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THESIS

AN ANALYSIS OF AH-1Z HELICOPTER PILOTS AND QUALIFICATIONS: THE IMPACT OF FLEET SQUADRON TRAINING PROGRESSION TIMELINES

by

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This research examines pilot qualifications for 111 AH-1Z pilots using data from 2012 to 2017 and compares them with Training and Education Command's pilot qualification timelines. Despite having a robust data-tracking capability, current methods do not use data to identify minimum, maximum, or average time-to-train for pilots. This study provides an empirical analysis of the data and develops a Markov model for forecasting pilot qualifications. While the data do not capture the true behavior of pilots exiting the system, which resulted in unreliable transition probabilities for the forecasting model, our empirical analysis does reveal that the time-to-train from Pilot Qualified in Model through Section Lead takes, on average, 15.1 months longer than current procedures specify, which leads to an overestimation of pilot proficiency and squadron readiness.

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LIST OF ACRONYMS AND ABBREVIATIONS

CRS	Chairman's Readiness System
ACP	Aviation Continuation Pay
AHC	Attack Helicopter Commander
AMC	Air Mission Commander
ANSQ	Advanced Night Systems Qualification
API	Aviation Preflight Indoctrination
APM	Aviation Production Management
ASB	Aviation Support Branch
ASM	Aviation Manpower and Support Branch
ATD	Aviation Training Division
ATS	Aviation Training System
AvPlan	Aviation Plan
CAT I	Category One
CAT II	Category Two
CCDR	Combatant Commander
CCRM	Core Competency Resource Model
CI	Confidence Interval
CJCS	Chairman of the Joint Chiefs of Staff
CMC	Commandant of the Marine Corps
CMMR	Core Model Minimum Requirement
CMTS	Core Model Training Standard
CNA	Center for Naval Analysis
CNAF	Commander, Naval Air Forces
CNO	Chief of Naval Operations
DoD	Department of Defense
DCA	Deputy Commandant of Aviation
DL	Division Lead
DRRS	Defense Readiness Reporting System

DRRS-MC	Defense Readiness Reporting System-Marine Corps
FAC	Forward Air Controller
FAC(A)	Forward Air Controller (Airborne)
FAC(A)I	Forward Air Controller (Airborne) Instructor
FL	Flight Lead
FLP	Flight Leadership Program
FMC	Full Mission Capable
FRS	Fleet Replacement Squadron
GAR	Grade Adjusted Recapitulation report
HMLA	Marine Light Attack Helicopter squadron
HMLAT	Marine Light Attack Helicopter Training squadron
HQMC	Headquarters Marine Corps
ISO	Initial Service Obligation
JTF	Joint Task Force
M&RA	Manpower and Reserve Affairs
MMOA	Manpower Management Officer Assignments
MAG	Marine Aircraft Group
MATSS	Marine Aviation Training System Sites
MAW	Marine Aircraft Wing
MAWTS-1	Marine Aviation Weapons and Tactics Squadron One
MC	Mission Capable
MCTFS	Marine Corps Total Force System
MCTL	Marine Corps Task List
MET	Mission Essential Task
METL	Mission Essential Task List
MEU	Marine Expeditionary Unit
MOS	Military Occupational Specialty
MPP	Manpower Plans and Policy
M-SHARP	Marine-Sierra Hotel Aviation Readiness Program
OCS	Officer Candidates School

NAPP	Naval Aviation Production Process
NIPDR	NAPP Integrated Production Data Repository
NMOS	Necessary Military Occupational Specialty
NSI	Night Systems Instructor
PMAA	Primary Mission Aircraft Authorized
PMC	Partial Mission Capable
PMOS	Primary Military Occupational Specialty
POI	Program of Instruction
PQM	Pilot Qualified in Model
RBA	Ready Basic Aircraft
RCQD	Requirements, Certifications, Qualifications, Designations
SL	Section Lead
T&R	Training and Readiness
TBS	The Basic School
TECOM	Training and Education Command
TFDW	Total Force Data Warehouse
TFSD	Total Force Structure Division
TMS	Type/Model/Series aircraft
TPM	Training Progression Model
TRL	Training Requirements Letter
UDP	Unit Deployment Program
UFT	Undergraduate Flight Training
UJTL	Universal Joint Task List
WTI	Weapons and Tactics Instructor

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I. INTRODUCTION

In his 31 January 2017 budget guidance memorandum, the U.S. Secretary of Defense, James Mattis, described a multi-phased approach to strengthening the U.S. Armed Forces. One of the phases put forth by Secretary Mattis was to improve warfighting readiness. This proposal is echoed in the Chairman's Readiness System (CRS) guide, a publication for the U.S. Armed Forces on readiness procedures, which asserts, "The fundamental purpose of our Armed Forces is to fight and win our Nation's conflicts. Therefore, it is critical the Department of Defense continually assesses warfighting readiness and capabilities" (Department of Defense [DoD], 2010, p. 1). To assess readiness, there must be an effective reporting method, and the current method of reporting readiness, as outlined in the CRS guide, has indeed effectively transformed our military force from operating as independent Services into a joint or multinational force, thus expanding our global outreach (DoD, 2010). In addition, since the establishment of the CRS in the early 1990s, steady advancements in technology and data-gathering have helped to capture more accurate and timely readiness information.

Paradoxically, however, this proliferation of data in recent years, although it has met many of the DoD's needs, has also led to a thirst for more data, which only increases as policymakers demand evidence with which to make strategic decisions within a heavily constrained defense budget. In particular, the branch of the military that is repeatedly asked to do more with less is the Marine Corps; the Marine Corps must therefore search for more efficient methods to improve warfighting readiness or risk loss in capability.

In line with this call for greater efficiency, the Commandant of the Marine Corps (CMC) published the Marine Operating Concept to better meet operational demands and to generate discussion about future challenges. One such challenge for the Marine Corps is aviation readiness: in the 2018 Marine Aviation Plan (AvPlan), the Deputy Commandant for Aviation (DCA) outlines a comprehensive readiness recovery strategy that will "improve readiness by adhering to procedures, focus on training practices, and managing an effective maintenance program to improve aircraft readiness, increase training capacity, and increase readiness for combat" (Headquarters Marine Corps [HQMC], 2017b, p. 8). Emphasis has thus been placed on aircraft readiness; nevertheless, a continuous challenge Marine aviation faces is maintaining an adequate flow of qualified aviators to meet operational commitments. Two organizations help to address this issue: Manpower and Reserve Affairs (M&RA) and Training and Education Command (TECOM). In a broad sense, M&RA is responsible for the assignment of pilots, and TECOM is responsible for policies regulating training across all Marine aviation. Recently, and in response to the CMC's Marine Corps Operating Concept, TECOM assigned new Military Occupational Specialties (MOS), specific job skills, for Marine aviation. According to the 2018 AvPlan, these new MOSs "are tied to critical readiness enablers" known as combat leadership qualifications (HQMC, 2017b, p. 16). These qualifications depend on training timelines and provide a critical starting point for improving warfighting readiness.

Both M&RA and TECOM rely on training timelines to help manage the flow of qualified aviators from flight school through the initial service obligation. A particularly pressing concern is that M&RA may dictate aviator tour length to fit into established career milestones without truly assessing whether these tour lengths give pilots sufficient time to achieve proficiency in specific qualifications, which are necessary to meet Marine Aviation Training & Readiness (T&R) program requirements. These T&R requirements are essential to readiness because they prescribe the amount and type of pilot qualifications needed for squadrons to successfully accomplish their mission. Current training timelines for pilots in tactical squadrons provide an estimated timeframe in which pilots are expected to earn qualifications but lack the details necessary to promote efficiency within the system, such as the average time-to-train per qualification within the first fleet tour. Therefore, no quantitative measure of effectiveness has been established to calculate if pilots are being trained within the time period given. Additionally, revisions to the pilot training syllabi for each community in Marine aviation are constrained to small working groups scheduled to meet every three years. Although this reactive and qualitative process has been successful, new quantitative methods may provide an opportunity to develop precise training timelines that could enable stakeholders to improve the Marine Corps' warfighting readiness.

A. PURPOSE

The purpose of our research is to examine data describing qualifications of AH-1Z pilots from Marine fleet squadrons to determine if pilots are meeting T&R procedures set forth by TECOM. To address this purpose, we provide our research questions and the answers to these questions as follows:

First, what effect does time-to-train for pilot qualifications have on pilot proficiency and squadron readiness? The results of our study indicate that the time-to-train for an AH-1Z pilot from PQM through the SL qualification takes, on average, 15.1 months longer than what is outlined in TECOM's AH-1Z Training Progression Model (TPM). Because pilots do not meet Marine Aviation's training and readiness planning parameters, we conclude that pilot proficiency and squadron readiness might be overestimated.

Second, what will the AH-1Z pilot qualification structure likely be at various dates in the future if present patterns of pilot attrition and progression continue? Our Markov model shows the data to be heavily right-censored; as a result, the model's transition probabilities regarding the proportion of pilots progressing to the next qualification, as well as the qualification forecasts, do not accurately reflect the behavior of the system. Transition probabilities would be improved however with more mature data.

Third, how does time spent in each qualification compare to the TPM? Three of the six qualifications we analyze are statistically significant in that pilots spend more time in each qualification than the TPM indicates. We report, on average, the number of months spent in each qualification to be as follows: ANSQ, 11.4—a difference of 7.4; AHC, 8.9—a difference of 2.9; and SL, 9.1—a difference of 5.1.

B. SCOPE AND METHODOLOGY

In order to analyze pilot qualifications and their effect on readiness, a review of applicable directives, orders, manuals, and publications will be used to link joint force readiness with lower echelon squadron readiness. Next, a thorough examination of the current Marine Aviation T&R program is conducted, and the aircraft community to be analyzed is discussed. Although the Marine Corps has 10 fleet Type/Model/Series (TMS) aircraft, this study analyzes the AH-1Z helicopter community to prevent irrelevant comparisons between different aircraft communities and their assigned syllabus. More specifically, this aircraft was selected because of the author's experience and familiarity with the AH-1Z T&R procedures.

Following this discussion, a Markov model will be used to analyze pilot qualification data. These data form transitional flows throughout a pilot's career used to estimate the expected time to earn certain qualifications, determine the probabilities of achieving each qualification, and the total time-to-train for each qualification. Lastly, the information derived empirically and from the Markov model is compared with the AH-1Z T&R TPM to identify any differences in TECOM's T&R requirements and procedures.

C. ORGANIZATION OF STUDY

The remainder of this thesis is organized as follows: Chapter II gives background information on Marine Corps Aviation with respect to training and readiness. Chapter III provides a literature review describing Markov theory and techniques used in manpower management forecasting, training optimization, and determining aircraft readiness. Chapter IV describes the data and tool used for analyzing the pilot qualifications. Chapter V analyzes the results produced from the model. Chapter VI summarizes findings, draws conclusions for each research question, and provides themes for further research.

II. BACKGROUND

A. INTRODUCTION

To set the framework for the data and methodology discussed in Chapter IV, this chapter provides information on the training and readiness process for Marine aviation, including relevant aspects of the Defense Readiness Reporting System (DRRS), the Marine Aviation T&R Program, and the Naval Aviation Production Process (NAPP). The first part covers the readiness process by outlining the structure of the CRS. We then define terminology related to readiness reporting, discuss the types of readiness, and identify how training readiness is measured. Next, we describe how aircraft readiness affects training and the tool used for reporting readiness in Marine aviation. The second part discusses pilot training and readiness procedures within the AH-1 helicopter community, and discuses timelines associated with pilot qualifications specific to the AH-1Z syllabus.

All of these topics help define the problem of whether pilots are earning qualifications within the published requirement and highlight how readiness may be impacted—a major concern for Marine Aviation.

1. Warfighting Readiness Process

Before describing training timelines and pilot qualifications, a discussion of the current readiness system helps to establish how tactical qualifications produce readiness for Marine aviation as an institution. To begin, by law the Chairman of the Joint Chiefs of Staff (CJCS) is required to report the status of the U.S. Military to the Secretary of Defense (Chairman: functions, 2016, (a)(4)(c)). To comply with this mandate, the CRS "provides an overall readiness assessment of the department's ability to execute the [National Military Strategy] and capture the overarching readiness for each level of warfighting: *strategic, operational, and tactical*" (DoD, 2010, p. 1). In addition, section 164 of Title 10 U. S. C. states that Combatant Commanders (CCDRs) are to "produce plans for the employment of the armed forces to execute national defense strategies and respond to significant military contingencies" (p. (b)(3)(A)). Therefore, this cyclical process is initiated by CCDRs, executed by the armed forces, evaluated by the CJCS, and strategically refined by the President and Secretary of Defense. The Marine aviation readiness process is used as a guide for this section and is shown in Figure 1:

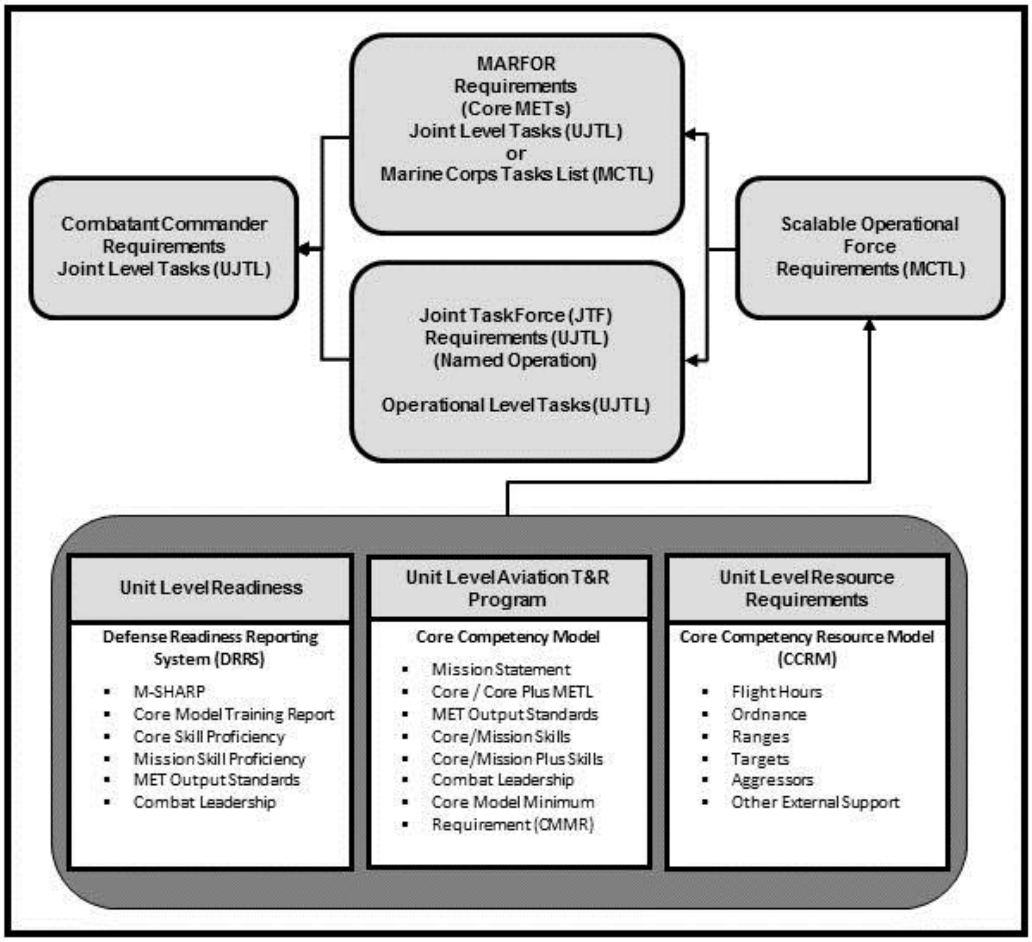


Figure 1. Capabilities-Based Training System. Source: HQMC (2016a).

a. Readiness Terminology

In Chapter I, we mention that the CRS has helped centralize readiness reporting by characterizing resources and capabilities for the joint force. The DoD uses the DRRS as a tool to capture the characterization of both resources—the status of equipment, personnel, and training—and capabilities—an assessment of output or tasks accomplished (DoD, 2010). The two reporting channels within DRRS-Marine Corps (DRRS-MC) are illustrated in Table 1:

Table 1. Measuring Readiness from Resources and Capabilities.

Chairman's Readiness System Defense Readiness Reporting System-Marine Corps Squadron Core and/or Assigned Missions	
<u>Resources</u>	<u>Capabilities</u>
Status of:	Assessment of output or tasks completed
Equipment, Personnel, & Training	Equipment, Personnel, & <u>***Training***</u>

Although resources are important for achieving a certain level of readiness, we use the capabilities-based construct in our study. More specifically, we focus on finding efficient methods for improving training readiness, which is boldfaced and underlined in Table 1.

To better address how capabilities are determined, we discuss two proxies for measuring readiness: Mission Essential Task (MET) and Mission Essential Task List (METL). A MET is "an externally focused action … critical to mission accomplishment," while a METL is "the sum of all METs required by all missions assigned to a unit" (HQMC, 2016a, p. 1-2). METs can further be classified into core and assigned, where core means the principal or main task and assigned means a unique or specific task; we use core METs for the purposes of this study. The T&R program manual explains the link between METs and METL:

> Reporting is based on unit capability to accomplish specific tasks, within an established Mission Essential Task List (METL) providing a common baseline for unit readiness reporting. Each MET has one or more associated output standards which are the key performance measures used as reporting criteria in DRRS. (HQMC, 2016a, p. 1-2)

In short, capability is determined by a unit's ability to accomplish the METs within their METL. Therefore, the number of METs completed within the METL determines a certain level of readiness.

As illustrated in Figure 1, METs fulfill requirements established by CCDRs and are derived from the Marine Corps Task List (MCTL) or Universal Joint Task List (UJTL). Furthermore, METs determine T&R standards—"performance measures and criteria that can be output, outcome, or process-oriented"—for each community (DoD, 2010, p. 11). Before discussing specific T&R standards, however, we must identify the different types of readiness and explain how readiness is defined.

b. Types of Readiness

As expected, readiness has a different definition for each level of warfighting. Since this research investigates pilot qualifications to distinguish how they impact readiness, the focus is on unit readiness from the tactical perspective, defined as "the ability to provide capabilities required by the Combatant Commander to execute assigned missions, and derived from the ability of each unit to conduct the mission(s) for which it was designed" (DoD, 2010, p. 2). Unit readiness is also listed as one of the five pillars of institutional readiness for the Marine Corps and is divided into three types of readiness: personnel, equipment, and training, as seen in Table 1 (HQMC, 2017a). All three types of readiness contribute to a unit's ability to accomplish its mission. However, as Table 1 emphasizes, this study focuses on finding efficient methods to improving training readiness; therefore, personnel and equipment readiness will not be covered in detail. Next, we describe how training readiness is measured.

c. Training Readiness Levels

Earlier, we note how the completion of METs contributes to a unit's capability assessment. However, a capability can be reported only by attaining a certain level of readiness. For training readiness, a Training-level (T-level), is defined as "an assessment of the unit's training to accomplish its mission" (HQMC, 2017a, p. 5-1). The T-level calculation gives the percentage of METs that meet a specific standard and is divided into four levels, as shown in Table 2:

Table 2. T-Level Percentages. Adapted from HQMC (2017a).

Rule	T1	T2	T3	T4
Percentage of Core METs Trained to Standard	$\geq$ 85%	70-84%	55-69%	<55%

For example, the readiness of a unit that is trained to standard in three out of four tasks would equate to 75% and represent a T2 level of readiness. For aviation squadrons to achieve their METs, a proportion of pilots must also be trained to standard in certain qualifications, known as combat leadership qualifications.

Combat leadership is the level of proficiency to which pilots are capable of managing their aircraft, section, and/or flight to accomplish unit METs (HQMC, 2016a). To calculate the combat leadership assessment, we compare the amount of qualifications required to the amount on hand. A generic example of a combat leadership assessment and its associated qualifications is provided in Table 3:[1]

Table 3. Combat Leadership Assessment Guidance Example. Adapted from HQMC (2011d).

Combat Leadership (CL) Designations	CMMR	On-Hand	CL Trained to Standard?
Aircraft Commander	12	14	Yes
Section Leader	6	4	No
Division Leader	4	4	Yes
Flight Leader	2	2	Yes
Mission Commander	2	1	No

The Core Model Minimum Requirement (CMMR) is "an objective readiness metric derived by the community to meet the required output standards defined within a unit's core METs and is shown in Table 3. This metric identifies the number of crews, composition of each crew, and the number of combat leaders required to meet the warfighting function of the unit" (HQMC, 2016a, p. 1-3). The AH-1Z CMMR can be

[1] The term *qualification* has been used to encompass a single training phase that covers four categories: Requirements, Certifications, Qualifications, and Designations (RCQDs). The definitions for RCQDs can be found in Appendix A; however, for the purposes of this study, the term qualification is synonymously used to reference RCQDs collectively.

found in Appendix A. By comparing the CMMR and on-hand columns, we can determine a percentage of the qualifications trained to standard, thus enabling a T-level classification. The combat leadership assessment with the associated T-levels is shown in Table 4.

Table 4. Combat Leadership Assessment. Adapted from HQMC (2011d).

Combat Leadership Rule	T1	T2	T3	T4
Percentage of CL Designations trained to standard	≥ 85%	70-84%	55-69%	<55%

Using both Tables 3 and 4, we determine three out of five, or 60%, of the combat leadership qualifications are trained to standard, which corresponds to T3. Although calculating T-levels is not the purpose of this research, understanding how the number of qualifications can impact training readiness shows the importance of finding methods to better forecast capabilities in Marine aviation.

Now that we have discussed training readiness, we must introduce aircraft readiness. The following section describes relevant aspects of aircraft readiness as it relates to training readiness and, ultimately, to squadron capability.

d. Equipment Category Levels and Aircraft Status Codes

For aircrew to train and become proficient, squadrons must maintain aircraft readiness. When describing the three types of readiness, we briefly mentioned equipment readiness, which can be further divided into two categories, *R-level*—equipment and supplies possessed—and *S-level*—equipment condition (HQMC, 2017a). Both of these categories are evaluated using a four-tiered system similar to a T-level. However, additional metrics determine aircraft readiness, which are then used to quantify equipment readiness.

To better understand how equipment readiness levels are determined, we must describe the maintenance terms Full Mission Capable (FMC) and Partial Mission Capable (PMC) as they relate to aircraft. An FMC aircraft is able to perform all of its missions, and a PMC aircraft can perform at least one but not all of its missions

(Commander, Naval Air Forces [CNAF], 2017). The total number of FMC and PMC aircraft together makes up a squadron's Mission Capable (MC) aircraft (Germershausen & Steele, 2015). The R-level is then calculated by dividing the total number of MC and FMC aircraft by the number of aircraft a squadron is responsible for reporting (HQMC, 2017a). To calculate the S-level, the number of aircraft a squadron is responsible for reporting is divided by the Primary Mission Aircraft Authorized (PMAA) (HQMC, 2017a). PMAA is the number of aircraft authorized for a squadron to complete its mission: for example, the AH-1Z PMAA for a Marine Light Attack Helicopter (HMLA) squadron is 15 aircraft (HQMC, 2016b).

The ideal scenario would be to have all FMC aircraft, but the aircraft readiness goal, according to the Chief of Naval Operations (CNO), is "73 percent MC and 56 percent FMC" (CNAF, p. 17-14). Consequently, since some aircraft may not be ready for tasking, another maintenance term must be introduced: Ready Basic Aircraft (RBA). Ready Basic Aircraft is the number of aircraft required for a squadron to fly training events to attain a training readiness level of T2. The 2017 AvPlan lists a total of 9 RBA for HMLA squadrons with AH-1Z aircraft. Several parameters that can help a HMLA squadron to achieve a T2 are shown in Figure 2:

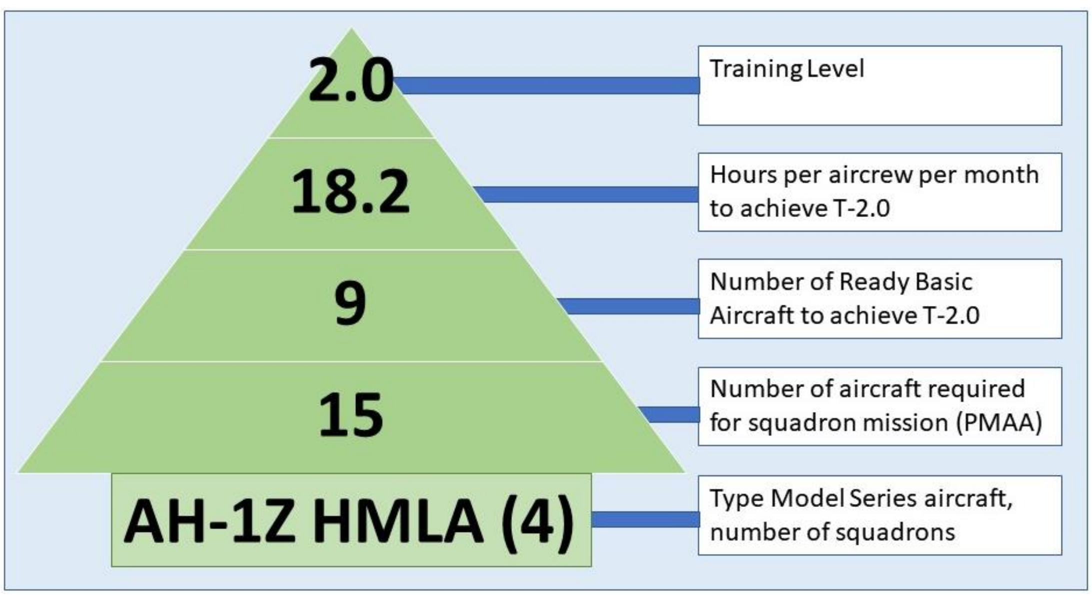


Figure 2. Squadron Readiness Metric. Adapted from HQMC (2016b).

Therefore, aircraft readiness is a critical component of overall training readiness. Currently, Marine Aviation's readiness does not meet requirements; however, the 2018 Marine AvPlan announced that appropriate funding in FY18 will allow for the "recovery of training capability by FY20 (T2.0)" (HQMC, 2017b, p. 8-9).

Now, having established all the required categories of information, the following section will discuss how training readiness is reported within the DRRS.

e. Readiness Reporting

The tool for inputting T-levels into the DRRS for aviation units is the Marine Sierra-Hotel Aviation Readiness Program (M-SHARP). The M-SHARP is a training management system used to "plan, schedule, log, track, and manage all training and readiness reporting requirements" (HQMC, 2016a, p. 2-17). According to a presentation by Marine Corps Task List Branch (2017), the M-SHARP accounts for "Over 20,000 personnel records, 1433 USMC inventory aircraft, 92 simulators, 35 T&R Manuals, 87 individual syllabi, [and] 70+ Standardized Reports" (p. 36). Given the magnitude of the M-SHARP, finding efficiencies within one helicopter community may not seem significant; however, providing a new model or technique that can be implemented into the M-SHARP structure and replicated across all communities may considerably increase capability for Marine aviation.

2. AH-1 Training and Readiness Procedures

Before explaining how our model may achieve this goal, we introduce T&R procedures for the Fleet Replacement Squadron (FRS) and for HMLA fleet squadrons, which establish the qualification timelines that will be evaluated in Chapters IV and V. First, we identify the Initial Service Obligation (ISO) for AH-1 pilots and discuss two Programs of Instruction (POIs) within FRS flight training that are relevant to this study. Additionally, we address the transition from the legacy model AH-1W to the upgrade model AH-1Z helicopter and illustrate the FRS pilot production output. Next, we discuss pilot training timelines and qualifications outlined by the AH-1Z T&R manual. Throughout this section, Appendix A may be referenced for specific T&R abbreviations and definitions. Lastly, we discuss how timelines associated with pilot qualifications might be formulated to improve planning, and provide accurate readiness information. The following section will discuss the process for AH-1 pilots to be trained and ready for HMLA fleet squadrons.

a. AH-1 Pilot Production Process: Fleet Replacement Squadron

Prior to being assigned to a fleet squadron, all Marine Aviators complete Undergraduate Fight Training (UFT) in accordance with the Naval Aviation Production Process (NAPP) (HQMC, 2011c). UFT comprises several stages; the time period for completion is dependent on the type of aircraft to which a student is selected. A 2006 study lists the average training time, from the time of commission until attainment of Primary Military Occupational Specialty (PMOS), to be three years for AH-1 pilots (Moskowitz et al., 2006). A general career timeline for rotary wing pilots is shown in Figure 3:

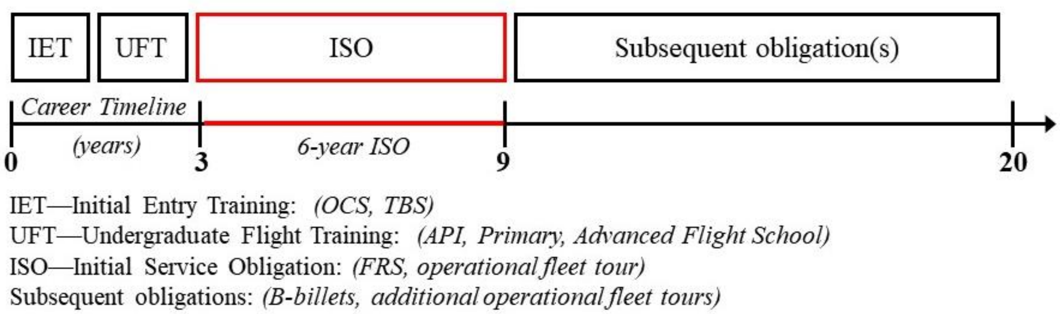


Figure 3. Marine Corps Flow of Aviator Inventory. Adapted from Moskowitz, Kimble, and Shuford (2006).

The red box indicates a six-year ISO, which begins once a pilot completes UFT and receives their "wings." After UFT, a pilot continues flight training at their assigned FRS, which for AH-1 pilots is HMLA Training Squadron 303 (HMLAT-303), based out of Camp Pendleton, CA. Although HMLAT-303 is responsible for several POIs, this research highlights the basic and series-conversion POIs for pilots.

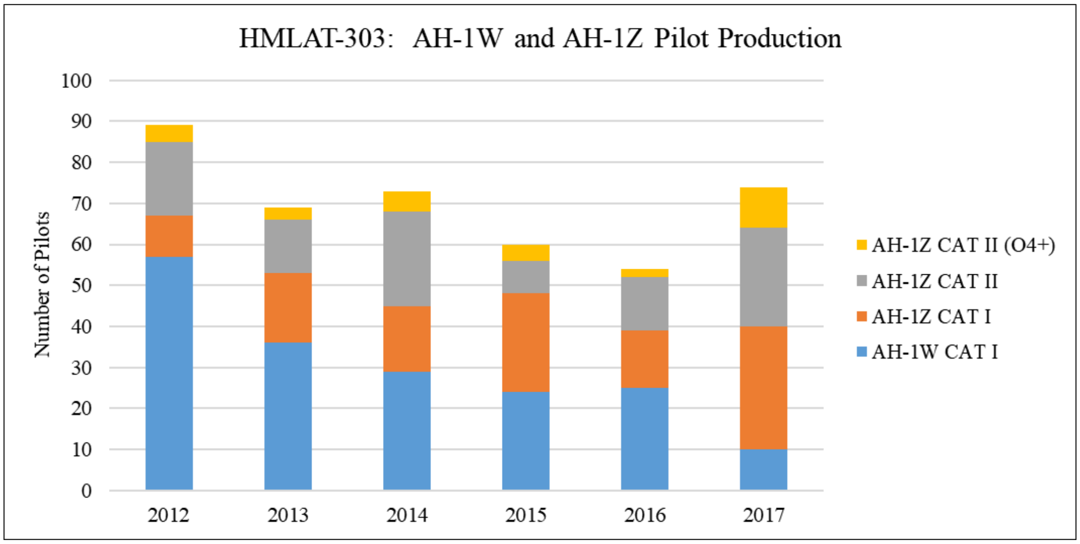
Before distinguishing between the two POIs, a brief discussion on the H-1 Upgrades Program helps provide context. In 1996, the Marine Corps awarded a contract to Bell Helicopter Textron Inc. for upgrading the aging fleet of UH-1N and AH-1W legacy aircraft (Myers & Davidovich, 2000). By April 2008, HMLAT-303 was balancing POIs for four TMS aircraft, which now included the upgraded UH-1Y and AH-1Z helicopters (R. Nunez, email to author, February 13, 2018). Over the past decade, HMLAT-303 has transitioned from the UH-1N to the UH-1Y and has recently completed its transition from the AH-1W to the AH-1Z (HQMC, 2017b). It is the AH-1 POIs that are the focus of the discussion that follows.

To begin, the FRS's primary responsibility is to train pilots to fulfill fleet requirements. The number of pilots assigned to a POI in the FRS is predicated on the Naval Aviation document called the Training Requirements Letter (TRL); the Marine Corps elements of the TRL is managed by Aviation Production Management (APM), who solicits input from stakeholders based on the needs of the fleet (G. Lehocky, email to author, October 18, 2017). Although the TRL captures more detail, for the purposes of the current study, Category I (CAT I) pilots are these assigned to the basic POI and CAT II pilots to the series-conversion POI. The basic POI trains newly "winged" aviators in *core skills*—fundamentals to perform basic functions—to replace aircrew rotation in fleet squadrons (HQMC, 2016a). The series-conversion POI retrains fleet-qualified pilots in a newer series of aircraft to maintain combat leadership in fleet squadrons (HQMC, 2016a).

Now that we have addressed CAT I & II terminology, we can describe the time period to complete FRS training and illustrate HMLAT-303 pilot production over the last six years. Both the AH-1W and AH-1Z T&R manuals portray the basic POI to be approximately 26 weeks and the series-conversion POI to be approximately 8 weeks (HQMC, 2014a & b). Therefore, CAT I pilots complete their core skills introductory training and earn Pilot Qualified in Model (PQM) in approximately six months.[2] Although CAT II pilots complete training much more quickly, follow-on training in their assigned fleet squadron is required to regain previously held combat leadership

[2] Upon PQM, AH-1W pilots receive the 7565 PMOS, whereas AH-1Z pilots receive the 7565 PMOS and 7513 NMOS.

qualifications. The FRS pilot production output for AH-1s from 2012–2017 and the breakdown between CAT I and II company-grade pilots is shown in Figure 4:[3]



Source: G. Lehocky, unpublished data (email to author, March 3, 2018).

Figure 4. Fleet Replacement Squadron Pilot Completion Reports for the AH-1W and AH-1Z from 2012 through 2017.

Figure 4 shows that the number of AH-1W CAT I pilots has decreased, while the number of AH-1Z CAT I & II pilots has increased. In Chapter IV, we will revisit FRS pilot production output when describing the number of observations used in this study.

Although HMLAT-303 has completed the transition process for the H-1 Upgrades Program, several active HMLA fleet squadrons have not. The 2018 AvPlan states that the

> Marine Corps is 100% complete with the UH-1Y transition and 40% complete with the AH-1Z transition. There are seven squadrons in the active fleet, one FRS and two reserve squadrons. The UDP in Okinawa is complete with the Z transition, leaving the east coast and the reserve component to complete. (HQMC, 2017b, p. 60)

The transition status of the seven active HMLA fleet squadrons across three Marine Aircraft Groups (MAG) is shown in Table 5:

[3] Figure 4 also distinguishes CAT II pilots who hold the rank of major or above during their series-conversion POI, but this is outside the scope of this study

Table 5. AH-1Z Transition Plan. Adapted from HQMC (2017b).

MAG	HMLA	Transition Period	Status
39	267	Dec-12 - May-13	Transition Complete
	169	Jul-13 - May-14	
	369	Jul-14 - Jul-16	
	469	Oct-16 - Jul-17	
24	367	Jul-17 - Jul-18	In progress
29	167	Jul-18 - Jul-19	Projected
	269	Apr-19 - Apr-20	Projected

Using this table, we can determine that the west-coast HMLA squadrons within MAG-39 are composed of AH-1Z CAT I & II pilots, whereas the east-coast HMLA squadrons within MAG-29 are composed of AH-1W CAT I pilots.[4] Furthermore, until HMLA-367 completes their transition, they will have a mixture of AH-1W CAT I and AH-1Z CAT I & II pilots. Although training various categories of pilots between two TMS helicopters may seem complex, the training has been similar in both content and duration. Having completed the FRS stage of training, pilots are assigned to a HMLA fleet squadron to begin earning qualifications. The following section describes the AH-1Z T&R syllabus and identifies the time period for pilots to earn these—the central focus of this study.

b. AH-1 Pilot Training Progression: HMLA Fleet Squadron

The AH-1Z T&R syllabus and time period to earn qualifications can best be summarized by the Training Progression Model (TPM), shown in Figure 5, which is used as a guide for this section. The TPM illustrates qualifications in a 48-month time period across six phases and "represents the recommended training progression for the minimum to maximum time per phase for the AH-1Z pilot" (HQMC, 2014b).

[4] According to the 2018 AvPlan, the reserves will assume the AH-1W model manager responsibilities, since HMLAT-303 W to Z transition is complete (HQMC, 2017b).

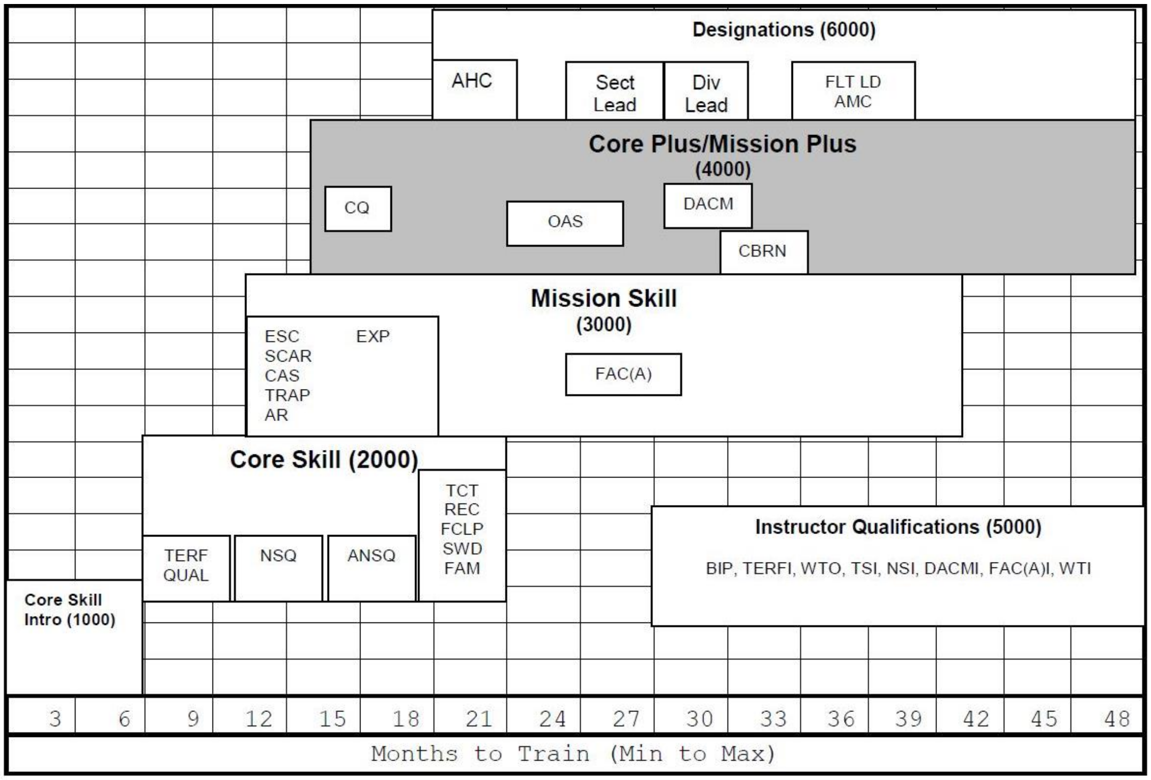


Figure 5. Current AH-1Z Training Progression Model.
Source: HQMC (2014b).

Although this TPM specifically addresses the AH-1Z pilot, both the AH-1W and AH-1Z TPMs are identical when comparing their respective July 2014 T&R manuals. To help explain the TPM, we use the CAT I pilot-to-fleet squadron pathway as an example.

Earlier, we determined that CAT I pilots earned PQM in the FRS after six months of core skill introductory training, known as the 1000-series phase (bottom left in the figure). After earning PQM, pilots begin their first fleet tour and are assigned to an operational squadron for about four years. This time period allows an operational, or fleet, squadron to train its pilots to a level of proficiency using the five remaining phases—2000 to 6000 series—illustrated in the TPM. Each phase contains a sequence of events that lead to a qualification. For example, a pilot must achieve a specific standard to complete an event and then complete all the events to earn the qualification. There are 28 qualifications (Appendix A) in the AH-1Z syllabus, excluding FRS events, that a pilot has potential to earn (HQMC, 2014b). The syllabus also has over 120 hours of academic courseware, lectures, and readings, and over 100 flight/simulator events, not including the Weapons and Tactics Instructor (WTI) course (HQMC, 2014b).[5] The breakdown of flight and simulator events by phase, TMS, and T&R effective date is shown in Table 6:

Table 6. AH-1 T&R Events Comparison. Adapted from HQMC (2011a, 2011b, 2014a, 2014b).

Weeks	Phase		March 2011 T&R Events				July 2014 T&R Events			
			AH-1W		AH-1Z		AH-1W		AH-1Z	
			Flights	Simulators	Flights	Simulators	Flights	Simulators	Flights	Simulators
27-165	Core Skill & Mission Skill	2000	13	9	15	9	15	10	15	10
		3000	15	1	15	2	20	2	20	2
54-190	Core Plus Skill Training[1]	4000	14	2	13	3	15	1	14	2
		5000	17	12	16	13	16	13	16	13
		6000	16	1	16	1	17	2	17	2
Total Flights & Simulators			75	25	75	28	83	28	82	29
Total Events per TMS			100		103		111		111	

[1]Excludes: WTI Course, FLSE, FRSI, NSFI, SOTC, and Autotrack codes/events

By comparing the previous and current editions of each AH-1 T&R manual, we can see that the number of events has increased but that these events are expected to occur within the same duration of training weeks.

Although the comparisons in Table 6 show the similarities between and evolution of AH-1 T&R events, the qualifications remain the same, in that they provide a fleet squadron the capability to fulfill its mission. To ensure this capability, a HMLA squadron must meet the minimum number of qualifications, as outlined in the AH-1Z CMMR. Additionally, and mentioned in the introduction, the 2018 AvPlan has implemented Necessary MOSs (NMOSs) that will serve as critical readiness enablers. The qualifications tied to readiness and the number of pilots with the associated qualification for a HMLA squadron is shown in Table 7:

[5] The 120 hours of academic lessons can be found in the AH-1Z T&R Matrix, however, each simulator and flight event require additional preparation that is not included in this calculation.

Table 7. Qualifications Tied to Readiness. Adapted from HQMC (2014b, 2017b).

		HMLA AH-1Z	Squadron		2018 AvPlan NMOS Initiative "Critical Readiness Enablers"
		Aircraft Authorized	15		
		Pilots Authorized	36		
		Designations/Qualifications	Number/Percentage of Total Pilots		
CMMR (Minimum)	ANSQ	Advanced Night Systems Qualification	12	33%	
	FAC(A)	Forward Air Controller (Airborne)	6	17%	
Combat Leadership (Minimum)	AHC	Attack Helicopter Commander	12	33%	
	SL	Section Leader	6	17%	7533
	DL	Division Leader	3	8%	7534
	FL	Flight Leader	4	11%	7535
	AMC	Air Mission Commander	4	11%	
CMTS (Optimum)	NSI	Night Systems Instructor	6	17%	7547
	FAC(A)I	Forward Air Controller (Airborne) Instructor	3	8%	7544

The AH-1Z CMMR in Appendix A uses seven qualifications to determine readiness of Core METs, five of which are considered combat leadership. The 2018 AvPlan lists five qualifications as NMOSs, but only three are included in the CMMR. For example, Section Leader is a combat leadership qualification within the CMMR and is also a part of the 2018 AvPlan NMOS. However, NSI and FAC(A)I are two qualifications listed as NMOS critical readiness enablers but are not included in the CMMR or reported in the DRRS. According to the 2018 AvPlan, “The [N]MOS initiative will inform assignment, retention, and promotion processes in an effort to optimize the return on investment in Marine aviation training” (HQMC, 2017b, p. 16). Despite the misalignment between the CMMR and the new NMOSs, these nine qualifications can be used to find efficiencies in the T&R program.

c. Finding Efficiencies in the T&R Program

In Chapter I, we stated that qualifications depend on training timelines and provide a critical starting point for improving warfighting readiness. Therefore, now that we have identified specific qualifications tied to readiness, we must describe the timelines for these qualifications. Again, the TPM is a good depiction of the process and squadrons are urged to “use the model as a guide to generate individual training plans” (HQMC, 2014b, p. 2-3). Listed below are eight paragraphs that describe the estimated time period and/or requirements for each of the nine qualifications mentioned using the AH-1Z T&R Matrix and TPM as a guide:

1. ANSQ is estimated to begin 8 months after completing the FRS and is expected to take approximately 3 months to attain; a pilot will complete 17 hours of academics, 15 hours of simulator events, and 23 flight hours to earn ANSQ. Additionally, a pilot must achieve ANSQ to complete the *mission skills phase* within the 3000-series, which is also a prerequisite for AHC.

2. To earn AHC a pilot must be ANSQ, and complete 24 academic hours, 3 simulator hours and 16.5 flight hours for the 3000-series phase—excluding FAC(A). This phase begins approximately one year after the FRS and takes about 4 months to attain AHC.

3. FAC(A) requires 5 academic hours, 7.5 flight hours, and is estimated to take 5 months within the remaining 3000-series time block. Although there are fewer flight hours when compared to AHC, the coordination with external agencies may increase the training duration to complete FAC(A). Additionally, pilots may conduct 4000 to 6000 series events concurrently, thus expanding the training time.

4. Before beginning SL, 50 flight hours as an AHC is required. SL entails 5 academic hours, 5 flight hours, begins approximately 18 months after completing the FRS, and takes approximately 6 months to attain.

5. Following SL, a pilot must have flown three flights as a SL and have 600 total flight hours to become eligible for DL training. After meeting prerequisites, DL training requires 4.5 flight hours; DL training is estimated to be completed within a 4-month window, beginning approximately 21 months after completing the FRS.

6. After SL and before beginning DL, a common approach is to begin the *instructor qualification phase* within the 5000-series. Several

qualifications must be attained after SL and prior to NSI but are not included in the CMMR or listed within the NMOSs, consequently, these qualifications will not be covered. Additionally, since the 5000-series qualifications are grouped together in the TPM, the approximate time periods cannot be determined. Nevertheless, NSI includes 6 academic hours, 1.5 simulator hours, and 7 flight hours within the 21-month training block of the 5000-series.

7. After NSI, a pilot may begin the 4 flight hours of FAC(A)I training. Because FAC(A)I is included in the 5000-series training block, the time period cannot be finitely determined.

8. FL and AMC are the last two qualifications we will discuss. To begin FL training, a pilot must have lead three flights as a DL and have accumulated 750 total flight hours; FL requires one 1.5-hour evaluation flight to become qualified. Additionally, AMC can begin after DL and also requires one 1.5-hour evaluation flight to become qualified. These qualifications are estimated to be completed within a 6-month window starting approximately 2 years after completing the FRS.

To prevent calculating timelines incorrectly, the distinction between time-to-earn a qualification and time-in-qualification must be addressed. As shown in the preceding paragraphs, the TPM gives an estimate of the time-to-earn each qualification. Although less noticeable, the time-in-qualification can also be derived from the TPM. Using paragraphs one and two—from above—as an example will help show the distinction. Paragraph one states that a pilot will train for 3 months to earn ANSQ and paragraph two states that a pilot will train for 4 months to earn AHC. Therefore, the time-to-earn AHC is the time-in-qualification for ANSQ. Each time-in-qualification is shown in Table 8:

Table 8. Time-to-Earn versus Time-In-Qualification (in months).

	Time-To-Earn	Time-In-Qualification
PQM	6	11
ANSQ	3	4
AHC	4	6
SL	6	4
FAC(A)	5	-
NSI	-	-
DL	4	6
FL/AMC	5	-
FAC(A)I	-	-

The time-in-qualification for FAC(A), NSI, FL, AMC, and FAC(A)I cannot be determined from the TPM. Additionally, time in SL is based on time-to-earn DL, and time in DL includes unaccounted time prior to FL/AMC. Although pilots continue to be fully qualified in their previous qualifications, highlighting the attainment of their highest qualification provides a metric for comparison in Chapter V's analysis. We provide another depiction of the TPM—using time-in-qualification for the nine qualifications discussed—in Figure 6:

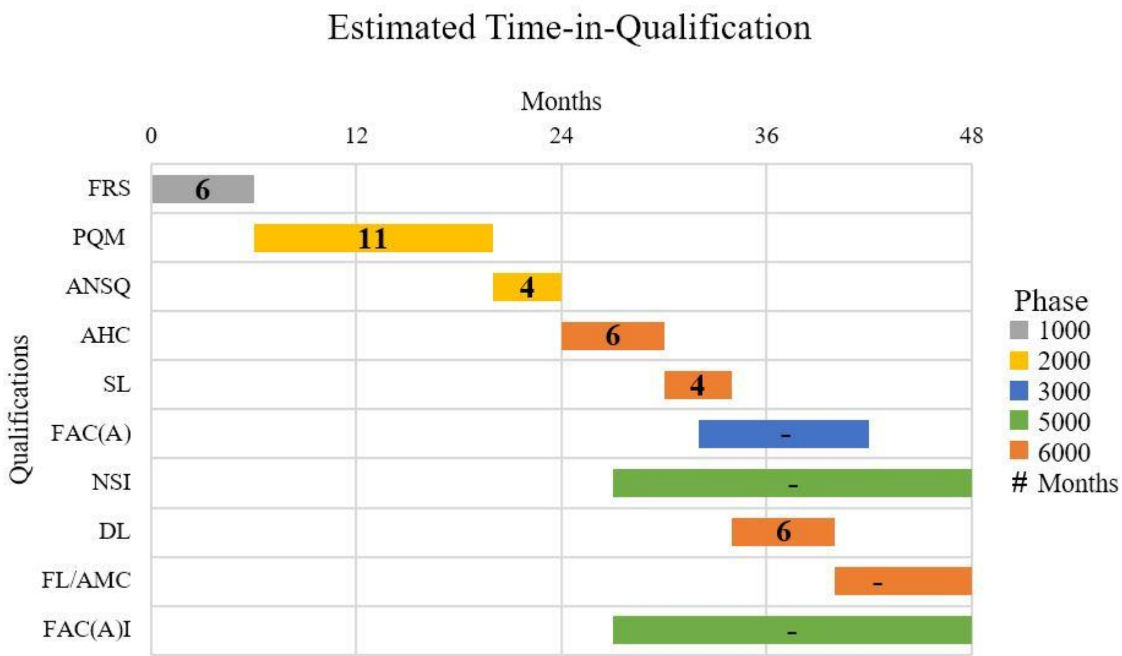


Figure 6. Training Progression Model Estimated Time-In-Qualification.

The actual time in each qualification may be affected by maintenance delays/cancellations, pilot/instructor availability, inclement weather conditions, mandated training, human factors, deployment rotations, etcetera; however, the timelines described above provide the flexibility for HMLA fleet squadrons to structure their training plans to meet mission requirements.

Although flexibility can be good, inefficiencies may occur as a result of these vague timelines. Currently, there is no validation method being used to determine if AH-1Z pilots earn qualifications within the time period set by TECOM. As Chapter I mentions, revisions and recommendations to the AH-1Z syllabus are constrained to small working groups scheduled to meet every three years. This process has been successful but with the vast amount of data in the M-SHARP, creating a model that calculates the probabilities of pilots earning qualifications over time may provide valuable insight. A model that captures precise timelines will help HMLA squadrons to produce and assess individual training plans and allow TECOM to evaluate procedures real-time. Furthermore, the standardization and evaluation process within the Aviation Training

System (ATS)—integrated training system across Marine aviation—may benefit by identifying the rate to which pilots' progress in qualifications. Lastly, by forecasting future proportions of pilots earning specific qualifications, shortfalls can be identified earlier in the process, thus helping both TECOM and M&RA.

B. CHAPTER SUMMARY

In this background, we covered two main topics that laid the framework for the data and methodology chapter. We first explained the warfighting readiness process by highlighting key terminology, types of readiness, and reporting systems as it relates to Marine aviation squadrons. Then, we discussed AH-1 T&R procedures by describing the pilot production process, identifying qualifications tied to readiness, and presenting timelines for specific qualifications. Before we can use this information to develop a model, we discuss previous research methods that are applicable to our study in the next chapter.

III. LITERATURE REVIEW

A. INTRODUCTION

The literature review compares theories and methods concerning probability theory, forecasting and optimization used in previous research and show their contribution to the approach used in this study. Since this study uses a Markov model for analysis, we show how manpower management uses Markov theory to develop forecasting techniques, which closely parallels the methods used in this research. Subsequently, we provide a different technique for manpower planning by presenting a specialized model that forecasts Marine Corps aviator inventory without using Markov principles. Next is a discussion of two studies that show an approach for optimizing a commercial airline's training that indicates key variables within their model. The last study focuses on improving Marine aviation by identifying how maintenance qualifications effect aircraft readiness. We begin by unpacking the Markov property.

1. Markov Theory

Andrei Markov (1856–1922) was a Russian mathematician who is known for his ideas in probability theory (Kouemou, 2011). Initially, many of Markov's theories focused on the central limit theorem, which eventually led him to the discovery of the *Markov property* (Maistrov, 1974). As Carl Harris describes it, the Markov property holds that "the probabilities of future events are completely determined by the present state of the process and the probabilities of its behavior from the present point on" (Harris, 2013, p. 930). In other words, the probabilities of future events occurring depends only on the current events and not those in the past. Using the Markov property, Markov then invented the *Markov Chain*, which was originally published in the early 1900s (Kouemou, 2011). Although the Markov Chain had no immediate application, the technique provided a different method for analysis of transitional probabilities that would later become very useful. Basharin, Langville, and Naumov (2004), present Markov's work as follows:

> Markov proved that the independence of random variables was not a necessary condition for the validity of the weak law of large numbers and the central limit theorem. He introduced a new sequence of dependent variable, called a chain, as well as a few basic concepts of chains such as transition probabilities, irreducibility and stationarity. (p. 23).

In short, the Markov Chain is a model that adheres to the Markov property to describe a sequence of possible events.

In the years following its publication, the Markov Chain was "taken up and developed further by scientists around the world and now the theory of Markov Chains is one of the most powerful theories for analyzing various phenomena of the world" (Basharin, Langville, & Naumov, 2004, p. 23). Classic examples of Markov Chains, such as the *Gambler's Ruin, Random Walk*, and *Coin Toss Sequence*, have helped to illustrate how the theory is applied to real world scenarios. In the *Gambler's Ruin* scenario, for example, the Markov Chain is used to determine the probability of a certain level of gain or loss based on a sequence of bets and on the "expected number of bets before the game terminates" (Harris, 2013, p. 931). In this example, Harris (2013) also points out the relevancy to insurance companies. Additional examples of how Markov Chains are currently being used are speech recognition software, algorithms for webpage rankings, and information theory (Hilgers & Langville, 2006).

In all of these examples, the goal is to forecast what might occur in the future by only using what is known at the current time. This property of Markov Chains bears directly on the question of how current readiness for Marine aviation can be forecasted, in that the current state of helicopter qualifications can help in determining the proportion of future qualification structures within a helicopter community—a process discussed further in the following section.

2. Markov in Manpower Planning

One particularly useful application of Markov Chains is in the area of manpower planning. Manpower planning is "the process of deciding how many people will be needed for a particular job or project, and how they should be used" ("Manpower planning," n.d.). The idea of manpower planning has undoubtedly been around for centuries, but the phrase itself became better known following the Second World War and with the advent of computing technology in the 1960s (Bartholomew, Forbes, & McClean, 1991). One prominent scholar of manpower planning, David Bartholomew, identifies the four purposes of manpower planning as *description*, *forecasting*, *design*, and *control,* and explains how Markov principles can be applied to this process (Bartholomew et al., 1991). This section discusses Bartholomew's techniques to provide the framework needed for Chapter IV's Data and Methodology. Each of Bartholomew's purposes of manpower planning is discussed in turn below.

a. Description and Forecasting

The approach by Bartholomew et al. (1991) begins by describing a system numerically to highlight potential problem areas within the organization. One example he uses is identifying the age distribution of an organization to determine the possibility of promotion bottlenecks. After retrieving data, the expected follow-on action is to forecast possible outcomes. However, as Bartholomew et al. (1991) points out, "Forecasts should never be interpreted as what *will* happen but as what *would* happen if the assumed trends continue" (p. 2). Although forecasts are necessary, they only serve as a guide for decision-making. Bartholomew goes on to describe how he designs a model using the Markov Chain and how an organization's objectives can be met through means of control.

b. Design

Because manpower planning is used for many organizations, the business practices are likely to be different. The first step to design, therefore, is identifying quantifiable categories to be measured within the manpower system, such as the number of people who hold a given grade, qualification, or job title (Bartholomew, 2013). Once the categories within the system have been identified, Bartholomew explains,

> the state of the system at any point in time can then be described by the numbers in these categories, often referred to as the stocks. Over time, changes occur as individuals join, leave the system or move within it. The numbers making these transitions are called the flows. The factors giving rise to change may be predictable or unpredictable but will include such

> things as individual decisions to leave, changes in demand for goods, management decisions on promotion or organizational structure and so on. (2013, p. 910).

Using our knowledge of the Markov property from the previous section, we can follow Bartholomew's logic. However, Bartholomew et al. (1991) introduce two new assumptions for using Markov models in manpower planning: to get a good forecast the system must consist of a finite number of states, and the transitional probabilities must be constant over time. Understanding the stocks, flows, and assumptions may provide further insight on how to better design an organizations structure, but the Markov Chain is the tool responsible for calculating the transitional probabilities that determine which policies may be effective (Bartholomew et al., 1991). The next section describes how a Markov Chain can be used to help management control a system for meeting objectives.

c. Control

Earlier, forecasting was mentioned as being a guide to decision-making, but control is needed to "devise strategies for ensuring that change takes place in the desired direction" (Bartholomew et al., 1991, p. 3). Two methods of control that can help structure an organization are referred to as fixed-recruiting and fixed-inventory. Fixed-recruiting allows the specified number of personnel being introduced to the system to be included when calculating the transitional probabilities. By dictating the number of people to hire, management can determine the future probabilities for the total number of employees in the organization. Bartholomew et al. (1991) presents a question that represents a fixed-recruiting objective by asking, "What will the grade (or age, or length-of-service) structure be at various dates in the future if present patterns of loss and promotion continue?" (p. 95). Another method of control is fixed-inventory. Fixed-inventory is where the end result is established beforehand and the model determines the number of personnel necessary to achieve the goal (Bartholomew et al., 1991). To address this idea, Bartholomew et al. ask "What should the promotion rates and recruitment numbers be in order to achieve a desired structure in a specified time?" (p. 95). Some of the principles described by Bartholomew can be seen in a more recent study in the following section.

d. Applying Markov to Manpower Planning for the U. S. Army

One study that provides a useful model for applying the Markov Chain to manpower planning is Mark Zais' 2014 study on U.S. Army personnel. He begins by categorizing the nine enlisted pay grades within the U.S. Army into five skill levels. Using this information, Zais constructs a model that determines the probabilities of progression for military personnel and loss information regarding continuation rates and separation behavior. From his results, Zais shows how certain policy changes could help shift the Army in the desired direction. Similarly, and in direct correlation to this research, *pilot qualification* can substitute *pay grade* to construct a model that determines probabilities of progression for pilots and continuation rates. The results from this model could then be used to evaluate policies for Marine aviation.

One of the limitations of Zais' study, however, is that he does not use a fixed-inventory model to show the number of soldiers needed to meet various end-strengths. Had his model included this information, decision-makers would have been able to see specific recruiting numbers that would be required to achieve an end-state. In response to this limitation, our research applies the fixed-inventory method to TECOM's established CMMR—minimum required crews to meet METs—to determine future probabilities of the number of pilots needed to maintain the combat leadership qualifications for training readiness goals.

The next section provides another approach to forecasting and focuses on aviators specifically.

3. Forecasting Aviator Inventory

To provide another approach to forecasting, in their 2006 Center for Naval Analysis study, Michael Moskovitz, Theresa Kimble, and Robert Shuford build a model that forecasts the Marine Corps aviator inventory. Their model used daily snapshots of Marine Corps personnel and focuses on qualified aviator inventory and the pilots currently serving under an obligation (Moskovitz, Kimble, & Shuford, 2006). The qualified inventory signifies winged aviators who either have an obligation or not. From this classification, they were left with a total of 3,617 aviators to be inputted into their model. Next, we discuss the model and analysis and identify the contributions and limitations within their study.

a. Model

The model is split into two programs: one uses data to run a simulation of how an aviator progresses through a proposed career path, and the other produces an eight-year inventory estimate (Moskovitz et al., 2006). The authors state that the program "is a predictive tool to calculate the number of projected qualified aviators over time and to help identify future aviator shortfalls" (Moskovitz et al., 2006, p. 4). They include several attributes but indicate that the Initial Service Obligation (ISO) date is critical for defining the aviator's current obligation (Moskovitz et al., 2006). Another key variable is the most current Aviation Continuation Pay (ACP) contract date, which helps determine the proportion of qualified aviators who are serving a subsequent obligation. Additionally, the authors use winging data as the number of pilots entering the system. Using these variables, along with other identifying attributes such as PMOS, date of rank, present grade, etc., the model "takes the current inventory of aviators and estimates the obligation" (Moskovitz, et al., 2006). These results are then compared to inventory levels from the Grade Adjusted Recapitulation (GAR) requirement to identify shortages. The GAR is a report that reflects the total Marine Corps Manpower requirements for each MOS each fiscal year (W. Hatch, class notes, July 18, 2017). A sample of the findings is presented in following section.

b. Analysis

The authors provide an analysis and explain how AH-1 aviator inventory compares to the GAR in Figure 7:

> The current onboard inventory [Point A] of AH-1 pilots is not fully meeting the requirement, but the inventory will be sufficient to meet the GAR in 6 years [Point B] if conditions hold and future aviators are trained as laid out in the winging plans … it appears likely that the AH-1 inventory will not drop below 85 percent of the GAR, which is the traditional measure of critical shortage. (Moskovitz et al., 2006, p. 13–14)

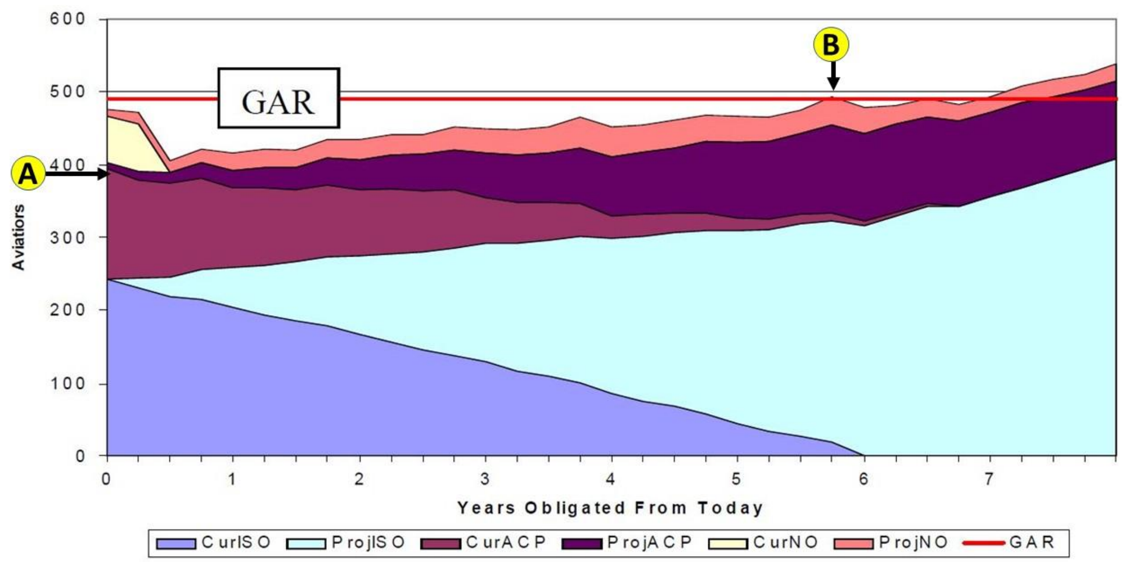


Figure 7. AH-1 Future Inventory Levels. Adapted from Moskovitz et al. (2006).

In short, the current inventory of AH-1 pilots in 2006 was not meeting manpower requirements, but had the trends continued, the projected inventory of AH-1 pilots might have met manpower requirements in six years. The next section discusses the contributions and limitations of this study.

c. Contributions and Limitations

Although this CNA report did not use Markov principles to forecast aviator inventory, it provided a way of identifying shortages when comparing results with Marine Corps requirements. The authors briefly mention that the "model's parameters, including the winging parameters, can be experimented with and changed to analyze the effects of changing the aviation environment" (Moskovitz, et al., 2006, p. 15). This method resembles the fixed-recruiting method in that it uses the idea of controlling the winging parameters to help move in the desired direction. However, the authors' method of analysis is not directed toward calculating transitional probabilities between states, but rather trying to estimate the obligation time of pilots for projecting inventory. Therefore, despite the study's robust analysis of pilot inventory, the method used for this study cannot help us determine the future probabilities of shortages in pilot qualifications for reporting training readiness.

4. Training Optimization

In addition to forecasting aviator inventory and finding efficient methods for improving training readiness, previous studies have also examined the question of training optimization—a task very similar to the one undertaken in our study. Training is a key aspect in pilot proficiency and progression. Björn Thalén's research describes the large cost associated with the airline industry and how savings can be achieved with efficient manpower planning (Thalén, 2010). Most research for reducing cost has focused on crew scheduling, but Thalén's research focuses on staffing and transition planning of pilots. Similar to the Marine Corps, the airline industry must identify pilots to promote and to which positions; Thalén uses an optimization problem to determine the number of pilots with the correct qualifications to minimize cost. An analysis of his mathematical model shows that data is required on a pilot's current position, available positions, and number of time periods. In a similar study, researchers designed a model that was able to provide "tremendous savings in time and costs to Continental by optimizing its pilot-transition and training plans" (Yu, Pachon, Thengvall, Chandler, & Wilson, 2004, p. 261).

Although Markov models are not used in these analyses, they do use data on the position/qualification of pilots to help create models for effective planning in the airline industry. Thalén's research is useful because it shows optimization of a system by focusing on the transition of pilots to available positions. Therefore, our research may also benefit from analyzing the transition of pilot qualifications within Marine aviation.

5. Maintenance Qualifications on Readiness

The final important component of training in Marine aviation is the availability of aircraft to conduct the training. Although our approach does not focus on aircraft readiness, a 2015 thesis by Zachary Germershausen and Scott Steele shows how qualifications may affect readiness. They use data on enlisted personnel, aviation maintenance qualifications, and aircraft readiness for certain Marine helicopter squadrons in their analysis. Since we addressed the relationship and importance between aircraft readiness and training readiness in Chapter II, we focus on one of the methods Germershausen and Steele used for their analysis and a potential drawback to their study below.

a. Monte Carlo Simulation Model

One of the methods Germershausen and Steele use in their analysis is a Monte Carlo simulation. This simulation calculated several different scenarios. One technique calculated that a HMLA squadron would only achieve the MC goal of 73% between 19-36% of the time using the status quo maintenance qualifications for a HMLA squadron (Germershausen & Steele, 2015). The low probability of meeting the MC goal suggests that training readiness likely suffered as well. Another technique calculated the number of maintenance qualifications needed to achieve the MC goal of 73%. The results indicated a substantial increase in certain qualifications would be needed to achieve the goal. Both of these techniques are similar to the fixed-inventory and fixed-recruiting methods mentioned earlier, and the information provided allows decision makers to focus on areas to move the organization in a desired direction.

b. Simulation Model Limitation

Providing decision makers precise information is optimal; however, one limitation to the Monte Carlo simulation is that it is *too* specific and cannot be easily duplicated to include other qualifications or TMS aircraft. Although simulation modeling might provide a more accurate prediction, Bartholomew (1991) explains that

> For all their virtues simulation models have certain drawbacks for practical work. Each situation requires its own tailor-made model and this can be a very time-consuming matter. It may not offer a sufficient advantage over a cruder model which is readily available in a software package. Given the uncertainties of all kinds which beset any manpower modelling exercise it is not worth straining after a degree of precision in matters of detail which will be swamped by variations in major factors. (p. 12)

For this reason, we use a Markov model for our tool in forecasting and controlling pilot qualifications. In doing so, our model will provide the flexibility for further analysis of other Marine Corps aircraft and pilot qualifications.

B. CHAPTER SUMMARY

In this literature review, we identified several studies that provided different techniques for analyzing data. We have explained the principles behind Markov theory, how the principles apply to manpower planning, and how manpower planning methods can be applied to forecasting pilot qualifications in this research. Although our main contributor is the Markov Chain model, each study provided valuable insight into the usefulness and limitations of various techniques for forecasting potential outcomes, using a sensitivity analysis, or determining optimal solutions. All of these studies helped to develop the foundation for building the model used in this research, which will be described in the next chapter.

IV. DATA AND METHODOLOGY

A. INTRODUCTION

Both the background and literature review have set the foundation necessary to understand how statistical methods can be used to analyze pilot qualifications. To interpret the results given in Chapter V, this chapter explains the data we analyzed describes our methodology for the Markov model. We begin by identifying database sources, structuring the data, and presenting descriptive statistics for our dataset.

B. DATASET FORMULATION

1. Data Sources

The data we use are derived from three sources—Total Force Data Warehouse (TFDW), Marine-Sierra Hotel Aviation Readiness Program (M-SHARP), and the Naval Aviation Production Process Integrated Production Data Repository (NIPDR)—and capture pilot assignments, dates, and qualifications from January 1, 2012 to December 31, 2017.

a. TFDW

The TFDW data provide a monthly snapshot of a Marine's administrative personnel file through the Marine Corps Total Force System (MCTFS). The panel data include all Marine company-grade AH-1 pilots and contain 38,240 snapshots (months) across 20 data fields within the six-year period. These data are used for determining which pilots have been assigned a Forward Air Controller (FAC) tour and when a pilot departs their operational squadron.[6]

[6] The Forward Air Controller (FAC) tour is not associated with the FAC(A) or FAC(A)I qualifications mentioned in Chapter II. The FAC tour requires a pilot to leave a HMLA squadron for 12 to 18 months and then return to the squadron to progress in flight leadership/pilot qualifications. FAC tours incur a fleet squadron extension beyond the standard 48-month timeline indicated by the TPM.

b. M-SHARP

The M-SHARP data include all AH-1Z pilots during the six-year period and contain 273 observations and 4,025 qualifications across 30 data fields. The fields primarily consist of dates for each qualification a pilot has attained. Although M-SHARP is updated in real-time, no archival system for M-SHARP exists to distinguish pilot qualification dates for pilots who are not assigned to one of the 280 units/detachments within the M-SHARP database construct. Therefore, we are constrained to cross-sectional data with a time element, which weakens the robust analysis of pilot qualifications.

c. NIPDR

The NIPDR data include all AH-1 CAT I and II pilots who completed HMLAT-303 flight training within the six-year period and contain 391 observations across 38 data fields. These time-series data differentiate among Programs of Instruction (POIs) for TMS aircraft and identify specific dates for pilots entering fleet squadrons. The NIPDR data were critical when forming our dataset because the TFDW and M-SHARP data do not clearly distinguish between CAT I and II pilots or between AH-1W and AH-1Z pilots.

2. Data Structure

All three sources individually provided the data in Microsoft Excel format. We then used Stata statistical software to import and merge the data—on EDIPI—to create a single dataset. By merging the source data, our dataset for analysis provides 2,956 TFDW monthly snapshots from 111 NIPDR observations (pilots) and include a total of 333 qualifications from M-SHARP. We used the dataset to empirically analyze time-to-train for pilot qualifications and to form the monthly flow of pilot qualifications for the Markov model. Prior to this empirical analysis and creation of pilot qualification flows, we truncated the data fields, cleaned the data, and created variables.

a. Data Fields

This section highlights the data fields we used from each source, presented in Tables 9 through 11:

Table 9. TFDW Data Fields and Descriptions.

Data Field	Description
EDIPI	DoD Number
TFDW Snapshot Date	Date data was pulled
PMOS	Primary MOS
Addl First MOS Code	Additional MOS and NMOS
Addl Second MOS Code	Additional MOS and NMOS
MCC	Monitored Command Code to FAC tour
Present Unit Joined Date	Date Pilot Joined Unit

Table 10. M-SHARP Data Fields and Descriptions.

Data Field	Description
EDIPI	DoD Number
ANSQ	Advanced Night Systems Qualification date
AHC	Attack Helicopter Commander date
SL	Section Lead date
NSI	Night Systems Instructor date
DL	Division Lead date
WTI	Weapons and Tactics Instructor date

Table 11. NIPDR Data Fields and Descriptions.

Data Field	Description
EDIPI	DoD Number
Unit	Unit pilot was assigned to at time of MSHARP data pull
Grade	Rank/Grade of pilot
Stop Date	Date when pilot completes FRS and is PQM
TTT Weeks	FRS total time to train in weeks

b. Data Cleaning

To capture the transition probabilities of AH-1Z pilots, our ideal dataset would have included all AH-1Z pilots; however, two issues did not allow this to occur. First, the qualification dates of several AH-1Z CAT II pilots showed dates in M-SHARP that were prior to their FRS completion date for the AH-1Z, suggesting that AH-1W qualifications were mixed in with the data. Although electronic logbooks can be accessed through the

M-SHARP database and canvassed to retrieve such information, the time to verify seven qualifications for 99 pilots over a six-year period would be too extensive. Second, mixing experience levels between AH-1Z CAT I and II pilots could misrepresent transition rates for our analysis. By eliminating AH-1W CAT I and AH-1Z CAT II pilots, the NIPDR data observations shrunk from 391 to 111.

Our next consideration was to include all AH-1Z CAT I pilots within the M-SHARP data who attained qualifications as a company-grade officer within their first tour in an HMLA but were not a part of the NIPDR data. However, the M-SHARP and TFDW data could not delineate between CAT I and CAT II pilots. Despite TFDW data listing PMOS, AMOS, and NMOS, the distinction between AH-1Z CAT I and II pilots could not be clearly identified with the 7513 NMOS. Many of the confirmed AH-1Z CAT II pilots from the NIPDR data did not have the 7513 NMOS in the TFDW data. Therefore, any AH-1Z CAT I pilot who completed the FRS prior to 1 January 2012 could not be identified and had to be excluded. This reduced the M-SHARP observations from 273 to 101.

Of the 111 NIPDR observations, 101 matched with the M-SHARP qualifications. Additionally, nine qualifications indicated inaccurate data, leaving a total of 93 complete observations between NIPDR and M-SHARP. The inaccurate data comprised qualification dates that were repeated for each of the 9 observations. Since qualifications are earned sequentially, the dates were manually corrected by referring to electronic logbooks on the M-SHARP database and inputting the accurate dates of qualifications for each of the nine observations. The remaining nine missing qualifications were identified as pilots who had recently completed the FRS—in late December 2017—and were not listed in the M-SHARP data. These nine observations were manually added to the M-SHARP qualifications by inputting their PQM date as their FRS completion date.

Now, with a total of 111 complete observations between NIPDR and M-SHARP, we compared TFDW snapshots to identify inaccuracies. The TFDW data matched 109 of the 111 observations. The two pilots missing were easily identified with the NIPDR data as being recent FRS completers and were manually added to the TFDW data by updating their data field *Present Unit Joined Date* to December 2017. Because these pilots are arriving to a fleet squadron, we know they are not FACs and are not departing the HMLA. Lastly, we used the 111 observations from the NIPDR and M-SHARP data to shape the TFDW snapshots, which were reduced from 38,240 to 2,956.

c. Data Coding

The main goal for coding the dataset was to form the data into a monthly flow of pilot qualifications to be used for a Markov model.[7] However, we also created variables to calculate the time period in which pilots hold each qualification. The variables created for our analysis are shown in Table 12.

For the *facstart*, *facend*, and *departunit* variables, we used TFDW snapshots to identify when a pilot departs on a FAC tour and when the pilot returns by comparing the data fields *Present Unit Joined Date* and *MCC*. Additionally, to identify a FAC, we sorted *Addl First MOS Code* and *Addl Second MOS Code* data fields to find the 7502 NMOS. We also used the snapshots to identify when a pilot completes their first fleet tour by comparing *TFDW Snapshot Date* and *MCC*. We denoted a pilot departing the HMLA with an MCC indicating a code other than one of the four AH-1Z HMLA codes and without the 7502 NMOS. Conversely, we identified the FAC departure/return with the 7502 NMOS.

[7] We also created 72 dummy variables (not listed in Table 12) that correspond to each month in the six-year period, which use the *pqm0, ansq1, ahc2, sl3, nsi4, dl5, wti6, facstart, facend, departunit* variables to determine the monthly qualification flows for the Markov model.

Table 12. Variables Created for Data Analysis and Markov Model.

Variables	Description
frs_comp	Reformatted stopdate %td
pqm0	0 = Pilot Qualified in Model, FRS complete
ansq1	1 = Pilots with the ANSQ qualification
ahc2	2 = Pilots with the AHC qualification
sl3	3 = Pilots with the SL qualification
nsi4	4 = Pilots with the NSI qualification
dl5	5 = Pilots with the DL qualification
wti6	6 = Pilots with the WTI qualification
frsttt_m	FRS time to train in months
pqmtime	Months in PQM
ansqtime	Months in ANSQ
ahctime	Months in AHC
sltime	Months in SL
nsitime	Months in NSI
dltime	Months in DL
wtitime	Months in WTI
factime	Number of months on FAC tour
facs	1 = FAC tour, 0 = No FAC tour
facstart	Date Forward Air Controller tour began (from TFDW data)
facend	Date Forward Air Controller tour ended (from TFDW data)
departunit	Date pilot departs HMLA and exits system (from TFDW data)
totime	Total months in squadron
hq	Highest qualification attained
hqd	Highest qualification date
ctis	Current time in squadron from hqd in months
hqtime	Time in highest qual before departing unit

3. Descriptive Statistics

We use the TFDW, M-SHARP, and NIPDR data to describe our dataset in Tables 13 through 18. To begin, the grade breakdown shows an O-4 in the data, but referring to the TFDW snapshots indicates a promotion to O-4 at the end of the pilot’s first fleet tour; therefore, the Major is retained for analysis, as shown in Table 13:

Table 13. TFDW Total Monthly Snapshots.

Grade	Frequency	Percent
O-2	225	7.61
O-3	2,671	90.36
O-4	60	2.03
Total	2,956	100

The 111 NIPDR observations are represented by the 111 PQM qualifications. Therefore, 25 pilots have completed the FRS, have been assigned to a HMLA, and are working toward earning the ANSQ qualification (111-86=25), as shown in Table 14:

Table 14. M-SHARP Number of Each Qualification.

Qualification	Number
PQM	111
ANSQ	86
AHC	63
SL	39
NSI	14
DL	11
WTI	9
Total	333

The grade breakdown of our dataset, which comes from the total FRS production between 2012 and 2017, is shown in Table 15:

Table 15. NIPDR Total Pilot Production.

Grade	Frequency	Percent
O-2	35	31.53
O-3	75	67.57
O-4	1	0.9
Total	111	100

Next, we show the pilot qualification breakdown by unit in Table 16. VMM-265 signifies AH-1Z pilots attached to a Marine Expeditionary Unit (MEU). "Other" includes MAG-39, HMLAT-303, VMX-1, MAWTS-1, and unassigned units and implies the unit where a pilot was assigned at the time of the M-SHARP data pull who completed their fleet tour with a HMLA before their assignment.

Table 16. Number of Qualifications Attained by Unit.

Unit	PQM	ANSQ	AHC	SL	NSI	DL	WTI	Total
HMLA-169	4	8	6	7	1	0	2	28
HMLA-267	10	3	5	5	0	0	2	25
HMLA-369	1	4	2	3	0	1	1	12
HMLA-469	7	6	3	2	1	0	1	20
VMM-265	2	1	2	0	1	0	1	7
Other	1	1	6	8	0	1	2	19
Total	25	23	24	25	3	2	9	111

The average current months in a squadron are calculated by dividing snapshot months by number of pilots who hold a specific qualification, shown in Table 17:

Table 17. Average Current Time in Squadron.

Variable	TFDW Snapshots	M-SHARP Qualifications	Average Months in Squadron[1]
PQM	158	25	
ANSQ	340	23	
AHC	817	24	
SL	987	25	
NSI	118	3	39.3
DL	88	2	44.0
WTI	448	9	49.8
Total	2956	111	

[1]PQM, ANSQ, AHC, SL will not be accurate because FAC unit is included

Lastly, we show the highest qualification for pilots who have departed their first fleet tour in the HMLA. Seventeen pilots started a FAC tour, nine have completed a FAC tour, two FACs have departed the HMLA, and no FACs attained NSI or above, as shown in Table 18:

Table 18. Highest Qualification Attained for the 11 Pilots that Have Departed the HMLA.

Qualification	Frequency	Percent
PQM	1	9.1
ANSQ	1	9.1
AHC	4	36.4
SL	2	18.2
NSI	0	0.0
DL	1	9.1
WTI	2	18.2
Total	11	100

C. MARKOV MODEL METHODOLOGY

Once our data had been identified, cleaned, coded, and described, it was ready for empirical analysis. Before we provide our summary statistics, we describe how our Markov model was constructed. In Chapter III, we saw that Bartholomew states that the first step in design is to identify quantifiable categories to be measured within the system. We have identified our categories to be pilot qualifications, discussed in the following section.

1. System Classification

Although qualifications build on each other to produce a higher skill level, not all are sequential. In Chapter II, we listed training that can be run concurrently; therefore, to reduce complexity and provide greater flexibility in our model, we chose seven qualifications where the dates occur sequentially that still represent the critical readiness enablers mentioned in Chapter II. The qualifications we use—in sequential order—are PQM, ANSQ, AHC, SL, NSI, DL, and WTI; therefore, we exclude FAC(A), FL, AMC, and FAC(A)I from our analysis. We include PQM in our analysis to establish when a pilot entered a squadron and include WTI to indicate the highest qualification attained before departing a squadron. To better explain the flow of qualifications within the Markov system, we provide a graphical depiction in Figure 8:

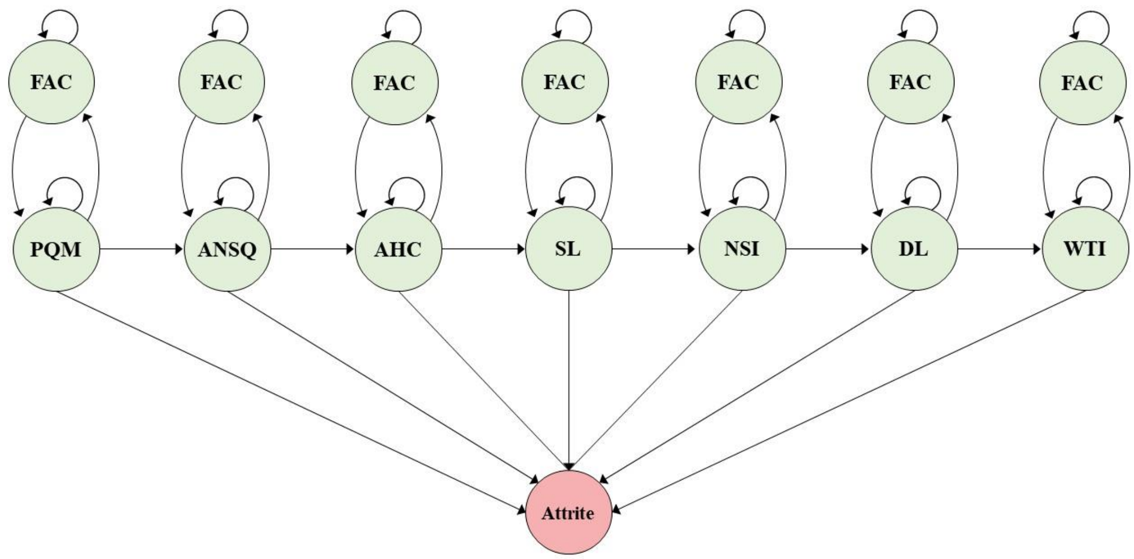


Figure 8. Pilot Qualification Flow System for Markov Model.

Each qualification is a state—what we refer to as a node—where a pilot can reside for a period of time. Additionally, our model complies with the assumptions mentioned in Chapter III by ensuring a finite state: in other words, every pilot in the data resides in one of the 15 nodes presented.

A node unique to our model is when a pilot is assigned a FAC tour. The aviation T&R program manual states that pilots "shall be assigned to an operational squadron for a minimum of 2 years (optimally 3 years) after completing Core Introduction Phase Training [FRS]" (HQMC, 2016a, p. 2-2). However, our data indicate that pilots have departed operational squadrons for FAC tours earlier than two years. Therefore, we constructed our model to allow for FAC departure/return flexibility for each of the seven qualifications.

A pilot makes one of five possible transitions each month: a pilot can either remain in the same qualification, progress to the next higher qualification, depart to a

FAC tour, return from a FAC tour, or attrite.[8] As each month passes, the number of pilots who remain, progress, depart, return, or attrite within the system form the flows and serve as the basis for determining transition probabilities.

2. Equations and Terminology

Before showing our Markov model results, we describe the equations and terminology within our model. The model contains three major components—the flows, the transition probability matrix, and the fundamental matrix—and two forecasting methods—fixed-inventory and fixed-recruiting—all of which are described in the following four sections.

a. Flow of Pilot Qualifications

The flows of pilot qualifications are determined by the changes to number of pilots in each node from one month to the next. To calculate these changes, we label the current state for pilot qualifications as f_i and the subsequent state as f_j, where $_i$ represents the rows and $_j$ represents the columns. Therefore, the total number of changes to pilot qualifications—n_i—equals the sum of f_{ii} and f_{ij} combinations and attrition. The number of qualifications for each node is shown in Table 19. Additionally, a graphical representation of the 72-month flow of qualifications can be found in Appendix C.

Table 19. Monthly Pilot Qualification Flows.

f_i \ f_j	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Attrite	Total (n_i)
PQM0	996	86						1	1	1,084
ANSQ1		821	61					2	1	885
AHC2			437	37				7	2	483
SL3				351	14			7	2	374
NSI4					76	11		0	0	87
DL5						23	9	0	1	33
WTI6							67	0	2	69
FAC7	0	0	1	2	0	0	0	222	2	227

[8] Attrite is used as a general term that signifies a pilot exiting the system.

By adding 996 + 86 + 1 + 1 ($f_{00} + f_{01} + f_{07} + f_{0Attrite}$), we find the total number of PQM qualifications to be 1,084. These numbers seem misleading since our descriptive statistics show 111 pilots with the PQM qualification; however, the number of transition states in the system equates to 111 pilots times 72 months, which equals 7,992. The total number of observable transition states within our model equals 3,242, which indicates the majority of our observations do not enter the model until approximately halfway through the 72-month time period (the graphical flows in Appendix C confirm this assumption). Next, we discuss transition probabilities.

b. Calculating the Transition Probabilities

After the pilot qualification flows are constructed, we calculate the transition probabilities matrix, known as the P-matrix. The P-matrix calculation is shown in Equation (1):

$$\hat{p}_{ij} = \frac{\sum_{t=1}^{T} f_{ij}(t)}{\sum_{t=1}^{T} n_i(t)} \qquad (1)$$

Using this equation, we can estimate the actual probability of transitioning between each node. The calculations from Equation (1) are shown in Table 20:

Table 20. Transition Probabilities Matrix (P-matrix).

p_i \ p_j	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Attrite	Total
PQM0	0.919	0.079	0	0	0	0	0	0.001	0.001	1
ANSQ1	0.000	0.928	0.069	0	0	0	0	0.002	0.001	1
AHC2	0	0	0.905	0.077	0	0	0	0.014	0.004	1
SL3	0	0	0	0.939	0.037	0	0	0.019	0.005	1
NSI4	0	0	0	0	0.874	0.126	0	0	0	1
DL5	0	0	0	0	0	0.697	0.273	0	0.030	1
WTI6	0	0	0	0	0	0	0.971	0.000	0.029	1
FAC7	0	0	0.004	0.009	0.000	0.000	0.000	0.978	0.009	1

As Table 20 shows, the probability that a PQM remains a PQM (p_{00}) is 0.919; the probability that a PQM progresses to ANSQ (p_{01}) is 0.079; the probability that a PQM departs on a FAC tour (p_{07}) is 0.001; and the probability that a PQM attrites is 0.001. This model does not allow pilots to transition to a previously held qualification; moreover, once pilots attrite, they have reached an absorbing state and cannot reenter the system.

c. Constructing the Fundamental Matrix

The last major component of our model is the fundamental matrix, known as the S-matrix. The S-matrix is calculated by taking the inverse of the difference between the I and P matrices and is shown in Equation (2):

$$\mathbf{S} = (\mathbf{I} - \mathbf{P})^{-1} \qquad (2)$$

We use the S-matrix to forecast pilots' expected time-in-qualification and to determine the proportion of pilots who progress for each qualification. The calculations from Equation (2) are presented in Table 21:

Table 21. Fundamental Matrix (S-Matrix).

S_i \ S_j	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7
PQM0	**12.318**	13.514	10.863	16.883	4.998	2.086	19.623	23.396
ANSQ1	0	**13.828**	11.085	17.143	5.075	2.118	19.925	23.279
AHC2	0	0	**11.544**	17.611	5.214	2.176	20.470	22.560
SL3	0	0	0.800	**19.735**	5.843	2.438	22.938	17.296
NSI4	0	0	0.000	0.000	**7.909**	3.300	31.050	0.000
DL5	0	0	0.000	0.000	0.000	**3.300**	31.050	0.000
WTI6	0	0	0.000	0.000	0.000	0.000	**34.500**	0.000
FAC7	0	0	2.629	11.416	3.380	1.410	13.269	**56.831**

The expected time-in-qualification is highlighted in boldface and is known as the main diagonal. For example, the expected time in PQM for a pilot who started out as a PQM (s_{00}) is 12.3 months. Off of the main diagonal, the expected time in ANSQ given that a pilot started out as a PQM (s_{01}) is 13.5 months. To identify the proportion of pilots who progress from PQM to ANSQ, we use Equation (3):

$$\frac{s_{ij}}{s_{jj}} \qquad (3)$$

The results from Equation (3) are interpreted in this case as the proportion of pilots who make it to ANSQ (s_{01}) given that they started in PQM (s_{11}), which is 0.977. We do not include the probability of attrition in our interpretations because every pilot will eventually attrite from the system. In the next section, we discuss the two forecasting methods to be used with our model.

d. Forecasting Methods

After building the Markov model, we use fixed-recruiting and fixed-inventory as the two methods for forecasting the behavior of the system. We begin by explaining fixed-recruiting with Equation (4):

$$\mathbf{n}(t + 1) = \mathbf{n}(t)\mathbf{P} + R\mathbf{r} \tag{4}$$

We use fixed-recruiting to examine how the pilot qualification structure will look in the future by maintaining a fixed number of pilots who enter the system. Two new variables are introduced with the fixed-recruiting method: R and $\mathbf{r}$. The variable R represents the total number of pilot accessions each month, and the variable $\mathbf{r}$ is a vector that represents how the new pilots are distributed. All pilots must enter the system through PQM; therefore, no distribution remains for the subsequent qualifications. We run the model using the initial inventory of qualifications and two pilot accessions per month to forecast the next three months of inventory, as shown in Table 22:

Table 22. Fixed-Recruiting Forecasting Method.

R	r							
2	1	0	0	0	0	0	0	0

Months	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Total
Inventory	23	22	16	16	3	1	7	12	100
n(1)	23	22	16	16	3	1	7	12	101
n(2)	23	22	16	17	3	1	7	13	103
n(3)	23	23	16	17	4	1	7	13	104

From this forecast, we identify that ANSQ, SL, NSI, and FAC increase by one, with the total by the end of month three rising to 104. Although a total of six pilots entered the system, only four are added to the total due to attrition.

Our second method for forecasting—fixed-inventory—also uses Equation (4) but sets a specific level of inventory for pilot qualifications rather than accessions per month. We use the initial qualification inventory and Excel's Solver to calculate the number of accessions per month that are required to achieve the target inventory level, as shown in Table 23:

Table 23. Fixed-Inventory Forecasting Method.

R	r							
2.537	1	0	0	0	0	0	0	0
2.547	1	0	0	0	0	0	0	0
2.558	1	0	0	0	0	0	0	0

Months	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Total	Target
n(0)	23	22	16	16	3	1	7	12	100	
n(1)	24	22	16	16	3	1	7	12	102	102
n(2)	24	23	16	17	3	1	7	13	104	104
n(3)	25	23	16	17	4	1	7	13	106	106

This forecasting method shows that three pilots each month are required to increase the pilot qualification inventory level to 106 by the end of the third month.

D. CHAPTER SUMMARY

This chapter describes the dataset and the model that we use for analyzing pilot qualifications. We first explained where the data came from and how we structured our dataset and provided descriptive statistics of the data. Then, we discussed the methodology used to create our Markov model by classifying the system into specific nodes, presenting our mathematical equations, highlighting terminology, and providing example interpretations. In the next chapter, we provide an empirical analysis of the data and the pilot qualification results of our Markov model.

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V. RESULTS

A. INTRODUCTION

The data and methodology defined in Chapter IV provide the basis for analyzing the results, which we present in two parts within this chapter. The first part contains an empirical analysis of the dataset by identifying the time pilots spent in each qualification and comparing the results to TECOM's TPM. The second part describes the Markov model results by indicating the expected time in each qualification and showing the possible outcomes for fixed-recruiting and fixed-inventory forecasting methods.

B. EMPIRICAL ANALYSIS

1. Measurable Qualifications

Before showing the summary statistics for time-in-qualification, we must clarify the number of measurable qualifications for this empirical analysis. For example, of the 111 pilots who have completed the FRS, 86 pilots have also completed PQM by attaining ANSQ—the next highest qualification. However, the remaining 25 pilots have not attained ANSQ; therefore, a definitive time period could not be calculated. This issue reverberates throughout each qualification and is shown in Table 24:

Table 24. Completed Qualifications.

Type of Qualification	Number of Qualifications	Qualification Status	
		Not Complete[1]	Complete[2]
PQM	111	25	86
ANSQ	86	23	63
AHC	63	24	39
SL	39	25	14
NSI	14	3	11
DL	11	2	9
WTI[3]	9	7	2
Total	333	109	224

[1]Number of pilots who are working to attain the next-highest qualification
[2]Number of qualifications to be included in calculations
[3]Seven pilots with the WTI qualification have not departed the HMLA

Although 333 qualifications are within the M-SHARP data, only 224 qualifications can capture the time period spent in each qualification. The difference between the total number of qualifications and the completed qualifications equals 109 and signifies the number of observations (pilots) who have not attained WTI and have not departed the HMLA. For example, seven pilots have attained the highest qualification of WTI but have not departed the HMLA. Without an end date, we cannot include these seven pilots when calculating the minimum, maximum, or average time in the WTI qualification.

2. Statistical Summary and Significance

Now that we have explained the reason for reducing the number of qualifications, we begin our time-in-qualification analysis. The objective of the cross-sectional-with-time-element analysis is to compare the average time spent in each qualification to the squadron training guidelines presented by TECOM's TPM, discussed in Chapter II. The summary statistics for time-in-qualification are shown in Table 25:

Table 25. Summary Statistics for Time-in-Qualification (in Months).

Variable	n	Mean	S.D.	Min	25th Percentile	Median	75th Percentile	Max
FRS	111	5.2	1.1	3	4.4	5	5.8	9.3
PQM	86	10.7	4.9	4	6.9	9.7	12.9	28.9
ANSQ	63	11.4	6.6	1.5	6.2	10.8	14.9	30.1
AHC	39	8.9	5.9	2	4.9	7.1	10.1	27.2
SL	14	9.1	3.5	5.4	5.8	8.1	11.8	15.2
NSI	11	6.2	5	0.7	2.1	6.3	8.3	17.3
DL	9	3.4	2	1.7	2.4	2.4	3.9	8.4
WTI	2	12.4	1.3	11.5	11.5	12.4	13.2	13.2

To further describe the results from Table 25, we test for statistical significance, where the null hypothesis is the mean time in the given qualification equals the TPM time-in-qualification.[9] ANSQ, AHC, and SL are statistically significant when the mean is greater than the null hypothesis, thereby rejecting the null in favor of the alternative

[9] NSI and WTI are not tested because the TPM does not provide precise time periods for these qualifications.

hypothesis.[10] In other words, on average, pilots spend more time in these qualifications than the TPM indicates. We present the results from Table 25 sequentially as follows:

- A 95% Confidence Interval (CI) for mean time spent in PQM is between 9.7 and 11.8 months. The TPM states pilots will hold PQM for 11 months before earning ANSQ; therefore, PQM does not take longer than the TPM guidelines.

- A 95% CI for mean time spent in ANSQ is between 9.7 and 13.0 months. The TPM shows pilots will hold ANSQ for 4 months before earning AHC; therefore, ANSQ takes longer than the TPM guidelines.

- A 95% CI for mean time spent in AHC is between 7.0 and 10.8 months. The TPM states pilots should hold AHC for 6 months before earning SL; therefore, AHC takes longer than the TPM guidelines.

- A 95% CI for mean time in SL is between 7.1 and 11.0 months. The TPM states pilots should hold SL for 4 months before earning the next highest qualification; therefore, SL takes longer than the TPM guidelines.

- A 95% CI for mean time in DL is between 1.8 and 4.9 months. The TPM shows pilots will hold DL for 6 months before earning the next highest qualification; therefore, DL does not take longer than the TPM guidelines.

We illustrate a comparison between our data and the TPM in the next section; however, a summary of these findings is shown in Table 26:

[10] The results of the one-sample T-tests can be found in Appendix B.

Table 26. Time-in-Qualification with Confidence Intervals (in Months).

	TECOM	Data	
Qualification	**TPM**	**Mean**	**95% Confidence Interval**
PQM	11	10.7	9.7 to 11.8
ANSQ	4	11.4	9.7 to 13.0
AHC	6	8.9	7.0 to 10.8
SL	4	9.1	7.1 to 11.0
NSI	-	6.2	-
DL	6	3.4	1.8 to 4.9
WTI	-	12.4	-

To show the time-in-qualification spread and outliers within the data, a graphical depiction of the summary statistics is illustrated in Figure 9:

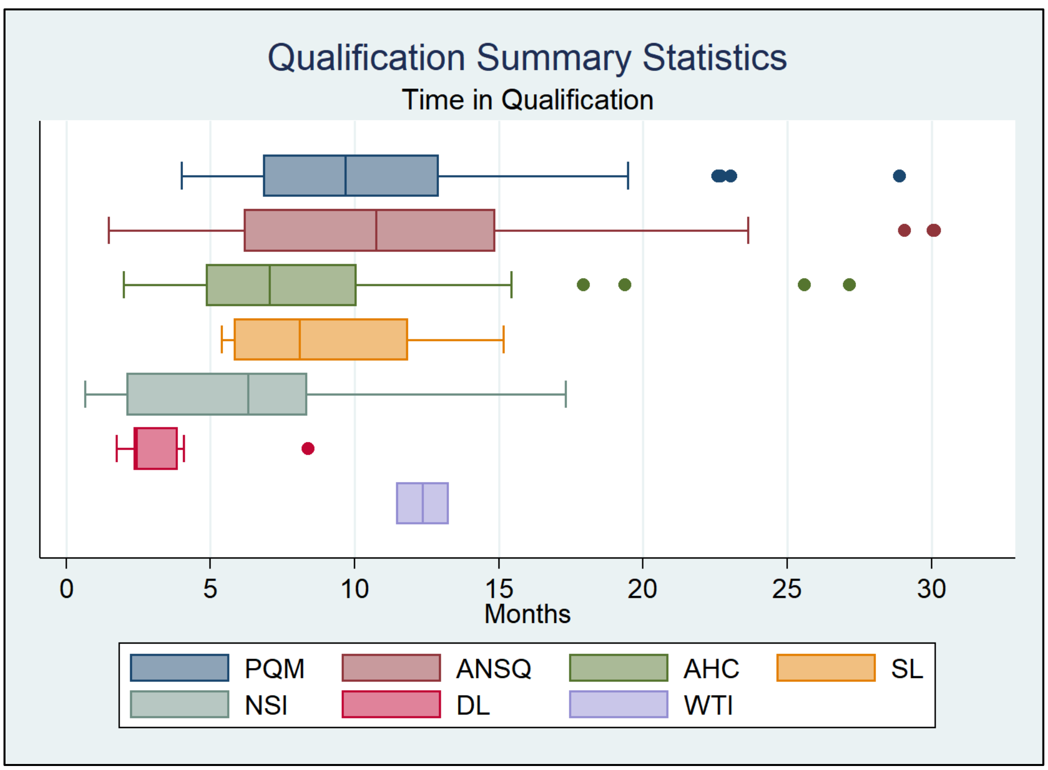

Figure 9. Time-in-Qualification Summary Statistics Box and Whisker Graph.

Time in PQM, ANSQ, and AHC show wide variability, with several outliers; however, these qualifications have a higher number of observations, which tighten the distribution around the central value. We show the distributions for PQM, ANSQ, and AHC in Figure 10. From Figures 9 and 10, we see the outliers elongating the right side of the distribution curves; therefore, we must also consider the median for comparing time-to-train.

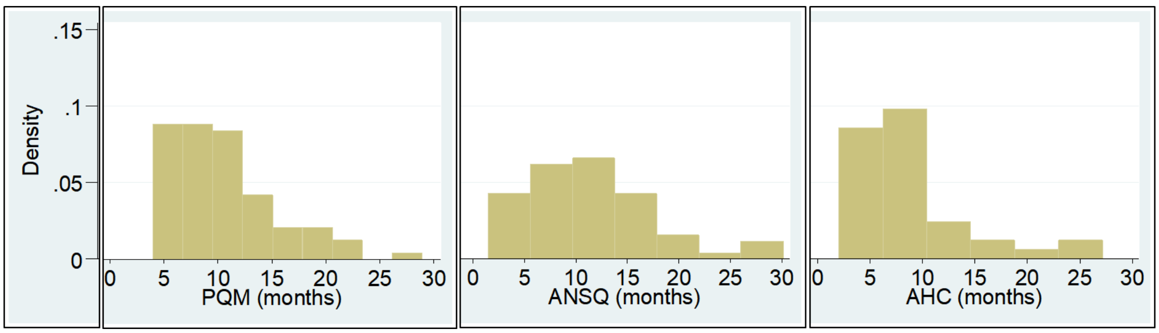

Figure 10. Qualification Distribution and Comparison for PQM, ANSQ, and AHC.

By contrast, the qualifications after AHC show only one outlier, suggesting lower variability. However, the smaller number of observations creates a wider range for capturing uncertainty, thereby weakening the impact of the results. A good example is shown with the two WTI qualifications: in this case, the median equals the mean, and the two observations represent the minimum and maximum. Despite the two WTI qualifications having a standard deviation almost as low as the 111 pilots who completed the FRS, the sample is unlikely to accurately portray the WTI qualification for the AH-1Z CAT I pilot population. Nevertheless, we provide a time-to-train comparison in the following section.

3. Time-to-Train Comparison

To begin, we use the TPM's 48-month total time-to-train as the basis for comparison. We initially included NSI and WTI in our comparison to show the total time-to-train within our data; however, the TPM does not indicate a time period for these two qualifications. To calculate the time-to-train, we total the mean and median for each qualification, as shown in Table 27:

Table 27. Time-in-Qualification Comparison (in Months).

	TECOM	**Data**		
Qualification	TPM	Mean	Median	Observations
PQM	11.0	10.7	9.7	86
ANSQ	4.0	11.4	10.8	63
AHC	6.0	8.9	7.1	39
SL	4.0	9.1	8.1	14
NSI	-	6.2	6.3	11
DL	6.0	3.4	2.4	9
WTI	-	12.4	12.4	2
Total	**48**	**62.1**	**56.8**	

From Table 27, we see both our mean and median time-to-train is longer than the specified TPM. Next, we compare the total time-to-train between our data and the TPM using two Gantt charts, as illustrated in Figure 11:

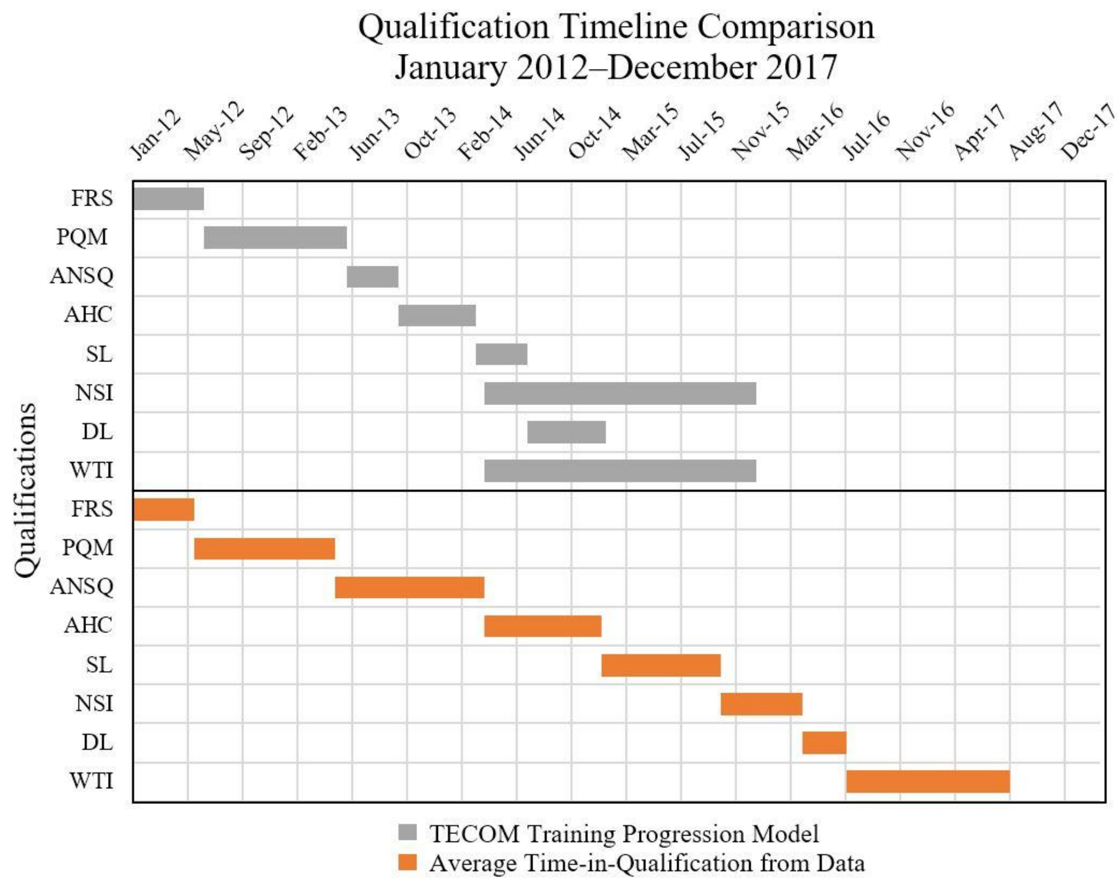

Figure 11. Qualification Time-to-Train Comparison.

Although our data clearly extend beyond 48 months, they also include NSI and WTI, which the TPM does not. Additionally, the low number of observations for NSI, DL, and WTI within our data may be inaccurately representing the true population. Therefore, we recalculate total time-to-train using the PQM, ANSQ, AHC, and SL qualifications, as shown in Table 28:

Table 28. Difference in Total Time-to-Train through Section Lead between TECOM TPM and Data Analysis.

Qualification	TPM	Mean	Difference	Median	Difference
PQM	11.0	10.7	-0.3	9.7	-1.3
ANSQ	4.0	11.4	7.4	10.8	6.8
AHC	6.0	8.9	2.9	7.1	1.1
SL	4.0	9.1	5.1	8.1	4.1
Total	**25.0**	40.1	**15.1**	35.7	**10.7**

As Table 28 shows, on average, pilots take 15.1 months longer to train through SL than the TPM recommends. By eliminating the unknown time periods and the qualifications with low observations, we produce a more accurate time-to-train. Although we do not capture the total time-to-train through WTI, we focus on the qualifications where the majority of AH-1Z pilots reside. Additionally, these four qualifications show the greatest difference when compared to the TPM, which suggests that pilots do not meet current training timelines. We show the total number of pilots who exceed TPM time in Table 29:

Table 29. Number and Percentage of Pilots Who Exceed TPM Time.

Qualification	Exceed TPM	Observations	Percentage
PQM	34	86	39.5%
ANSQ	58	63	92.1%
AHC	25	39	64.1%
SL	14	14	100.0%

In the next section, we further our analysis using Markov models for describing time spent in qualifications and forecasting the number of qualifications.

C. MARKOV MODELS

Our next method for analyzing pilot qualifications is presented in three parts. First, we interpret the Markov model's expected time-in-qualification results and compare these with our empirical analysis from the previous section. Second, we show the proportion of pilots progressing to the next highest qualification. And third, we describe the results of our fixed-recruiting and fixed-inventory forecasting methods. We begin with expected time-in-qualification.

1. Expected Time-in-Qualification

In Chapter IV, we discussed how to construct the S-matrix and interpreted the expected time-in-qualification for PQM—12.3 months. Following the main diagonal, the same interpretations are made for each qualification, as shown in Table 30. However, three qualifications are substantially different from our empirical analysis and require further investigation.

Table 30. Fundamental Matrix (S-Matrix).

	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7
PQM0	**12.318**	13.514	10.863	16.883	4.998	2.086	19.623	23.396
ANSQ1	0	**13.828**	11.085	17.143	5.075	2.118	19.925	23.279
AHC2	0	0	**11.544**	17.611	5.214	2.176	20.470	22.560
SL3	0	0	0.800	**19.735**	5.843	2.438	22.938	17.296
NSI4	0	0	0.000	0.000	**7.909**	3.300	31.050	0.000
DL5	0	0	0.000	0.000	0.000	**3.300**	31.050	0.000
WTI6	0	0	0.000	0.000	0.000	0.000	**34.500**	0.000
FAC7	0	0	2.629	11.416	3.380	1.410	13.269	**56.831**

To begin, the expected time in SL indicates 19.7 months, whereas the maximum time for SL from our statistical summary shows 15.2 months. This discrepancy suggests the pilots who are transitioning from SL to the next-highest qualification are taken into consideration within the Markov model, which is a benefit to this analysis. For example, a pilot who has earned SL may stay a SL until he departs the HMLA—exits the system. Using the mean time-to-train from Tables 27 and 28, the difference between total time-to-train and time-to-train through SL is 22.0 months (62.1 – 40.1 = 22.0); therefore, it is possible for the expected time-in-qualification to be 19.7 months, as listed in the S-matrix.

We now discuss the 34.5 months expected time-in-qualification for WTI. A closer look into the data reveals the first WTI qualification date as October 2015. Although the seven pilots with the WTI qualification have not exited the system, the ending period of 31 December 2017 leaves a maximum of 25 months for a pilot to hold the WTI qualification. Additionally, only two of the nine pilots with the WTI qualification have exited the system, which suggests the transition probabilities skew the outcomes. This skew is evidenced by the lack of mature data and can be seen in the graphical depiction of the flows in Appendix C. In other words, the observation period does not capture the stocks and flows in their entirety, thus misrepresenting the actual transition probabilities.

Similar to WTI, the expected time in a FAC tour shows an unrealistic 56.8 months. As mentioned, there are 17 total pilots who have either started or completed a FAC tour, nine who have completed a FAC tour, and two who have departed the HMLA. Again, because the data are heavily right-censored, the transition probabilities are skewed.

In short, although the Markov model correctly calculates the transition probabilities of the system, the lack of mature data does not correctly describe the actual behavior of WTI qualifications and FAC tour lengths. Therefore, we exclude these from further analysis, as highlighted in Table 31.

Table 31. Expected Time-in-Qualification Comparison (in Months).

Qualification	TECOM TPM	Markov Model	Empirical Analysis	Observations
PQM	11.0	12.3	10.7	86
ANSQ	4.0	13.8	11.4	63
AHC	6	11.5	8.9	39
SL	4.0	19.7	9.1	14
NSI		7.9	6.2	11
DL	6.0	3.3	3.4	9
WTI		**34.5**	12.4	2
FAC	12 to 18	**56.8**	14.4	9

2. Proportion of Pilots Progressing in Qualification

Next, we show the proportion of pilots who progress in qualification by using Equation (3) from Chapter IV. These proportions are shown in Table 32.

Table 32. Proportion of Pilots Progressing in Qualification

P(ANSQ|PQM)	0.977
P(AHC|PQM)	0.941
P(SL|PQM)	0.855
P(NSI|PQM)	0.632
P(DL|PQM)	0.632

P(AHC|ANSQ)	0.960
P(SL|ANSQ)	0.869
P(NSI|ANSQ)	0.642
P(DL|ANSQ)	0.642

P(SL|AHC)	0.892
P(NSI|AHC)	0.659
P(DL|AHC)	0.659

P(NSI|SL)	0.739
P(DL|SL)	0.739

P(DL|NSI)	1.000

Again, we interpret these results as the proportion of pilots who make it to a higher qualification given that they started in a lower qualification. We show the effect that these proportions have on pilot progression in Table 33.

Table 33. Number of Pilot Qualifications Using Proportions of Pilots Progressing to the Next Qualification.

Qualification	Number of Qualifications Calculated from Proportions									
PQM	25									
ANSQ	24	0.977	24							
AHC	23	0.941	23	0.960	23					
SL	21	0.855	20	0.869	20	0.892	20			
NSI	15	0.632	15	0.642	15	0.659	14	0.739	14	
DL	15	0.632	15	0.642	15	0.659	15	0.739	14	1

For comparison, we begin by using the 25 pilots from Table 24 who have not completed the PQM qualification. The proportion of pilot qualifications decreases as pilots progress through the system, and PQM, ANSQ, AHC, and SL are similar to the numbers presented in Table 24. However, in Table 33, the NSI qualification reduces to 14, whereas Table 24 identifies a decrease to 3. Once more, the transition probabilities seem to limit the power of the fundamental matrix.

3. Forecasting Number of Pilot Qualifications

The final part to our analysis forecasts the number of pilot qualifications using two methods, fixed-recruiting and fixed-inventory.

a. Fixed-Recruiting

We use fixed-recruiting to address what the expected breakdown for each qualification will be over the next 12 months if the number of accessions remains constant. To provide context, the monthly accession numbers from 2012 through 2017 are shown in Table 34.

Table 34. HMLA Pilot Accessions, 2012–2017.

Pilot Category	n	Mean	Min	Max
AH-1Z CAT I	111	1.5	0	5
AH-1Z CAT II	99	1.4	0	7
AH-1W CAT I	181	2.5	0	9
Total	391	5.4		

In Chapter II, we listed the transition plan for seven HMLA squadrons. Four of these squadrons consecutively completed the upgrade transition during our six-year observation period. Therefore, although the mean accessions for AH-1Z CAT I pilots indicate 1.5 per month, the number of accessions has been increasing to support this transition plan, as shown in Figure 12:

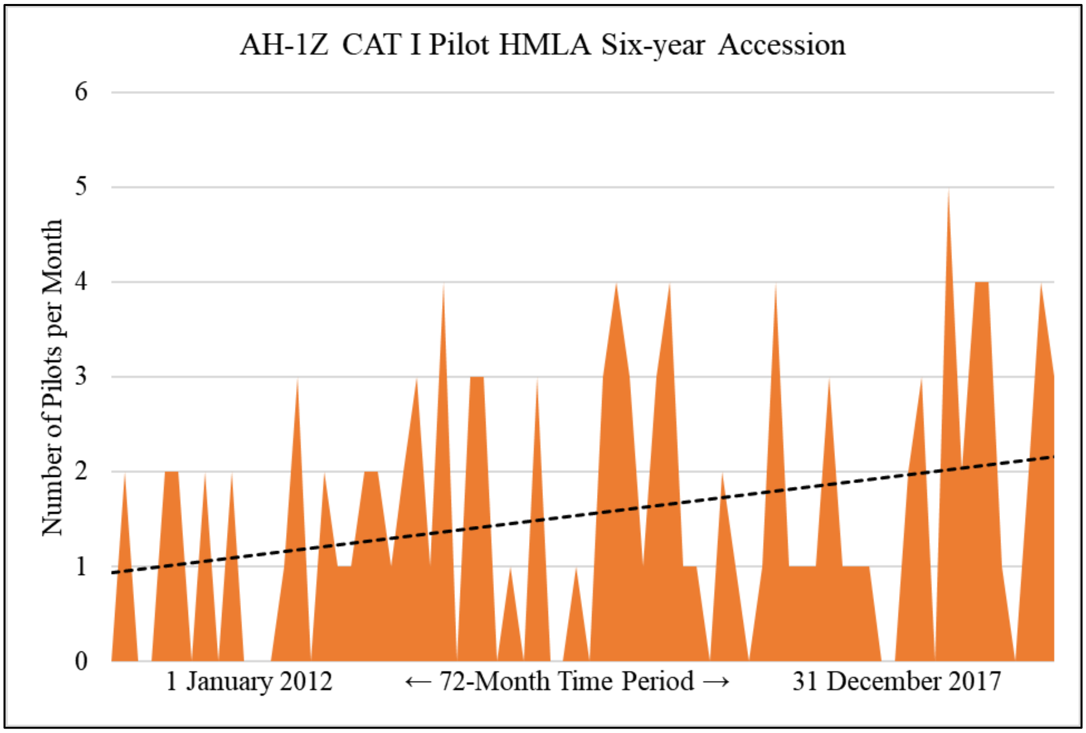

Figure 12. AH-1Z CAT I Pilot Fleet HMLA Squadron Accessions: 2012–2017.

Before we present our results, we validate our fixed-recruiting model by ensuring an accurate forecast of the December 2017 pilot qualifications inventory. To begin this 12-month forecast, we input the December 2016 ending inventory and use the actual number of pilot accessions each month, indicated by *R*. The pilot qualifications forecasted for December 2017 are shown in the last row in Table 35:

Table 35. Fixed-Recruiting Validation Forecast.

Months	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Total	R	r
31-Dec-16	13	19	13	13	7	0	2	10	77		
n(1)	14	19	13	13	7	1	2	10	79	2	1
n(2)	16	18	13	14	6	1	2	11	81	3	1
n(3)	15	18	13	14	6	2	2	11	81	0	1
n(4)	18	18	13	14	6	2	3	11	86	5	1
n(5)	19	18	13	14	6	2	3	11	87	2	1
n(6)	21	18	13	15	5	2	4	12	91	4	1
n(7)	24	19	13	15	5	2	4	12	94	4	1
n(8)	23	19	14	15	5	2	5	12	95	1	1
n(9)	21	20	14	15	5	2	5	12	94	0	1
n(10)	21	20	14	15	5	2	6	13	96	2	1
n(11)	23	20	14	16	5	2	6	13	99	4	1
31-Dec-17	25	21	14	16	5	2	7	13	102	3	1

We then compare our December 2017 forecast to the actual inventory for December 2017, as shown in Table 36:

Table 36. Fixed-Recruiting Validation Forecast Comparison.

31-Dec-17	**PQM0**	**ANSQ1**	**AHC2**	**SL3**	**NSI4**	**DL5**	**WTI6**	**FAC7**	**Total**
Forecast	25	21	14	16	5	2	7	13	102
Actual	23	22	16	16	3	1	7	12	100

The forecast for each qualification is similar to the actual inventory, which indicates the model correctly applies the transition probabilities of the system. Next, we discuss the results of our forecasts for holding accessions constant.

Four fixed-recruiting models are run to forecast pilot qualification inventory levels for four different monthly accessions.[11] Our first model is shown in Table 37:

Table 37. Fixed-Recruiting Results When $R = 2$.

Months	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Total
Inventory	23	22	16	16	3	1	7	12	100
n(1)	23	22	16	16	3	1	7	12	101
n(2)	23	22	16	17	3	1	7	13	103
n(3)	23	23	16	17	4	1	7	13	104
n(4)	23	23	16	17	4	1	7	13	106
n(5)	24	23	16	18	4	1	8	14	107
n(6)	24	23	16	18	4	1	8	14	109
n(7)	24	23	17	18	4	2	8	14	110
n(8)	24	24	17	18	4	2	8	15	111
n(9)	24	24	17	19	5	2	8	15	113
n(10)	24	24	17	19	5	2	9	15	114
n(11)	24	24	17	19	5	2	9	16	115
n(12)	24	24	17	20	5	2	9	16	117

Using the actual inventory of pilot qualifications from December 2017, we set two accessions per month (R)—both entering the system as PQMs (**r**). The 24 accessions over the 12-month period increase total pilot qualifications from 100 to 117. However,

[11] Additional forecasts are run with 3, 4, and 5 pilot accessions per month and can be found in Appendix B.

because of the inaccurate transition probabilities for WTI qualifications and FAC tours, the total number of qualifications holds little value. Therefore, although this model calculates the transition probabilities of pilot qualifications correctly, the forecasts do not accurately represent attrition behavior.

b. Fixed-Inventory

In our last model, we use fixed-inventory to find the number of accessions per month required to properly staff HMLA-167, which is scheduled to complete its transition between the AH-1W and AH-1Z helicopters by mid-2019. The forecast is shown in Table 38:

Table 38. Fixed-Inventory Results.

Months	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Total	Target	R	r
Inventory	23	22	16	16	3	1	7	12	100			
n(1)	24	22	16	16	3	1	7	12	102		2.864	1
n(2)	25	23	16	17	3	1	7	13	105		2.862	1
n(3)	26	23	16	17	4	1	7	13	107		2.860	1
n(4)	27	23	16	17	4	1	7	13	109		2.858	1
n(5)	27	24	16	18	4	1	8	14	112		2.856	1
n(6)	28	24	17	18	4	1	8	14	114		2.854	1
n(7)	28	25	17	18	4	2	8	14	116		2.853	1
n(8)	29	25	17	18	4	2	8	15	118		2.852	1
n(9)	29	26	17	19	5	2	8	15	120		2.851	1
n(10)	30	26	17	19	5	2	9	15	123		2.850	1
n(11)	30	27	17	19	5	2	9	16	125		2.849	1
n(12)	31	27	18	20	5	2	9	16	127	127	2.848	1

First, we divide the initial inventory for each qualification by the four fully transitioned HMLA squadrons to estimate the number of qualifications needed for HMLA-167. Next, we round each qualification up to the next integer and total, which equals 27. The table of organization indicates 36 pilots for a full HMLA squadron (HQMC, 2014b); however, we assume AH-1Z CAT II pilots implement HMLA-167's transition plan.[12] We then add the 27 new pilot qualifications to the initial inventory to indicate a target inventory level of 127 at the end of the 12-month forecast.

[12] AH-1Z CAT I and CAT II pilots from the West coast HMLA squadrons will be used to fulfill combat leadership qualifications. However, 27 AH-1Z CAT I pilots are likely to be produced by the FRS to ensure staffing across all five AH-1Z HMLA squadrons by mid-2019.

Using Excel's Solver, we find 2.8 as the average number of accessions each month needed to reach an inventory level of 127 pilots with the corresponding qualifications. Despite the issues noted from the model's transition probabilities, the forecasted number of accessions seems accurate when compared to the 2017 average monthly accessions of 2.5 for AH-1Z CAT I pilots.

D. CHAPTER SUMMARY

This chapter provided two sets of results. Our empirical analysis reveals that pilots' time-in-qualification is longer in duration and is statistically significant for the ANSQ, AHC, and SL qualifications when compared to TECOM's TPM. Additionally, the time-to-train though the SL qualification takes, on average, 15.1 months longer than the TPM guidelines, and the total time-to-train is likely to extend beyond 48 months. However, our Markov model shows the data to be heavily right-censored, thus affecting the transition probabilities when determining expected time-in-qualification for WTI and FAC. As a result, the model's transition probabilities regarding the proportion of pilots progressing to the next qualification, as well as the qualification forecasts, do not accurately reflect the behavior of the system. Next, we provide a summary along with recommendations and conclusions.

VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

Qualified pilots are vital to Marine Corps aviation readiness, and timelines are a critical factor in producing qualified pilots. The desired end result is for Marine aviation to be ready to fulfill its mission by ensuring the appropriate number of pilots possess the required set of qualifications. The research identifies that specific qualifications—tied to warfighting readiness—require more time to complete than current processes allocate.

In our research, we correlate pilot qualifications to warfighting readiness by using the capabilities-based construct of the DRRS. To achieve the capabilities-based construct, squadrons must have pilots qualified to complete METs. Therefore, we focus on the ANSQ, AHC, SL, DL, NSI, and WTI qualifications to determine the average number of months spent in each qualification and the total time-to-train during an AH-1Z pilots' first fleet tour in a HMLA squadron. The empirical analysis identifies that the time-to-train though the SL qualification takes longer than the TPM specifies. We also include a Markov model in our analysis to forecast pilot qualifications; however, the data do not fully capture the true behavior of pilots exiting the system, which results in unreliable transition probabilities for the model.

B. CONCLUSIONS AND RECOMMENDATIONS

1. What effect does time-to-train for pilot qualifications have on pilot proficiency and squadron readiness?

a. Conclusion

Training aviators is essential for the Marine Corps to maintain the T2 level of readiness. Using data to measure pilots' ability to complete qualifications enables us to determine whether standards are being achieved within the allocated time. The results of our study indicate that time-to-train for an AH-1Z CAT I pilot from PQM through the SL qualification takes, on average, 15.1 months longer than what is outlined in TECOM's AH-1Z TPM. Because pilots do not meet Marine Aviation's training and readiness planning parameters, we conclude that pilot proficiency and squadron readiness are being overestimated.

b. Recommendation

Marine Aviation Weapons and Tactics Squadron One (MAWTS-1)—T&R syllabus Sponsor and Model Manager for the AH-1Z helicopter—should further examine time-to-train for AH-1Z pilots during the next scheduled working group to ensure training timelines correspond with current pilot performance. Additionally, Manpower Plans and Policies (MPP-30) should adjust aviation planning models to support up to six-year tour lengths instead of the current four-year model for AH-1Z pilots. Extending these models will allow Manpower Management Officer Assignments (MMOA-2) to effectively manage tour rotations for HMLA squadrons. Furthermore, both of these recommendations hinge on Aviation Support Branch (ASB) implementing the minimum, maximum, and average time-to-train within the M-SHARP software. Lastly, placing an emphasis on using data to better forecast time-to-train will support Aviation Production Management (APM) in shaping the requirements for new students in flight school and provide decision makers with an accurate representation of pilot proficiency.

2. What will the AH-1Z pilot qualification structure likely be at various dates in the future if present patterns of pilot attrition and progression continue?

c. Conclusion

The data did not adequately support using the Markov model for forecasting, in that it appears pilots remain in their first fleet tour longer than is feasible. Not being able to distinguish between AH-1Z CAT I and II pilots within the M-SHARP data forced us to reduce the 283 M-SHARP observations—losing a large portion of seasoned pilots in higher-level qualifications. We salvaged the analysis by supplementing the M-SHARP data with NIPDR data. The six-year observation period (using CAT I pilots identified from the NIPDR data) showed 11 out of the 111 pilots exited the fleet and an average of 1.5 pilots per month entered the fleet. The low number of pilots exiting the system alters the transition probabilities for the Markov model, which therefore does not capture true pilot qualification behavior. Although the Markov methods do not provide reliable forecasts for the future pilot qualification structure in the AH-1Z helicopter community, the process itself identified ways to improve data-gathering for future research.

d. Recommendation

The ASB should create a way for the M-SHARP data to be archived; researchers could then provide more robust time-series data analyses for finding efficiencies in future aviation matters. Additionally, Total Force Structure Division (TFSD) should assign new PMOSs when Marine aviation squadrons transition from legacy to upgrade aircraft. Had this occurred, the TFDW data could have been used to distinguish between AH-1W and AH-1Z pilots as well as CAT I and II pilots; however, many AH-1Z pilots showed having the 7565 PMOS without having the 7513 NMOS.

3. How does time spent in each qualification compare to the Training Progression Model?

e. Conclusion

We examined six qualifications in our empirical analysis. Three of the six are statistically significant in that pilots spend more time in each qualification than the Training Progression Model indicates. We report, on average, the number of months spent in each qualification to be as follows: ANSQ, 11.4—a difference of 7.4; AHC, 8.9—a difference of 2.9; and SL, 9.1—a difference of 5.1.

f. Recommendation

The Aviation Training Division (ATD) should implement a flight progression and performance program that distinguishes between top and bottom performers by using the time-to-train functionality within M-SHARP, mentioned in recommendation one. Furthermore, ATD should use Marine Aviation Training System Sites (MATSS) to facilitate the program within the ATS structure, mirroring the Flight Leadership Program (FLP) already in place. This new program would provide a quantitative measure of individual and aggregate pilot-performance characteristics to squadron, group, and wing commanders for further analysis.

C. FURTHER RECOMMENDED RESEARCH

1. Follow Current Cohort of AH-1Z Pilots

Research data limitations did not allow the Markov model to forecast the future pilot qualification structure of the AH-1Z helicopter community. However, using the data collected and following the cohort of 111 pilots in our research through their first tour completion will provide accurate transition probabilities for a robust Markov model analysis.

2. Analyze Data for a Different Aircraft

The Marine Corps' transition plan for the AH-1Z created inconsistent PMOS and NMOS codes in the TFDW data. Additionally, cross-sectional M-SHARP data could not distinguish between initial accession and series-conversion pilots. The same research methodology with another Type/Model/Series aircraft not in transition could provide a more effective analysis.

3. Identify Relationship between Time-to-Train and High-Quality Pilots

The 2018 AvPlan shows concern for retaining pilots and maximizing return on investment for Marine aviation. Although many external factors affect pilots' time-to-train, pilots who regularly complete training more quickly may possess a higher level of capability. Therefore, identifying the relationship between time-to-train and high-quality pilots could be used by Manpower and Support Branch (ASM) to establish bonuses for retaining these high-quality pilots.

Such research initiatives, along with many others, will continue to become increasingly important to decision-makers eager to maximize both readiness and efficiency as the DoD marches into the data-driven future.

APPENDIX A. MARINE TRAINING AND READINESS PROGRAM ABBREVIATIONS AND DEFINITIONS

Appendix A provides additional information regarding the AH-1Z helicopter community. Tables 39 through 47 and Figures 13 through 14 are derived from Marine Aviation Training and Readiness program manuals.

Table 39. Tactical Manned Flight Communities. Adapted from HQMC (2016a).

Aircraft	Unit
Fixed Wing	
AV-8B	VMA
TAV-8B	VMAT
FA-18A/C	VMFA
FA-18D	VMFA(AW)
KC-130T/J	VMGR
EA-6B	VMAQ
F-35B	VMFA
Rotary Wing	
AH-1W/Z	HMLA
UH-1Y	HMLA
CH-53E	HMH
Tiltrotor	
MV-22B	VMM

Table 40. HMLA AH-1 Tactical Squadron Table of Organization. Adapted from HQMC (2014a) and HQMC (2014b)

Category	Squadron	Squadron(-)	Detachment
AH-1W			
Aircraft	18	12	6
Pilots	44	28	14
AH-1Z			
Aircraft	15	10	5
Pilots	36	24	12

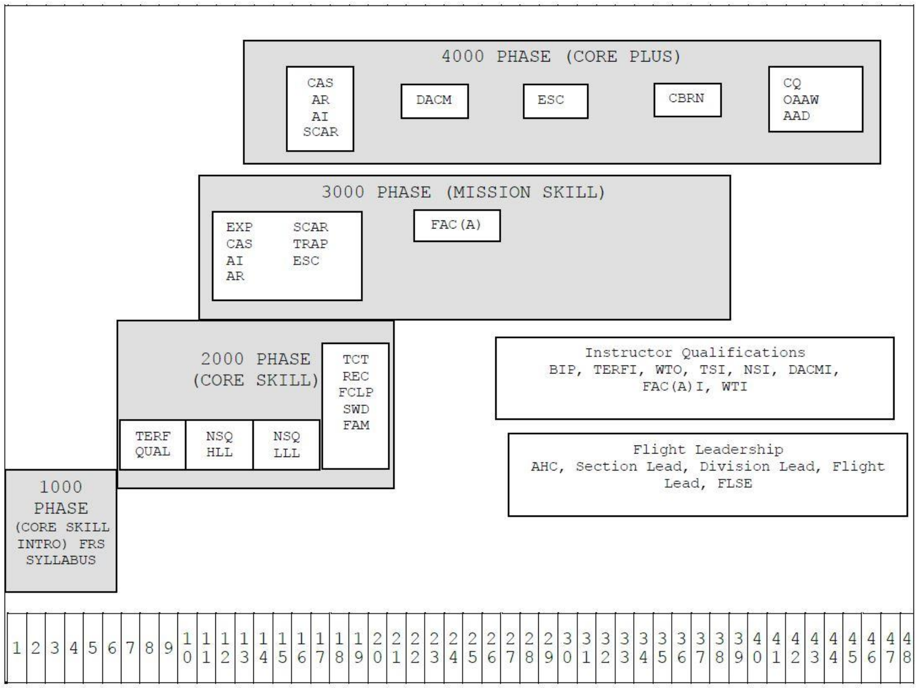

Figure 13. AH-1W Training Progression Model. Source: HQMC (2011a).

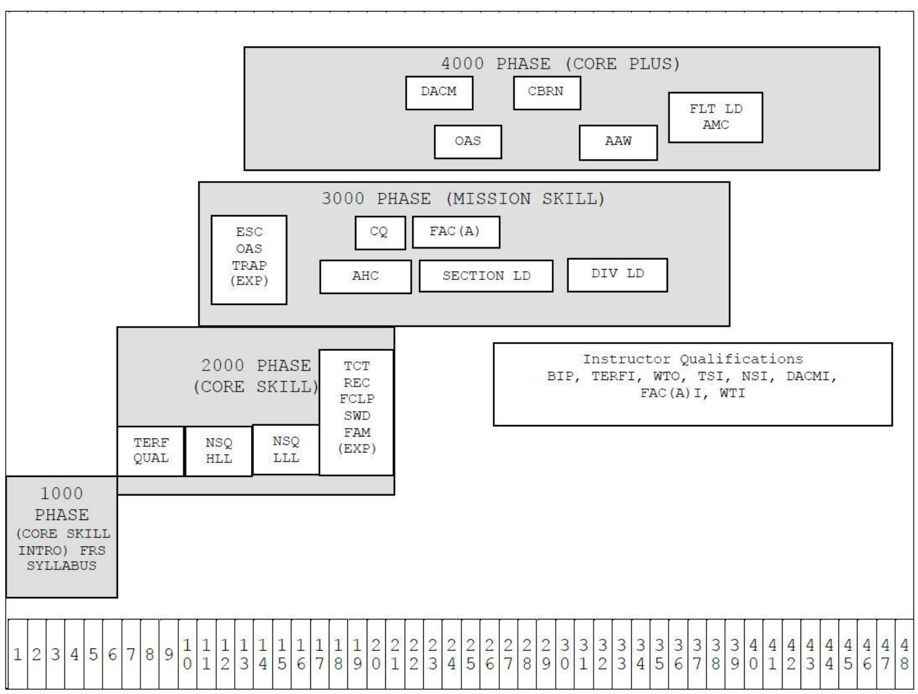

Figure 14. AH-1Z Training Progression Model. Source: HQMC (2011b).

Table 41. Skill and Stage Abbreviations. Adapted from HQMC (2014b).

AHC	Attack Helicopter Commander
AI	Air Interdiction
AMC	Air Mission Commander
ANSQ	Advanced Night Systems Qualification
BIP	Basic Instructor Pilot
CAS	Close Air Support
CQ	Carrier Qualification
DACM	Defensive Air Combat Maneuvering
DACM I	Defensive Air Combat Maneuvering Instructor
DL	Division Leader
ESC	Aerial Escort
EXP	Expeditionary Shore-Based Sites
FAC(A)	Forward Air Controller (Airborne)
FAC(A) I	Forward Air Controller (Airborne) Instructor
FCP	Functional Check Pilot
FL	Flight Leader
FLSE	Flight Leadership Standardization Evaluator
FWDACM	Fixed Wing Defensive Air Combat Maneuvering
NATOPS	Naval Aviation Training and Operating Procedures Standardization
OAAW	Offensive Anti-air Warfare
OAS	Offensive Air Support
PQM	Pilot Qualified in Model
QUAL	Qualification
RCQD	Requirements Certifications Qualifications Designation
RECCE	Reconnaissance
RWDACM	Rotary Wing Defensive Air Combat Maneuvering
SCAR	Strike Coordination and Reconnaissance
SIM	Simulator
SL	Section Leader
SWD	Specific Weapons Delivery
TCT	Threat Counter-Tactics
TERF	Terrain Flight
TERF I	Terrain Flight Instructor
TRAP	Tactical Recovery of Aircraft and Personnel
WTI	Weapons and Tactics Instructor
WTO	Weapons Training Officer

Table 42. AH-1Z Pilot Qualifications and Designations. Adapted from HQMC (2014b).

AH-1Z Pilot RCQD		
Qualificaitons		
Instrument	NSQ	CQ
NATOPS	ANSQ	RW DACM
TERFQ	FAC(A)	FW DACM
Designations		
FCP	AMC	CRMI/CRMF
PQM	BIP	FLSE
AHC	TERFI	FAC(A) I
SL	NI/ANI	DACM I
DL	WTO	NSI
FL	TSI & CSI	WTI

Table 43. Core Model Definitions. Adapted from HQMC (2014b).

Term	Definition
Core Model	The Core Model is the basic foundation or standardized format by which all T&Rs are constructed. The Core model provides the capability of quantifying both unit and individual training requirements and measuring readiness. This is accomplished by linking community Mission Statements, Mission Essential Task Lists, Output Standards, Core Skill Proficiency Requirements and Combat Leadership Matrices
Core Skill Introduction	Entry level training required to receive or be eligible for assignment of primary MOS. Includes such training as systems/equipment, operations familiarization, initial crew procedures, and initial exposure to core skills.
Core Skill	Fundamental, environmental, or conditional capabilities required to perform basic functions. These basic functions serve as tactical enablers that allow crews to progress to the more complex Mission Skills. Primarily 2000 Phase events but may be introduced in the 1000 Phase.
Mission Skill	Mission Skills enable a unit to execute a specific MET. They are comprised of advanced event(s) that are focused on MET performance and draw upon the knowledge, aeronautical abilities, and situational awareness developed during Core Skill training. 3000 Phase events.
Core Plus Skill	Training events that can be theater specific or that have a low likelihood of occurrence. They may be Fundamental, environmental, or conditional capabilities required to perform basic functions. 4000 Phase events.
Core Plus Mission	Training events that can be theater specific or that have a low likelihood of occurrence. They are comprised of advanced event(s) that are focused on Core Plus MET performance and draw upon the knowledge, aeronautical abilities, and situational awareness. 4000 Phase events.
Core Skill Proficiency (CSP)	CSP is a measure of training completion for 2000 Phase events. CSP is attained by executing all events listed in the Attain Table for each Core Skill. The individual must be simultaneously proficient in all events within that Core Skill to attain CSP.
Mission Skill Proficiency (MSP)	MSP is a measure of training completion for 3000 Phase events. MSP is attained by executing all events listed in the Attain Table for each Mission Skill. The individual must be simultaneously proficient in all events within that Mission Skill to attain MSP. MSP is directly related to Training Readiness.
Core Plus Skill Proficiency (CPSP)	CPSP is a measure of training completion for 4000 Phase "Skill" events. CPSP is attained by executing all events listed in the Attain Table for each Core Plus Skill. The individual must be simultaneously proficient in all events within that Core Plus Skill to attain CPSP
Core Plus Mission Proficiency (CPMP)	CPMP is a measure of training completion for 4000 Phase "Mission" events. CPMP is attained by executing all events listed in the Attain Table for each Core Plus Mission. The individual must be simultaneously proficient in all events within that Core Plus Mission to attain CPMP
Core Model Training Standard (CMTS)	CMTS is an objective optimum training standard used by squadrons that reflects the number of individuals trained to CSP/MSP, per crew position. The CMTS is for internal squadron planning only and is not utilized for readiness reporting. The numbers are determined by individual communities.
Core Model Minimum Requirement (CMMR)	CMMR represents the minimum crew definition qualifications and designations, the number of crews required per MET, and minimum Combat Leadership requirements for readiness reporting purposes.

Table 44. HMLA AH-1Z METs and Output Standards. Adapted from HQMC (2014b).

Squadron/Squadron(-)/Detachment (15/10/5 Aircraft)			
Core			
Marine Corps Task (MCT)	**Mission Essential Task**	**Output Standard**	
		Maximum Daily Sorties *	**Maximum MCT Sorties**
MCT 1.3.3.3.2 EXP	Conduct Aviation Operations From Expeditionary Shore-Based Sites	20/16/8	20/16/8
MCT 3.2.3.1.1 CAS	Conduct Close Air Support		20/16/8
MCT 3.2.3.1.2.1 AI	Conduct Air Interdiction		20/16/8
MCT 3.2.3.1.2.2 AR	Conduct Armed Reconnaissance		20/16/8
MCT 3.2.3.1.2.3 SCAR	Conduct Strike Coordination and Reconnaissance		20/16/8
MCT 3.2.5.4 FAC(A)	Conduct Forward Air Control (Airborne)		12/8/4
MCT 6.2.1.1 TRAP	Conduct Aviation Support of Tactical Recovery of Aircraft and Personnel		20/16/8
MCT 6.1.1.11 ESC	Conduct Aerial Escort		20/16/8
Core Plus			
MCT 1.3.3.3.1 CQ	Conduct Aviation Operations From Expeditionary Sea-Based Sites	20/16/8	10/6/4
MCT 3.2.3.2 OAAW	Conduct Offensive Anti-air Warfare		10/6/4
MCT 6.1.1.8 AAD	Conduct Active Air Defense		10/6/4
* A 15/10/5 plane Mission Capable HMLA(AH-1Z) Squadron/Squadron(-)/Detachment is able to execute 20/16/8 total overall sorties on a daily (24 hour period) basis during contingency/combat operations.			

Table 45. HMLA AH-1Z Core Model Minimum Requirement (CMMR) for MET Capability. Adapted from HQMC (2014b).

Core METs	**Crew Position**		**Crews Required per**		
MCT	**Pilot**	**Copilot**	**SQD**	**SQD(-)**	**DET**
1.3.3.3.2 (EXP)	MSP, AHC	ANSQ	12	8	4
3.2.3.1.1 (CAS)	MSP, AHC	ANSQ	12	8	4
3.2.3.1.2.1 (AI)	MSP, AHC	ANSQ	12	8	4
3.2.3.1.2.2 (AR)	MSP, AHC	ANSQ	12	8	4
3.2.3.1.2.3 (SCAR)	MSP, AHC	ANSQ	12	8	4
3.2.5.4 (FAC(A))*	MSP, AHC, FAC(A)	ANSQ	6	4	2
6.2.1.1 (TRAP)	MSP, AHC	ANSQ	12	8	4
6.1.1.11 (ESC)	MSP, AHC	ANSQ	12	8	4
Core Plus METs	**Crew Position**		**SQD**	**SQD(-)**	**DET**
1.3.3.3.1 (CQ)	MSP, AHC, CQ	ANSQ, CQ	12	8	4
3.2.3.2 (OAAW)	MSP, AHC, DACM	ANSQ, DACM	5	3	2
6.1.1.8 (AAD)	MSP, AHC, DACM	ANSQ, DACM	5	3	2

Combat Leadership	
Squadron/Squadron(-)/Detachment (15/10/5 Aircraft)	
Designation	**Pilots**
Attack Helicopter Commander (AHC)	12/8/4
Section Leader (SL)	6/4/2
Division Leader (DL)	3/2/1
Flight Leader (FL)**	4/3/1
Air Mission Commander(AMC)**	4/3/1

* A FAC(A) capable crew requires 1 FAC(A) per aircraft.

** Flight Leader and AMC Combat Leader requirements apply to HMLA squadron, not individual

Note: Crew definitions for training are identified within each T&R event and are based off of aircraft in SQD/SQD(-)/DET: 15/10/5

Table 46. Mission Essential Task List Standards. Adapted from HQMC (2014a) and HQMC (2014b).

Core MET Standards:
AH-1W Squadron (18)/Squadron(-)(12)/Detachment (6) {18/12/6} Aircraft AH-1Z Squadron (15)/Squadron(-)(10)/Detachment (5) {15/10/5} Aircraft
Personnel:
19/13/6 AH-1W aircrews formed 16/11/5 AH-1Z aircrews formed 90% of squadron T/O personnel MOS qualified and deployable And Level 2 (L2) IAW ALERTS. 100% critical MOS fill
Equipment:
70% Full Mission Capable (FMC) aircraft of PAA 12/8/4 AH-1W aircraft 10/7/3 AH-1Z aircraft or Upon establishment, 100 percent RFT entitlement IAW T/M/S standard. Operational support equipment fully supports MCT
Training:
12/8/4 AH-1W aircrews MET-capable IAW T&R requirements[1] 12/8/4 AH-1Z aircrews MET-capable IAW T&R requirements[2]
Output Standards:
24/16/8 AH-1W sorties daily sustained during contingency/combat 20/16/8 AH-1Z sorties daily sustained during contingency/combat
[1] AH-1W aircrews FAC(A) is 8/6/2 [2] AH-1Z aircrews FAC(A) is 6/4/2

Table 47. HMLA AH-1Z Core Model Training Standard (CMTS). Adapted from HQMC (2014b).

HMLA AH-1Z Core Model Training Standard (CMTS)	
Core Skill Phase (2000 Phase)	
Stage	Pilots
TERF	30/20/10
TCT	30/20/10
REC	30/20/10
FCLP	26/20/10
SWD	26/20/10
ANSQ	26/20/10
FAM	30/20/10
Core Missions (3000 Phase)	
Stage	Pilots
EXP	24/18/10
CAS	24/18/10
AI	24/18/10
AR	24/18/10
SCAR	24/18/10
FAC(A)	6/4/2
ESC	24/18/10
TRAP	24/18/10
Core Plus Skills (4000 Phase)[1]	
Stage	Pilots
ESC	3/12 2/9 1/5
CAS	3/12 2/9 1/5
AR	3/12 2/9 1/5
AI	3/12 2/9 1/5
SCAR	3/12 2/9 1/5
OAAW (FW/RW) DACM	4/16 2/10 2/8
CBRN	2/36 1/24 1/12
Core Plus Missions (4000 Phase)[1]	
Stage	Pilots
CQ	4/24 2/18 2/10
OAAW	4/14 2/8 2/6
AAD	4/14 2/8 2/6
Note1: In the Core Plus METS the first number represents the number of individuals the squadron is expected to train at all times in order to retain a cadre of capability within the squadron. The second number represents the number of MET capable individuals the squadron is recommended to train if that MET becomes required within an Assigned Mission/Directed Mission Set.	

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APPENDIX B. STATISTICAL SUMMARIES AND T-TESTS

Appendix B provides additional summary statistics and lists the T-test results reported in Chapter V.

Table 48. Summary Statistics for Time-in-Qualification—Excluding FACs

Variable	n	Mean	S.D.	Min	25th Percentile	Median	75th Percentile	Max
FRS	94	5.3	1.2	3	4.5	5.1	6	9.3
PQM	70	10.6	5.1	4	6.6	9.7	12.4	28.9
ANSQ	47	11.1	6.3	1.5	6.2	10.3	14.9	30.1
AHC	30	8.4	4.5	2	5	7.3	10.1	19.4
SL	14	9.1	3.5	5.4	5.8	8.1	11.8	15.2
NSI	11	6.2	5	0.7	2.1	6.3	8.3	17.3
DL	9	3.4	2	1.7	2.4	2.4	3.9	8.4
WTI	2	12.4	1.3	11.5	11.5	12.4	13.2	13.2

Table 49. Summary Statistics for Time-in-Qualification—FACs Only

Variable	n	Mean	S.D.	Min	25th Percentile	Median	75th Percentile	Max
FRS	17	4.6	0.7	3	4.2	4.7	5.1	5.9
PQM	16	11.3	4.3	4	8.8	9.5	15.5	17.9
ANSQ	16	12.2	7.3	1.7	7.2	12	15.2	30.1
AHC	9	10.5	9.3	3.5	4.1	5.7	9.9	27.2
FAC Tour	9	14.4	1.1	12.6	13.9	14.2	14.7	16.1

Table 50. Summary Statistics for Time in Squadron

Variable	n	Mean	S.D.	Min	25th Percentile	Median	75th Percentile	Max
Total	11	42.1	17.3	11.3	31.3	42.4	59.6	64.7
Current	88	26.9	14.8	4.5	15.6	24.7	37	64.7

Table 51. FRS Completion T-Test

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
frsttt_m	111	5.164067	.1078108	1.135858	4.950411	5.377723

```
    mean = mean(frsttt_m)                                         t =  -7.7537
Ho: mean = 6                                     degrees of freedom =      110

    Ha: mean < 6                Ha: mean != 6                Ha: mean > 6
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```

Table 52. PQM Time-in-Qualification T-Test

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
pqmtime	86	10.74236	.5331131	4.943888	9.682388	11.80233

```
    mean = mean(pqmtime)                                          t =  -0.4833
Ho: mean = 11                                    degrees of freedom =       85

    Ha: mean < 11               Ha: mean != 11               Ha: mean > 11
 Pr(T < t) = 0.3151         Pr(|T| > |t|) = 0.6301          Pr(T > t) = 0.6849
```

Table 53. ANSQ Time-in-Qualification T-Test

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
ansqtime	63	11.37005	.8283202	6.574588	9.714266	13.02584

```
    mean = mean(ansqtime)                                         t =   8.8976
Ho: mean = 4                                     degrees of freedom =       62

    Ha: mean < 4                Ha: mean != 4                Ha: mean > 4
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

Table 54. AHC Time-in-Qualification T-Test

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
ahctime	39	8.905935	.9368917	5.850887	7.009297	10.80257

```
    mean = mean(ahctime)                                          t =   3.1017
Ho: mean = 6                                     degrees of freedom =       38

    Ha: mean < 6                 Ha: mean != 6                 Ha: mean > 6
 Pr(T < t) = 0.9982         Pr(|T| > |t|) = 0.0036          Pr(T > t) = 0.0018
```

Table 55. SL Time-in-Qualification T-Test

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
sltime	14	9.051424	.9221906	3.450521	7.059153	11.0437

```
    mean = mean(sltime)                                           t =   5.4776
Ho: mean = 4                                     degrees of freedom =       13

    Ha: mean < 4                 Ha: mean != 4                 Ha: mean > 4
 Pr(T < t) = 0.9999         Pr(|T| > |t|) = 0.0001          Pr(T > t) = 0.0001
```

Table 56. DL Time-in-Qualification T-Test

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
dltime	9	3.3843	.673686	2.021058	1.830777	4.937822

```
    mean = mean(dltime)                                           t =  -3.8827
Ho: mean = 6                                     degrees of freedom =        8

    Ha: mean < 6                 Ha: mean != 6                 Ha: mean > 6
 Pr(T < t) = 0.0023         Pr(|T| > |t|) = 0.0047          Pr(T > t) = 0.9977
```

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APPENDIX C. MARKOV MODELS

Appendix C provides additional models that are relevant to Chapters IV and V and are presented in Tables 57 through 59 and Figures 15 and 16.

Table 57. Fixed-Recruiting Results When R = 3 and **r** =1.

Months	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Total
n(0)	23	22	16	16	3	1	7	12	100
n(1)	24	22	16	16	3	1	7	12	102
n(2)	25	23	16	17	3	1	7	13	105
n(3)	26	23	16	17	4	1	7	13	107
n(4)	27	23	16	17	4	1	7	13	110
n(5)	28	24	16	18	4	1	8	14	112
n(6)	29	24	17	18	4	1	8	14	115
n(7)	29	25	17	18	4	2	8	14	117
n(8)	30	25	17	18	4	2	8	15	119
n(9)	30	26	17	19	5	2	8	15	122
n(10)	31	26	17	19	5	2	9	15	124
n(11)	31	27	18	19	5	2	9	16	126
n(12)	32	27	18	20	5	2	9	16	129

Table 58. Fixed-Recruiting Results When R = 4 and **r** =1.

Months	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Total
n(0)	23	22	16	16	3	1	7	12	100
n(1)	25	22	16	16	3	1	7	12	103
n(2)	27	23	16	17	3	1	7	13	107
n(3)	29	23	16	17	4	1	7	13	110
n(4)	31	24	16	17	4	1	7	13	114
n(5)	32	24	16	18	4	1	8	14	117
n(6)	33	25	17	18	4	1	8	14	121
n(7)	35	26	17	18	4	2	8	14	124
n(8)	36	27	17	19	4	2	8	15	127
n(9)	37	28	17	19	5	2	8	15	131
n(10)	38	29	18	19	5	2	9	16	134
n(11)	39	30	18	19	5	2	9	16	137
n(12)	40	31	18	20	5	2	9	16	141

Table 59. Fixed-Recruiting Results When R = 5 and $\mathbf{r}$ =1.

Months	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Total
n(0)	23	22	16	16	3	1	7	12	100
n(1)	26	22	16	16	3	1	7	12	104
n(2)	29	23	16	17	3	1	7	13	109
n(3)	32	23	16	17	4	1	7	13	113
n(4)	34	24	16	17	4	1	7	13	118
n(5)	36	25	16	18	4	1	8	14	122
n(6)	38	26	17	18	4	1	8	14	127
n(7)	40	27	17	18	4	2	8	14	131
n(8)	42	29	17	19	4	2	8	15	135
n(9)	44	30	18	19	5	2	8	15	140
n(10)	45	31	18	19	5	2	9	16	144
n(11)	46	32	19	20	5	2	9	16	148
n(12)	48	34	19	20	5	2	9	16	153

Flows

	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Attrite	Total
PQM0	996	86						1	1	1,084
ANSQ1		821	61					2	1	885
AHC2			437	37				7	2	483
SL3				351	14			7	2	374
NSI4					76	11		0	0	87
DL5						23	9	0	1	33
WTI6							67	0	2	69
FAC7	0	0	1	2	0	0	0	222	2	227
Total	996	907	499	390	90	34	76	239	11	3,242

	P-Matrix								Ab-Matrix	
	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7	Attrite	Total
PQM0	0.919	0.079	0	0	0	0	0	0.001	0.001	1
ANSQ1	0.000	0.928	0.069	0	0	0	0	0.002	0.001	1
AHC2	0	0	0.905	0.077	0	0	0	0.014	0.004	1
SL3	0	0	0	0.939	0.037	0	0	0.019	0.005	1
NSI4	0	0	0	0	0.874	0.126	0	0	0	1
DL5	0	0	0	0	0	0.697	0.273	0	0.030	1
WTI6	0	0	0	0	0	0	0.971	0.000	0.029	1
FAC7	0	0	0.004	0.009	0.000	0.000	0.000	0.978	0.009	1
									0.080	

I-Matrix

1	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0
0	0	1	0	0	0	0	0
0	0	0	1	0	0	0	0
0	0	0	0	1	0	0	0
0	0	0	0	0	1	0	0
0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	1

S-Matrix

	PQM0	ANSQ1	AHC2	SL3	NSI4	DL5	WTI6	FAC7
PQM0	**12.318**	13.514	10.863	16.883	4.998	2.086	19.623	23.396
ANSQ1	0	**13.828**	11.085	17.143	5.075	2.118	19.925	23.279
AHC2	0	0	**11.544**	17.611	5.214	2.176	20.470	22.560
SL3	0	0	0.800	**19.735**	5.843	2.438	22.938	17.296
NSI4	0	0	0.000	0.000	**7.909**	3.300	31.050	0.000
DL5	0	0	0.000	0.000	0.000	**3.300**	31.050	0.000
WTI6	0	0	0.000	0.000	0.000	0.000	**34.500**	0.000
FAC7	0	0	2.629	11.416	3.380	1.410	13.269	**56.831**

Figure 15. Markov Model Matrices.

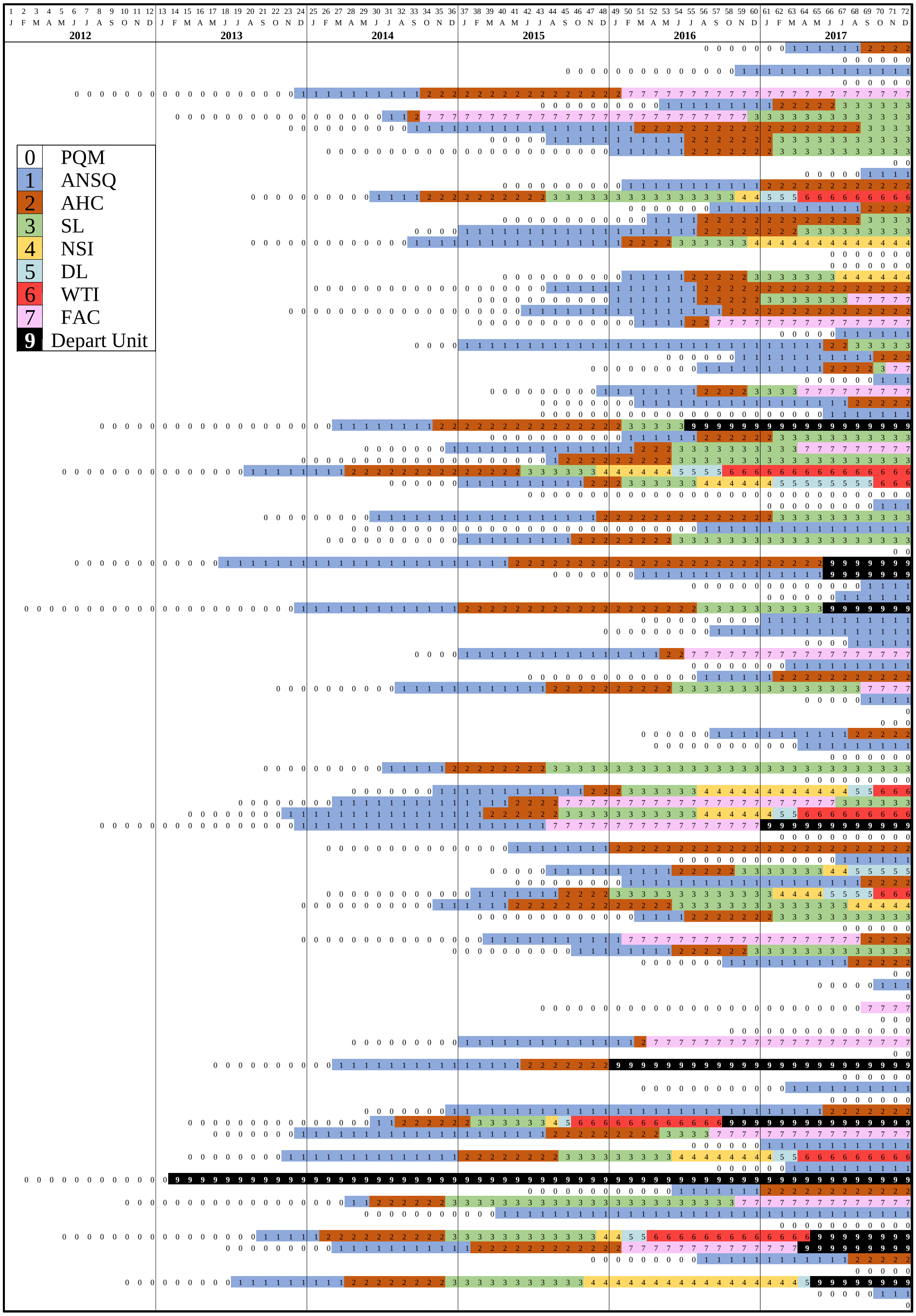

Figure 16. 72-Month Flow of Qualifications

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