2020-03

RECRUITMENT AND PROMOTION SCHEDULEAN ANALYSIS OF THE ROYAL AUSTRALIAN AIR FORCE AIR INTELLIGENCE ANALYST EMPLOYMENT CATEGORY

Clark, Vivienne

Monterey, CA; Naval Postgraduate School

http://hdl.handle.net/10945/64845

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

RECRUITMENT AND PROMOTION SCHEDULE—AN ANALYSIS OF THE ROYAL AUSTRALIAN AIR FORCE AIR INTELLIGENCE ANALYST EMPLOYMENT CATEGORY

by

Vivienne Clark

March 2020

Thesis Advisor: Chad W. Seagren
Second Reader: Jesse Cunha

Approved for public release. Distribution is unlimited.

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** March 2020	**3. REPORT TYPE AND DATES COVERED** Master's thesis

4. TITLE AND SUBTITLE
RECRUITMENT AND PROMOTION SCHEDULE—AN ANALYSIS OF THE ROYAL AUSTRALIAN AIR FORCE AIR INTELLIGENCE ANALYST EMPLOYMENT CATEGORY

5. FUNDING NUMBERS

6. AUTHOR(S) Vivienne Clark

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release. Distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT (maximum 200 words)

In 2015, the Royal Australian Air Force (RAAF) instituted Plan Jericho, a comprehensive plan to transform the RAAF into the world's first 5th Generation Air Force. As a key contribution to realize Plan Jericho, the Director General Personnel-Air Force is proposing how to structure and manage the workforce. During the initial workforce review, the project team identified a gap in the Air Intelligence Analyst (AIA) workforce.

This thesis develops a Markov model to forecast the number of AIA recruits needed to meet the RAAF AIA workforce demand through 2030. This thesis further examines the estimated Time-in-Grade (TIG) for promotion of AIAs based on historical separation behavior. Data was collected from the Australian Defence Force's Human Resource Data Warehouse for three AIA Streams from 2002 to 2018.

The Markov model forecasts the RAAF needs to recruit 173 personnel in Stream A, 404 personnel in Stream B, and 438 personnel in Stream C from fiscal year (FY) 19 through FY30 to meet the total AIA workforce demand. The model also provides managerially relevant measurement of expected TIG for promotion. The model, however, has some limitations due to the limited state-space and small sample size, and consequently, should be reviewed yearly. As one of the few personnel models of its type within the RAAF, it will provide a valuable tool for workforce planning and enable the realization of Plan Jericho.

14. SUBJECT TERMS
Air Intelligence Analyst, Recruitment, Promotion, Royal Australian Air Force, Markov model, Fundamental Matrix, Optimization, Manpower Planning, Sensitivity Analysis

15. NUMBER OF PAGES
63

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

RECRUITMENT AND PROMOTION SCHEDULE—AN ANALYSIS OF THE ROYAL AUSTRALIAN AIR FORCE AIR INTELLIGENCE ANALYST EMPLOYMENT CATEGORY

Vivienne Clark
Flight Lieutenant, Royal Australian Air Force
BEcon, Shenyang Agricultural University, 2005
MCom, The University of Sydney, 2007

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 2020

Approved by: Chad W. Seagren
Advisor

Jesse Cunha
Second Reader

Marigee Bacolod
Academic Associate, Graduate School of Defense Management

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

In 2015, the Royal Australian Air Force (RAAF) instituted Plan Jericho, a comprehensive plan to transform the RAAF into the world's first 5th Generation Air Force. As a key contribution to realize Plan Jericho, the Director General Personnel-Air Force is proposing how to structure and manage the workforce. During the initial workforce review, the project team identified a gap in the Air Intelligence Analyst (AIA) workforce.

This thesis develops a Markov model to forecast the number of AIA recruits needed to meet the RAAF AIA workforce demand through 2030. This thesis further examines the estimated Time-in-Grade (TIG) for promotion of AIAs based on historical separation behavior. Data was collected from the Australian Defence Force's Human Resource Data Warehouse for three AIA Streams from 2002 to 2018.

The Markov model forecasts the RAAF needs to recruit 173 personnel in Stream A, 404 personnel in Stream B, and 438 personnel in Stream C from fiscal year (FY) 19 through FY30 to meet the total AIA workforce demand. The model also provides managerially relevant measurement of expected TIG for promotion. The model, however, has some limitations due to the limited state-space and small sample size, and consequently, should be reviewed yearly. As one of the few personnel models of its type within the RAAF, it will provide a valuable tool for workforce planning and enable the realization of Plan Jericho.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ACOL	Annual Cost of Living
ADF	Australian Defence Force
AFS	Average Funded Strength
AIA	Air Intelligence Analyst
CMB-P	Career Management Board–Promotion
CI	Confidence Interval
DFR	Defence Force Recruiting
DGPERS-AF	Director General Personnel–Air Force
DOD	Department of Defence
DWD-AF	Directorate of Workforce Design–Air Force
DWP-AF	Directorate of Workforce Planning–Air Force
EV	Expected Value
FY	Fiscal Year
HCA	Healthcare Administrator
HR	Human Resource
IET	Initial Employment Training
IMPS	Initial Minimum Period of Service
INTMGR	Intelligence Manager
LOS	Length of Service
LSL	Long Service Leave
MPE	Mean Percentage Error
MSE	Mean Squared Error
MWD	Military Working Dog
RAAF	Royal Australian Air Force
SNCO	Senior Non-Commissioned Officers
TIG	Time-in-Grade
WOFF	Warrant Officer

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

Writing a master’s thesis is hard, and it’s even harder for a non-native speaker. Without the ongoing advice and guidance from my thesis advisor, Dr. Chad Seagren, second reader, Dr. Jesse Cunha, and RAAF sponsor, Squadron Leader Mark Powell, none of this could have become a reality. To Dr. Seagren, thank you for sharing your wisdom and using your extensive knowledge to help me sort out the data. To Dr. Cunha, thanks for your constructive feedback and advice. To SQNLDR Powell, thanks for being my mentor and providing directions when I was lost during the development of this thesis.

To Colette O’Connor and Matthew Norton from the Graduate Writing Center, thanks for working with me and sharing the art of English writing. I could not have completed this thesis without your encouragement and guidance.

To Air Commodore “Bill” Kourelakous and Wing Commander Amanda McCurran, thanks for encouraging me to apply to NPS in the first place. To the Royal Australian Air Force, thanks for providing me this amazing opportunity and experience of a lifetime.

Finally, thank you to my amazing husband, my mum, and the kids. Cameron, you put your career on hold for 18 months to support me, and I could not have achieved this degree without your sacrifice. Thanks for always having faith in me and being there for me. To my mum, Li Hua, you have taught me to strive for excellence and to not give up. I am the person I am today because of you. To my beautiful kids, Isabella and Evelyn, you are the source of my happiness and inspiration. I’m so glad that we share this journey together.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. OBJECTIVE

The purpose of this thesis is to develop a model that determines the recruitment schedule and the estimated Time in Grade (TIG) for promotion within the Air Intelligence Analyst (AIA) employment category in the Royal Australian Air Force (RAAF) to meet AIA workforce demand through 2030. The thesis statistically examines the separation behavior of individual AIA and its impacts on AIA recruitment and promotion. A fixed inventory Markov model is developed from historical data and validated. Based on the prediction of the developed Markov model, the RAAF can set recruitment targets for each year over the next 11 years, build up AIA inventory, and best use the existing inventory to close gaps at each rank to achieve supply-and-demand parity.

B. BACKGROUND

In 2015, the RAAF instituted Plan Jericho, a comprehensive plan to transform the RAAF into the world's first 5th Generation Air Force. This plan accompanied the RAAF's biggest purchases of air assets with advanced capabilities, such as the F-35A Lighting II, EA-18G Growler, MQ-EC Triton, and P-8A Poseidon advanced airborne Command and Control aircraft.

All these capabilities have one thing in common: an ability to gather information at an order of magnitude greater than what they replaced. This advance has led to an initial review of the impacts on the RAAF's workforce. The initial analysis from the Project Jericho team noted that the AIA workforce needs to grow to deliver future advanced capabilities manpower requirements. This development is largely due to the fact that the 4th Generation workforce is maintenance heavy and the 5th Generation workforce is information heavy. In the AF14 Plan Jericho document, it is stated:

> We must develop contemporary trade structures and organizations that reflect the requirements of the future Air Force. The way in which we recruit, train and look after our people must enhance our capability, not detract from it. We have accomplished much in this space, with the review of the Air Intelligence workforce and the Maintenance

Productivity Improvement Program, but there is more work to be done. (Royal Australian Air Force, 2014)

Subsequently, the Australian government has approved the RAAF to expand its current workforce. Based on the data from Directorate of Workforce Design–Air Force (DWD-AF), the AIA employment category needs to grow by a total of 171 personnel in AIA Stream A, by 253 in Stream B, and by 513 in Stream C (Figure 1) at each rank over the next 11 years to meet the RAAF end-strength requirement through 2030 (Mark Powell, personal communication, May 02, 2019.) The RAAF consequently needs to have a data-based analysis and methodology to grow its current AIA employment category to meet the increase in capability and end-strength requirements.

	Total Position Demand Growth by FY														
	AIA Stream A					AIA Stream B					AIA Stream C				
FY	E02 and Under	E05	E06	E08	Total	E02 and Under	E05	E06	E08	Total	E02 and Under	E05	E06	E08	Total
19-20	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
20-21	0	0	0	0	0	0	0	0	0	0	4	2	0	0	6
21-22	5	2	0	0	7	0	0	0	0	0	4	5	0	0	9
22-23	5	4	1	0	10	10	5	1	0	16	15	15	5	0	35
23-24	5	5	1	0	11	12	5	1	0	18	15	18	5	0	38
24-25	8	8	1	0	17	14	8	1	0	23	32	20	5	0	57
25-26	12	8	1	0	21	16	8	2	0	26	32	24	5	0	61
26-27	12	8	1	0	21	20	10	2	0	32	32	24	5	0	61
27-28	12	8	1	0	21	20	10	4	0	34	32	24	5	0	61
28-29	12	8	1	0	21	20	10	4	0	34	32	24	5	0	61
29-30	12	8	1	0	21	20	10	4	0	34	32	24	5	0	61
30-31	12	8	1	0	21	22	10	4	0	36	32	24	5	0	61
					171					253					513

Figure 1. Position Demand Growth by Rank/Year. Adapted from Directorate of Workforce Design–Air Force (DWD-AF) (personal communication, May 02, 2019).

This thesis develops a fixed inventory Markov model based on the transition rates from the AIA personnel flows among various states to forecast the number of recruitments to meet AIA workforce demand through 2030. The model provides much more accurate forecasting than current methods for manpower planning purposes. The model also assists recruiting and training organizations to adjust their plans accordingly, further improving productivity and reducing costs. Additionally, it provides a better estimate for TIG promotion each year, which may also impact separation behavior.

This is one of the few personnel models of its type within the RAAF. In addition to providing a critical resource tool for the management of AIAs, it is also intended to be used as a base model for future workforce analyses. This will enable workforce planners to forecast recruitment to meet yearly end-strength requirements and plan promotion targets for all other workforce employment categories within the RAAF.

1. RAAF AIAs

The AIA employment category consists of highly skilled and professional enlisted airmen and airwomen. They provide specialist intelligence and advice from a variety of sources and use such intelligence to support the RAAF and the wider Australian Defence Force (ADF) missions and operations. In 2012, the AIA employment category was formed from the previous Signals Operator-Technical, Signals Operator-Linguist, and Geospatial Intelligence Analyst employment categories. The AIA employment category is composed of three specialist streams:

- geospatial intelligence
- signals intelligence
- operational intelligence

Due to the sensitive nature of the AIAs' employment and to protect their privacy and identities, each of the three AIA specialist streams is represented by the letter A, B or C.

The three specialist streams contribute to the ADF capability by providing expertise on electronic intelligence, technical signals, human/communication intelligence, and counterintelligence. According to the latest data from the ADF Human Resource (HR) Data Warehouse, as of May 2019 there are 521 active AIAs serving in a permanent capacity across the three specialist streams in the RAAF (Mark Powell, personal communication, May 02, 2019).

2. Rank and Rates

AIAs join the RAAF as recruits (E00) and once AIA recruits complete their recruit training, they achieve the Aircraftman/woman trainee rank (E01). AIAs are promoted to aircraftman/woman (E02) following graduation from Initial Employment Training (IET) and then to Leading Aircraftman/woman (E03) after 12 months effective service. AIAs can advance from E02 through to E08. According to the RAAF AIA Employment Profile (EP), each of the individual AIA specialist stream does not have a Warrant Officer (WOFF, E09) rank, instead they converge to WOFF in the form of the Intelligence Manager (INTMGR) employment category (RAAF, personal communication, 2019). AIA Senior Non-Commissioned Officers (SNCO) airmen/women from all specialist streams can advance to the role of INTMGR by successfully completing the skill grade requirements for their respective specialist streams and that of INTMGR.

Table 1 illustrates the RAAF AIA enlisted rank structure. Junior Enlisted includes rank codes from E00 to E03, Non-Commissioned Officers include rank code E05, and SNCOs include rank codes E06 and E08.

Table 1. AIA Enlisted Rank Structure

Enlisted Corps	Rank	Code
Junior Enlisted	Aircraftman/woman Recruit	E00
	Aircraftman/woman Trainee	E01
	Aircraftman/woman	E02
	Leading Aircraftman/woman	E03
Non-Commissioned Officers	Corporal	E05
Senior Non-Commissioned Officers	Sergeant	E06
	Flight Sergeant	E08

3. Recruitment Target and Recruitment

Currently, the annual recruitment targets in the RAAF are determined by the factors affecting end strength relative to establishment, separation, change to position establishment, and promotion. Directorate of Workforce Planning–Air Force (DWP-AF) calculates a three-year average of separation rate for each rank and uses that as a basis for estimating future separation. The recruitment targets are then derived to fill the forecasted supply-demand gap. Such calculation has omitted some key factors in separation decisions, such as completion of the Initial Minimum Period of Service (IMPS) at either four or six years depending on the employment category. In addition to IMPS, the calculation has omitted accrual of Long Service Leave, which is three months' leave at full pay, six months' leave at half-pay, or payable in full on a pro-rata basis upon separation at ten years of service.

Once the annual recruitment targets are set, DWP-AF passes the numbers on to Defence Force Recruiting (DFR), which is managed by the Manpower Group. DFR is responsible for delivering the annually targeted number of candidates for the Royal Australian Navy, Australian Army, and Royal Australian Air Force. DFR is a collaborative organization with ADF personnel, the Australian Public Service, and other contractors. All applicants go through a set of evaluations, including psychometric, medical, psychological, and physical tests to determine the applicant's suitability for enlistment or appointment in the service.

The minimum academic entry-level requirement for AIAs is to pass Year 10 English and Math. There are a few avenues of entry to the AIA employment category, such as re-muster, inter-Service transfer, lateral transfer, and re-enlistment. The predominant method of entry into the RAAF, however, is general entry through DFR.

4. Training

Airmen/women recruits complete three months' basic recruit training at the No. 1 Recruiting Training Unit in Wagga Wagga or equivalent Service training for inter-Service transfers. Following completion of recruit training, airmen/women complete 11 weeks of the AIA Initial Employment Training (IET) Course held at Air Intelligence Training Flight, RAAF Base Edinburgh, South Australia.

AIAs undertake training throughout their careers to achieve specific skillsets and qualifications as shown in Figure 2. AIAs are also required to undertake other formal or informal workplace-based learning activities, such as workbooks/journals and yearly unit induction training. In addition, with the progression of their career, AIAs are expected to complete Professional Military Education and Training to progress in rank.

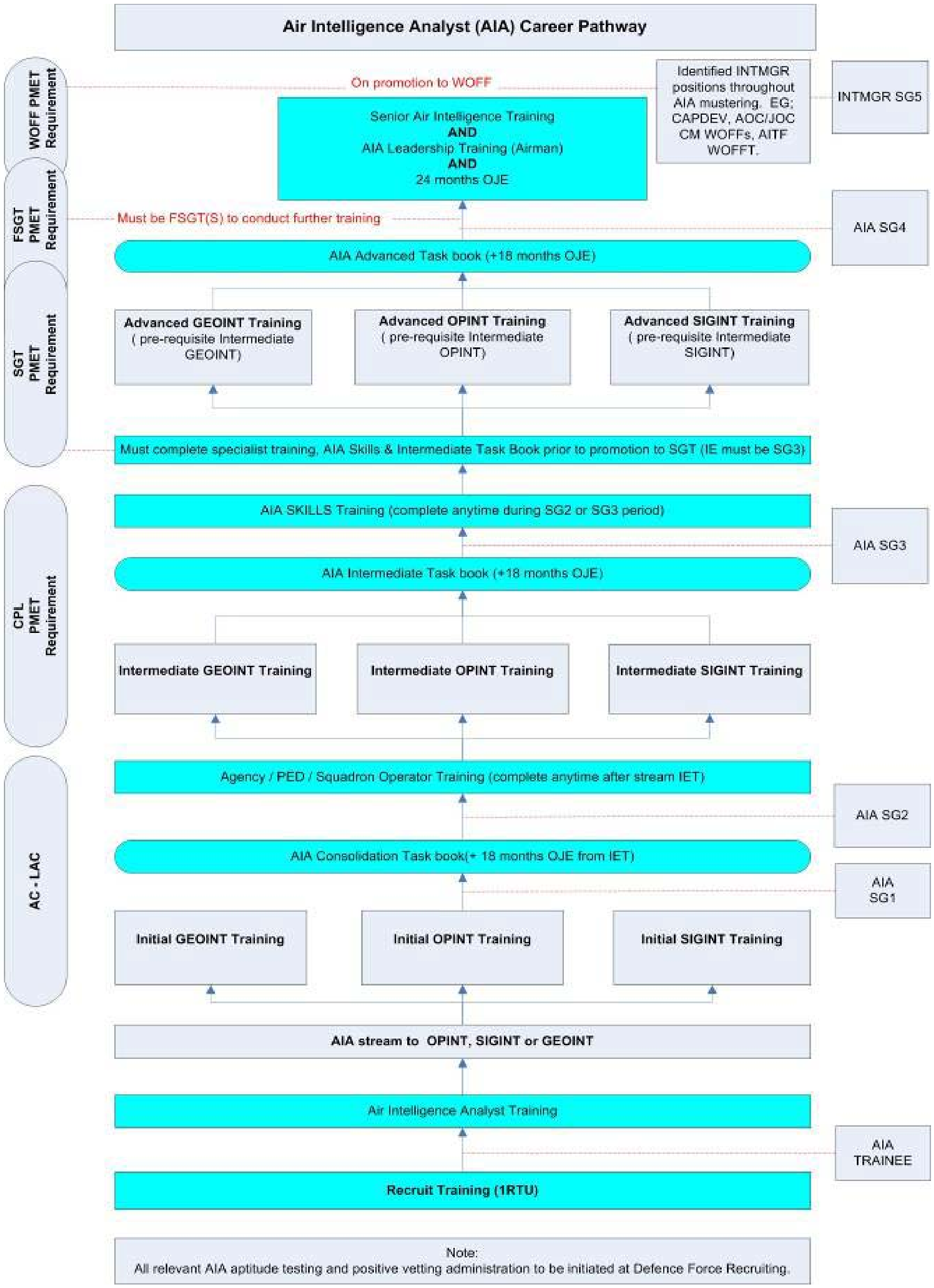


Figure 2. AIA Career Pathway Training Requirements. Source: RAAF (2017).

5. Promotion

The Air Force Promotion System encompasses different types of promotion. The two most common types of promotions are Time Based Promotion and Career Management Boards-Promotion (CMB-P).

The Time-Based Promotion is time and competency based, and applies to an E02 being promoted to an E03 on completion of 12 months' effective service post-graduation from IET. The Air Force also conducts CMB-P to meet its end-strength requirement. It is determined on the basis of factors affecting strength relative to establishment, separation, and changes to establishments. In short, it is vacancy driven and influenced significantly by separations and changes to the volume of positions at subsequent ranks. The annual targets are provided by DWP-AF and approved by Director General Personnel-Air Force (DGPERS-AF).

To be eligible for presentation to a CMB-P, members must meet the skill grade required of the employment category and the following minimum TIG requirement by 01 January of the year of the CMB-P:

- Two years TIG for E03; or
- Three years TIG for E05 and above.

The Promotion Cell from the DGPERS-AF runs CMB-P evaluations once a year for each employment category across officers and enlisted airmen/women. The board is normally held from January to March in Canberra. To be eligible for presentation to a CMB-P, members must meet the minimum TIG requirements at their current rank by 01 January of the year of the CMB-P. The promotion list is published on the DGPERS-AF's website in April.

6. Separation

The RAAF offers indefinite tenure following completion of the IMPS, which is six years for most employment categories. Members can request voluntary separation from the air force after completing their IMPS. The RAAF does not actively terminate personnel except for medical, disciplinary, or administrative reasons. Personnel are also released if they fail the Initial Military Training or IET.

The workforce demand is a key factor in determining whether the separation rate is healthy or not. A healthy separation rate is when the observed separation rate results in enough residual workforce to transition to the next rank. If there is an excess in the residual workforce that results in pooling, then the separation rate is too low. If there is too little workforce to satisfy demand across the ranks, however, then the separation rate is too high.

Since the relabeling of the AIA employment category in 2012, the three specialist streams have collectively experienced an average rate of 6% separation (Figure 3). According to the Australian Department of Defence's (DOD) most recent annual report, as of 30 June 2018, the permanent Air Force, 12-month rolling separation rate is 6.7% (Department of Defence [DOD], 2019). The AIA employment category has a relatively low separation rate, which could be caused by high local unemployment rates, poor economic conditions, and the fact that fewer people were recruited a few years ago compared to now, with the smaller cohorts completing their IMPS and voluntarily separating upon becoming eligible to do so.

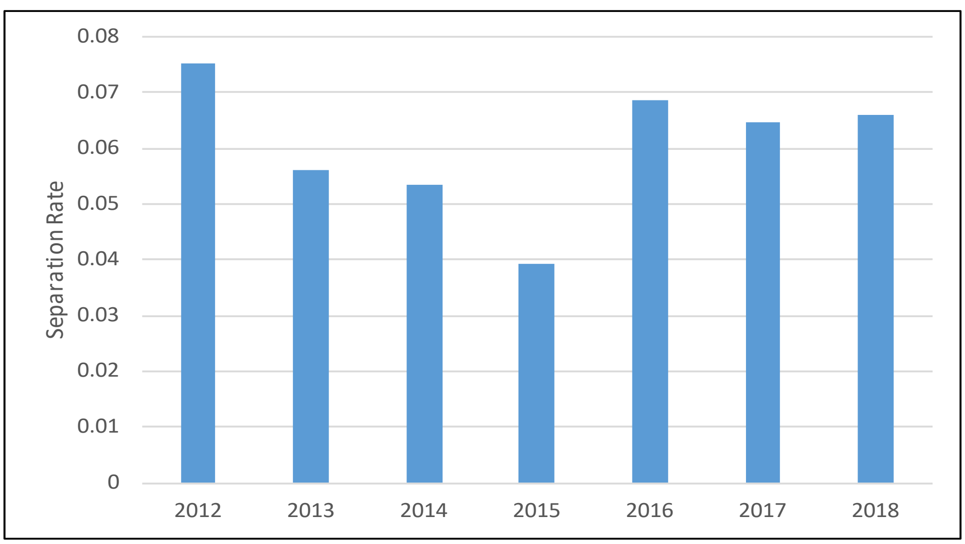


Figure 3. AIA Separation Rate by Year. Adapted from DWD-AF (personal communication, May 02, 2019).

The separation rate by individual AIA specialist streams in Figure 4 illustrates that the separation rate is more inconsistent than the collective separation rate for the year.

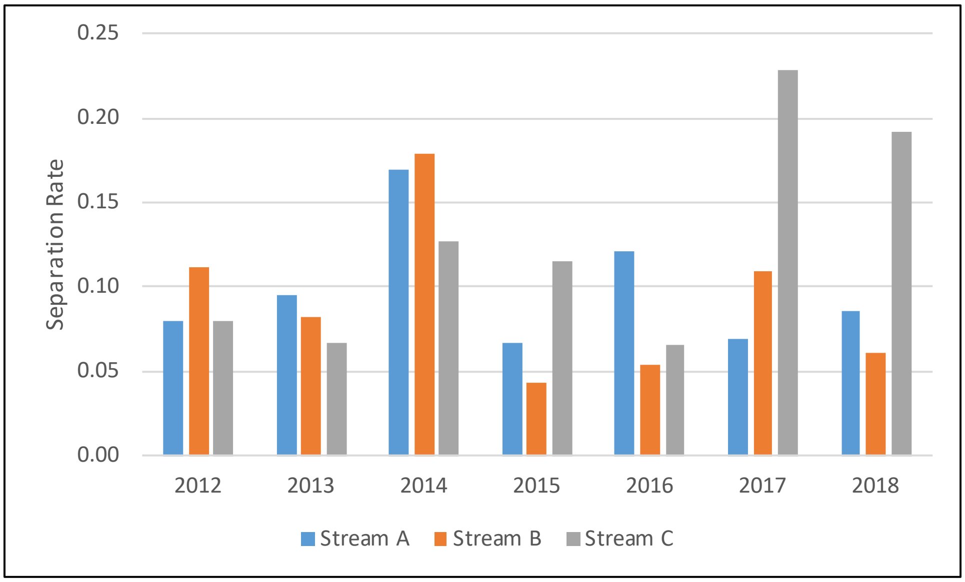


Figure 4. AIA Separation Rate by Year and Streams. Adapted from DWD-AF ((personal communication, May 02, 2019).

7. End Strength

The ADF uses Average Funded Strength (AFS) figures for workforce planning and budgeting. In the Defence Annual Report 2018–19, it is stated:

> Defence budgets for its ADF workforce on an average funded strength basis and for the APS workforce on an average staffing level basis. Defence uses actual full-time equivalent, which is paid strength on a particular date, to provide the most accurate indicator of current staffing levels. Workforce planning is based on average funded strength and average staffing levels respectively for the financial year and these averages are used to plan for an affordable workforce. (DOD, 2019, p. 87)

The Australian Government allows a 1% (positive or negative) variance of the AFS, and if the AFS is exceeded by 1%, then the individual service is required to fund the difference from other parts of its budget (DOD, 2019.)

C. ORGANIZATION OF STUDY

This chapter provides the overall objectives, background, and organization of the study. Chapter II provides a literature review of the Markov model theory, DOD and RAAF applications of the Markov models, other foreign military applications of the Markov models, and retention and promotion in the military. Chapter III describes the data and methodology used to develop the Markov model. Chapter IV shows the model's implementation for this thesis. Chapter V offers conclusions and recommendations.

II. LITERATURE REVIEW

Despite its interest in manpower planning and management, the RAAF will find minimal research on such topics. Among the studies available, Powell (2016) conducts an econometric analysis combined with Markov models on the canine supply for the RAAF Military Working Dogs (MWD) program. MWDs constitute one of the key elements of RAAF physical security and combat capabilities. Powell chooses canine supply as his research topic due to the increased physical security demand in the RAAF, which is associated with the biggest air assets acquisition.

Powell (2016) uses a fixed inventory Markov model to determine the number of MWDs needed to be acquired by the RAAF from 2016 to 2023 to meet its end-strength requirement. His study is one of the first and only attempts to use both econometric and Markov models for manpower (or *dogpower)* planning in the RAAF. Clearly, there is a gap in the literature regarding the Markov model on RAAF manpower planning and management.

There are, however, numerous studies conducted on Markov models in both civilian planning and foreign military manpower planning. For example, Sales (1971), Price et al. (1980), and Bartholomew et al. (1991) study civilian manpower planning. Zais and Zhang (2015) construct and estimate a Markov model to capture the U.S. Army personnel dynamics over time. Sjulj et al. (2008) apply Markov models to design the force structure for the Slovenian armed forces.

This chapter provides an academic literature review on manpower planning and methodologies relevant to this study. First, Section B provides an overview of the Markov model theory. Then, Section C discusses DOD and RAAF Application of the Markov models. Section D discusses other foreign military application of the Markov models. Finally, Section E explores the relationship between retention and promotion in the military.

A. MARKOV MODEL THEORY

Markov models are stochastic models that use probabilities for describing the behavior of a system. According to Charnes et al. (1972), "the Markov models generally multiply a vector of personnel in various job categories by a matrix of transition rates. This allows one to obtain a projection of the current workforce based upon past trends" (p. I-3). In particular, these models are very useful in manpower planning to predict and control the personnel flow of the system. For example, Davis (1973), Sales (1971), and Bartholomew et al. (1991) use Markov models in various civilian studies. As such, the application of Markov models is very common in manpower planning.

There have been a variety of studies on the development and application of Markov models on manpower planning in a non-military environment. The most well-known development and application of Markov models in civilian studies is by Bartholomew (1967).

Bartholomew (1967) introduces the Markov model with limited inventories for manpower systems. According to Bartholomew:

> In [the Markov model] we assume that the total size of the system is fixed rather than the total number of recruits. The recruitment needs are then determined by the losses together with any change which is planned in the system… In manpower applications, where the states are grades, the internal transitions will correspond to promotion, demotion or transfers. (pp. 56–57)

Bartholomew (1967) discusses three categories of personnel flows, which are wastage, promotion, and recruitment. He believes the wastage flow can be controlled to some extent by sacking people or by offering them financial or other inducements to leave. The RAAF, however, does not actively terminate personnel other than for medical, disciplinary, training failure, or administrative reasons; and financial inducements are also not allowed. According to Bartholomew, another method to control personnel flows is to maintain control over the promotion flows, which can be managed by direct management decisions. The RAAF's promotion rate is vacancy based and varies each year depending on separation rates. The most practical method of control for the RAAF is to control recruitment flows. A fixed inventory model is more applicable to the RAAF AIA workforce as the model predicts the recruitment numbers necessary to achieve the end-strength targets for each year until 2030.

B. DOD AND RAAF APPLICATION OF MARKOV MODELS

For studies that focus on applications of Markov models to Australian military manpower systems, see Wang (2005) and Powell (2016).

Wang (2005) conducts a study on existing models used in workforce planning for the Australian DOD. He classifies Markov chain models as one of the four military workforce planning techniques used by the Australian Army as the basis for the construction of its Combat Force Sustainment Model. He highlights that one of the potential limitations of the Markov models in workforce planning is the sample size requirement. He agrees with what Heneman and Sandver (1977) point out in their study that “If the number of individuals in an initial state is small, the state transition probabilities will tend to be unstable” (p. 539).

Whereas Markov models have been vastly used in the context of manpower systems based on personnel flow, Powell (2016) provides a Markov model to forecast canine supply in the RAAF MWDs to meet a fixed inventory requirement. As a system, the flow of dogs is very similar to the concept of personnel flow. He defines *dogpower* based on the fact that the MWDs flow between each state of the system is the same as it would be for a manpower system.

Powell then constructs three finite states of “Minimum Level of Capability,” “Operational Level of Capability,” and “Retired.” He then derives the aggregate transition rates from the total MWDs’ “flows into, between, and exiting at the various states” (p. 57). To satisfy the Markovian stationarity assumption, Powell calculates the standard errors and constructs an upper and lower Confidence Interval (CI) of the transition probabilities. During the validation process, he finds that 79% of the time the aggregate transition rates fall into the CI, which satisfies the third assumption of the Markov model. Therefore, his model is valid.

Although the study conducted by Powell is valid and has been applied in the *dogpower* system in the RAAF, his study has some limitations. He uses the sample data to represent the population for the RAAF MWDs, and this may not reflect the true *dog* flow of the system. Even if he tries to mitigate the potential bias by conducting a random control trial, however, as he states "the stationarity of MWDs retiring still may not truly represent the actual rate, thereby leading to a biased forecast" (p. 60).

He recommends further research to collect data from the point MWDs enter RAAF Security and Fire School for team/re-team and basic training, and to collect graduation rates.

C. APPLICATION OF MARKOV MODEL BY FOREIGN MLITARIES

Numerous studies have been conducted on Markov models in military manpower planning. They can be found in Skulj et al. (2008), Sobondo (2014), and Zais and Zhang (2015).

Skulj et al. (2008) use Markov models to design the desired force structure for the Slovenian armed forces. They identify 120 types of military segments, including civil servants, then use administrative data from 2001 to 2005 to calculate the transition probabilities of such segments. By assuming all future transitions (after 2006) are equal to the average transitions from 2001 to 2005, they identify significant gaps in the projected sizes of seven selected segments compared to the desired structure. This is largely due to the fact that manpower structure changes over time. In their study, the Markov model could not provide an answer on how to achieve the manpower structure. To address this issue, they recommend the decision makers to use simulation methods to achieve the desired manpower structure for the Slovenian armed forces.

Sobondo (2014) develops a Markov model to forecast U.S. Navy Medical Service Corps Healthcare Administrators (HCA) inventory levels from Fiscal Year (FY) 14 to FY18. During stock forecast validation, she uses the method of Measure of Effectiveness–percentage of satisfactory estimates. She notices some subspecialties in certain years have a lower percentage of satisfactory estimates than others, which was caused by small sample sizes and the limited number of observations. She suggests to collect additional years of data for future studies. However, her aggregate model is valid and provides the optional accession numbers for the HCA community to meet inventory requirements from FY14 onwards until FY18.

Zais and Zhang (2016) construct and estimate a Markov model that intends to capture the U.S. Army personnel dynamics on whether personnel decide to stay or leave the service over time. The personnel data is provided by the U.S. Department of Defense and covers the October 2007—September 2009 span. Whereas the traditional approach for personnel retention analysis is a logistic regression model, they use the data to calculate the transition probabilities and then use both the Markov model and a dynamic programming model to evaluate U.S. military personnel stay-or-leave decisions.

D. RETENTION AND PROMOTION IN THE MILITARY

Promotion is an important indicator of performance recognition and a way to keep valuable employees. A few studies have been done to examine the relationship between promotion and retention in both civilian and military environments. One of them is the study conducted by Buddin et al. (1992) examining promotion tempo and enlisted retention in the United States Army and United States Air Force. The study is designed to look at the impacts of promotion opportunities on a member's retention decision.

The study focuses on first-term reenlistment and promotion to paygrade E05, as the first term reenlistment point is a critical decision point for moving enlisted personnel into professional military careers. Buddin et al. use data representing male soldiers with four-year enlistment terms up to completion of their first enlistment during FY83 to FY89. Normally, retention models can use military/civilian pay ratio and the Annual Cost of Living (ACOL) retention model. They, however, use "a joint model of promotion and retention" (p. 9) to augment the pay ratio and ACOL models. Their method closes the gap in retention and promotion study.

Buddin et al.'s study and finding are relevant for the purpose of this study, as the RAAF AIAs have six-year IMPS and, at that time, the AIAs could be ranked as senior E03 or junior E05. The outcome of CBM-P can be vital to their reenlistment decision. Furthermore, similar to the RAAF promotion system, the U.S. Army promotes to fill vacancies, so that promotion rates vary considerably across employment categories. In hard-to-fill specialties with low retention rates, the promotion tempo is high as an incentive to encourage retention.

According to Buddin et al. (1992), that retention model is “sensitive to the specification of individual promotion opportunities at the end of the first term” (p. vi). Expected time to E05 promotion has a significant effect on first-term retention in both the pay ratio and the annualized cost of leaving formulations of the retention model. Holding other factors constant, a 10% promotion slowdown is associated with 14% to 18% reductions in U.S. Army and Air Force retention rates, respectively.

The study recommends that policy makers should consider promotion policy as an essential part of the compensation package to retain high-quality military personnel.

E. CHAPTER SUMMARY

The Markov model has a history of use in both the civilian and military environment. The interest in developing and applying a Markov model to forecast the RAAF AIA workforce recruitment and promotion schedule is based specifically on the previous studies from Bartholomew (1967).

Powell’s (2016) research was the first and among the few to combine an econometric analysis and Markov models to the RAAF *dogpower* planning. Although his study has some limitations, the methodology used in this research has laid the foundation for the application of Markov modeling in the RAAF. He has guided this research thesis and works actively to implement Markov modeling as a useful manpower planning tool in the RAAF.

III. DATA AND METHODOLOGY

This chapter describes the data and methodology used in the thesis. Sections A outlines the data source, the dataset variables, and the constructed variables used. Section B and C explains the Markov models from a theoretical perspective and how the models are incorporated and applied to the RAAF AIA employment category recruitment forecasting. Section D explains the fundamental matrix as a useful tool in personnel management especially in providing managerially relevant measurement of expected TIG for promotion.

A. DATA SOURCE

The dataset for this thesis is provided by DWD-AF. The data was de-identified by DWD-AF prior to this analysis. The data contains pre-collected movement transaction data pulled from the ADF's HR Data Warehouse from 2002 to 2018. There are 7137 observations in total, and each observation represents a promotion, continuation, or separation event for an individual Permanent Air Force AIA.

1. Dataset Variables

Following is the list of variables used in this thesis and they are present in the dataset pulled from ADF's HR Data Warehouse, except for the New ID variable and the Job Code variable.

a. New ID

This variable is a two-letter and five-digit number combination assigned to each individual represented in the data. The variable has been put together as a randomized alphabetical and numeric combination to de-identify each individual. This New ID is a replacement of each individual's PMKey (service number).

b. *Rank Code*

This variable is a three-digit code representing each rank level for AIAs. As AIA is an enlisted workforce, the rank codes are prefixed with "E" and a two-digit number after that. In the dataset, the AIAs' rank codes range from E00 to E09, with E00 the lowest and E09 the highest. However, since the relabeling of AIA in 2012, the AIA employment category does not have a Warrant Officer (E09) rank, instead members converge on promotion to E09 into a separate skill grade role of INTMGR. Figure 5 shows the distribution of AIA ranks from FY02 through FY18.

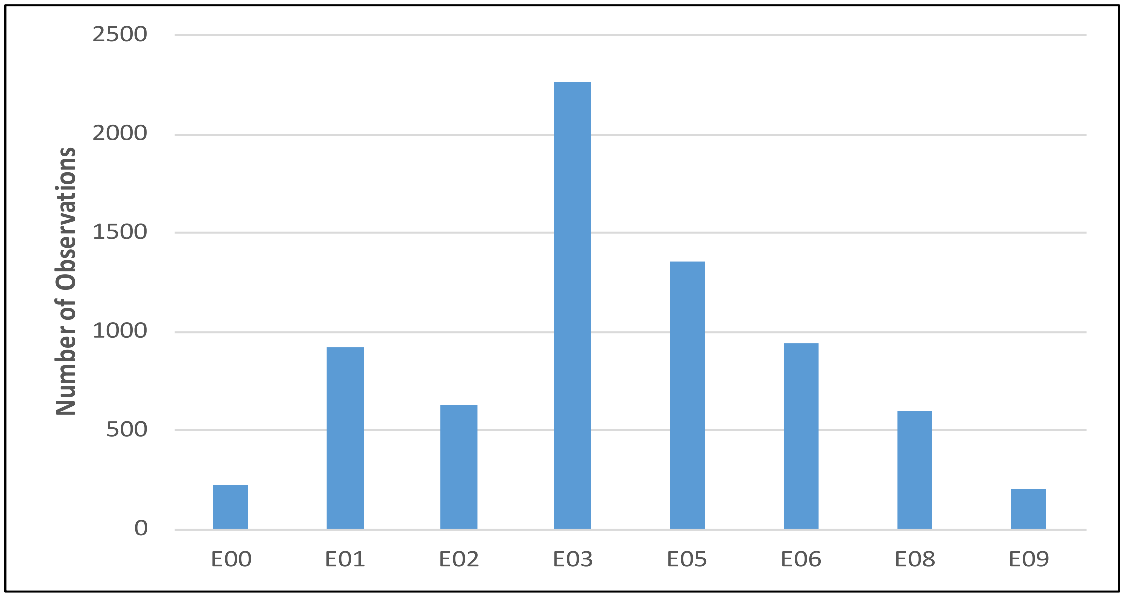


Figure 5. Observations by AIA Rank. Adapted from DWD-AF (personal communication, May 02, 2019).

c. *Job Code*

This variable represents contains the three streams of AIAs corresponding to their specialist streams–Geospatial, Operations, or Signals. To protect their privacy and identities, each of the three AIA specialist streams is represented by the letter A, B or C. Figure 6 shows the observations by AIA specialist streams in the dataset.

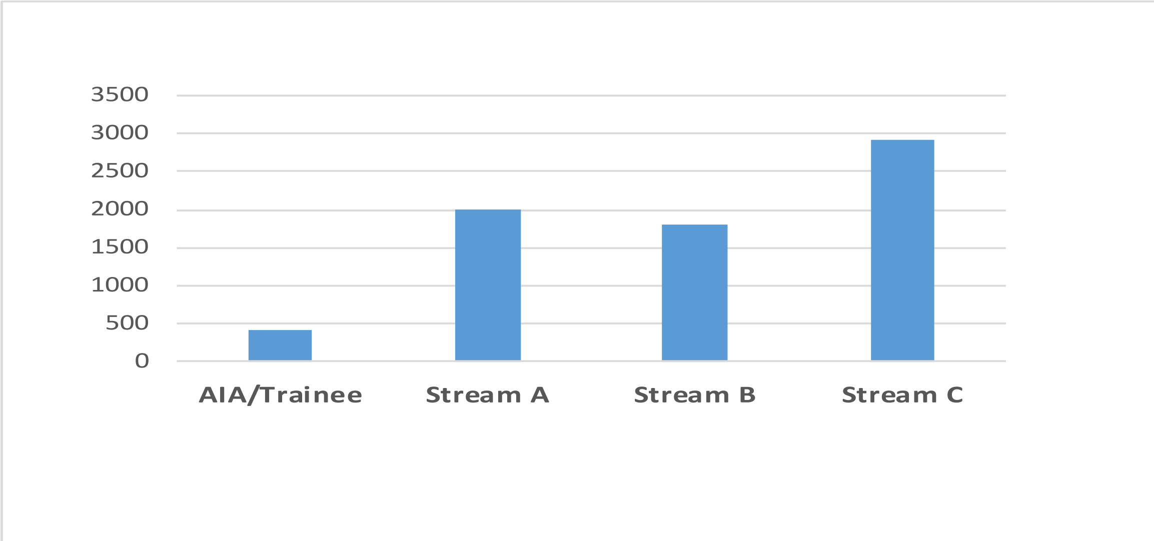


Figure 6. Observation by AIA Streams. Adapted from DWD-AF (personal communication, May 02, 2019).

d. Fiscal Year

This variable represents the fiscal year (FY) of the observation.

e. Time in Grade

This variable represents years of service at current rank/grade at the time of the observation.

2. Constructed Variables

For this thesis, a few variables were created in addition to the dataset variables. These include:

a. Promote in FY_XX

This is an indicator variable that represents whether the AIA is promoted during FY_XX from the previous time step (one FY). Being promoted is indicated by "1" and not being promoted is indicated by "0".

b. Continue in Year_XX

This is an indicator variable that represents whether the AIA continues in the current grade during FY_XX from the previous time step (one FY). Continuing in the current grade is indicated by "1" and not continuing in the current grade is indicated by "0".

c. Separate in Year_XX

This is an indicator variable that represents whether the AIA is separated during FY_XX from the previous time step (one FY). Being separated is indicated by "1" and not being separated is indicated by "0".

d. Accessions in Year_XX

This is an indicator variable that represents whether the AIA is recruited during FY_XX from the previous time step (one FY). Being recruited is indicated by "1" and not being recruited is indicated by "0".

e. Below the Zone

This variable indicates the AIA does not meet the minimum TIG requirement prior to the promotions by 01 January of the year of the CMB-P.

f. Above the Zone

This variable indicates the AIA meets the minimum TIG requirement prior to the promotions by 01 January of the year of the CMB-P.

B. MARKOV MODEL THEORY

The Markov model is a very useful tool in manpower planning and management as it uses probability to describe the behavior of a system. It can predict the aggregate behavior of a system such as inventory and end strength based on the flow of personnel within the system.

The following three fundamental assumptions of Markov models are applied in this thesis:

1. The system has a countable number of states.

2. The Markovian Property: the probability of the state of the system transition to the future state only depends on its current state.

3. Stationary Transition Probabilities: the transition probabilities remain the same over time.

For the purpose of this thesis, the state-space used in the Markov models is finite. In addition, the states are also mutually exclusive and exhaustive. For the AIA population in the RAAF, the state-space is partitioned by rank. As ranks E00 and E01 correspond to airmen/airwomen under training and AIAs are promoted to E02 on completion of IET, these three ranks are combined into one as "E02 and Under." So, the states of the systems are "E02 and Under," E03, E05, E06, E08, and attrite. For example, for all E03s, there are three possible outcomes for each individual after one year. First, an E03 might remain as an E03. Next, an E03 might be promoted to E05. Finally, an E03 might attrite from the RAAF. The attrite state includes those AIAs who separate from the Permanent Air Force. Figure 7 shows the conceptual model.

The Markovian Property is the property that the probability of the state of the system transition to the future state only depends on its current state**.** In practice, however, the promotion to the next rank does not simply depend on being in the current rank. For example, for an E05 AIA to be eligible to be promoted to E06, the AIA must meet the minimum three-years TIG and skills requirement. For an E05 AIA with less than one year of TIG, he/she is highly unlikely to be promoted to E06 within the next year, which might violate the Markovian Property. This is due to the fact that one's chance for promotion not only depends on the current grade (or current state), but might also depend on additional conditions or requirements.

To accommodate the additional minimum TIG requirements for promotion, the state-space is expanded from the normal rank to include whether the individual is categorized as below the promotion zone or above the promotion zone. If the AIA does not meet the minimum TIG requirement, then he/she is categorized as "E0X below the zone" and so on for each rank. For instance, if an E05 AIA has less than three years of TIG, he/she is counted in the state-space "E05 below the zone," and an E05 AIA with more than three years of TIG is counted in the state-space "E05 above the zone."

For the transition probability to be stationary, the probability that an element transitions from state "i" to "j" is constant over time. The method for determining whether the Markov model meets this assumption is demonstrated in the Validation section.

C. THE CONCEPTUAL MODEL

This thesis uses the flow of AIA personnel in each FY to build the Markov model. AIAs can flow through the system by continuing at the same rank/grade, being promoted to the next rank/grade, or leaving the system. Leaving the system could be the result of either voluntary or involuntary separation, and the "attrite" state is defined as when an AIA leaves the system.

All the possible states and allowable transitions for AIAs are shown in Figure7. The figure illustrates the AIAs' annual flow at each rank/grade in state "i" and the likelihood that the AIAs will transition to the next state "j." The probability of the transition is represented by "p_{ij}." For example, the transition probability p_{11} is the probability that an "E02 and Under" AIA might remain at the current rank/grade, p_{12} is the probability that an "E02 and Under" AIA might rise to E03, p_{13} is the probability that an "E02 and Under" AIA might leave the system in the next time step.

As demotion rarely happens in the RAAF, for this thesis it is assumed that demotion in the system is not allowed.

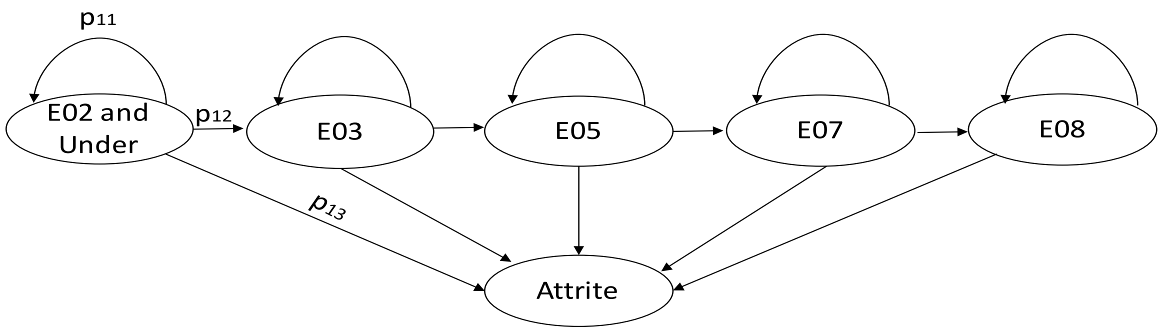


Figure 7. Conceptual Markov Model

1. Transition Matrix

To build a transition matrix, the AIA aggregate flows are calculated at each rank/grade between states (shown in Table 2) with a time step of one FY. For instance, the AIA Stream A flows from FY15 to FY16 are portrayed as FY16 flows. The same method is repeated for other AIA streams and years. Table 2 shows three years of aggregate flows for Stream A.

Table 2. Aggregate Flows FY16 through FY18—Stream A

Aggreg	Flows							
Type-A	Under E02	E03	E05	E06	E08	E09	Attrite	total
Under E02	19	55	0	0	0	0	13	87
E03	0	168	28	0	0	0	14	210
E05	0	0	71	13	0	0	12	96
E06	0	0	0	50	4	0	2	56
E08	0	0	0	0	27	0	3	30

The aggregate transition probabilities matrix for Stream A is derived from the aggregate flows for each transition then divided by the total inventory from that rank/grade. The annual transition probability is calculated as (Figure 8):

$$\hat{p}_{ij}(t) = \frac{f_{ij}(t)}{n_i(t)}$$

Figure 8. Transition Probability

The same method is repeated for each p_{ij} in the aggregated flows and each time step. The aggregated transition probabilities for Stream A are shown in Table 3. The sum of each row is to 1 because each individual within the system is accounted for.

Table 3. Aggregate Transition Probabilities Matrix FY16 through FY18—Stream A

Aggreg	**Probs**							
Type-A	**Under E02**	**E03**	**E05**	**E06**	**E08**	**E09**	**Attrite**	**total**
Under E02	0.22	0.63	0	0	0	0	0.15	1
E03	0	0.80	0.13	0	0	0	0.07	1
E05	0	0	0.74	0.14	0	0	0.13	1
E06	0	0	0	0.89	0.07	0	0.04	1
E08	0	0	0	0	0.9	0	0.10	1

2. Validation

To satisfy the Markov model's third assumption of stationarity, the transition probabilities need to remain relatively stable over time. The process that Sales (1971) outlines is used to show how the stationarity is calculated. That process is as follows:

First, calculate the annual $p_{ij}(t)$ for each year then calculate the standard error for each p_{ij}. The standard error for each p_{ij} is calculated as shown in Figure 9:

$$s.e.\left(pij(t)\right) = \sqrt{\frac{pij(t)\left(1 - pij(t)\right)}{ni}}$$

Figure 9. Standard Error Equation

Next, create intervals with margins of error equal to one standard error (see Figure 10). Then compare the aggregate transition probability to the corresponding probability for each year. If the aggregate transition probability is contained in the CI, it is considered sufficiently close to be stationary. The hope is that every transition rate is contained in the annual CI interval, but Sales (1971) gives reason to believe that anything over 70% is sufficient.

$$\{\hat{p}ij(\mathrm{t}) - \hat{se}(t), pij(t) + \hat{se}(t)\}$$

Figure 10. Lower and Higher Limits CI Equation

For Stream A, the lower and upper limits of 70% CI of transition probabilities for FY16 are shown in Table 4.

Table 4. Lower and Upper CI for FY 16—Stream A

FY16	Lower					
Type-A	Under E02	E03	E05	E06	E08	Attrite
Under E02	0.18	0.46	0	0	0	0
E03	0	0.80	0.07	0	0	0
E05	0	0	0.54	0.12	0	0
E06	0	0	0	0.79	0	0
E08	0	0	0	0	0.81	0

FY16	Upper					
Type-A	Under E02	E03	E05	E06	E08	Attrite
Under E02	0.34	0.64	0	0	0	0.26
E03	0	0.88	0.14	0	0	0.08
E05	0	0	0.71	0.26	0	0.26
E06	0	0	0	0.96	0	0.21
E08	0	0	0	0	0.99	0.19

For the model to be valid, the annual rates for each state "i" to state "j" transition have to be close to the aggregate estimate for that state "i" to state "j" transition. For Stream A, the number of satisfactory transition estimates that fall into the CI is equal to 31 as per Table 5. In the Markov model, there are14 i-to-j transitions for each of the three years, which makes a total of 14·3=42 transitions estimated. Thus, the proportion of satisfactorily stationary transition is 31/42 = 0.74. According to Sales (1971), this classifies as sufficiently stationary; therefore, the Markov model for AIA Stream A satisfies the third assumption of Markov modeling.

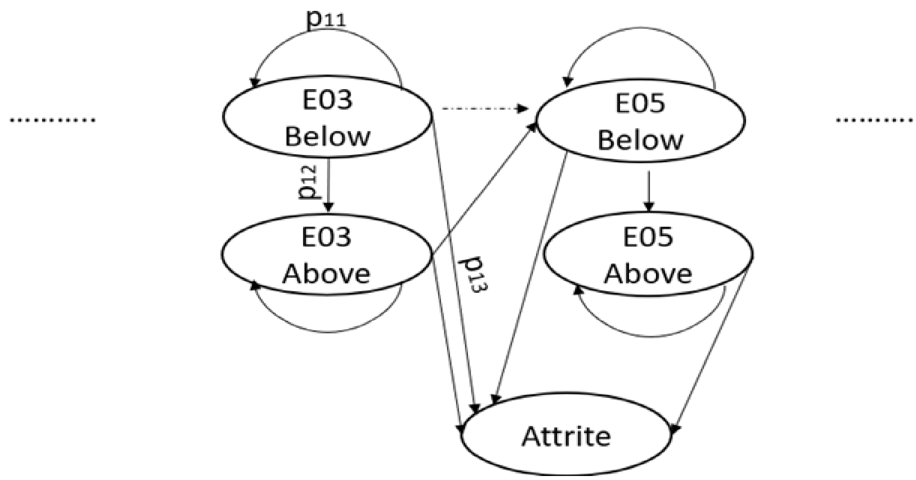
Table 5. Measurement of Effectiveness FY16 through FY 18—Stream A

Sum	Under E02	E03	E05	E06	E08	Attrite
Under E02	1	3	0	0	0	2
E03	0	3	2	0	0	3
E05	0	0	1	3	0	2
E06	0	0	0	2	2	1
E08	0	0	0	0	3	3

By contrast, the proportion of satisfactory transition estimates for Stream B and Stream C is only 63% and 58%. These values are not sufficiently stationary.

One way to attempt to address this issue is to further petition the state-space by incorporating the minimum TIG requirement for promotion. For instance, if an E03 AIA has less than three years of TIG, he/she is counted as "E03 below the zone," and "E03 above zone" otherwise. The transition probability p_{11} is the probability that an "E03 Below the Zone" AIA might remain at the current rank/grade; p_{12} is the probability that an "E03 Below the Zone" AIA might transit to "E03 Above the Zone," and p_{13} is the probability that an "E03 Below the Zone" AIA might leave the system in the next time step. Only an "E03 Above the Zone" should be promoted to the next rank/grade. That said, the empirical data on which the model is based does have instances of "E03 below" members being promoted to the next higher rank/grade. Partitioning the state space in this manner is a relatively easy way to improve our chances of finding a model that is stationary. It also improves the quality of the model by more closely adhering to the Markovian principle.

Furthermore, due to Time Based Promotion, an E02 AIA can be promoted to E03 on completion of 12 months' effective service post-graduation from IET. Therefore, for all E02s, there are only two possible outcomes for each individual after the time step of one FY. First, an E02 might be promoted to E03. Second, an E02 might attrite from the RAAF. Figure 11 illustrates the simplified version of the Markov model with expanded space.



Due to the minimum TIG requirement for promotion, in theory, only E03 Above AIAs should be promoted to the next rank/grade. However, in practice, there are some instances in which some E03 Below AIAs are promoted to the next rank/grade, which appears to violate the minimum TIG requirement. These transitions have to be taken into consideration during the development of the Markov model.

Figure 11. The Markov Model with Expanded Space

By expanding the states, the proportion of satisfactory transition estimates for AIA Stream A, B and C on a two-year model is 66%, 66% and 71%, respectively. These values are close enough to be considered sufficiently stationary.

3. Fixed Inventory Model

As the aggregate transition matrix for each AIA stream is close enough to be considered sufficiently stationary, the fixed inventory equation developed by Bartholomew et al. (1991) is used to forecast the total number of AIAs in each state.

According to Bartholomew et al. (1991), the Fixed Inventory Model consists of a transition matrix, an inventory vector, and a recruitment vector, and he defines the equation as:

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

For the purpose of this thesis, the variables in the equation are defined as:

- **n**(t) is the predicted inventory for AIAs at time step (t). Time steps are annual.

- **n**(t-1) is the inventory of AIAs at the previous time step (t-1).
- **P** is the aggregate transition probabilities matrix.
- R(t) is the total number of AIA recruits entered the system at time step (t).
- **r** is the recruitment vector, which describes the distribution of new AIA recruits across states.

D. FUNDAMENTAL MATRIX

According to Ross (2006), the fundamental matrix is used to estimate the time periods the Markov model in state "j," given that it starts in state "i." It is a very useful tool in personnel management as it provides managerially relevant measurement of expected TIG for promotion. The equation for fundamental matrix as shown in Figure 12:

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

Figure 12. Fundamental Matrix Equation

The main diagonals in the fundamental matrix represent the expected TIG for promotion for the given rank/grade.

E. CHAPTER SUMMARY

This chapter outlined the dataset and the methodology used to develop a fixed inventory Markov model for this thesis. The Markov model developed in this chapter is used as a manpower planning tool for the forecasting of the RAAF AIA recruitment schedule and estimated TIG for promotion.

IV. MODEL IMPLEMENTATION

This chapter examines the validity and accuracy of the Markov model by cross-validation, which shows that the Markov model is accurate in predicting the RAAF AIA inventory level. The chapter then outlines the implementation of the Markov model in Excel and subsequently forecasts the AIA accessions required to meet the end-strength requirement through 2030. Finally, this chapter provides the estimated TIG for promotion for each rank/grade by using the fundamental matrix.

A. MODEL CROSS VALIDATION

The Markov model is developed to predict the future AIA recruitment numbers, and the cross-validation process is applied to compares the recruitment numbers predicted from the Markov model for certain years with actual recruitments numbers from those years. The comparison reveals how well the model predicts from a managerial perspective. To cross-validate the Markov model, a two-year aggregate transition matrix using FY17 and FY18 personnel flows for Stream A is developed (Table 6).

Table 6. Aggregate Transition Matrix FY17 through FY18—Stream A

Aggreg	Probs									
Stream A	E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above
E01	0.38	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E02	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E03below	0.00	0.00	0.66	0.28	0.03	0.00	0.00	0.00	0.00	0.00
E03above	0.00	0.00	0.00	0.59	0.31	0.00	0.00	0.00	0.00	0.00
E05below	0.00	0.00	0.00	0.00	0.56	0.21	0.05	0.00	0.00	0.00
E05above	0.00	0.00	0.00	0.00	0.00	0.50	0.39	0.00	0.00	0.00
E06below	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.11	0.00	0.00
E06above	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.18	0.00
E08below	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.43
E08above	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83

Let **n**(2017) be the actual inventory on 30 June 2017 and **n**(2018) be the estimate for the inventory on 30 June 2018. The estimated inventory of **n**(2018) forecasted from the Markov model is then compared with the actual 2018 inventory levels of each rank/grade. As Table 7 shows, the biggest proportion of deviation of the predicted inventory from the actual inventory is 45% overestimated at rank "E08 Below the Zone" (shown in the box outlined in red in Table 7). This overestimation means that the predicted Stream A inventory in FY18 is 45% more than the actual inventory. This proportion of deviation is largely due to the small inventory size: there were only two AIAs in 2017 and five AIAs in 2018; therefore, the flow of one person could be the source of this significant proportion of deviation.

Considering the small sample size at certain rank/grade, the benchmark of 25% for proportion of deviation is chosen and deemed reasonable for the purposes of this thesis. As the flows of rank E02 and below can be controlled for, any significant proportion of deviation (above 25%) in these ranks/grades can be ignored. The proportion of deviation for other ranks/grades is insignificant as it is less than 25%, which means that the developed Markov model is accurate in predicting the AIA inventory number and subsequently can be used to forecast the number for RAAF AIA recruitment.

Table 7. Cross-Validation Results—Stream A

Stream A	E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above	
n(2017)	17	9	40	27	17	8	11	9	2	6	
est 2018	18.48	7.29	35.36	27.19	19.23	7.56	13.16	8.04	2.73	5.86	
act 2018	14	9	32	26	25	8	14	6	5	5	MAPE
Prop Dev	0.32	0.19	0.11	0.05	0.23	0.06	0.06	0.34	0.45	0.17	0.18

The same method is applied to other AIA streams and years. The Markov model is likewise valid for AIA Stream B and Stream C due to the insignificant proportion of deviation between predicated and actual inventory, as shown in Table 8 and Table 9, respectively.

Table 8. Cross-Validation Results—Stream B

Stream B	E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above	
n(2018)	0	27	16	16	16	3	7	6	6	4	
est 2019	21.00	22.00	38.07	14.42	17.43	3.16	7.25	5.90	5.66	4.49	
act 2019	19	22	40	12	16	4	9	5	5	6	MAPE
Prop Dev	0.11	0.00	0.05	0.20	0.09	0.21	0.19	0.18	0.13	0.25	0.16

Table 9. Cross-Validation Results—Stream C

Stream C	E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above	
n(2017)	29	16	46	16	26	12	13	17	7	6	
est 2018	22.75	6.90	50.98	14.45	31.98	11.34	10.85	19.04	6.26	7.20	
act 2018	34	16	50	9	31	9	12	21	6	8	MAPE
Prop Dev	0.33	0.57	0.02	0.61	0.03	0.26	0.10	0.09	0.04	0.10	0.16

In addition to the proportion of deviation for each AIA stream at each rank/grade level, the Mean Absolute Proportional Error (MAPE) is also calculated from rank E03 Below to rank E08 Above. MAPE is used to measure the percentage of error between the estimated value of the inventory and the actual value of the inventory. For instance, Stream A has a MAPE of 18%, so the MAPE is small enough for the workforce planners to believe that the estimated value is close to the real value.

Based on the outcomes of the cross-validation process for each AIA stream, the Markov model is accurate and valid for inventory forecasting purposes. The results of this modeling should adequately prepare workforce planners for forecasting high or low inventory numbers.

B. INVENTORY FORECAST

In the fixed inventory Markov model, workforce planners set the end-strength targets ahead of time and then use the model to forecast the number of recruits needed to achieve the end-strength targets.

1. RAAF AIA End-Strength Targets

The Markov model provides an estimate for the RAAF AIA inventory levels; however, the target end-strength is determined by the DWD-AF. To meet the incremental increases in AIA workforce from FY19 through FY30, DWD-AF sets the yearly end-strength target (Table 10). By 2030, the end-strength targets for the total AIA employment category are 151 in Stream A, 166 in Stream B, and 266 in Stream C.

Table 10. AIA Yearly End-Strength Target. Adapted from DWD-AF ((personal communication, May 02, 2019).

	Total Position Demand by FY														
	AIA Stream A					AIA Stream B					AIA Stream C				
FY	E02 and Under	E05	E06	E08	total	E02 and Under	E05	E06	E08	total	E02 and Under	E05	E06	E08	total
19-20	65	30	25	10	130	45	35	30	20	130	80	60	45	20	205
20-21	65	30	25	10	130	45	35	30	20	130	84	62	45	20	211
21-22	70	32	25	10	137	45	35	30	20	130	84	65	45	20	214
22-23	70	34	26	10	140	55	40	31	20	146	95	75	50	20	240
23-24	70	35	26	10	141	57	40	31	20	148	95	78	50	20	243
24-25	73	38	26	10	147	59	43	31	20	153	112	80	50	20	262
25-26	77	38	26	10	151	61	43	32	20	156	112	84	50	20	266
26-27	77	38	26	10	151	65	45	32	20	162	112	84	50	20	266
27-28	77	38	26	10	151	65	45	34	20	164	112	84	50	20	266
28-29	77	38	26	10	151	65	45	34	20	164	112	84	50	20	266
29-30	77	38	26	10	151	65	45	34	20	164	112	84	50	20	266
30-31	77	38	26	10	151	67	45	34	20	166	112	84	50	20	266

If the only method of entry into the RAAF AIA workforce in a given year is general entry, then 100% of new accessions join the RAAF AIA as E01. Based on a two-year Markov model, the actual distribution of AIA accession vector r in FY17 for Stream A and Stream C use this information (Table 11). Therefore, no accession is assumed to arrive at other ranks for Stream A and Stream C.

Table 11. Accession Vector r—Streams A and C in FY17 (actual)

R (Accession)	E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above
r (Vector)	1	0	0	0	0	0	0	0	0	0

In practice, the RAAF can manage r by using various recruiting methods, such as re-muster, inter-Service transfer, lateral transfer, and re-enlistment. Therefore, the accession distribution can vary based on the establishment of the positions and the end-strength requirement. For example, in FY18, 44.68% of the new accessions joined the RAAF AIA Stream B as E01, 46.81% joined as E02, and 8.51% joined as E03 Below the Zone (Table 12).

Table 12. Accession Vector r—Stream B in FY18 (actual)

R (Accession)	E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above
r (Vector)	0.4468	0.4681	0.0851	0	0	0	0	0	0	0

2. Optimization of Accession

To determine the number of AIA accessions that will meet the end-strength targets, an optimization is formulated to find the accession number R that minimizes the difference between the predicted inventory and the end-strength targets. According to Table 13, in year two, the RAAF will need to recruit 11 personnel in Stream A so that the total inventory predicted from the model is equal to the end-strength target.

Table 13. Optimization in Excel—Stream A

Total	Target		R
144			
130	130		0
130	130		11
137	137		20
140	140		18
141	141		16
147	147		20
151	151		18
151	151		14
151	151		14
151	151		14
151	151		14
151	151		14
MSE	0.02		

3. Results

Based on the fixed inventory Markov model, the RAAF needs to execute the developed AIA recruitment plans as shown in Table 14 for Stream A, Table 15 for Stream B, and Table 16 for Stream C to meet the total AIA workforce demand through 2030. The numbers are further broken down into the end-strength targets at each rank/grade from FY19 through FY30 and the yearly accession numbers (R) to meet the requirement, assuming the distribution of accession for all AIAs remains the same as per Tables 11 and 12. For instance, in FY20, AIA Stream A needs a new accession number of 11 to achieve the end-strength targets.

The yearly accession numbers in each AIA stream are broadly consistent with the previous recruitment behavior.

Table 14. Aggregate Inventory Forecast and Recruitment Schedule FY19 through FY30—Stream A

Year	E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above	Total	Target
n(2018)	14	9	32	26	25	8	14	6	5	5	144	
n(2019)	5	6	30	24	23	9	16	6	4	6	130	130
n(2020)	13	2	26	23	21	9	18	6	3	7	130	130
n(2021)	25	6	19	21	20	9	20	7	3	7	137	137
n(2022)	27	11	18	18	18	9	21	7	3	7	140	140
n(2023)	26	12	23	16	16	8	22	8	3	7	141	141
n(2024)	30	11	27	16	15	8	23	8	3	7	147	147
n(2025)	30	13	29	17	14	7	23	9	3	7	151	151
n(2026)	26	13	32	18	14	6	22	9	3	8	151	151
n(2027)	24	11	34	20	14	6	22	9	4	8	151	151
n(2028)	23	10	33	21	15	6	22	9	4	8	151	151
n(2029)	22	10	32	22	16	6	21	9	4	8	151	151
n(2030)	23	10	31	22	17	7	21	9	4	8	151	151

R	r- E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above
0	1	0	0	0	0	0	0	0	0	0
11	1	0	0	0	0	0	0	0	0	0
20	1	0	0	0	0	0	0	0	0	0
18	1	0	0	0	0	0	0	0	0	0
16	1	0	0	0	0	0	0	0	0	0
20	1	0	0	0	0	0	0	0	0	0
18	1	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0
173										

Table 15. Aggregate Inventory Forecast and Recruitment Schedule FY19 through FY30—Stream B

Year	E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above	Total	Target
n(2018)	0	27	16	16	16	3	7	6	6	4	101	
n(2019)	17	18	37	14	17	3	7	6	6	4	130	130
n(2020)	12	12	36	23	20	3	8	6	5	5	130	130
n(2021)	11	11	30	26	24	4	8	6	5	5	130	130
n(2022)	18	18	28	25	27	4	9	6	5	5	146	146
n(2023)	15	15	34	24	29	5	10	6	5	5	148	148
n(2024)	15	15	33	26	31	6	11	7	5	5	153	153
n(2025)	14	15	33	26	32	6	12	7	6	5	156	156
n(2026)	16	16	32	26	33	6	13	8	6	5	162	162
n(2027)	15	16	33	26	34	7	14	9	6	5	165	164
n(2028)	15	16	33	27	34	7	15	9	7	5	169	164
n(2029)	17	18	34	27	35	7	16	10	7	6	176	164
n(2030)	0	0	33	27	36	7	16	11	8	6	143	166

R	r- E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above
38	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
38	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
27	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
24	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
39	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
33	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
33	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
32	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
35	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
34	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
34	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
38	0.4468	0.4681	0.0851	0	0	0	0	0	0	0
404										

Table 16. Aggregate Inventory Forecast and Recruitment Schedule FY19 through FY30—Stream C.

Year	E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above	Total	Target
n(2018)	34	16	50	9	31	9	12	21	6	8	196	
n(2019)	43	8	54	12	33	10	10	22	6	8	205	205
n(2020)	46	10	49	14	36	11	8	22	6	9	211	211
n(2021)	46	11	48	14	39	12	8	22	6	9	214	214
n(2022)	69	11	47	14	42	13	7	21	7	9	240	240
n(2023)	64	16	47	13	45	14	8	21	6	9	243	243
n(2024)	76	15	52	13	47	15	8	20	6	9	262	262
n(2025)	71	18	55	14	48	16	8	20	6	9	266	266
n(2026)	63	17	60	15	51	17	9	20	6	9	266	266
n(2027)	57	15	62	16	53	18	10	20	6	9	266	266
n(2028)	54	14	62	17	55	18	10	20	6	9	266	266
n(2029)	51	13	61	17	58	19	11	21	6	9	266	266
n(2030)	49	12	59	17	61	20	11	21	6	9	266	266

R	r- E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above
30	1	0	0	0	0	0	0	0	0	0
31	1	0	0	0	0	0	0	0	0	0
29	1	0	0	0	0	0	0	0	0	0
52	1	0	0	0	0	0	0	0	0	0
38	1	0	0	0	0	0	0	0	0	0
52	1	0	0	0	0	0	0	0	0	0
42	1	0	0	0	0	0	0	0	0	0
37	1	0	0	0	0	0	0	0	0	0
34	1	0	0	0	0	0	0	0	0	0
32	1	0	0	0	0	0	0	0	0	0
31	1	0	0	0	0	0	0	0	0	0
30	1	0	0	0	0	0	0	0	0	0
438										

4. Sensitivity Analysis

Conducting the sensitivity analysis provides the RAAF a better managerial tool for manpower planning, especially in setting and predicting end-strength targets, as the uncertainty and variability of the inventory are accounted for.

The inventory estimates the Markov model predicts are point estimates. The inventory estimates at *t* = year in the model depends on the inventory estimates at *t* = *year*-1, which depends on the pervious inventory estimates, etc. To measure the uncertainties of all those estimates, a Monte Carlo Simulation is conducted in the statistical software R to sample the neighborhood of the transition matrix, resolve the optimal solution over a five-year planning horizon, and then provide CIs for the estimates.

For instance, as shown in Figure 13, a 95% CI around the optimal accession number for AIA Stream A in year three (R3) is between 18 and 22. It is therefore possible to be 95% confident that the accession number in year four will be between 16 and 20. The planning figure can be extremely helpful in preparing the Recruit training and IET.

	R1	R2	R3	R4	R5	opt_values
lower	-2.561613	9.561939	17.88785	15.59428	13.49289	0.000000e+00
mean	-0.515581	11.610204	19.91669	17.57501	15.40404	5.988982e-27
upper	1.635497	13.722077	21.92524	19.49702	17.30824	1.292470e-26

Figure 13. EV of R—95% CI—Stream A, 1000 Replications

It is also possible to get a sense of how closely the RAAF will achieve its end-strength goals by executing the optimal accession plan but experience reasonable variation in transition rates. For this sensitivity analysis, the neighborhood of the transition matrix is sampled, the optimal accession plan is executed as per Table 14 (page 35), and the estimated end-strengths are examined. The Expected Value (EV) of annual end-strength targets and a 95% empirical CI is shown in Figure 14. The means of annual estimated end-strength targets match the target in every year. Furthermore, in year two, the lower bound of the CI has a deficit of 4 and the upper bound of the CI has surplus of 4 compared to the target. Therefore, with reasonable variation in the AIAs' transition behavior, the RAAF can be 95% confident that the estimated value of annual end-strength is +/- 4 from the desired end-strength targets, which is about 3%.

	Y1	Y2	Y3	Y4	Y5
lower	127.9583	126.3323	131.9811	133.8875	133.8313
mean	129.9968	130.0138	137.0415	140.0772	141.1158
upper	132.0531	133.7656	142.2373	146.5269	148.6578
target	130.0000	130.0000	137.0000	140.0000	141.0000

Figure 14. EV of Annual End-Strength—Stream A, 5000 Replications

The same method is used in R to conduct sensitivity analysis for Stream B and C. Results are shown in Figures 15 and 16 for Stream B and in Figures 17 and 18 for Stream C. The means of annual estimated end-strength targets for Stream B match the target in every year. Furthermore, in year two, the lower bound of the CI has a deficit of 3 and the upper bound of the CI has surplus of 3 compared to the target. Therefore, with reasonable variation in the AIAs' transition behavior, the workforce planners can be 95% confident that the estimated value of annual end-strength is +/- 3 from the desired end-strength targets, which is about 2%.

	R1	R2	R3	R4	R5	opt_values
lower	36.01148	24.11658	20.89376	36.49984	29.71677	3.231174e-27
mean	37.46341	26.47845	23.65942	39.34208	32.76763	2.166413e-25
upper	38.84257	28.79438	26.31510	42.06845	35.62343	1.787849e-25

Figure 15. EV of R—95% CI—Stream B, 1000 Replications

	Y1	Y2	Y3	Y4	Y5
lower	128.7018	127.1486	125.6748	140.4555	141.3540
mean	130.0004	130.0182	130.0417	146.0642	148.0849
upper	131.3480	133.0719	134.7179	152.1630	155.4652
target	130.0000	130.0000	130.0000	146.0000	148.0000

Figure 16. EV of Annual End-Strength—Stream B, 5000 Replications

For Stream C, the workforce planners can be 95% confident that the estimated value of annual end-strength is +4/-6 from the desired end-strength targets in year two, which is about 2%.

	R1	R2	R3	R4	R5	opt_values
lower	27.15888	26.61261	24.23928	46.64283	32.01409	3.231174e-27
mean	29.91482	30.56144	28.87330	51.82870	37.92853	9.940185e-24
upper	32.73551	34.63147	33.58490	57.03663	43.90920	1.835933e-24

Figure 17. EV of R—95% CI—Stream C, 1000 Replications

	Y1	Y2	Y3	Y4	Y5
lower	202.2068	205.3604	205.8180	229.3511	229.7384
mean	205.0014	211.0259	214.0675	240.1188	243.1812
upper	207.8097	216.7676	222.5912	251.2731	257.1490
target	205.0000	211.0000	214.0000	240.0000	243.0000

Figure 18. EV of Annual End-Strength—Stream C, 5000 Replications

These are excellent outcomes and the sensitivity analysis can be a useful managerial manpower planning tool for the RAAF.

C. PROMOTION

Promotion is an important indicator of performance recognition and a way to keep valuable employees. The relevant measurement of expected TIG for promotion can be a useful tool in personnel management, especially for the explanation and prediction of separation behaviors.

The fundamental matrix for Stream A based on a two-year model is shown in Table 17. The main diagonal shows the expected TIG at that particular rank/grade.

Table 17. Fundamental Matrix—Stream A.

S Matrix										
Stream A	E01	E02	E03below	E03above	E05below	E05above	E06below	E06above	E08below	E08above
E01	1.62	0.69	2.03	1.39	1.14	0.48	1.51	0.67	0.28	0.71
E02	0	1.00	2.93	2.01	1.64	0.69	2.18	0.97	0.40	1.03
E03below	0	0	2.93	2.01	1.64	0.69	2.18	0.97	0.40	1.03
E03above	0	0	0	2.42	1.70	0.71	2.25	1.01	0.41	1.07
E05below	0	0	0	0	2.26	0.95	3.00	1.34	0.55	1.42
E05above	0	0	0	0	0	2.00	4.93	2.20	0.91	2.33
E06below	0	0	0	0	0	0	6.33	2.83	1.17	3.00
E06above	0	0	0	0	0	0	0	4.25	1.75	4.50
E08below	0	0	0	0	0	0	0	0	2.33	6.00
E08above	0	0	0	0	0	0	0	0	0	6.00

Additionally, Table 18 indicates the expected TIG for each AIA stream based on a two-year model at each rank/grade for promotion. For instance, the average expected time for an E03 AIA Stream A to be promoted to the next rank (E05) is 5.35 years, and 10.58 years for an E06 AIA to be promoted to E08. However, it only takes 7.25 years and 9.18 years for an E06 AIA Stream B and C to be promoted to E08, respectively.

Table 18. Expected TIG for Promotion for AIAs

Estimated TIG - Steam A		Total
E01	1.62	1.62
E02	1.00	1.00
E03below	2.93	
E03above	2.42	5.35
E05below	2.26	
E05above	2.00	4.26
E06below	6.33	
E06above	4.25	10.58
E08below	2.33	
E08above	6.00	8.33

Estimated TIG Steam B		Total
E01	1.00	1.00
E02	1.00	1.00
E03below	1.79	
E03above	1.93	3.73
E05below	3.18	
E05above	1.80	4.98
E06below	3.50	
E06above	3.75	7.25
E08below	3.67	
E08above	3.50	7.17

Estimated TIG Steam C		Total
E01	1.59	1.59
E02	1	1.00
E03below	4.17	
E03above	1.94	6.11
E05below	7	
E05above	3.13	10.13
E06below	2.58	
E06above	6.6	9.18
E08below	2.5	
E08above	3.75	6.25

As the Markov model is built on two-year aggregate transition probabilities and some of the ranks/grades have a very small sample size, the actual expected TIG might be different.

D. LIMITATIONS

The primary limitation of the Markov model used in this thesis is the state-space. Using only rank states to calculate transition probabilities does not provide a true reflection of the manpower system. The model does not capture all the personnel characteristics needed to determine the individuals’ retention decisions. Further study should focus on AIA employment category attrition and retention analysis.

Second, the personnel flows in the Markov model are built on historical data. For forecasting purposes, the model assumes that the historical behavior will continue. The future promotion probabilities in the RAAF, however, will be shaped by operational priorities and capability requirements instead of historical trends. Furthermore, military attrition behavior is associated with economic conditions and the unemployment rate, which can be unpredictable. This limitation can be addressed by reviewing the model yearly based on the most current data.

Lastly, the sample size is small. For example, some of the states have fewer than five observations, which could cause statistical significance problems: in the FY18 flows, there was only one AIA E01 in Stream B. If one AIA attrites, the model will generate an attrition rate of 100%, which is extremely high, as E01s are still under IMPS therefore the attrition rate should be low.

E. SUMMARY

The Markov model forecasts that the RAAF needs to recruit a total of 173 personnel in AIA Stream A, 404 personnel in AIA Stream B, and 438 personnel in AIA Stream C from FY19 through FY30 to meet the total AIA workforce demand through 2030. The Markov model also provides managerially relevant measurement of expected TIG for promotion. Nevertheless, the model has some limitations due to the limited state-space and small sample size. As a result of these limitations, the model needs to reviewed annually.

V. CONCLUSION AND RECOMMENDATIONS

The objective of this thesis has been to develop a Markov model to forecast the accessions for the AIAs to meet the RAAF AIA workforce end-strength requirement through 2030. The Markov model proved to be valid during the measurement of effectiveness and cross-validation process. Based on the prediction of the Markov model, the RAAF can set accession numbers for each year over the next 11 years to meet the end-strength targets through 2030. Therefore, the RAAF can build up inventory in the AIA workforce and best use the existing inventory to close gaps at each rank and achieve supply-and-demand parity.

A. RECOMMENDATIONS

The cross-validation process shows that the Markov model is a useful manpower planning tool for forecasting inventory levels and accessions. It is therefore recommended the RAAF workforce planners use the Markov model developed in this thesis as a basic manpower planning tool, not only for the AIA employment category but also as the standard for other specializations. To ensure accuracy and relevance, this model should be reviewed and updated annually based on the flow of personnel for all specializations in the RAAF.

B. FUTURE STUDIES

As a result of the limitations of the model, described in the previous chapter, the following areas are recommended for future studies that can be used to refine the developed tool:

- AIA employment category attrition and retention analysis.
- Survival analysis at the cohort level.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Bartholomew, D. J. (1967). *Stochastic models for social processes*. London: Wiley.

Bartholomew, D.J. (1971). The statistical approach to manpower planning. *Journal of the Royal Statistical Society*. *20*(1), 3–26.

Bartholomew, D.J., Forbes, A.F., & McClean, S. I. (1991). *Statistical techniques for manpower planning*. Chichester, England: John Wiley & Sons.

Buddin, R. (1992). *Promotion tempo and enlisted retention*. Santa Monica, CA: RAND.

Charnes, A., Niehaus, R., & Cooper, W. (1972). Studies in manpower planning. Retrieved from http://hdl.handle.net/2027/mdp.39015004730183

Davies, G. S. (1973). Structural control in a graded manpower system. *Management Science*, *20*(1), 76–84. https://doi.org/10.1287/mnsc.20.1.76

Department of Defence, Australian Government. (2019). *Defence annual report 18–19*. https://www.defence.gov.au/annualreports/18-19/DAR_2018-19_Complete.pdf

Heneman, H., & Sandver, M. (1977). Markov Analysis in Human Resource Administration: Applications and Limitations. *The Academy of Management Review*, *2*(4), 535–542. Retrieved March 2, 2020, from www.jstor.org/stable/257506

Powell, M. (2016.). *Canine supply for physical security: An analysis of the Royal Australian Air Force military working dog program*. Monterey, CA: Naval Postgraduate School.

Price, W. L., Martel, A., & Lewis, K. A. (1980). A review of mathematical models in human resource planning. *OMEGA*, *8*(6), pp. 639–645.

Ross, S. (2006). *Introduction to probability models*. https://doi.org/10.1016/C2012-0-03564-8

Royal Australian Air Force. (2014). *AF14-Plan-Jericho*. http://airpower.airforce.gov.au/APDC/media/PDF-Files/Air%20Force%20Publications/AF14-Plan-Jericho.pdf

Royal Australian Air Force (2017, September 11). *Employment profile Air Intelligence Analyst*. https://objective/id:AB20937290

Sales, P. (1971). The validity of the Markov chain model for a class of the civil service. Journal of the Royal Statistical Society. Retrieved from http://www.jstor.org/stable/2987007

Skulj, D., Vehovar, V., & Stamfelj, D. (2008). The modelling of manpower by Markov chains—A case study of the Slovenian armed forces. (Report). *Informatica*, *32*(3), 289–291.

Sobondo, J. (2014). *A Markov model for forecasting inventory levels for Navy Medical Service Corps healthcare administrators* [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. http://hdl.handle.net/10945/41401

Wang, J., & Defence Science and Technology Organisation Salisbury. (2005). *A review of operations research applications in workforce planning and potential modeling of military training* (Report no. DSTO-TR-1688). Retrieved from http://www.dtic.mil/docs/citations/ADA432084

Zais, M., & Zhang, D. (2016). A Markov chain model of military personnel dynamics. *International Journal of Production Research*, *54*(6), 1863–1885. https://doi.org/10.1080/00207543.2015.1108533

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California