{n}(t) = \mathbf{n}(t-1)\cdot\mathbf{P} + R(t)\mathbf{r}$$

Defining the following indices based on Bartholomew et al (1991):

- **n**(t) is the predicted stocks or inventory vector at time t. Time is labeled in discrete increments, such as $t = 0,1,2,3,...T$. For this study, time steps are annual.
- **n**(t-1) is the inventory vector at the previous time step. **n(**0) represents the initial inventory vector.
- **P** is the matrix of transition probabilities. The transition probability p_{ij} is the probability an officer will transition from state i to state j in one time step.
- $R(t)$ is the number of HCA officers accessed into the system during time (t).
- **r** is the recruitment vector that determines the proportion of total recruits distributed among each state. For example, if **r** = (0.80, 0.20, 0, 0), then 80% of the new personnel recruited will enter category one, 20% will enter category two, and 0% will enter category three or category four.

b. Analysis

Using a fixed inventory model allows manpower planners to adjust various inputs to the model and assists to facilitate the understanding of the behavior of the HCA community. Additionally, the fixed inventory model uses transition probabilities, an inventory vector, and an accession (or recruiting) vector to estimate a number of manpower outputs.

We examine the expected behavior of the system once the trajectory of recruiting is fixed through the forecasted time period. This is known as the fixed recruiting model.

For a given sequence of recruitment vectors, it is possible to determine the expected end strength of the system (that is the distribution between states) at each time-step. Alternatively, we can seek a sequence of recruiting vectors which would produce a given goal or target structure.

Utilizing a fixed recruiting model allows manpower planners the ability to decide ahead of time what the recruiting mission is going to be through the future years. Like the fixed inventory model, it utilizes transition probabilities, an inventory vector, and an accession (or recruiting) vector as well. The only difference is that end strength targets are set (i.e. fixed) ahead of time and the model provides us with the number of recruits necessary to achieve these goals.

3. Fundamental Matrix

The Fundamental Matrix provides the expected time spent in transient states, and is given by:

$$\mathbf{S} = (\mathbf{I} - \mathbf{P_T})^{-1}$$

The fundamental matrix is the collection of s_{ij}'s in which s_{ij} = E[time steps a person spends in state *j* given that they started in state *i*]. Additionally, the main diagonals give the expected time in grade (E[TIG]). Essentially, the fundamental matrix of the model describes the expected length of time individuals remain within each state and the conditional probability of individuals ever achieving a state (Seagren, 2013). The fundamental matrix also allows manpower planners to determine from a given starting point which absorbing state an individual is likely to end up in.

The **C** matrix is constructed by multiplying **S**, the fundamental matrix by **Ab,** where **Ab** is the matrix of transitions to the absorbing states (Seagren, 2013).

$$\mathbf{C} = \mathbf{S}^* \, \mathbf{Ab}$$

Hence, the following relationships will hold:

- c_{ij} = P(an individual ends up in absorbing state *j* | the individual started out in state *i*).

E. CHAPTER SUMMARY

This chapter provides the background information of the data set used for this thesis, including basic descriptive statistics for the data and the methodology on how to construct fixed inventory and fixed recruiting Markov models. The Markov model proves to be a useful tool for accession and end strength planning for the MSC HCA community.

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IV. MODEL IMPLEMENTATION AND VALIDATION

This chapter outlines the implementation of the MSC HCA officer manpower models in Excel. In addition, it assesses the validity of the models with respect to the stationary assumption. We construct each subspecialty model and the aggregate in one Excel workbook.

A. STOCK FORECAST

This study bases the behavior of the MSC HCA manpower model on stocks and flows. Stocks are the distribution of HCA officers in each pay grade and the total population of the HCA community. Flows, on the other hand, are the transitions to the next state. The two main types of flows within our system are: Flows into the system (recruitment), and flows between the various parts of the system (promotion, lateral moves, and attrition) (Bartholomew, 1971).

Suppose, for example, the future inventory requirements for HCAs are given by the "Target" column in Table 9. We can use the equation: $\mathbf{n}(t) = \mathbf{n}(t-1)\cdot\mathbf{P} + R(t)\mathbf{r}$, to forecast the accessions required to achieve these inventory targets. Table 8 gives the accession mission that achieves these goals.

Table 7. Aggregate Accession Vector **r** for FY10 through FY13

	O-1	O-2	O-3	O-4	O-5	O-6
Accession Vector (r)	0.22	0.62	0.05	0.04	0.03	0.05

Table 8. Aggregate *R* for FY14 through FY18

	R
FY14	76
FY15	72
FY16	72
FY17	72
FY18	72

Table 9. Aggregate Inventory Forecast (Fixed Inventory Model) for FY13 to FY18

		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	31	107	392	266	109	83	988	992
FY14	n(1)	33	114	372	278	110	85	992	992
FY15	n(2)	33	116	359	285	112	87	992	992
FY16	n(3)	33	117	349	290	113	89	992	992
FY17	n(4)	33	118	342	292	115	91	992	992
FY18	n(5)	33	119	337	293	117	93	992	992

Table 10 represents a fixed recruiting model stock forecast, when the number of accessions into the system remains fixed at 60 per year. This is useful when manpower planners have a desired number of new accessions they want to bring in for future FYs.

Table 10. Aggregate Inventory Forecast (Fixed Recruiting Model) for FY13 to FY18

		O-1	O-2	O-3	O-4	O-5	O-6	Total
FY13	n(0)	31	107	392	266	109	83	988
FY14	n(1)	29	104	371	277	110	85	976
FY15	n(2)	29	102	353	284	111	86	965
FY16	n(3)	28	101	337	287	112	87	953
FY17	n(4)	28	100	324	288	114	89	943
FY18	n(5)	28	99	313	287	115	90	932

The model in Table 8 (page 33) indicates that manpower planners have to bring in 76 new accessions in FY14 in order to meet end strength targets. This would bring the HCA manning level to 100%. They would also have to bring in 72 new accessions and trainees for each FY thereafter (FY15 to FY18). Note that this is the optimal solution without regards to fiscal or other policy constraints.

We can apply the exact same techniques to each of the 10 HCA subspecialties. Using the fixed inventory model, Figure 5 shows the forecasted 1800s inventory levels for the future FYs. Forecasting using both the fixed inventory and fixed recruiting models can provide insight into policy changes within the HCA community. For example, the

1800s, which make up the largest proportion of the HCA category receives the largest number of new accessions yearly. Reducing the number of billets for the 1800s would reduce the number of 1800 accessions at all ranks. By adjusting the number of accessions to represent this policy, the model forecasts the shape and size of the HCA community in the following years. Adjusting the accession inputs or the transition probabilities within the model provides a variety of policy evaluation tools for manpower planners.

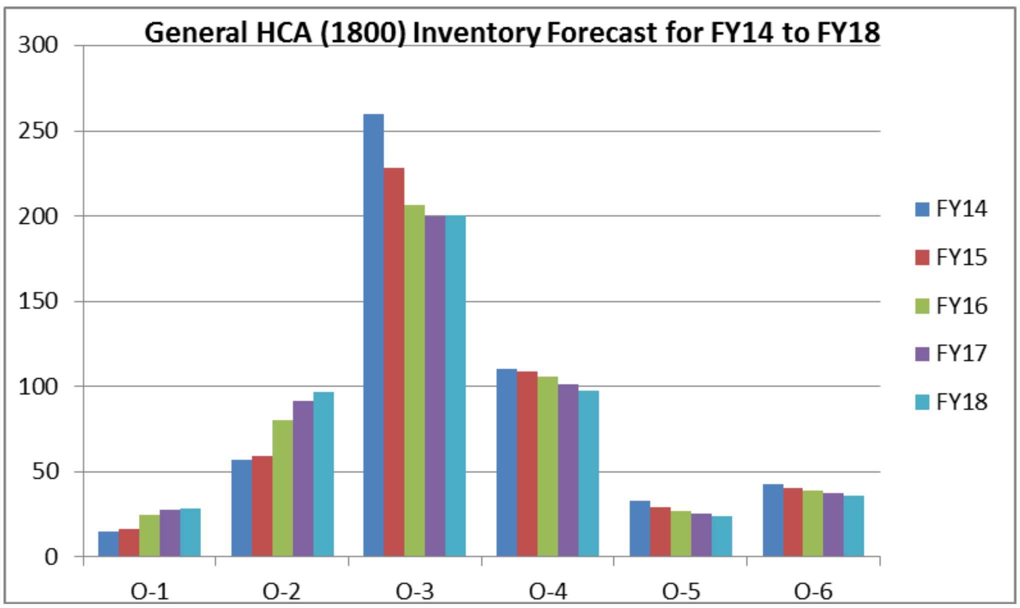

Figure 5. General HCA (1800) Inventory Forecast by Rank and FYs for FY14 to FY18

Figure 6 and Figure 7 show the future FYs inventory forecast for the 1801 and 3130 subspecialties, respectively. Determining the end strengths for each subspecialty level in the HCA community is necessary for manpower planners to balance the force structure, minimize personnel excesses and shortages that impact training and labor costs, and manage career progression.

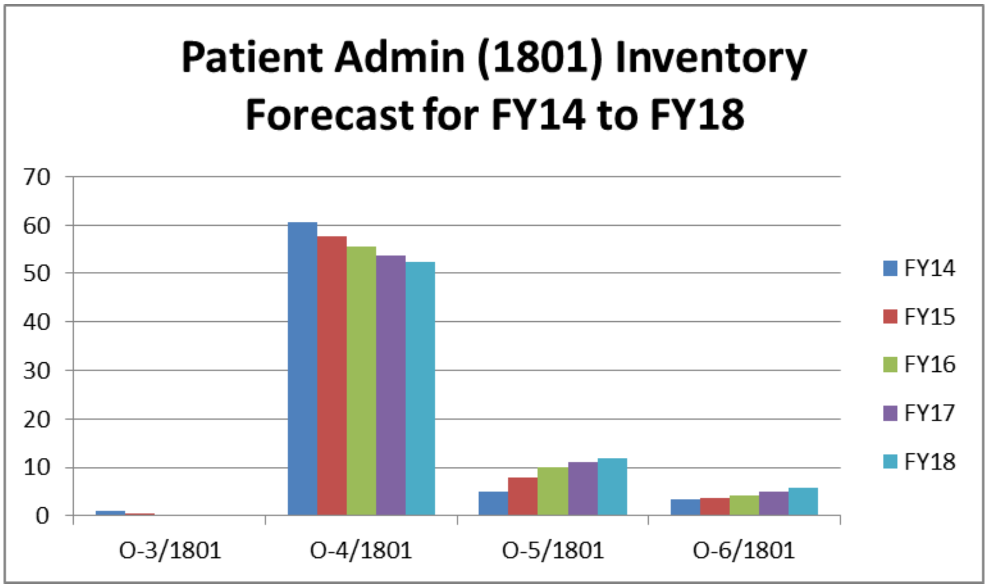

Figure 6. Patient Administration (1801) Inventory Forecast by Rank and FYs for FY14 and FY18

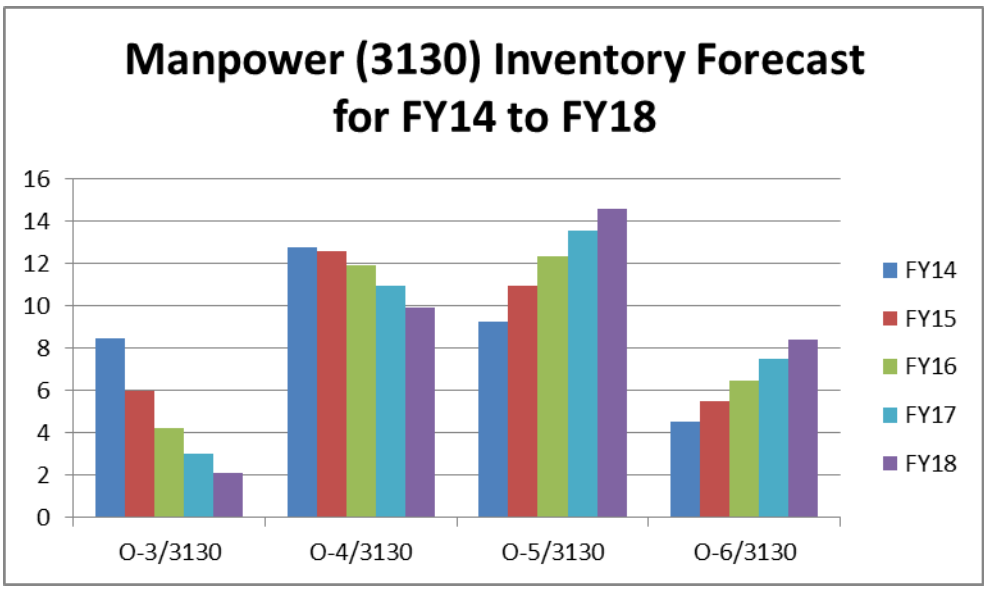

Figure 7. Manpower (3130) Inventory Forecast by Rank and FYs for FY14 and FY18

B. FUNDAMENTAL MATRIX

The fundamental matrix illustrated in Table 11 helps to evaluate the HCA community. The main diagonals show the E[TIG] for each grade. For instance the E[TIG] for an ensign with the subspecialty of 1800 is 1.94 years and the E[TIG] for a lieutenant with a subspecialty of 1800 is 4.21 years. The same idea applies to the other pay-grades.

Table 11. Fundamental Matrix

	O-1/1800	O-2/1800	O-3/1800	O-4/1800	O-5/1800	O-6/1800
O-1/1800	1.94	1.61	3.32	1.32	0.25	0.20
O-2/1800		1.79	3.69	1.47	0.28	0.23
O-3/1800			4.21	1.68	0.32	0.26
O-4/1800				4.60	0.88	0.71
O-5/1800					3.28	2.65
O-6/1800						5.81

Table 12. Conditional Probabilities of Attaining Given States

	Latmove	Attrition
O-1/1800	0.57	0.43
O-2/1800	0.55	0.45
O-3/1800	0.51	0.49
O-4/1800	0.41	0.59
O-5/1800	0.22	0.78
O-6/1800	0.09	0.91

Additionally, Table 12 indicates various conditional probabilities derived by multiplying the fundamental matrix **S**, by the matrix of transition probabilities into the absorbing states, **Ab**. In this model, a lieutenant with the subspecialty of 1800 has a 51% probability of ever making a lateral move to another subspecialty (at some point in his/her career) and a 49% probability of ever attriting outright. Both of these types of data provide manpower planners a description of how long an individual remains at various states within the HCA community, as well as their probability of ever attaining differing states within the community.

Table 13. Summary of Fundamental Matrix and Conditional Probabilities, FY14 and FY18

		1800	1801	1802 & 3121	1803 & 6201	1804	1805	3110 - 3112	3130	3150	3211
Expected Time in Grade (years)	O-1	2	1	1	1	1	1	1	1	1	1
	O-2	2	1	1	1	1	1	2	1	1	1
	O-3	4	2	3	2	4	2	3	3	2	6
	O-4	5	5	5	3	6	5	3	6	4	3
	O-5	3	4	1	4	9	6	3	4	6	6
	O-6	6	8	7	8	2	7	4	4	4	1
Latmoves	O-1	0.57	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
	O-2	0.55	0.00	0.00	0.42	0.20	0.00	0.68	0.00	0.00	0.00
	O-3	0.51	0.28	0.32	0.42	0.20	0.25	0.68	0.66	0.00	0.00
	O-4	0.41	0.23	0.29	0.24	0.20	0.17	0.61	0.77	0.00	1.00
	O-5	0.22	0.00	0.00	0.29	0.00	0.15	0.47	0.87	0.00	1.00
	O-6	0.09	0.00	0.00	0.00	0.00	0.09	0.14	0.67	0.00	0.00
Attrites	O-1	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	O-2	0.45	0.00	0.00	0.52	0.80	0.00	0.32	0.00	0.00	0.00
	O-3	0.49	0.66	0.46	0.52	0.80	0.75	0.32	0.34	0.80	1.00
	O-4	0.59	0.67	0.35	0.63	0.80	0.83	0.39	0.23	0.75	0.00
	O-5	0.78	0.75	0.00	0.43	1.00	0.85	0.53	0.13	0.00	0.00
	O-6	0.91	0.00	1.00	0.00	1.00	0.91	0.86	0.33	1.00	0.00

C. MODEL VALIDATION

For the Markov model to satisfy the stationary requirement, the transition rates for each i to j transition for each year must be sufficiently similar to the aggregate transition probability. Using Sales graphical method for validation, we use the following steps to validate the model in this study:

First, we aggregate the transition probability for each p_{ij} (Table 6). Then, we calculate the standard error for each p_{ij} as:

$$SE(p_{ij}(t)) = \left(\frac{p_{ij}(1 - p_{ij})}{n_i(t)} \right)^{\frac{1}{2}}$$

With the standard error, we then calculate the confidence interval for each p_{ij} given as, $\{\hat{p}_{ij}(t) - \hat{se}(t), p_{ij}(t) + \hat{se}(t)\}$. Finally, we compare each yearly confidence interval to determine whether it contains $\hat{p}_{ij}$ (Sales, 1971). The study uses the graphical method in Figure 8 to confirm annual rates are sufficiently close to the aggregate (red line). This means that our estimated p_{ij} (the aggregate) should fall within 70% confidence interval we build around each annual $p_{ij}(t)$. For example, Figure 8 shows the validation from the probability of continuing in the state O-4/1800 given that the person started in state O-4/1800. Thus, two-thirds of the estimated annual transition probabilities are sufficiently close to the aggregate. We repeat this process for each p_{ij}.

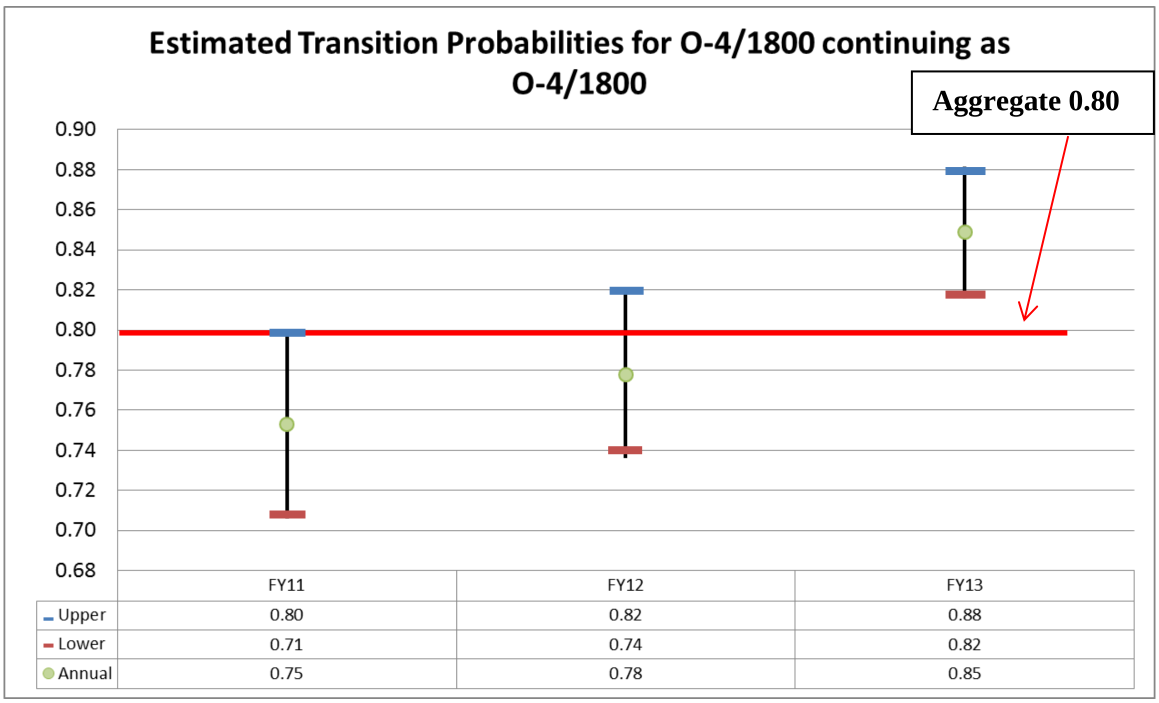

Figure 8. Estimated Transition Probabilities for 70% Confidence Interval for O-4/1800 continuing as O-4/1800

1. Measure of Effectiveness—Percentage of Satisfactory Estimates

We calculate the proportion of confidence intervals that contain the corresponding aggregate transition probabilities. An estimate is satisfactory when the interval for the yearly $\hat{p}_{ij}(t)$ contains the aggregate $\hat{p}_{ij}$. Using O-4/1800 to O-4/1800 as an example (Figure 8), we find that of the three time annual transition rates we construct, only two (66%) fall within the 70% confidence interval. The higher the proportion becomes, the higher the confidence we have in the estimator or model and vice versa as seen in Figure 9 and Figure 10. The overall model validation provides 61% proportion of satisfactory intervals for all years, FY11 through FY13 as seen in Figure 9. This is a valid model. However, the model slightly improves by dropping the first transition year FY11. The model, using data from FY12 through FY13 provides improved validity with 62% satisfaction (Figure 10). The difference in satisfaction is not significant because as stated earlier, this model is already a valid model using FY11 through FY13. But the case in which the overall model is less than 60% proportion of satisfactory intervals (invalid model), we continue to shrink the window of empirical data until we achieve a valid model, or only one year remains. According to Seagren, 2013, any Markov model with annual transitions built from one year of data is going to be stationary using this method.

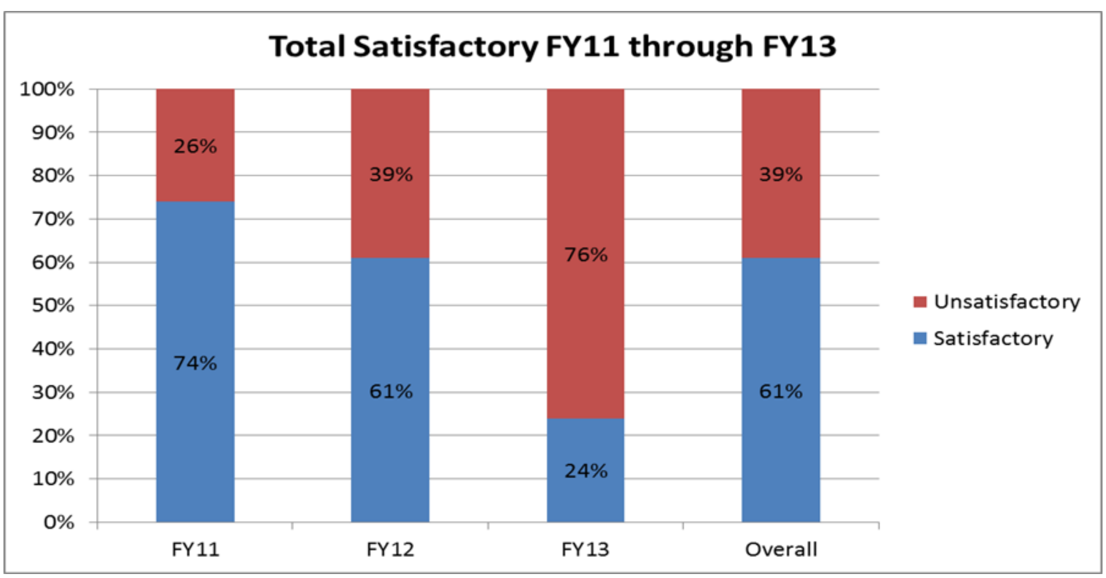

Figure 9. Subspecialty 1800 Overall Model Satisfactory Validation by Year, FY11 through FY13

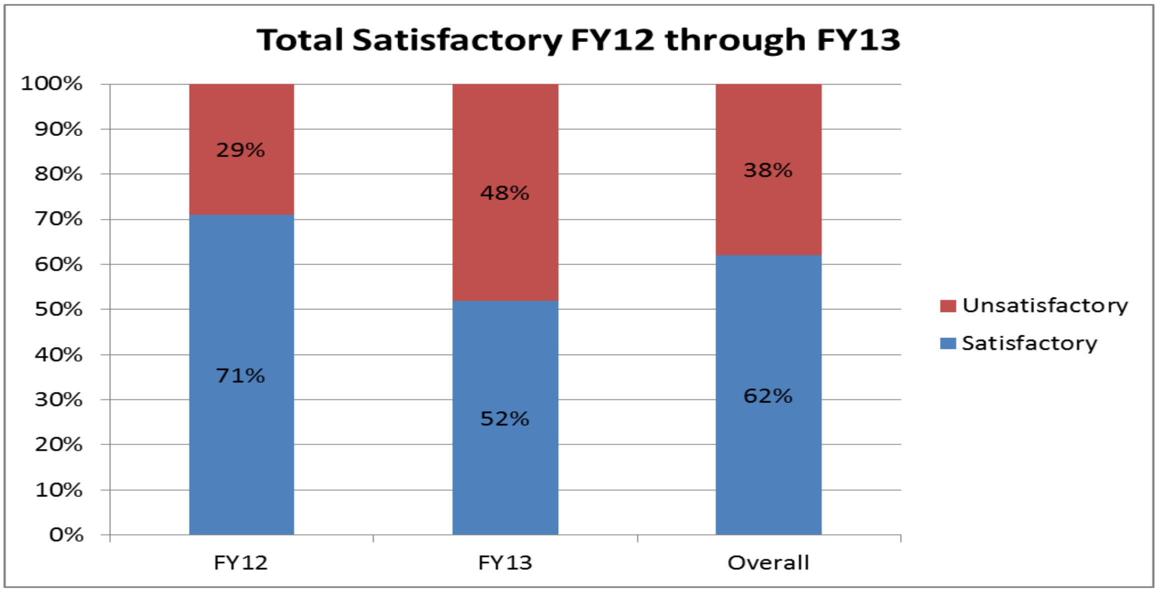

Figure 10. Subspecialty 1800 Overall Model Satisfactory Validation by Year, FY12 to FY13

Table 14 highlights the proportion of satisfactory interval for each valid model in bold fonts, by subspecialties and year.

Table 14. Model Satisfactory Validation for Each Subspecialty by Year

During	1800	1801	1802 & 3121	1803 & 6201	1804	1805	3110 - 3112	3130	3150	3211	Aggregate
FY11-FY13	**61%**	**64%**	56%	53%	37%	53%	**61%**	**71%**	30%	38%	**74%**
FY12-FY13			**69%**	**64%**	**71%**	57%			44%	**85%**	
FY13						**100%**			**100%**		

D. LIMITATIONS

The primary limitation with the model is the small sample size of some subspecialties and the number of observations which result in an invalid model. Therefore, the transition probabilities will be highly variable because of the small sample size. As a result, we find certain transitions for given years might be abnormally high or low. This is a relatively more significant problem for those subspecialties with smaller inventories. Furthermore, the number of years' worth of data provided by DMDC is not sufficient enough to test the measure of effectiveness and predictive validity of the models. As a result of these limitations, future studies need to collect further years of data in order to further validate the stock forecasts and measure of effectiveness of the models.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

This research develops a Markov model to forecast the inventory for HCA officers and to best match the accessioning plan to their recruiting and training targets. Focusing on the HCA category of MSC officers allows for an in-depth analysis and a more specific emphasis on one comparable group. Today, there are many manpower tools available to determine accessions. However, due to the periodic rotations of community managers and manpower planners within the MSC, it is necessary to have a standard tool to manage the accessioning process. This would lower training cost and reduce the learning curve for newly reporting community managers and manpower planners. Furthermore, the use of the Markov model would develop an effective and functional force planning for the MSC HCA community.

B. CONCLUSIONS AND RECOMMENDATIONS

How many HCA accessions are required to meet inventory requirements over the next five years? How many HCA personnel should be classified into each subspecialty?

a. Conclusion

Our model indicates that 76 new accessions are required to meet inventory requirements in FY14 and 72 in each FY thereafter (FY15 through FY18). The appendix provides the results of the fixed inventory model for each subspecialty showing the number of personnel that should be accessed for training or classified into each subspecialty over the next five years (Table 15-24).

The model provides the optimal accession mission to bring the HCA manning levels to 100%. However, due to exogenous factors such as budgetary restrictions, scarcity of training resources, and other limitations, the solution to the fixed inventory model may prove infeasible in reality. The forecasts of the model should be weighed by the workforce experience and analysis of manpower planners, and the HCA leadership.

Given that there are a limited number of decision making tools, the model proves to be the only empirical tool currently available for aiding in future policy decisions.

b. Recommendation

We recommend BUMED manpower planners use the Markov model we develop in this research as an accession planning tool to minimize deviation from target inventory levels. Manpower planners should consistently update the Markov model with their accessioning plans, to ensure that it reflects the most accurate billet requirements and authorizations to allow for the optimal mix of accessions to meet recruiting, accessioning and training goals.

How effective is the Markov model in determining inventory requirements for the MSC HCA community?

c. Conclusion

The validation results demonstrate that the aggregate model for HCA officers is valid and is currently optimal for use in force structure policy decision making. We validated the models for each subspecialty and show that they either pass or fail the stationary assumption required of Markov models by FYs. By shrinking the window of empirical data, we find that approximately 70% of all transition probability estimates are satisfactorily close to the respective aggregate estimate for each of the models.

When using the Markov model as a planning tool, consistency and accuracy are important because budget analysts, community managers, and manpower planners rely on manpower estimates during the fiscal year. In addition, program managers, recruiting and training commands all rely on the most accurate manpower estimates to conduct programming, budgeting, mission planning and execution. The Markov model also proves to be an excellent decision making tool in future policy decisions.

d. Recommendation

Manpower planners should continue to collect data and closely monitor lateral transfers to improve the model's validity. As the number of observations in smaller subspecialties matures, the collection of additional years of data should improve the model's validity as developed by this research.

C. FURTHER RESEARCH

The following topics are recommended for future research.

1. A study that assesses the continuation behavior of HCS and CCP officers versus HCA officers. Since data is currently available, we believe that researchers should explore in the near future.
2. Analysis of behavior between training and recruiting accessions among the various HCA subspecialties.
3. Analysis of loss in terms of actual losses to the Navy, particularly to subspecialty changes.
4. An examination of the inventory of secondary subspecialties when determining how many of the specialties we need to train.

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VI. APPENDIX. FIXED INVENTORY MODEL FOR ALL SUBSPECIALTY CODES (TABLES 15 – 24)

The appendix provides the fixed inventory model for each subspecialty code in Tables 15 to 24. These show the number of new accessions manpower planners should bring into the system and the training numbers for each subspecialty for future FYs.

Table 15. 1800 Inventory Forecast for FY13 to FY18

1800		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	31	97	278	110	38	45	599	483
FY14	n(1)	15	57	260	110	33	43	517	483
FY15	n(2)	17	59	228	109	29	41	483	483
FY16	n(3)	25	80	206	106	27	39	483	483
FY17	n(4)	28	91	200	101	25	38	483	483
FY18	n(5)	29	97	200	97	24	36	483	483

R	**r**					
0	0.24	0.68	0.05	0.01	0	0.02
40	0.24	0.68	0.05	0.01	0	0.02
69	0.24	0.68	0.05	0.01	0	0.02
66	0.24	0.68	0.05	0.01	0	0.02
65	0.24	0.68	0.05	0.01	0	0.02

Table 16. 1801 Inventory Forecast for FY13 to FY18

1801		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	0	0	2	21	5	3	31	70
FY14	n(1)	0	0	1	61	5	3	70	70
FY15	n(2)	0	0	1	58	8	4	70	70
FY16	n(3)	0	0	0	56	10	4	70	70
FY17	n(4)	0	0	0	54	11	5	70	70
FY18	n(5)	0	0	0	52	12	6	70	70

R	**r**					
43	0.0	0.0	0.0	1.0	0.0	0.0
8	0.0	0.0	0.0	1.0	0.0	0.0
9	0.0	0.0	0.0	1.0	0.0	0.0
9	0.0	0.0	0.0	1.0	0.0	0.0
9	0.0	0.0	0.0	1.0	0.0	0.0

Table 17. 1802 & 3121 Inventory Forecast for FY13 to FY18

1802 & 3121		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	0	3	22	28	8	4	65	83
FY14	n(1)	0	9	14	37	11	12	83	83
FY15	n(2)	0	7	9	40	9	18	83	83
FY16	n(3)	0	6	6	41	9	21	83	83
FY17	n(4)	0	6	4	41	9	24	83	83
FY18	n(5)	0	6	2	40	9	26	83	83

R	**r**					
36	0	0.25	0	0.25	0.25	0.25
28	0	0.25	0	0.25	0.25	0.25
25	0	0.25	0	0.25	0.25	0.25
24	0	0.25	0	0.25	0.25	0.25
24	0	0.25	0	0.25	0.25	0.25

Table 18. 1803 & 6201 Inventory Forecast for FY13 to FY18

1803 & 6201		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	0	2	15	8	6	2	33	33
FY14	n(1)	0	0	11	8	11	2	33	33
FY15	n(2)	0	0	6	8	15	3	33	33
FY16	n(3)	0	0	4	7	18	4	33	33
FY17	n(4)	0	0	2	5	20	6	33	33
FY18	n(5)	0	0	1	4	20	7	33	33

R	**r**					
6	0	0	0	0	1	0
6	0	0	0	0	1	0
5	0	0	0	0	1	0
5	0	0	0	0	1	0
5	0	0	0	0	1	0

Table 19. 1804 Inventory Forecast for FY13 to FY18

1804		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	0	0	5	8	3	0	16	19
FY14	n(1)	0	0	4	8	3	4	19	19
FY15	n(2)	0	0	3	7	3	5	19	19
FY16	n(3)	0	0	2	7	4	7	19	19
FY17	n(4)	0	0	2	6	4	8	19	19
FY18	n(5)	0	0	1	5	4	9	19	19

R	**r**					
4	0	0	0	0	0	1
3	0	0	0	0	0	1
4	0	0	0	0	0	1
4	0	0	0	0	0	1
5	0	0	0	0	0	1

Table 20. 1805 Inventory Forecast for FY13 to FY18

1805		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	0	0	18	50	31	20	119	164
FY14	n(1)	0	0	11	66	37	51	164	164
FY15	n(2)	0	0	6	62	40	56	164	164
FY16	n(3)	0	0	4	58	42	60	164	164
FY17	n(4)	0	0	2	54	44	64	164	164
FY18	n(5)	0	0	1	50	44	68	164	164

R	**r**					
56	0	0	0	0.36	0.09	0.55
17	0	0	0	0.36	0.09	0.55
17	0	0	0	0.36	0.09	0.55
17	0	0	0	0.36	0.09	0.55
17	0	0	0	0.36	0.09	0.55

Table 21. 3110-3112 Inventory Forecast for FY13 to FY18

3110 - 3112		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	0	3	36	23	10	6	78	79
FY14	n(1)	0	11	31	24	8	5	79	79
FY15	n(2)	0	13	32	23	6	5	79	79
FY16	n(3)	0	14	34	22	5	4	79	79
FY17	n(4)	0	14	35	22	5	3	79	79
FY18	n(5)	0	14	36	22	4	3	79	79

R	r					
19	0	0.5	0.25	0.25	0	0
17	0	0.5	0.25	0.25	0	0
16	0	0.5	0.25	0.25	0	0
16	0	0.5	0.25	0.25	0	0
16	0	0.5	0.25	0.25	0	0

Table 22. 3130 Inventory Forecast for FY13 to FY18

3130		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	0	0	12	12	4	3	31	35
FY14	n(1)	0	0	8	13	9	5	35	35
FY15	n(2)	0	0	6	13	11	5	35	35
FY16	n(3)	0	0	4	12	12	6	35	35
FY17	n(4)	0	0	3	11	14	7	35	35
FY18	n(5)	0	0	2	10	15	8	35	35

R	**r**					
7	0	0	0	0	0.75	0.25
4	0	0	0	0	0.75	0.25
5	0	0	0	0	0.75	0.25
5	0	0	0	0	0.75	0.25
5	0	0	0	0	0.75	0.25

Table 23. 3150 Inventory Forecast for FY13 to FY18

3150		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	0	1	1	4	1	0	7	19
FY14	n(1)	0	0	1	17	1	0	19	19
FY15	n(2)	0	0	0	16	2	0	19	19
FY16	n(3)	0	0	0	15	3	0	19	19
FY17	n(4)	0	0	0	15	4	0	19	19
FY18	n(5)	0	0	0	14	5	0	19	19

R	**r**					
14	0	0	0	1	0	0
3	0	0	0	1	0	0
3	0	0	0	1	0	0
3	0	0	0	1	0	0
3	0	0	0	1	0	0

Table 24. 3211 Inventory Forecast for FY13 to FY18

3211		O-1	O-2	O-3	O-4	O-5	O-6	Total	Target
FY13	n(0)	0	1	3	2	3	0	9	7
FY14	n(1)	0	0	2	1	3	0	7	7
FY15	n(2)	0	0	2	2	3	0	7	7
FY16	n(3)	0	0	2	2	3	0	7	7
FY17	n(4)	0	0	1	2	3	0	7	7
FY18	n(5)	0	0	1	2	3	0	7	7

R	**r**					
0	0	0	0	1	0	0
1	0	0	0	1	0	0
1	0	0	0	1	0	0
1	0	0	0	1	0	0
1	0	0	0	1	0	0

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