WORKFORCE MODELLING TOOLS USED BY THE CANADIAN FORCES

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ABSTRACT
Military organizations are unique in that they require significantly more workforce planning than other organizations. Since personnel generally join the military at the lowest rank and then work their way up, personnel requirements must be forecasted well in advance to ensure a stable and sufficient workforce. Paramount to achieving this is determining the number of positions required at each rank in an occupation. For an occupation to be sustainable, it must have a sufficient number of positions at each rank, such that, for each pair of adjacent ranks, the lower rank can produce a sufficient number of personnel eligible for promotion to fill all vacancies that occur at the higher rank. The R3 Model and the EMES simulation were recently created to help the Canadian Forces assess the sustainability of their occupations. These models can be applied to all occupations, military or civilian, that follow a similar flow of personnel.

Keywords: workforce modelling, occupation structure, occupation sustainability

1. INTRODUCTION

The Canadian Forces (CF) conducts on-going workforce planning to ensure its personnel requirements are met. Similar to most organizations, the military identifies its capability requirements and translates these into functional work areas, which are then broken down into occupations, and finally positions. However, the military is unique in that it does not recruit individuals to occupy specific positions at various levels of an occupation, but rather, it generally recruits new members into the most junior rank only, and then provides them with the necessary training and development for employment at the next rank. Members continue to move up the ranks in their occupation by obtaining the qualifications required for promotion. Obtaining these qualifications can take years; therefore, forecasting personnel requirements well in advance is paramount to ensuring a sufficient and stable workforce. However, an accurate forecast of the required number of recruits to the most junior rank will be of limited use if an occupation's structure is not sustainable. Since all ranks, excluding the most junior rank, are supplied by their preceding rank, it is necessary that each rank be capable of producing sufficient members qualified for promotion to fill vacant positions at the next rank. Therefore, one of the most significant workforce planning activities conducted by the CF is the design of sustainable occupation structures.

This paper presents how modelling and simulation has been applied to support military occupation structuring projects. In particular, two user-friendly tools created by the Workforce Modelling and Analysis team at Defence Research & Development Canada will be discussed. The first is the Risk-based Rank Ratio (R3) model, which provides minimum bounds on the number of positions required at each rank in an occupation (Christopher and Boileau 2012) and the resulting minimum rank-to-rank ratio required between each pair of adjacent ranks. The second model is the Excel-based Military Employment Structure (EMES) simulation tool, which allows the user to analyze the effect of various parameters on an occupation's sustainability (Straver 2010).

2. R3 MODEL

In the development of an occupation's structure, the general rule-of-thumb for military occupations has been to have a pyramid-shaped structure with the number of positions at one rank equal to three times the number of positions at the next rank (or equivalently, a three-to-one (3:1) rank-to-rank ratio) to ensure occupation sustainability and allow for optimal career progression and succession planning (Mundell, Préfontaine, and McCabe 2006). However, it has been found that a 3:1 ratio is excessive for most occupations and in some cases it is not feasible due to limited resources (Boileau 2012). Therefore, the R3 Model was created in MS Excel to allow the user to calculate the minimum number of positions required at each rank to ensure occupation sustainability, based on a set of input parameters.

2.1. Model Parameters

An occupation is considered sustainable if, for each pair of adjacent ranks in the occupation, the number of candidates produced for promotion out of the lower rank is greater than or equal to attrition at the higher rank plus promotions out of the higher rank. Therefore, the number of personnel required at one rank, such that all vacancies at the next rank can be filled, is driven by expected attrition at both ranks, the time required to obtain the necessary qualifications for promotion to the next rank, and the desired number of candidates for promotion per vacant position. As such, the model allows the user to input occupation-specific data for each of these parameters, as shown in Figure 1. In addition, the user must specify the desired number of positions at the most senior rank in the occupation. The model is then able to calculate the number of positions required at each preceding rank level and subsequently, the rank-to-rank ratio between each pair of adjacent ranks. Each parameter is discussed in more detail below.

	A	B	C	D	E	J	K
1	R3 Model						
2							
3	Rank	Attrition Rate	Min Promo Req't	Additional Promo Req't	Candidates per Promo	Occupation Structure	Ratio
4	GO	20.0%				10	
5	Col	15.0%	1	1	5	16	1.6
6	LCol	11.3%	3	0	4	36	2.3
7	Maj	7.4%	4	0	2	53	1.5
8	Capt	6.0%	4	0	2	74	1.4
9					Total	189	
10							
11	User Changeable Cell						

Figure 1: R3 Model Interface

2.1.1. Attrition Rate

The attrition rate is the annual rate of personnel losses to an occupation. This rate is specified by rank in the R3 Model, as shown in column B of Figure 1. These rates can be derived based on historical data, or alternatively, the user can specify the maximum attrition rate for which they want the occupation to be sustainable. The model uses this parameter to determine expected annual attrition at each rank, and subsequently the number of annual promotions required to fill all vacancies.

2.1.2. Promotion Requirements

The promotion requirements parameter specifies the number of years an individual must attain in their current rank to qualify for promotion to the next rank. In the CF, there are minimum time-in-rank (TIR) requirements for promotion specified by the CF Administrative Orders (CFAO); however, for some occupations and ranks, additional time may be required to obtain the qualifications and experience necessary to ensure readiness for the duties at the next rank. For this reason, the R3 Model specifies the minimum TIR requirements for promotion as per the CFAO, and also allows the user to enter any additional TIR required to qualify for promotion. These promotion requirements are shown in columns C and D of Figure 1, respectively, and together make up the total TIR requirement for promotion. The model uses this parameter in calculating the number of positions required at each rank such that a sufficient pool of candidates for promotion can be produced each year.

2.1.3. Candidates Per Vacancy

This parameter specifies the preferred number of members eligible for promotion per vacancy at the next rank. For example, if the number of candidates per vacancy is two at the Captain rank, this means that for each vacancy at the Major rank, there are two Captains eligible for promotion to fill that vacancy. The number of candidates can also be thought of as a promotion rate, which is equal to the number of members promoted divided by the number of candidates. Therefore, given *c* candidates for promotion per vacancy, the promotion rate is equal to *1/c*. The optimal number of candidates per vacancy, or alternatively, the optimal promotion rate is one that balances selection and stagnation. For example, it is desirable to have multiple candidates to choose from to ensure that only the best candidates are selected for promotion. However, as the number of candidates increases, the promotion rate decreases, which could lead to stagnation. Overall, the choice of candidates per vacancy is somewhat arbitrary. These numbers are shown in column E of Figure 1. This parameter is used to determine the total number of candidates for promotion required annually at each rank.

2.1.4. Occupation Structure

The occupation structure specifies the number of positions at each rank in the occupation. The purpose of the model is to output the occupation structure for all ranks except the most senior rank. The model uses the number of positions at the most senior rank as the starting point in the algorithm's calculation sequence; therefore, the last parameter that must be specified in the R3 Model is the desired number of positions at the most senior rank. This number will depend on the requirements of the occupation.

2.2. Model Assumptions

Prior to explaining the model algorithm, it is important to discuss the assumptions build into the model. First, it is assumed that promotions operate on a pull-based system and not a push-based system, meaning that a promotion will only occur if there is a vacant position to fill. Second, it is assumed that vacancies at a rank can only be filled via promotions from the rank immediately below. Third, it is assumed that all promotions are awarded at one point in time each year; more specifically, at the end of the year. This is a reasonable assumption for military occupations because merit boards are generally held once per year. Finally, it is assumed that promotions will be awarded in a top-down sequence, meaning that vacancies will be filled at the most senior rank first, followed by the second most senior rank, and so on. This ensures that vacancies created as a result of promotions will be filled.

2.3. Model Algorithm

The model algorithm calculates the number of positions required at each rank and subsequently, the rank-to-rank ratio between each pair of adjacent ranks. For simplicity, several columns used in the model algorithm are hidden from the user in the model interface. These columns are revealed in Figure 2 and Figure 3.

	E	F	G	H	I	J
1						
2						
3	Candidates per Promo	Attrition Volume	Required Promotions	Selection Pool	TIR Pool	Occupation Structure
4		2.0				10
5	5	2.4	2.0	11.8	4.4	16
6	4	4.1	4.4	19.8	15.9	36
7	2	3.9	8.5	18.3	34.4	53
8	2	4.4	12.4	26.4	47.5	74
9	Total					189

Figure 2: Hidden Calculation Columns: F to I.

	J	K	L	M	N	O	P	Q	R	S	T	U
1												
2												
3	Occupation Structure	Ratio	TIR:	1	2	3	4	5	6	7	8	9
4	10											
5	16	1.6		4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	36	2.3		8.4	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	53	1.5		12.4	11.5	10.6	0.0	0.0	0.0	0.0	0.0	0.0
8	74	1.4		16.8	15.8	14.9	0.0	0.0	0.0	0.0	0.0	0.0
9	189											

Figure 3: Hidden Calculation Columns: L to U.

The following notation is used to describe the model algorithm:

R: number of ranks
A_r: annual attrition rate for rank r
E_r: total TIR required for promotion out of rank r
C_r: number of candidates per promotion out of rank r
O_r: number of positions at rank r
L_r: expected annual attrition volume at rank r
P_r: annual number of required promotions from rank r to rank r-1
S_r: total number of candidates required in the selection pool at rank r at the beginning of each year
V_r: expected annual attrition volume from the selection pool at rank r
$Y_{r,t}$: total number of members required at rank r with t years of TIR
T_r: total number of members required at rank r that are not in the selection pool.
K_r: number of positions at rank r per position at rank r-1.

Note that in the above notation, rank r ranges from 1 to R, where rank 1 refers to the most senior rank and rank R refers to the most junior rank.

The calculation sequence used to derive the occupation structure will be explained below by examining the top two ranks in the structure; however, the generic equations presented are applicable at all other levels.

The first step in the algorithm is to determine the expected attrition volume at the most senior rank. Expected attrition is calculated as

$$L_r = A_r \times O_r,\ (r = 1,\dots,R). \qquad (1)$$

Therefore, as shown in cell F4 of Figure 2, expected attrition at the General rank is L_1= 20.0% x 10 = 2.

These personnel losses create vacancies that must be filled via promotions from the rank below; therefore, the next step in the algorithm is to determine the number of required promotions from rank 2 to fill the vacancies at rank 1. It is important to note that vacancies occur at a rank as a result of attrition *and* promotions out of that rank; however, there are no promotions out of the most senior rank. The annual number of required promotions is calculated as

$$P_r = A_{r-1} + P_{r-1},\ (r = 2,\dots,R). \qquad (2)$$

Since the General rank does not have promotions out, the required number of promotions from Colonel to General is $P_2 = 2 + 0 = 2$, as shown in cell G5 of Figure 2.

The next step in the algorithm is to determine the total size of the selection pool required at the second most senior rank. A selection pool is made up of members at rank r who will have TIR greater than or equal to E_r by the end of the year; that is, by the time promotions are awarded. Since attrition occurs throughout the year, the total size of the selection pool represents the number of members required in the pool at the beginning of the year such that a sufficient number of members will remain in the pool by the end of the year. This figure is calculated as

$$S_r = \frac{P_r \times C_r}{1 - A_r},\ (r = 2,\dots,R). \qquad (3)$$

Cell H5 of Figure 2 shows that the total required number of Colonel candidates is S_2= (2 x 5) / (1 – 15.0%) = 11.8.

The entire population at rank r can be thought of as different pools of members that are divided up based on their TIR. Since it is assumed that promotions occur at the end of the year, each member's TIR at the end of the year is of more interest than their TIR at the beginning of the year. Therefore, the population at rank r (for $r > 1$) is divided up based on each member's TIR at the end of the year. However, members with TIR greater than or equal to E_r are grouped together into one pool, which is known as the selection pool discussed previously. So, the entire population at rank r (for $r > 1$) is divided up into TIR pools (denoted by $Y_{r,t}$, where $t = 1,..,E_r$–1) and a selection pool (denoted as S_r). Each year, as members accumulate an additional year of TIR, they move from one TIR level to the next and eventually to the selection pool. When a member is promoted, they move from the selection pool at rank r to the lowest TIR level at rank r-1 and start the cycle over again. This means that the selection pool is sustained by the highest TIR level pool, and the highest TIR pool is sustained by the second highest TIR pool, and so on. Therefore, the next step in the model algorithm is to determine the required size of each TIR pool for the second highest rank. The size of a TIR pool is calculated as

$$Y_{r,t} = \frac{P_r + V_r}{(1 - A_r)^{E_r - t}},\ (r = 2,\dots,R \text{ and } t = 1,\dots E_r\text{-}1), \qquad (4)$$

where

$$V_r = S_r \times A_r, (r = 2,...,R). \quad (5)$$

Cells M5 to U5 in Figure 3 show the total number of Colonels required in TIR pools 1 to 9, respectively. Since the total TIR required for promotion from Colonel to General is two years, a TIR pool is only required for one year of TIR; those who will have two or more years of TIR at the end of the year are in the selection pool. Figure 3 shows that the total number of Colonels required in TIR pool 1 is $Y_{2,1}$ = (2 + 1.8) / [(1 – 15.0%)$^{(2-1)}$] = 4.4.

The next step in the algorithm is to determine the total number of members required at the second most senior rank, excluding those in the selection pool. This figure is calculated as

$$T_r = \sum_{t=1}^{E_r - 1} Y_{r,t}, (r = 2,...,R). \quad (6)$$

Therefore, the total number of members required in addition to the selection pool at the Colonel rank is $T_2 = Y_{2,1}$ = 4.4, as shown in cell I5 of Figure 2.

The second last step in the algorithm is to determine the total number of positions required at the second highest rank. As previously mentioned, the entire population at rank r (for $r > 1$) is divided up into TIR pools and a selection pool; therefore, the number of positions required at rank r is calculated as

$$O_r = S_r + T_r, (r = 2,...,R). \quad (7)$$

The result of equation (7) is rounded to the nearest whole number. As shown in cell J5 in Figure 3, the required number of Colonel positions is O_2 = 11.8 + 4.4 = 16.2, or 16 after rounding.

Finally, the last step in the model algorithm is to calculate the rank-to-rank ratio between the second most senior and the most senior rank. This figure is calculated as

$$K_r = \frac{O_r}{O_{r-1}}, (r = 2,...,R). \quad (8)$$

Therefore, the number of Colonel positions required per General position is K_2 = 17 / 10 = 1.7, as shown in cell K5 of Figure 3.

The above sequence of steps is repeated for each rank until the rank-to-rank ratio is identified at rank R.

2.4. R3 Model Applications and Limitations

An officer occupation version of the R3 Model was presented in this paper; however, the algorithm is conceptually identical for non-commissioned member occupations. Therefore, by simply modifying the rank list, this model can be applied to any occupation that has a similar flow of personnel.

The R3 Model allows the user to provide a strategic assessment of the sustainability of an occupation structure; however, it is not capable of forecasting the health and stability of an occupation based on its current demographics. Other models, such as the EMES simulation, can be used to forecast the state of an occupation.

3. EMES SIMULATION

The overall sustainability of an occupation is dependent on both its structure and population. Therefore, the EMES simulation tool was created to allow the user to simulate the flow of personnel through the occupation and forecast the state of the occupation. By experimenting with different parameter values, the user can determine how sensitive an occupation is to changes in that parameter. In addition, the user can determine how long, if ever, it will take for an occupation to transition to a stable and healthy state, in response to a change in a parameter; for example, if promotion requirements are changed or if there is a change to the occupation structure.

The EMES simulation is a stochastic, entity-based model, where each entity represents a CF member with a set of attributes. For each time interval, attrition, promotions, and intake of personnel are simulated. At the end of the simulation, the model output provides a forecast of how many positions are filled at each rank, for each time interval, thus indicating if the occupation is sustainable under the conditions specified by the model parameters.

3.1. Simulation Model Parameters

The user must enter occupation-specific data for several parameters prior to running the model. Each model parameter is discussed below.

3.1.1. Simulation Run Setup

In the EMES model, the user must specify the number of iterations to simulate and the duration of each iteration in years. Currently, the model allows for a maximum simulation period of 30 years.

3.1.2. Occupation Structure

The user must specify the required number of positions at each rank, for each year of the simulation. This parameter is used to determine the number of vacancies at each rank, and subsequently the number of promotions. In addition, this parameter is used along with the total population to evaluate the overall health of the occupation.

3.1.3. Starting Population (Optional)

The model allows the user to supply a table that lists each member currently in the occupation of interest by a set of attributes. The table has four attribute fields: rank, years of service (YOS), TIR, and entry plan. The function of each of these attributes is discussed later.

Each member listed in this table represents an entity in the model.

3.1.4. Attrition Rate

As previously discussed, the attrition rate is the annual rate of personnel losses to an occupation. It has been found that attrition is closely related to YOS. For example, attrition has generally peaked at 20 YOS because CF members are entitled to an immediate annuity at this point. Therefore, the EMES simulation uses a YOS-based set of attrition rates. The model allows the user to specify a different set of attrition rates for each simulation year. This parameter is used to determine the probability of attrition for each member, based on their YOS for a given year.

3.1.5. Promotion Requirements

As in the R3 Model, the promotion requirements parameter specifies the number of years an individual must attain in his/her current rank to qualify for promotion to the next rank. These numbers should reflect the total time required to obtain all the qualifications and experience necessary for promotion eligibility. The EMES simulation allows the user to enter these requirements for each entry plan, so as to reflect varying training requirements for different types of recruits. For example, a person who transfers in from a different military occupation may not require as much training as a new recruit, due to their previous military experience.

3.1.6. Intake Plan

Recall that vacancies at the most junior rank in an occupation are filled via intake. The user may specify the number of new personnel recruited for each year of the simulation period, or he/she may allow the model to calculate the required number of recruits based on a user-specified rule; for example, based on the number of vacancies at the most junior rank or the total number of vacancies at all ranks. The model allows the user to specify intake for up to two different entry plans. Further, although intake is normally only applicable to the junior rank as noted previously, the model is flexible enough to allow the user to enter intake at each rank in case the need arises.

3.1.7. Attribute Assignment Rules

When the model simulates intake, it must assign attributes to each new entity. Since intake is specified by rank and entry plan, these attributes are already known. Therefore, assignment rules must be defined for the YOS and TIR attributes. The user may specify an exact value, or use a probability distribution to assign these attributes.

3.2. Simulation Model Assumptions

All assumptions pertaining to the R3 model are also applicable to this model. Similar to how promotions only occur at the end of the year in the R3 model, this model assumes that all intake occurs at the end of the year, following promotions. In addition, the model assumes that all entities are part of the trained effective strength (TES), meaning that each member occupies one of the positions in the occupation structure. That is, the time that an individual spends in training (prior to joining the TES) is not explicitly modelled.

3.3. Simulation Model Algorithm

Three types of Excel files are used to run the EMES simulation. The first is a scenario file, which contains all the user-specified parameters for a specific scenario. This file also contains the final simulation output for that particular scenario. The second file is the main model file. This file contains a worksheet for each year of the simulation and a worksheet that is used to create new entities. The last file, which is called the batch file, is used to run scenarios through the model. The user lists the name of each scenario file and then runs the batch file script. This script runs each scenario file through the model, one-by-one, until all scenario files have been completed.

The main algorithm of the EMES simulation is in the model file. For each year in the simulation, the same sequence of events is simulated. The first step in the algorithm is to populate the starting population section. For the very first year in the simulation period, this section is populated based on the starting population specified in the scenario file. For all other years, the starting population is copied from the previous year's ending population. As shown in Figure 4, each entity is represented in a row, where all calculations pertaining to that entity are done.

	A	B	C	D	E	F	G
3	Starting Population		918				
4	Rank	YOS	TIR	Intake Plan	P(Attrition)	Random #	Attrition ?
5	CWO	22	1	1	9%	0.33	0
6	CWO	26	3	1	21%	0.78	0
213	WO	33	9	1	13%	0.02	1
214	WO	35	3	1	21%	0.01	1
215	WO	36	3	1	36%	0.96	0
216	WO	16	0	1	2%	0.41	0
217	SGT	11	2	1	1%	0.94	0
218	SGT	14	2	1	2%	0.31	0
219	SGT	16	2	1	2%	0.56	0

Figure 4: Starting Population and Attrition.

The next step in the algorithm is to simulate attrition. This is done using the Monte Carlo method. Each member's YOS is used to obtain that member's probability of attrition from the scenario parameters. As shown in Figure 4 above, if a member's attrition probability is greater than the random number, the member attrits and leaves the simulation.

The third step in the algorithm is the simulation of promotions. The model first determines the number of vacancies at each rank by comparing the total population to the total number of positions at each rank. It uses each individual's TIR and entry plan attributes to determine whether the qualifications for promotion have been met, and then determines the total number of candidates at each rank. Since it is assumed that promotions occur at the end of the year, one year of experience is added to each member's TIR attribute when determining eligibility for promotion. The actual number of promotions out of a rank is equal to the minimum of the number of vacancies at the next rank and the number of candidates. When an individual is promoted, this creates a vacancy at the previous rank; for this reason, the number of promotions is calculated from senior to junior rank so that vacancies created by promotions are filled. Finally, for each rank, promotions are randomly awarded to candidates using the Monte Carlo method.

	Q	R	S	T	U	V
3	Promotion Calculations					
4	Rank	Occupation Structure	Members (after attrition)	Next Rank	Candidates	Positions Open at Next Rank
5	Pte	279	239	Cpl	58	69
6	Cpl	206	137	MCpl	137	62
7	MCpl	171	109	Sgt	80	-22
8	Sgt	141	163	WO	97	13
9	WO	119	106	MWO	80	4
10	MWO	76	72	CWO	68	6
11	CWO	17	11			

Figure 5: Promotion Calculations.

The second last step in the algorithm is to update the attributes of all members that did not attrit. The YOS attribute is incremented by one for all remaining members. For those who were promoted, their rank is updated to the next rank and their TIR attribute is reset to zero. For those who were not promoted, their rank remains the same and their TIR attribute is incremented by one. The entry plan attribute remains the same for all members.

The last step in the algorithm is the simulation of intake. The model first determines the number of new entities to create based on the intake plan defined by the user. Next it creates a row for each new entity in the Intake worksheet and assigns their entry plan and rank attribute at the same time, since these attributes are already known. Next, the model assigns YOS and TIR attributes based on the attribute assignment rules specified by the user. After all new entities have been created, the model appends this list of new members to the remaining population at the end of their intake year.

The above sequence of steps is repeated for each year until the end of the simulation period is reached; this is considered one iteration. The above is replicated for the number of iterations specified by the user.

3.4. Simulation Model Output

Several statistics are tracked during the simulation for each rank and year. These statistics include population size, percentage of positions filled, attrition volume, number of candidates for promotion, number of promotions, promotion rate, and average TIR at promotion. These results are averaged over all iterations. The user can use these data to evaluate the health of the occupation. Figure 6 shows sample output.

12	Average % Positions Filled					
13	Rank	2012	2013	2014	2015	2016
14	CWO	100%	100%	100%	100%	100%
15	MWO	100%	99%	97%	99%	100%
16	WO	92%	96%	95%	98%	100%
17	Sgt	100%	92%	93%	99%	100%
18	MCpl	65%	88%	92%	100%	100%
19	Cpl	93%	90%	97%	79%	75%
20	Pte	105%	107%	102%	115%	119%
21	Total	93%	96%	97%	99%	100%

Figure 6: Forecast of Positions Filled.

4. CONCLUSION

Sustainability is an important factor to consider when designing an occupation structure. In the past, the only guideline provided for creating a sustainable structure was the general rule of 3:1 rank-to-rank ratios. Nowadays, the CF conducts analyses using the R3 and EMES models to make more informed decisions about an occupation's position structure. More specifically, the R3 model allows a user to determine the minimum number and ratio of positions required at each rank to ensure occupation sustainability based on expected attrition and promotion requirements, and the EMES simulation allows the user to evaluate the robustness of an occupation's structure by experimenting with various parameters that affect the flow of members through the occupation. Both of these models can be customized to reflect the unique characteristics of a given military occupation. These models could also be applied to non-military occupations that follow a similar flow of personnel. Overall, modelling and simulation have successfully been applied to this particular component of workforce planning within the CF.

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