Modelling and Simulating Canadian Armed Forces Career Progression

Etienne Rollin
Department of National Defence
NDHQ Carling Campus, Ottawa, K1A 0K2
CANADA

etienne.rollin@forces.gc.ca

Stan Isbrandt
Department of National Defence
NDHQ Carling Campus, Ottawa, K1A 0K2
CANADA

stan.isbrandt@forces.gc.ca

ABSTRACT

Due to the hierarchical nature of military occupations, it can take decades for a recruit to advance to higher ranks. Therefore, good planning is crucial to make sure that the health of Canadian Armed Forces occupations and, more generally, Canada's ability to contribute to NATO operations are preserved in the future. With that in mind, and building on existing capabilities, the Canadian Department of National Defence develops military occupation models to simulate career progression through their rank structure. Built within ORIGAME, a Python-based discrete event simulation environment, a model can be used to explore the effects of changing policies by simulating events such as intake, attrition, promotions, and training; and can be customized with features such as geographic location, occupation specializations, and feeder-receptor occupation structures. The results can then be automatically summarized as a projection of occupation strength for each rank, the time in rank, the years of service profile, and other characteristics. Two models, a generic one based on the Sonar Operator occupation and a more complex one for the Marine Technician occupation, will be described, and simulation results will be presented.

Keywords: Modelling, Simulation, Military personnel, Forecasting, Projection

1.0 INTRODUCTION

This paper is divided into four sections. This first section will describe the context that motivated the development of a new discrete event military career progression tool called the ORIGAME Human Resources Career Analysis 2 (OHRCA2) model. It introduces the framework in which the tool was created and gives examples of the type of analysis that can be performed. The second section will introduce the Generic Model of that tool, illustrated with the Sonar Operator occupation of the Canadian Armed Forces (CAF). It will describe the input parameters and different career events modelled and will show results of the simulation. The third section will introduce a customized version of the Generic Model, the Marine Technician Model, which includes several additional features that are specific to the occupation, increasing the accuracy of the simulation. Finally, the fourth section will summarize aspects of the model and describe future work to improve the tool.

Although both models described later in this publication are based on CAF Non-Commissioned Member (NCM) occupations, the OHRCA2 model is not limited to this type of structure. The CAF officer occupations, or any other hierarchical structure, can also be modelled without making modifications to the OHRCA2 code. Models can also be based on the whole Force rather than a single occupation even though computing resources might require limiting the output information for large services.

1.1 Context

Since personnel costs are substantial, management of the Department of National Defence (DND) personnel is clearly paramount. Costs such as salary, combined with personnel-related costs such as common and individual training amount to a major portion of the DND's yearly budget. Although it is difficult to specify exact cost amounts, in Ref. [1] an analysis was carried out around 2008 to show that the personnel-associated costs amount to approximately 50% of the DND's yearly budget. In fact, it stated that: "Since the personnel costs account for approximately 50% of the DND/CAF budget, any change in CAF population will have immediate and long-term consequences." The budget proportion is possibly different now, but even if it had declined, say, to around 40% of the 2023-24 DND expected expenditure of $41.5 billion [2], that would amount to around $16.6 billion for personnel-related costs.

Simulation modelling can assist with military personnel management. Two aspects of typical military occupations can provide some structure to military modelling that tends to make projections more usable than similar occupational modelling for civilian occupational groups. One aspect is that military occupations tend to have all (or most) member intake at, or near the bottom of an occupation's rank structure. The members then progress to varying rank levels before leaving at some time. For example, it takes on average 25.9 years for a Sonar Operator recruit to reach the highest rank of the occupation [3]. So, the person promoted to the highest rank today was part of the hiring process more than two decades ago. Similarly, today's recruitment plan will affect staffing of the highest-ranked positions in more than two decades from now. In contrast, with typical civilian occupations, members may join or leave at varying levels, including top levels. Another aspect that helps provide structure when modelling on yearly "steps" of projection is that at each step military members will age one year, earn one more year of service (YOS), and one more year of time in rank (TIR). These attributes are integral to career progression policies involving terms of service (TOS), and promotability.

Here the discussion will focus on how modelling of military occupations, or of military occupational groupings, can project career progression patterns through the ranks over time. Such projections can be done using either assumptions that reflect current understanding of the status quo, or assumptions that would illustrate the effect of changing policies. Changes modelled can be of many different kinds. For example, it is possible to project an existing occupation using current intake plans, current Preferred Manning Levels (PMLs) at the ranks, and current attrition patterns to see if personnel flow smoothly through the occupation over 20 projected years or more. Simulation modelling can indicate how likely there could be issues, such as a future shortage of promotable members to satisfy requirements at a higher rank.

Simulations can alternatively project career progression patterns under changed assumptions. A simple example would be the case where the number of positions available at various ranks are changed in order to accommodate a revised occupation size due to a need to reduce or increase the size of an occupation. Again, it is possible to simulate whether the assumed values are expected to provide a good personnel flow over time. A different example is where unplanned events change the nature of expectations, such as how COVID-19 resulted in decreased recruitment for military occupations. In this case an occupational model could simulate what would be the likely downstream effect of such an unexpected event over time.

Personnel simulation modelling can contribute to meeting military expectations as expressed in a recent Canadian defence policy document titled "Strong, Secure, Engaged" [4]. The document describes force capabilities important to meeting Canada's operational commitments. It states that to meet its objectives

"Canada needs an agile, multi-purpose, combat-ready military, operated by highly trained, well-equipped women and men". Personnel planning for occupations in conjunction with simulation modelling can provide confidence that implemented policies will provide consistent, effective personnel flow through the ranks over time, with sufficient training to be operationally ready as required.

"Strong, Secure, Engaged" also refers to the monetary budget needed to maintain Canada's military. Canada's military roles cover many aspects, including collaborative defence commitments with the United Nations (UN), the North Atlantic Treaty Organization (NATO), and the North American Aerospace Defense Command (NORAD). Considering that a very large proportion of the budget is needed to fund personnel and personnel training required for operational effectiveness, simulation modelling can provide a means to leverage personnel cost by verifying that personnel are operationally available as needed, with appropriate training to be effective.

1.2 Importance of Good Planning

As mentioned previously, all, or most members of a typical military occupation enter at the bottom level. With few exceptions the members progress to some higher rank levels, and then either leave to pursue another livelihood or to retire. If they do not leave voluntarily, then they will have to leave once they reach a mandatory retirement point, which in the Canadian military could be upon reaching a maximum allowed age.

This career pattern results in limited ways in which managers can shape the population of an occupation. For instance, it may be impractical or difficult to introduce new members into an occupation at intermediate rank levels since they would already need to have appropriate knowledge and work expertise associated with the occupation. It may be possible, in some cases, to have occupational transfers of members from a related occupation, but this could then have adverse effects for the occupation, which would lose some of its members.

Career management is easiest when an occupation is comfortably in a steady state situation, where intake balances with members leaving, and where the experience profile histogram of members' YOS is a monotonically decreasing value from early YOS values to YOS values near mandatory retirement age, and no significant disruptions are happening. Disruptions to an occupation, such as significant increases to rank PML values when an occupation is increasing in size, or significant decreases in occupational size (such as the Canadian "functional review" in the 1990s, which affected many occupations) create issues that can affect an occupation in various ways.

Disruptions can alter an occupation's steady state creating multi-year impacts on an occupation. For instance, occupations with significantly reduced intake in recent years due to COVID-19 will have a YOS pattern which persists basically for a generation. A low number of members in, say, the 1 to 3 YOS range, compared to expectations, will, 5 years down the line, result in a low number of members in the 6 to 8 YOS range, and after 10 years will result in a low number of members in the 11 to 13 YOS range. The progression of this low dip in members will evolve relentlessly for many years. When a significant dip is passing through the YOS range where an intermediate or higher rank normally has most of its members, the number of members who are eligible for promotion to the next rank may be reduced. For instance, this could result in more promotions of members who have less than normal experience and others that are experienced but were previously passed over (for promotion). In more extreme cases a significant dip might even create problems in maintaining sufficient promotable members at one rank level to sustain the PML of the next rank.

What adds to the complexity of military career modelling is the specialization of members. Each member is trained to perform a set of duties based on an occupation, but even some occupations have a sub-occupation level of specialization. For example, members of the Marine Technician occupation are trained on distinct parts of the ship such as propulsion, steering, machinery control systems, power generation and distribution, hull systems, and so on. Furthermore, each vessel class has their own system making a position specific to only a reduced group of individuals. Planning is important to have the right people, in the right place, at the right time. For instance, on January 22, 2023, the HMCS Fredericton, a Halifax class frigate, joined the Standing NATO Maritime Group 2 (SNMG 2) via its Operation Reassurance, the CAF's current largest overseas mission. This ship is staffed by 250 members occupying positions assigned to about 20 different occupations, each one as important as the other. The impact of being understaffed in just one of the occupations can result in a unit being unable to deploy.

1.3 Previous Work

Military occupational modelling has a history of many years of effort within Canadian defence. This includes several variations of discrete event simulation modelling of occupations:

- Simple occupational structures with one rank stream from recruit to the top rank.
- Feeder - terminal structures. One example is where members join in one of three or so related but independent "feeder" sub-occupations with lower ranks which subsequently join at an intermediate rank level for a "terminal" supervisory occupation that manages the feeder occupations.
- General Officer Flag Officer model. This is typically a model of the officer corps, including Captain through General levels, exploring the flow of officers maintaining the General ranks projected over several years.
- Combinations of related occupations, e.g., combat arms, modelled together for a multi-year projection.

One aggregate model currently used is the CAF Long Range Planning Model (LRPM) [5] and [6], an MS Excel personnel flow model based on a combination of historical and steady state rates, used by the occupation stakeholders to determine the Strategic Intake Plan (SIP), the authorized number of recruits categorized by different intake plans to make sure that each occupation stays healthy, or recovers from being understaffed, without exceeding the number of authorized positions.

Another MS Excel aggregate model being used is the Occupational Structure Sustainability Model (OSSM). Given occupational parameters (ranks, attrition rate by rank, minimum time in rank for promotion, and one of desired PML or desired promotion rate or desired average TIR at promotion) calculations are carried out providing the steady state characteristic values that would result.

In addition to the aggregate models listed above, other groups have relied on different types of modelling for military workforce projections. For example, a Canadian group [7] has published an interesting comparison between their discrete event simulation model and an analytical model allowing them to validate the approach taken to answer military personnel questions. Another model example [8] used a flow model to study both the active and the reserve component of the United State Air Force, an approach different than the one used by the OHRCA2 model where the focus is on individual occupations. A similar total force model can also be simulated with OHRCA2 if necessary.

1.4 Modelling Framework

The OHRCA2 model described in this paper was developed within the ORIGAME (which stands for Operational Research Integrated Graphical Analysis and Modelling Environment) software, version 0.7.1. An example of the interface can be seen in Figure 1. ORIGAME originated with a Technical Demonstration Project funded by Defence Research and Development Canada (DRDC) to create an improved modelling environment for many sorts of analyses and problems that were encountered in personnel and operational research projects [9]. Even though commercial modelling was commonly used there was a desire for software that was more suitable for the range of modelling that was being done. A team of interested analysts created and continually refined the specifications for ORIGAME and related publications. In 2023, ORIGAME was made available to the public as open-source software (available at https://github.com/DND-DRDC-RDDC/OS_ORIGAME). Although OHRCA2 is not publicly available, other Countries can use the information contained in this publication and create similar projection tools to help with their workforce projection analyses. The OHRCA2 career progression model has benefitted greatly in being implemented in ORIGAME for some of its noteworthy features:

- A graphical interface that is “open-ended”, allowing great flexibility in model structure.
- Uses Python (version 3.5.2) as the underlying programming language and allows the importing of Python modules.
- Several basic graphical “parts” facilitate the creation of flexible model representations.
- Visual parts can be used to represent data structures, data containers, or Python code portions.
- Can show a visual representation of part interactions (e.g., linked arrows).
- Provides features that enable discrete event simulation programming.
- Allows easy use of database features, including SQLITE as a default database.
- Easy import/export of MS Excel spreadsheets and MS Access databases, or other databases, either locally, or with Open Database Connectivity (ODBC).
- The use of ORIGAME has no licensing or per seat costs for the Canadian government, and DND had control of the software.

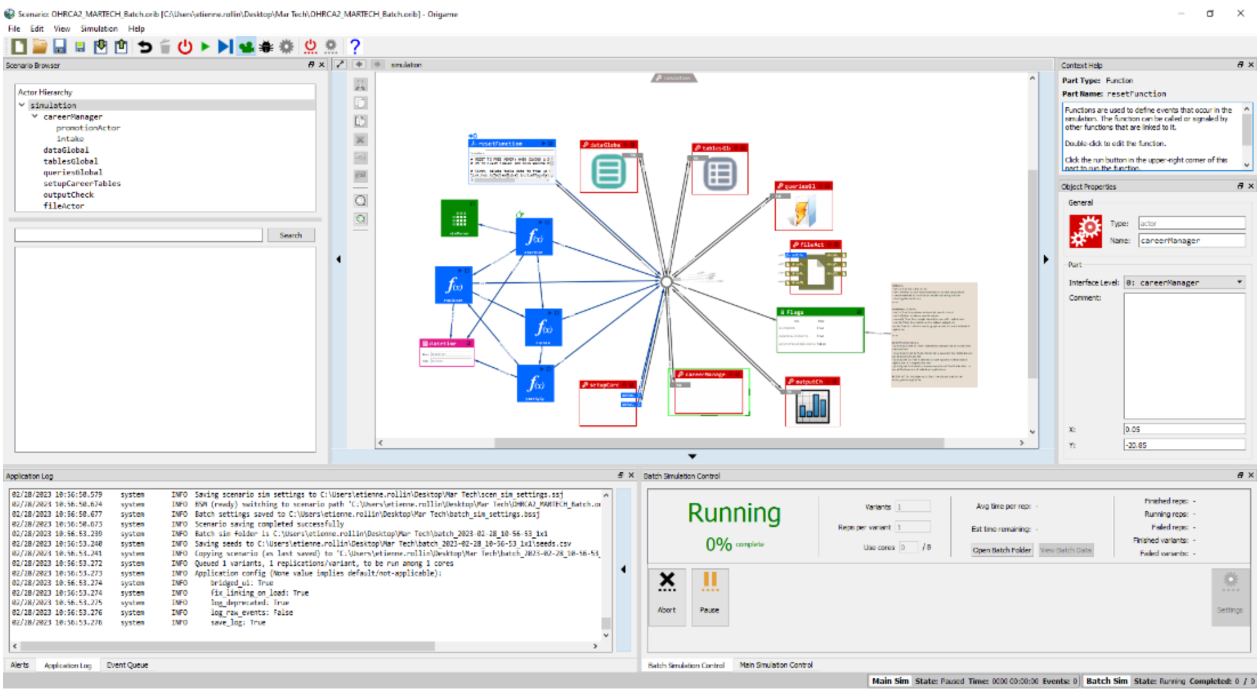

Figure 1: Diagram of the OHRCA2 model created within the ORIGAME software.

2.0 OHRCA2 GENERIC MODEL

2.1 Description of the Model

An OHRCA2 model should address this question: “Does an occupation expect to have a smooth personnel flow over time?” Relevant indicators could include:

- PML levels are maintained.
- “Healthy” promotion rates from lower ranks to higher ranks. Acceptable probability of promotion is desired with no excess “stagnation” of members at a rank (“stagnation” could lead to problems with morale, or more members than average leaving the occupation).
- Yearly intake levels should not vary up and down too much, which would result in peaks and valleys in the YOS experience profile. This could result in some rank levels having a less than average TIR than desired, which indicates a lower average experience level of members.

If simulation modelling indicates significant issues, then “what-if” scenarios can be explored to see if the issue can be resolved, or at least mitigated. As an example, consider the situation where an occupation has a significant shortfall in promotable members from one specific rank to the next higher rank. Depending on the situation, it might be considered desirable to promote to a proportion less than the desired PML over several ranks. In other words, it would “share the pain” by spreading a shortfall over the ranks instead of having a bigger problem at just the one rank.

A simulation run for the Generic Model using ORHCA2 follows a pattern of computation as follows:

- Read in model information from Excel spreadsheets and initial setup.
- For each replication, simulate appropriate number of Run Years and for each Run Year, cycle through:
  - Application of yearly attrition.
  - Application of TOS (e.g., maximum age policy).
  - Members are aged one year (Age, YOS, TIR values are increased by 1).
  - “Push” promotions and “Pull” promotions are simulated.
  - Member intake is done according to planned defined intake or calculated custom code.
- On completion of replications some final code is run to tabulate collected simulation data and generate several charts showing various results (e.g., average YOS by Rank by Run Year).

Inputs for the Generic Model are provided in structured Excel spreadsheets as follows:

- Initial Population, with one row per member, with fields representing model attributes such as YOS, TIR, Rank (a RankID number), etc.
- Attrition Rates, showing percentage probability of a member leaving in a modelled year, classified by YOS and Rank.
- PML Values, showing Preferred Manning Levels by Rank.
- Production, which has values used to simulate distributions for entry member Rank and YOS.
- Ranks, showing Rank name and number, minimum TIR for promotion, and whether the rank is “Push” promoted upward or not.
- Simulation Parameters, specifying number of simulation replications, number of Run Years per Replication, maximum age allowed under TOS, and some other basic items.

Unless specified differently, the input data included in models is taken from the Director Research and Workforce Analysis Data Mart, built from data extracts of Guardian, the CAF Human Resources Management System, dated April 15, 2023. Data are current to March 31, 2023. The initial population of the model is taken directly from the current CAF Regular Force population, and each member is assigned a rank, age, YOS and TIR. For sensitivity reasons, some of the input data is only provided on an aggregate level or simply omitted from this publication.

Any code customizations needed must be done before running a model. With a basic model this may be as simple as providing a number, or a set of numbers, to define intake values year by year.

The first model discussed in this paper is the Generic Model applied to the Sonar Operator occupation of the CAF Regular Force. It was chosen for its very simple structure, relatively healthy staffing and the stability of the occupation.

2.1.1 Rank Structure

Being an NCM occupation in the Royal Canadian Navy (RCN), the rank structure for the Sonar Operator occupation is a linear progression from entry level at Sailor 3rd Class (S3) through to Chief Petty Officer 1st Class (CPO 1), as shown in Table 1 and Figure 2. The model simulation uses the generic OHRCA2 application with data-driven parameters.

The S3 rank includes recruits and carries out basic training. Once members are in the S2 rank they have reached Trained Effective Strength. Members are "Push" promoted at appropriate times from S3 through to the S1 rank level. Promotions to the Master Sailor level and higher are based on merit, meeting TIR requirements for promotion and the need to fill vacancies and are referred to as "Pull" promotions in a model.

The initial population of the model is taken directly from the current CAF Regular Force population, and each member is assigned a rank, age, YOS and TIR. Figure 3 shows the number of members and the number of vacant positions for each rank, with their corresponding historical attrition rate.

Table 1: NCM ranks, abbreviations, and their equivalent NATO rank code.

CAF Navy Rank	CAF Navy Rank Abbreviation	NATO Code
Chief Petty Officer 1st Class	CPO 1	OR-9
Chief Petty Officer 2nd Class	CPO 2	OR-8
Petty Officer 1st Class	PO 1	OR-7
Petty Officer 2nd Class	PO 2	OR-6
Master Sailor	MS	OR-5
Sailor 1st Class	S1	OR-4
Sailor 2nd Class	S2	OR-3
Sailor 3rd Class (Basic)	S3 (B)	OR-2
Sailor 3rd Class (Recruit)	S3 (R)	OR-1

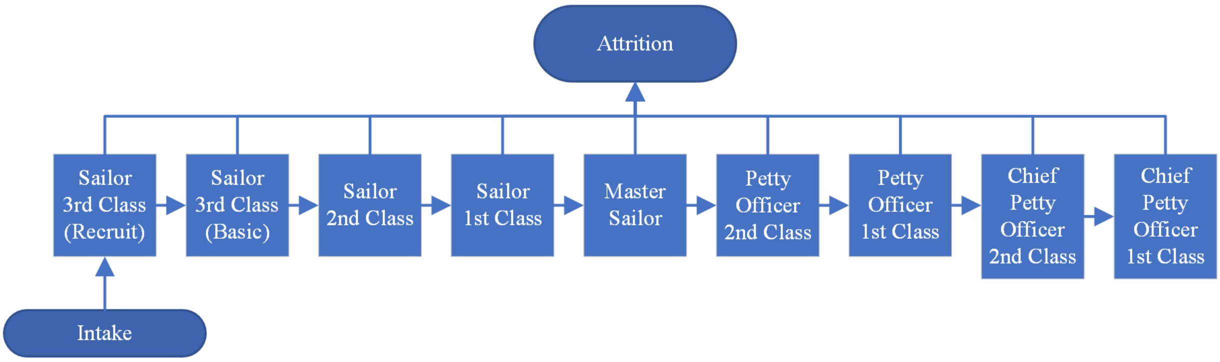

Figure 2: Diagram of a generic military career progression structure for Navy non-commissioned members.

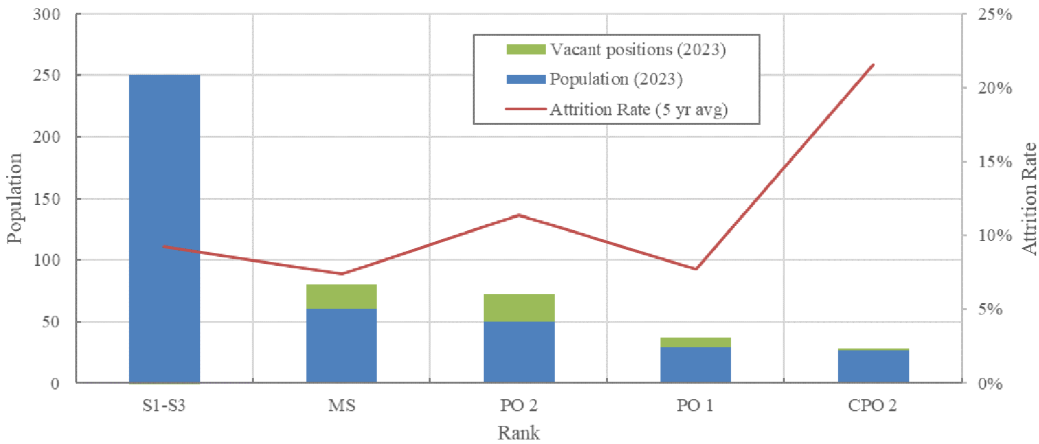

Figure 3: Current population, number of positions and historical attrition rate for the Sonar Operator occupation at each rank.

2.1.2 Intake

In the simulation, new recruits are created at the lowest rank, without previous experience. The number of recruits for the first 10 years of simulation is taken from the strategic intake plan (SIP), which outlines the recruitment targets for each occupation within the CAF. This SIP is calculated so that the trained population reaches but does not exceed the number of authorized positions. For simulated years greater than 10, where no SIP has been defined, the number of recruits is set to ensures the equilibrium between intake and losses. To do so, the model was simulated until it reached a steady state for the required PML and from this state, the average yearly losses was calculated. A summary of the intake for the Sonar Operator occupation used in the model is shown in Figure 4.

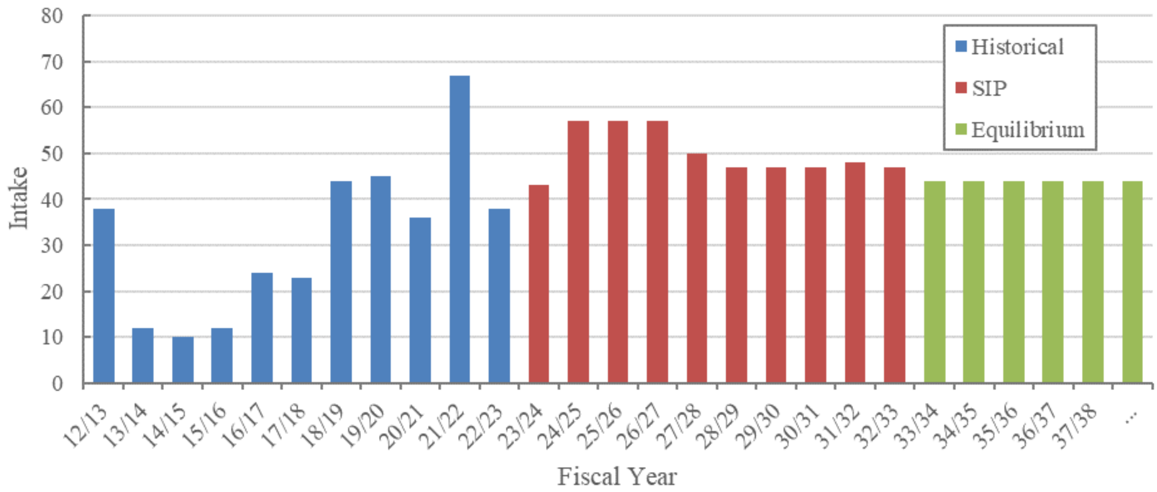

Figure 4: Sonar Operator intake historical numbers compared to the intake used in the model.

2.1.3 Promotions

Promotion occurs every year on two different conditions. First, a member should have reached the minimum experience level required to be promoted, as described in Table 2. Second, to be promoted to the rank of Master Sailor (MS) and above, there should be a vacant position available. The selection of which promotable individuals are promoted is made randomly to avoid unintended promotion patterns.

Table 2: Minimum experience requirements to be promoted for most non-commissioned members' occupations.

Promoted From	Promoted To	Minimum Time in Rank for Promotion
S3 (R)	S3 (B)	N/A
S3 (B)	S2	30 months qualifying service
S2	S1	4 years qualifying service
S1	MS	2 years seniority as S1
MS	PO 2	2 years seniority as MS
PO 2	PO 1	3 years seniority as PO 2
PO 1	CPO 2	3 years seniority as PO 1
CPO 2	CPO 1	2 years seniority as CPO 2

2.1.4 Attrition

Each year, a member has some likelihood of leaving the CAF. Given a member's rank, a probability of leaving the CAF is calculated from the last 5 years of historical data, and a random number will determine if the member stays or leave. Figure 3 shows the attrition rate for the Sonar Operator occupation at each rank.

An exception is made for the recruits' first year of service, where a correction is applied to the yearly attrition rate to compensate for the fact that the simulation adds them at the beginning of each year. In reality, recruits are hired throughout the year, so not everyone will spend a full year in service, therefore has a lower chance to leave the CAF. On average, members will spend half a year in service during their first year, so the simulation will apply a factor of 0.5 to the yearly attrition rate to the first year of every new recruit.

2.2 Results

The Generic Model using the Sonar Operator data was run 100 times, using the same initial population and assumptions, but using different random number seeds. The simulation output files record a snapshot of each member and their attributes for each simulated year, along with the intake, promotion, and release information. The health of an occupation is determined by the number of trained members compared to the number of positions available. In the Generic Model, there is no differentiation between trained and untrained numbers, so a conversion has to be made for comparison purposes. In this study, the conversion simply used the current fraction of members that are trained at each rank and applied this fraction to the simulation data. Results of 100 repetitions are shown in Figure 5. The figure shows the historical population, followed by the average population from the simulation, both shown in comparison to the number of authorized positions. Since each repetition was performed with a different random number seed, coloured bands are added surrounding the average line to indicate the range covered by 75% of the simulations (in green) and by the maximum and minimum values (in yellow).

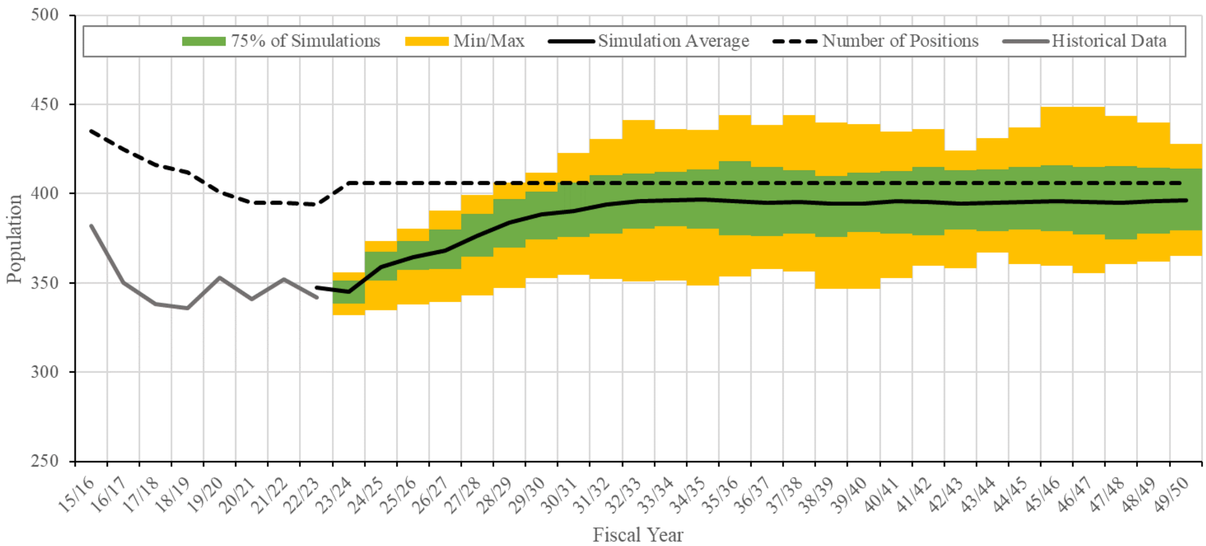

Figure 5: Simulation results for the trained effective strength of the Sonar Operator occupation based on 100 repetitions. Green areas represent regions containing 75% of the scenarios, while yellow ones represent 100%. The average population is represented by a solid line while the dashed line is the number of positions.

The first interesting observation is the average simulated population over the 10 years between fiscal year 39/40 and 49/50 results in 97.4% of positions being filled, indicating the most likely scenario being an evolution towards a healthy occupation status. Note that for the DND, an occupation is considered healthy if 95% to 100% of the positions are filled. The status is considered critical below 90%.

The second observation is the variations of all 100 repetitions. Considering each repetition individually, it is found that only 1.7% of the repetitions will fall in the critical category for a given year after 49/50. Assuming that the number of new recruits matches the SIP and that the other parameters, such as the attrition rate, stay the same, it is very unlikely that this occupation's health would become critical.

The third observation is the evolution of the population from the current level to a stable level. Based on the results of the simulation and the assumptions described above, the occupation will most likely recover and reach healthy levels in 28/29.

It should be noted that projecting the workforce situation for 20, 50 or even 100 years might seem pointless since the status of the CAF changes regularly; new occupations are created, others merge and the PMLs are adjusted regularly based on each occupation's requirements. It is nevertheless useful to observe the evolution of the system after enabling specific staffing policies. Another interpretation of the long-term projection is to measure the transient time, setting expectations on the time it takes to transform the workforce. Finally, these projections can uncover information about the steady state structure of the occupation, not necessarily as a target, but as a system, giving insight as to how a stable workforce system behaves, given some assumptions.

3.0 OHRCA2 MARINE TECHNICIAN MODEL

3.1 Customization of the Model

Some CAF occupations are more complex than the Sonar Operator one discussed in the previous section. One strength of OHRCA2 is the possibility to customize a model to add specific features related to complex occupations. This section will describe why and how the Generic Model was modified to accurately represent the Marine Technician occupation and will present some results obtained simulating this model. It has specialties and other attributes that generate specific categories of positions, with very limited flow among them. This restriction leads to more variability in staffing caused by complex rules. It is difficult to predict the evolution of the system and to accurately forecast career progression implementing those complex rules. It is important to not only understand the cause of problems but also to identify indicators that lead to them.

3.1.1 Rank Structure

As the Marine Technician occupation is an NCM occupation just like the Sonar Operator occupation, the rank structure is identical to the one found on Figure 2. However, one major difference between the Marine Technician Model and the Generic Model is the specialization of members starting at the S1 rank (seeFigure 6). About 2/3 of members trained to be Mechanical specialists while the other 1/3 are trained to be Electrical specialists. Positions are specific to a specialization, and this attribute is important in the simulation since it adds a constraint in manning those positions that are critical to the deployment of the Navy vessels. Then, at the rank of PO 1, this constraint is relaxed, as those positions are more administrative in nature. Change in specialization (mechanical to electrical or vice versa) is exceedingly rare. In the Marine Technician Model, those specializations can be considered as non-communicating groups. In fact, in the last 3 years, only one member changed specialization out of the roughly 700 members in those specialized positions.

In addition to a member specialization, the model assigns a geographical location, either the east or the west coast, to a member that will be kept for their whole career. In fact, during the last 5 years, only 1.7% of members at the rank of S1 and above have changed coast. That accounts for 22 transfers from one coast to the other every year, both directions being almost equal. In the simulation, the coast attribute is not changed, making them hermetic categories, similar to the electrical/mechanical specializations. The initial members' coast distribution is 59% on the east coast and 41% on the west coast. Note that members located inland (e.g. at the National Defence Headquarters Carling in Ottawa) are considered on the east coast.

Finally, for simplification purposes, when representing sub-groups, the ranks have been grouped in three categories, as seen on Figure 6. S3 (B) and S2 are grouped as junior ranks; S1, MS and PO 2 are grouped as intermediate ranks; and PO 1 and CPO 2 are grouped as senior ranks. Note that S3 (R) members are not modelled for reasons discussed later in Section 3.1.2, and CPO 1 are modelled but left out of the analysis since on promotion to CPO 1, members leave the Marine Technician occupation to join the Chief Petty Officer 1st Class and Chief Warrant Officer (CPO1/CWO) Corps.

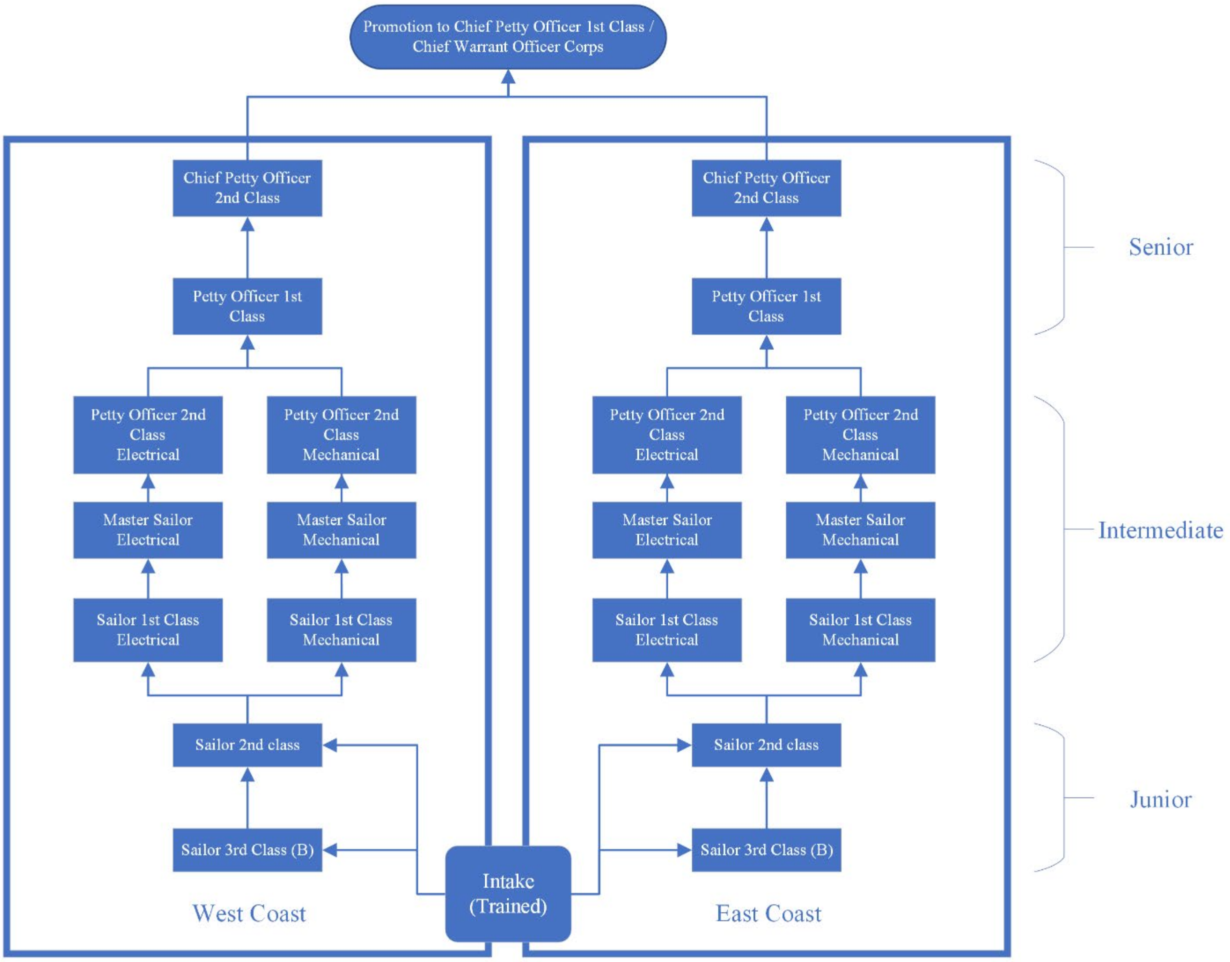

Figure 6: Marine Technician Career progression model with the distinct categories specific to the occupation.

3.1.2 Intake

The Marine Technician Model also manages the intake differently from the Generic Model. Intake is done at the Occupational Functional Point (OFP). In the CAF, positions are filled by trained individuals available to perform work. During their basic training, members do not fill a position in the establishment. Starting the model at the OFP level has advantages. First, the Navy has recently stood up the Sailor occupation for their S3 (R) and S3 (B), to pool new NCM recruits within a single occupation. Those recruits will undergo common basic training and later be assigned to an occupation depending on the Navy's needs and the members' preferences and aptitudes. This allows adjustments to the intake later, reducing the time span between intake and OFP, but also reducing the uncertainty due to attrition during the basic training period.

Since the intake is now performed at the OFP level, new members will already have experience in the CAF. They will have a different rank, TIR, and YOS. To model the experience level correctly, these three parameters are generated from probability tables generated using the last 5 years of Marine Technician data. Note that data from rehires and transfers from a different occupation or from the Reserves to the Regular Force (permanent) were included in the calculations.

Similar to the Sonar Operator occupation, the expected intake is taken from the SIP, although this time the number must be corrected for two reasons. First, the attrition rate during training is non-negligible. It is around 10% for Marine Technicians, so the intake should be smaller than the SIP. Second, there is a delay between recruitment and the moment members finish training. For transfers, this delay is approximately half a year, while for new recruits, this delay can be as long as 3 years. Therefore, a SIP for this year counts towards an intake in the future. Since there is already the LRPM, a very robust tool to convert the SIP to a trained intake, for both numbers and time, the Marine Technician Model uses the results of that tool to set its trained intake. Figure 7 shows the historical trained intake and the expected trained intake from the LRPM. In 17/18, the low intake numbers can be explained by administrative disruptions, since the Marine Technician occupation was created from merging four occupations. The intake recovered and made up the losses on the next year. In 20/21, another drop is visible, because of the COVID-19 lockdown, but this time, intake did not seem to recover in the following years. The SIP is a target, not the actual intake. In the last 5 years, the proportion of the SIP recruited is 59.4%. For the model, the trained intake is assumed to be the SIP, but later, in the results section, the effect of not achieving the SIP will also be explored.

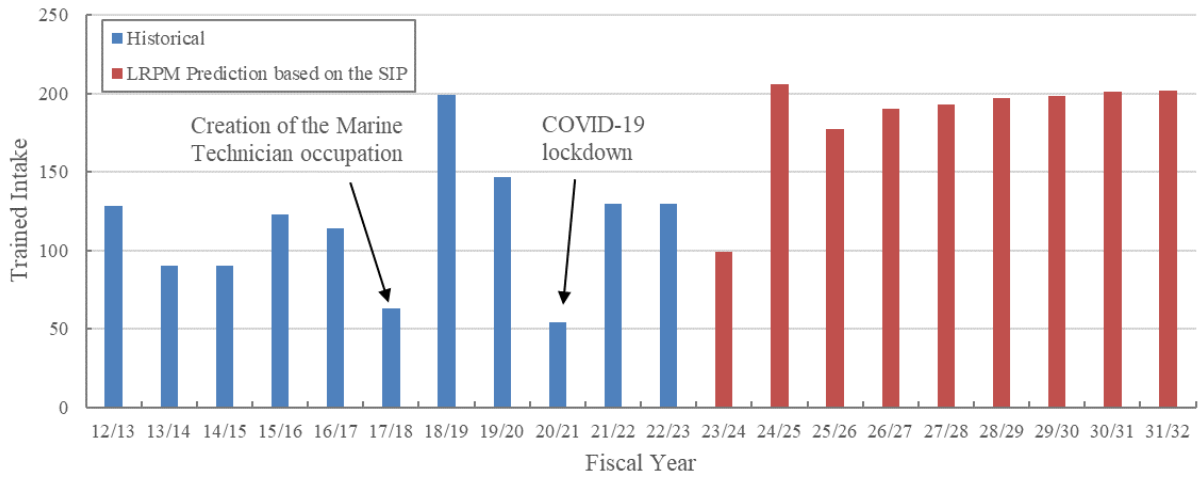

Figure 7: Marine Technician trained intake historical data and expected intake used in the Marine Technician Model.

3.1.3 Promotions

Just as in the Generic Model, the Marine Technician Model promotes members if they meet the experience level requirements (Table 2) and if there is a vacant position in the rank above (for ranks of MS and above). This algorithm was not sufficient for the Marine Technician occupation; an earlier model was promoting too many members and was leaving lower ranks severely understaffed. To reduce this problem and mimic how promotions are given in real life, an extra condition had to be included. A promotion does not occur if the rank promoted from becomes less healthy than the rank promoted to. That way, promotions do not deplete the lower ranks, and in an understaffed occupation, vacant positions are shared relatively evenly across all ranks.

3.1.4 Attrition

Another difference between the Generic Model and the Marine Technician Model is related to the attrition. When looking at the attrition rate as a function of the YOS on Figure 8, attrition peaks are can be found at 4, 9 and 20 YOS corresponds to the end of a term of service. So, since each member's YOS increases by 1 each year, they will eventually hit high attrition years. This, combined to a very uneven YOS profile for current members as seen on Figure 9, leads to fluctuating member losses when a peak or a trough in the YOS distribution eventually coincides with the attrition peaks. This fluctuation is not something that can be observed if the attrition is rank based as in the Generic Model, where the same number of people would be released, but it would be at a steadier rate. Therefore, the Marine Technician Model is YOS-based to increase the year-to-year precision of the model. Note that both methods would be equivalent if the YOS distribution would be closer to a steady state.

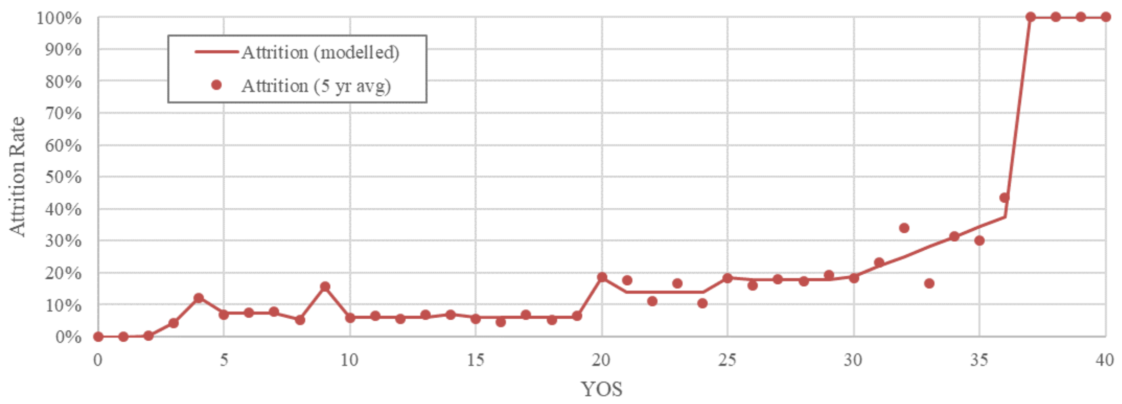

Figure 8: Marine Technician Attrition Rate by Years of Service. The dots are actual data, while the solid line is the data used in the model.

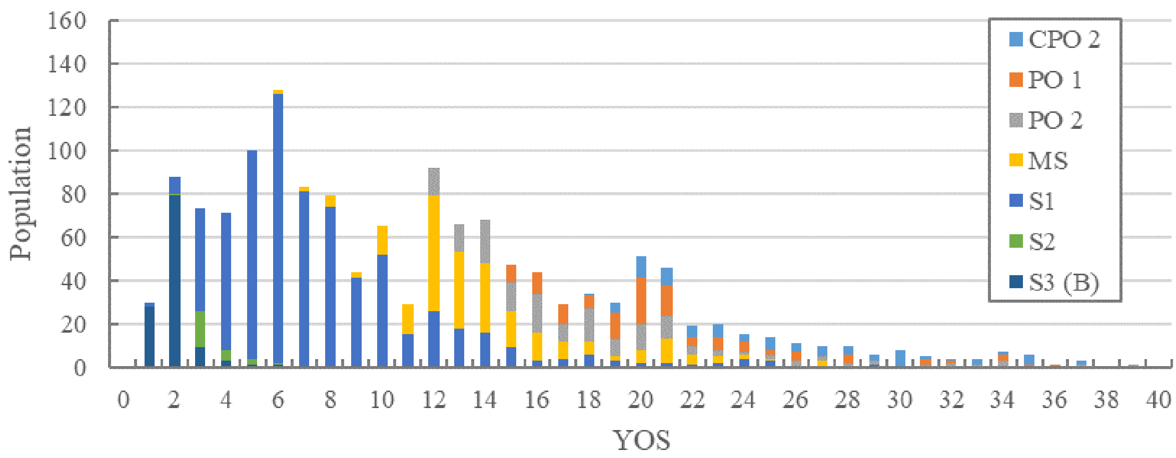

Figure 9: Current YOS distribution for trained Marine Technicians, organized by rank.

3.2 Results

Since the Marine Technician Model only includes trained members, results of simulations can be directly used and compared with the number of positions, without the correction factor used in the Sonar Operator simulation that includes both the untrained and trained members. Figure 10 uses the same layout as Figure 5 to display the number of trained members compared to the number of positions available. Assuming the SIP is achieved, and only looking at the last 10 years of simulated data (39/40 to 49/50), the Marine Technician Model shows that the number of filled positions is, on average, 95.4%, which is considered as healthy. Taking the repetitions individually, none of them crosses the critical level once the occupation is expected to recover, most likely in 31/32, based on the average population results.

On a specialization level, Figure 11 shows similar information on the population as a function of time, but this time, for each category described in Section 3.1.1, namely the rank group, coast, and job specialization, a few more observations can be made. First, it appears that the junior ranks' staffing level is low, even on the long term. Since almost all positions are filled when the rank is ignored, the problem is mostly just rebalancing ranks by increasing the TIR at promotion of those junior ranks. In fact, this might already be occurring considering that the training schedule might restrict members' opportunities to be promoted when they reach the minimum TIR. Modelling training might show that junior rank promotions take more time than planned and the staffing level is more uniform at all levels. This will be discussed later in section 4.1.1.

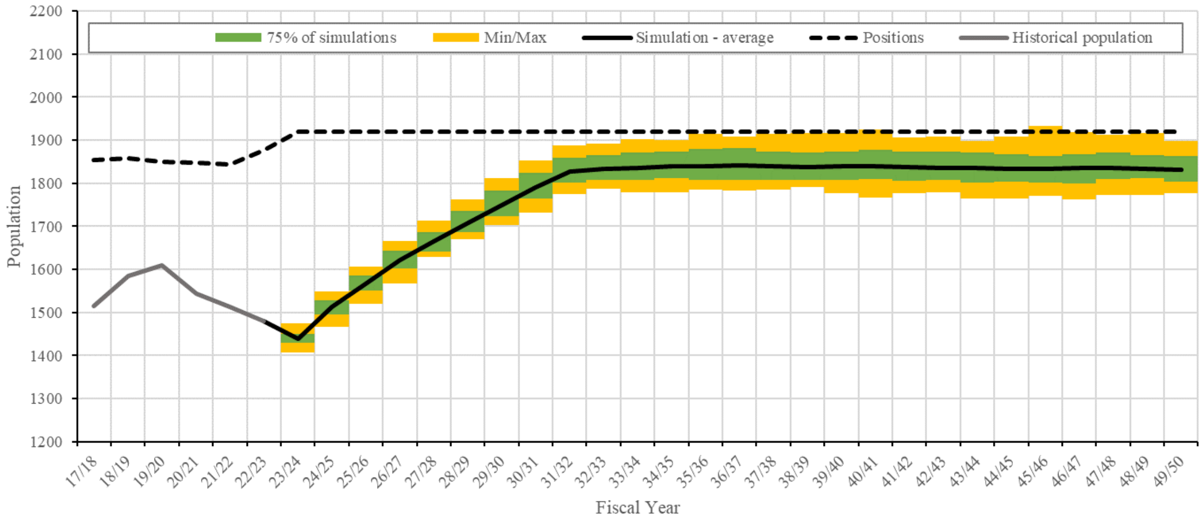

Figure 10: Simulation results for the trained population of the Marine Technician occupation based on 100 repetitions. Green areas represent regions containing 75% of the scenarios, while yellow ones represent 100%. The average population is represented by a solid line while the dashed line is the number of positions.

The second observation is that the electrical specialization eventually exceeds the number of positions, especially on the east coast. This simply shows that historical intake privileged this specialization due to its lower staffing level. In the future, a re-evaluation of the needs of each specialization will be made by the occupation authority, and adjustments will be made. The model does not include an algorithm that adjusts input parameters dynamically, for example to assign specialization. Although such an algorithm would be easy to include in the model, it would obscure trends. It is important to note that simulating the model 100 years in the future is not to forecast the occupation for that long, but more to show trends and get a snapshot of the steady state of the model, given some assumptions.

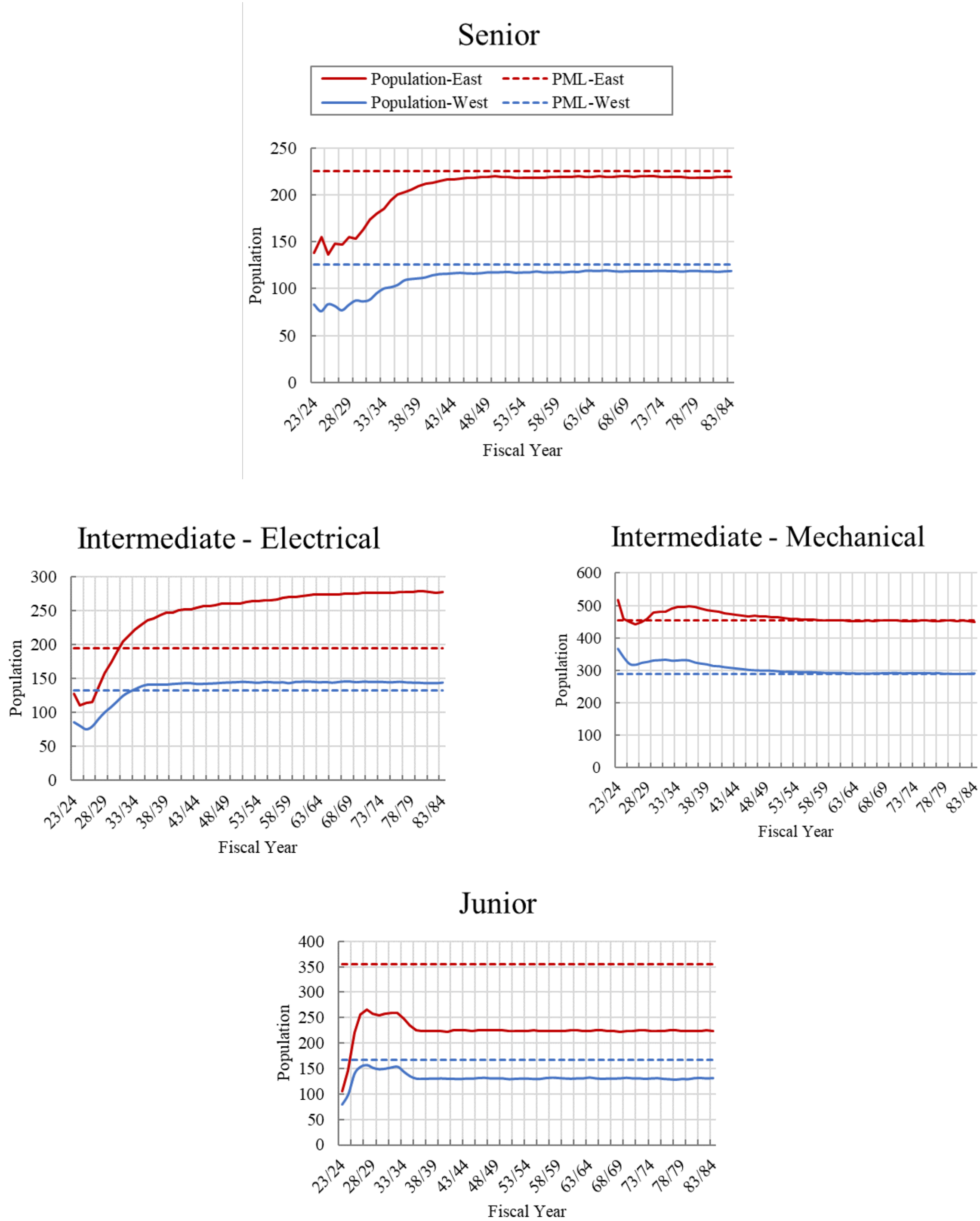

Figure 11: Marine Technician population simulation of each specialization category as a function of time. Solid lines are the population while the dashed lines are the number of positions. The colour red represents the east coast, and the blue represents the west coast.

Following up on the idea of exploring the steady state of the model, it is interesting to compare the YOS distribution of current members (Figure 9) to the steady state of the model (Figure 12). The steady state consists of an average of the 100 repetitions, taken on the simulated year 100.

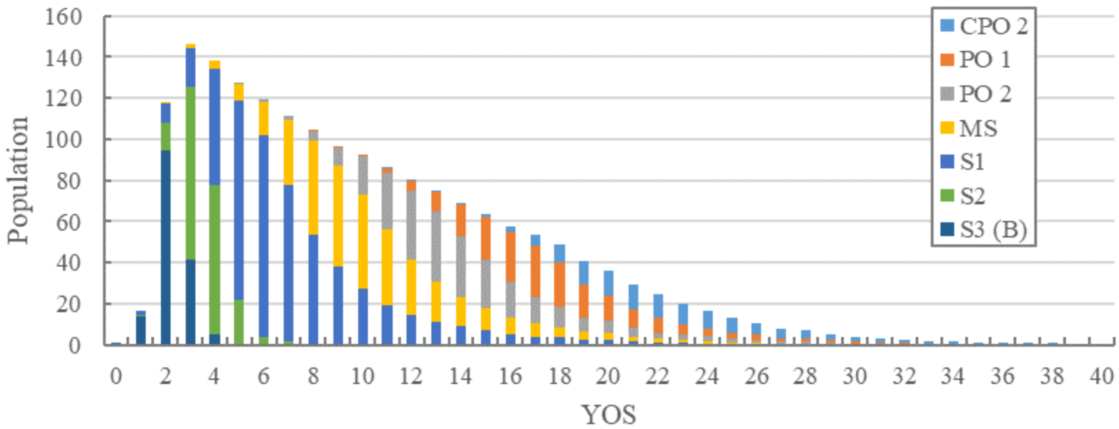

Figure 12: Steady state YOS distribution for trained Marine Technician, organized by rank.

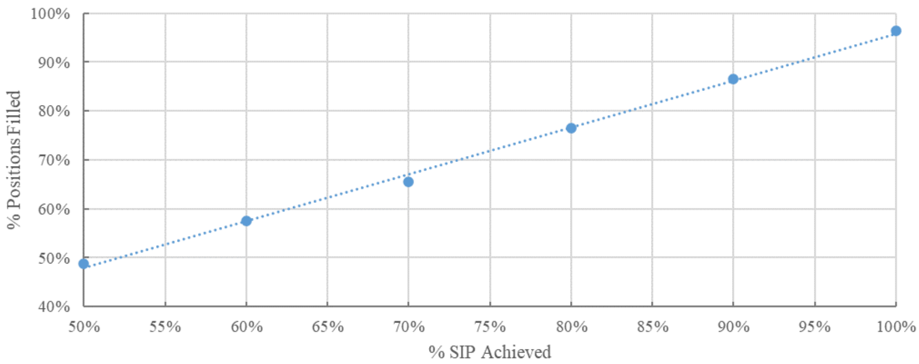

Figure 13: Marine Technician simulated steady state population for different SIP fraction achieved, including a linear regression over the results.

As mentioned in Section 3.1.2, the actual intake does not necessarily match the SIP. So far, the results shown were assuming that the intake matched the SIP. Nevertheless, it is interesting to run the Marine Technician Model for different fractions of the SIP achieved. Common sense would dictate that for a long enough period, the fraction of the SIP achieved would eventually translate to the same fraction of positions filled. By letting the model reach steady state (between 40 and 60 years of simulations), results show this exact conclusion. This can be seen in Figure 13. Using a linear regression on data shows that each percentage point of the SIP constantly missed results in a 1.04% drop in the fraction of the number of positions filled.

4.0 CONCLUSION

This paper introduced a new discrete event simulation tool, OHRCA2, to forecast military workforce progression within CAF occupations. This tool will help to determine the strength for different member categories based on a set of attributes. Through two models, the Generic Model and the Marine Technician Model, it was demonstrated that some military occupations have specific features that require a flexible tool to take into account any career progression specificity of the occupation. For example, the Marine Technician Model generates new recruits at experience levels based on current members' data and promotes members within a rank structure that includes job specializations and geographical location.

Being a discrete event simulation, the new OHRCA2 tool simulates yearly snapshots of members and their attributes in addition to important career events, including intake, promotion, and attrition. This data can later be explored to inspect both the transient and the steady state aspect of a model to forecast the state of the military workforce, verify the potential of new policies, or identify early signs of staffing problems. Possible solutions to alleviate problems can be explored by running "what-if" scenarios.

4.1 Future Work

4.1.1 Training

Although most career progression modelling may not require it, OHRCA2 can simulate course loadings and assignments on a yearly basis in conjunction with career progression modelling. This capability can indicate whether planned occupational course training capacity is sufficient to meet an occupation's needs over time. Both required occupational courses (necessary for promotion) and optional courses (needed by the occupation but not necessary for promotion) can be included in a model to see if the provided training capacity is likely to meet expected course demands.

Using the Marine Technician occupation as an example, each vessel class has their own set of courses adding to the specialization of members. Each member is trained on either the Kingston, Halifax, Victoria, Orca or Harry DeWolf class, and just like the electrical/mechanical specialization, a member would be assigned to a specific class and would be required to pass a list of courses to be promoted. This functionality is already present in OHRCA2, but testing needs to be performed before using it in a model.

4.1.2 Dynamic Attrition Rate

It is possible to add an attrition rate module that depends on not only the rank and/or the YOS, but also other factors. The first one that comes to mind is if the time in rank for a given member becomes too long or, in other words, a member is not being promoted; one can imagine the likelihood of leaving the CAF increases. So, adding the time in rank as a parameter in the attrition module could increase the authenticity of the model. Another factor is if the number of members in a specialization decreases significantly, the remaining members might be overworked and become displeased by their condition, increasing the attrition rate for those members.

The OHRCA2 code can allow for a change in the attrition rate with minimal modifications. The information about the members' behaviour for the conditions listed earlier is not readily available; a collaboration with other researchers will be necessary to implement a dynamic attrition rate in the model. Although the economy can also affect the attrition rate, including economic factors and market conditions is beyond the scope of the model. Adding too many uncertain factors might hide some valuable insight in factors that are more certain and more amenable. However, a sensitivity analysis can be performed by varying the value of different factors, and measuring the impact on the outputs of the model can identify the most important factors and put limits on the effect of such factors.

4.1.3 Automation

In its current state, OHRCA2 does not exploit all the benefits of ORIGAME. The Python-based programming environment allows direct entry of MS Access databases, performs SQL database queries, and generates input data for the model, a task that is currently manually performed outside ORIGAME. One can imagine that when a new CAF military personnel data snapshot is produced, typically every month, OHRCA2 would automatically update the input parameters, like the initial population, attrition rate, experience distribution, etc. and proceed with generating a refined forecast based on these new parameters. Furthermore, although OHRCA2 already generates several graphs automatically with Python libraries, it would also be possible to generate standard reports at the end of a simulation, for example within MS Power BI. These tasks are not a priority at the moment, but they remain a possibility.

5.0 ACKNOWLEDGMENTS

The authors would like to acknowledge Lynne Serré for her work on the OHRCA model, Michelle Straver for her advice on methods to analyze historical CAF HR data and Eloise Sheppard for editing assistance of this paper.

6.0 REFERENCES

[1] B. Solomon, P. Chouinard and L. Kerzner, "The Department of National Defence Strategic Cost Model. Volume II - Theory and Empirics," Center for Operational Research and Analysis, Ottawa, ON, Canada, Technical Report 2008-03, October 2008.

[2] C. Penney, "Canada's Military Expenditure and the NATO 2% Spending Target," Parliamentary Budget Officer, Ottawa, ON, Canada, June 9, 2022.

[3] R. Ueno, "Historical study of time in rank trend at promotion," Director General Military Personnel Research and Analysis, Ottawa, ON, Canada, Scientific Letter DRDC-RDDC-2021-L217, August 2021.

[4] "Strong, Secure, Engaged: Canada's defence policy," Department of National Defence, Ottawa, ON, Canada, 2017.

[5] S. Okazawa, M. Straver and L. Arseneau, "Occupation Promotion Recruitment and Attrition Model (OPRAM)," Director General Military Personnel Research and Analysis, Ottawa, ON, Canada, Scientific Report DRDC-RDDC-2018-R273, December 2018.

[6] I. Lai and M. Straver, "Recent modifications to the Canadian Armed Forces (CAF) Long Range Planning Model (LRPM)," Director General Military Personnel Research and Analysis, Ottawa, ON, Canada, Scientific Letter DRDC-RDDC-2021-L037, January 2021.

[7] J. A. Henderson and R. M. Bryce, "Verification Methodology for Discrete Event Simulation Models of Personnel in the Canadian Armed Forces," 2019 Winter Simulation Conference (WSC), National Harbor, MD, USA, 2019, pp. 2479-2490, doi: 10.1109/WSC40007.2019.9004841.

[8] L. M. Harrington, J. H. Bigelow, A. D. Rothenberg, J. Pita, and P. Emslie, "A Methodology for Modeling the Flow of Military Personnel Across Air Force Active and Reserve Components", Santa Monica, CA: RAND Corporation, 2016, doi: 10.7249/rr825.

[9] S. Okazawa, "A discrete event simulation environment tailored to the needs of military human resources management," 2013 Winter Simulations Conference (WSC), Washington, DC, USA, 2013, pp. 2784-2795, doi: 10.1109/WSC.2013.6721649.