

Military Manpower Planning

Towards Simultaneous Optimization of Statutory and Competence Logics using Population based Approaches

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Keywords: Military Manpower Planning, Statutory and Competence Logic, Flow Network.

Abstract: Military manpower planning aims to match the required and available staff. Statutory and competence logics are two linked aspects of the military manpower management. Military manpower management involves the long term planning with strategic goals, and also the short term human resources management with operational goals. These two aspects are interdependent; therefore this article proposes a technique to combine both logics in the same integrated model. A combined model allows the simultaneous optimization for both logics. In this article we illustrate a model based on flow network. We present integer programming and goal programming to find optimal solutions.

1 INTRODUCTION

The military organization is assigned a variety of missions regarding the security of the country. To ensure these missions, the organization defines a hierarchic structure of job positions which have to be fulfilled by soldiers with the right competences. The military organization has a strict hierarchical structure and can recruit only at the lowest ranks, which restricts the recruitment policy; therefore military manpower planning is of major importance.

In order to meet the organization's demand over the following years, human resources managers use two manpower planning approaches, namely statutory logic and competence logic. The competence logic deals with the assignment of soldiers with the required characteristics to each job position in order to fulfill the operational goals and reach the optimal competence manpower distribution which is defined by specific required personnel amounts on different job positions groupings. This usually goes with a short term time horizon. On the other hand, the statutory logic is used to estimate the strategic evolution of the statutory manpower distribution which is personnel amounts on different ranks, usually over the long term time horizon. It considers recruitment,

promotion and retirement policies. The strategic logic goals are attainability and/or maintainability. Attainability means reaching a targeted statutory manpower distribution. Maintainability means keeping this attained distribution and maintaining it to get a steady state.

However, the two logics are interdependent and affect each other. The assignment policy related to competence logic should be adapted to the available workforce which corresponds to the long term planning prediction. Furthermore, strategic policies must be modified if the assignment does not meet the requirements. We define in this article a technique to coalesce both logics in an integrated model, which allows a simultaneous optimization of the combination of the statutory and the competence logics. The proposed model gives detailed information about the impact of new human resource management policies on the workforce distribution in the coming years.

2 PROBLEM DESCRIPTION

The military organization has to be always fully operational and ready. Therefore, it employs military manpower planning to provide the optimal required

workforce able to fill the actual job positions needed to accomplish the organization's missions. The military organization can recruit only at the lowest military ranks (Jaquette et al., 1977) (Wang, 2005) (Hall, 2009) and it has a well-defined and fixed hierarchical structure which limits the possible transitions.

In general, soldiers are characterized by a military rank, an affiliation and individual skills and competences. Military ranks define the hierarchy between soldiers. The main role in the organization is defined by the affiliation, for instance: infantry, aviation and marine. Each affiliation has some unique competences. We distinguish two types of competences: the competence related to the affiliation (ex: pilot for aviation), we call it basic skill; and the one not related to any affiliation, which we call an extra competence (ex: administration).

New recruits follow training to gain the first basic skill of the affiliation, i.e. each recruited trainee is assigned to an affiliation and follows basic courses for a determined skill (Hall, 2015). The trainee gets a promotion to the first active rank if he succeeds in the training, which makes him eligible to occupy a real job in the military organizational structure.

Promotions are granted after serving for some years in a certain rank. In order to get a promotion, many factors are regarded. They can be related to individual prerequisites as well as the whole workforce situation. Promotions can be of two types (Downes, 2015): push promotions depend only on the individual prerequisites. Second, pull promotions depend on the individual prerequisites and on the vacancies available in the following rank, i.e. fulfilling the required prerequisites of the next rank does not mean getting the promotion automatically due to the limitations in number for each rank.

Every job position has responsibilities that define assigned missions and required knowledge; thus there is the need to set access conditions to any job position (Hall, 2009). The defined conditions are related to the soldier's rank and prerequisites. Advanced ranks and job positions require more trained personnel. Therefore, training is a continuous task and not limited to new recruits. Moreover, each job position has a level of priority. These priorities define which position must be occupied before others.

For many reasons, military organizations carry out job transfers by changing soldiers' job positions. Each job transfer considers the match between requirements of the job position and characteristics of the transferred soldier. Soldiers have some

preferences for career paths, which are sequences of job positions. Most soldiers would rather follow a career path requiring their main skill. Although these preferences are considered in the planning of transfers, they cannot be always respected due to job positions which are not on preferred career paths but the organization needs to fulfill them.

On the whole, the military personnel have low attrition rates except during basic training. During basic training, there is a considerable rate of attrition. This attrition can be voluntary (i.e. trainee decision), or involuntary (because of health issues, academic failures).

The main challenge is to model the military manpower system in a way that permits for human resource managers to incorporate both strategic and operational policies. The model should be able to simulate the effect of different policies on the manpower distribution on statutory and competence levels. Moreover, it has to provide an opportunity for a simultaneous optimization of the solutions for the statutory logic and the competence logic.

3 RELATED WORKS

Military human resources management consists of two aspects, statutory logic with strategic goals and competence logic with operational goals. This section focuses on appropriate modeling methods for both logics.

Wang (2005) expressed in his review that effective military workforce planning means "there will continue to be sufficient people with the required competencies to deliver the capability output required by the Government at affordable cost". According to Wang, the mainly used approaches in workforce planning are: Markov chain models, computer simulation models, optimization models and supply chain management through system dynamics.

The statutory logic was mostly approached using Markov chain models, computer simulation models and system dynamics. Guerry and De Feyter (2009) present a review of Markov manpower planning. They illustrate different applications of Markov chains in general manpower planning problems. In a military context, Škulj et al. (2008) tackle statutory logic problems within the Slovenian armed forces using Markov chains. The manpower system is modeled as a Markov chain and the transition matrix is estimated from data on previous year's transitions. Based on available personnel data, Zais and Zhang (2016) build a Markov model to simulate US army

personnel in order to meet the strategic goals. They exploit the estimated parameters to predict the individual stay/leave decision using dynamic programming. The literature review of An *et al.* (2007) illustrates the use of system dynamics in manpower planning for the statutory logic.

Furthermore, optimization models were also used in the statutory manpower planning. A manpower system modeling is proposed by Thompson G. L. (1979) based on transshipment model. This model is used to compute optimal promotions, retirements and attrition. The officers' recruitment problem is modeled by Henry and Ravindran (2005) with a goal programming approach.

However, optimization techniques were the main approaches used for competence logic. Cai *et al.* (2013) use a minimum cost flow model to approach the manpower allocation problem with several workers doing a set of tasks requiring different skills. Hall and Fu (2015) classify the military manpower based on military rank and rank seniority. They use this classification in a network model. They employ linear programming to generate an optimal manpower distribution. A linear weighted goal programming is used for manpower planning in the army medical department by Bastian *et al.* (2015).

Although the statutory logic and the competence logic were tackled by these works, the consideration of interdependency between the two logics was neglected. Gass S. I. (1991) attempts to consider both logics at the same time. He uses a classification based on rank, skill, function and hired time. He employs a Markov model to tackle the statutory logic and he approaches competence logic problems with network flows. However, this work puts a clear separation between the two logics.

In this article, we merge both logics in the same integrated model to have a simultaneous simulation of the two logics at the same time. The simultaneous representation of the logics permits the optimization of the solution for both logics. The obtained solution could be not optimal for any of the logics but it is optimal for the combination of the two logics. The presented model provides manpower managers with a better tool to measure the impact of their policies on both the statutory and the competence levels.

4 FLOW NETWORK MODEL AND SOLVING APPROACHES

4.1 Flow Network Model

In order to fulfill the organization's demand and requirement, we have to find the optimal workforce transitions able to direct the manpower distribution to a steady state of the required distribution. The required distribution should respect the strategic and the operational goals of the organization. In previous studies, the manpower system was modeled using flow networks for both statutory logic (Thompson, 1979) and competence logic (Cai *et al.*, 2013) (Hall and Fu, 2015), thus there is an opportunity to consider the same approach to model both logics at the same time.

We model the military manpower system as a flow network. We consider the military manpower as the flow passing through the network. The network has nodes representing homogenous personnel groups and arcs representing the possible personnel transitions. A homogenous group is a yearly cluster of personnel having the same characteristics and occupying job positions sharing identical requirements or following the same training. The personnel transitions are recruitment, promotion, job transfer, towards training and retirement. Each arc is a possible transition respecting the eligibility to this represented transition. Nodes are grouped in layers to form annual distributions, where each layer represents all possible groups for one year. These nodes are transshipment nodes except for the first layer's nodes, which are source nodes supplying with the initial flow representing manpower available in the organization, and the last layer's nodes, which are sink nodes. The arcs are going from one layer to the other to denote that transitions are performed once per year. For each layer, we add two special nodes, a source node and a sink node. The source node supplies the basic training with new recruits and the sink node receives the disappearing flow representing personnel going into retirement. The arcs coming from the source node and going to the sink node have limited capacities. The recruitment flow depends on the organization's recruitment capacity and the retirement flow depends on the policy of the organization and the number it had recruited.

Training nodes represent a homogenous group going through the same training to preserve the characteristics on the trainees. Typically, training can be followed even at advanced stages of a career,

therefore we find for the same training multiple training nodes. Training can be for a competence or a basic skill, as a new knowledge or as improving an already acquired skill or competence.

The organization’s requirements are expressed by the need for a certain distribution. We group job positions based on their requirements which are a combination of rank and skill/competence. These groupings appear in the model as sub-groups of nodes. The flow running to nodes inside one of these sub-groups represents personnel occupying the considered job position and having only the required characteristics or having additional skill/competences.

In this model, we will consider attrition only for the basic training as it has a considerable rate comparing to the other stages of the career which present a very low rate of attrition. However, the retirement depends generally on the number of years spent in the organization. We can determine the number of retirees each year using initial manpower data as long as the initial manpower did not fully retire. For the manpower generated by the model, we can use the number of recruits each year.

We illustrate a representation of the model using a virtual simplified example. The example is a military organization with 910 job positions. Personnel in this organization can have one of the three ranks: rank1, rank2 and rank3. This organization requires two skills (skill1 and skill2) and one competence. The optimal distribution based on job positions requirements is illustrated in the table 1.

In this example, we have two types of promotions. We consider the first promotion (rank1

to rank2) as a push promotion and the second one (rank2 to rank3) as a pull promotion. The first promotion is acquired after three years of service in rank1, and the second promotion is possible after two years of service in rank2. Each soldier is trained for one and only one skill at the beginning of his career, and the competence can be trained while in rank1 or rank2 only. When a soldier is promoted to rank3, he has to work at least two years, imposing that promotion to rank3 is granted only for soldiers who still have at least two years left in their careers. We consider that a career in this organization lasts 10 years i.e. soldiers go to retirement 10 years after their recruitment.

Table 1: The optimal competence distribution of the example.

	Rank1	Rank2	Rank3
Skill1	150	100	70
Skill2	150	100	70
Competence	200		70
Total	910		

We denote skill1, skill2 and competence respectively as “S1”, “S2”, and “C”. The modeling of this organization is shown in figure 1 (for a better illustration we consider only two years). Figure 2 illustrates the superposition of those layers to see the possible movements of the manpower. The requirement sub-groups are marked by dash ellipses. Note that nodes concerned with pull promotion have a loop arc to ensure that soldiers who did not get a promotion can stay on the same job position for the next year. This loop arc is not available on the nodes concerned with a push promotion to force the personnel for the next rank.

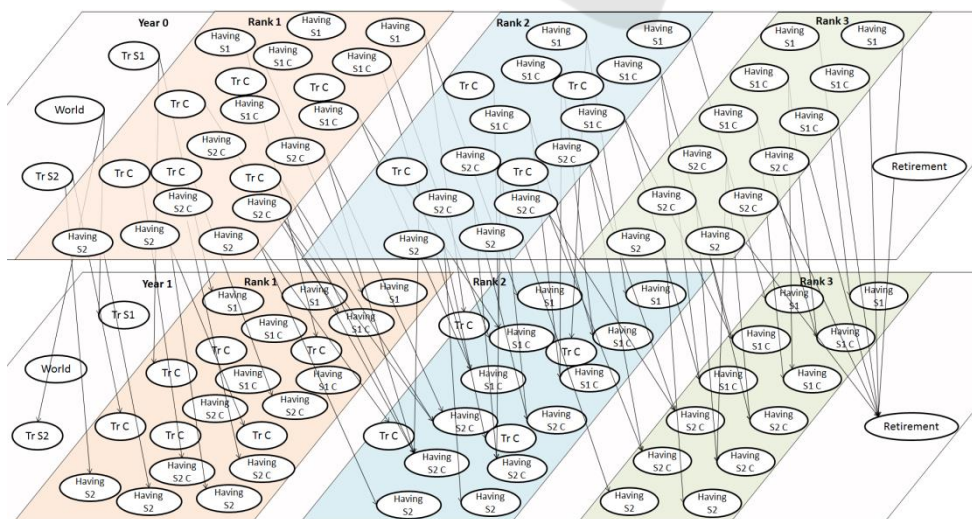


Figure 1: Flow network representation of the example.

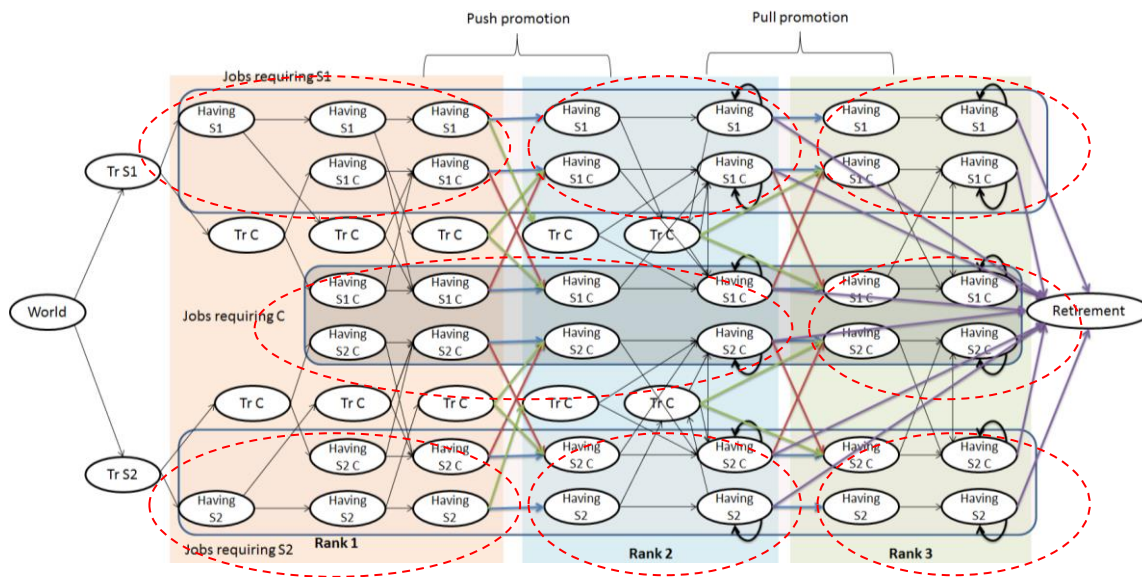


Figure 2 : Superposition of the flow network layers.

4.2 Integer Programming Solution

Generally, flow network problems can be solved by simplex algorithms using linear programming such as illustrated in (Bazaraa and *al.*, 2009) for minimum cost flow networks. Our model has human resources management policies to consider. Additionally, the problem is not always balanced (demand and supply are different). Therefore, a modification of this solution approach is mandatory.

4.2.1 Integer Programming using Two Virtual Nodes

First, we associate with each arc of the graph a cost of the flow passing through this arc. This cost expresses the transition difficulty and desirability for the organization. Thus we need a human resources manager to determine the costs. Having defined the arcs' costs, the objective function of our integer program is the total cost of the flows running through the network that has to be minimized.

In order to solve a flow network problem, the available flow has to be equal to the demand. This condition is not always satisfied for the military organization. Therefore, we use two virtual nodes, a virtual source node and a virtual sink node, so as to equilibrate the demand and the available supply. These virtual nodes, which have infinite capacities, are connected to all nodes representing homogenous groups of personnel working in the organization (i.e. not training nodes). The role of these nodes is to supply the organization with virtual workforce in

case of personnel lack and to receive the surplus in case of personnel excess. The use of the virtual workforce out of these nodes has to be a last solution, so the costs of the arcs going to a virtual sink or coming from a virtual source have to be higher than the costs of all the other arcs.

The costs of the virtual arcs define the relative severity of having a vacancy or a surplus on a certain job position. A higher arc cost means that using this arc is difficult and the vacancy or the surplus should be pushed to another node with an arc of lower virtual cost.

Our integer program has the objective to minimize the total cost of the flows running through the network, which is subject to some constraints. Some of the constraints regard only the flow model we developed and others depend on the organizations' policies.

The constraints related to the model are the initial manpower conditions and the transshipment conditions. The initial manpower conditions express that the manpower present on the first layer must move to the next layer. The transshipment conditions ensure that the flow arriving to a layer must leave it, unless it is a disappearing flow (retirement flow).

The most important constraints concerning the organizations' policies are the expressions regarding the requirements and the retirement. We include constraints imposing the number of personnel arriving each year to a subset of nodes equal to the required demand. Also the number of personnel on nodes of the same rank should be equal to the

targeted amount by the organization. If these constraints cannot be satisfied the solver uses the virtual node to balance them. The retirement condition concerns the disappearing flow which must be equal to the allowed yearly retirement. Additionally, we consider the recruitment conditions which depend on the organization's capacity of training new recruits.

4.2.2 Integer Programming using Multiple Virtual Nodes

The approach with two virtual nodes considers a linear severity of vacancies and surpluses i.e. x vacancies (surpluses respectively) inside the same sub-group have the same severity as x times the severity of one vacancy (surplus respectively) inside this sub-group. However, this assumption is not totally coherent with real life applications. In fact, if the surpluses or vacancies inside the same grouping reach a certain level, some military organizations would rather push them to other job positions groupings which were more important initially. In order to add this possibility to the model, we use multiple virtual nodes. The one virtual nodes couple is replaced with several virtual nodes couples, which creates severity steps for vacancies and surpluses. We define for each arc connecting a node to a virtual node a maximum flow capacity which denotes the limit of the concerned severity step. Figure 3 shows how three virtual nodes couples are connected to one node. The virtual costs imposed on the arcs determine the order of virtual nodes use. If we set $cost1 < cost2 < cost3$, then virtual source 1 is the first virtual node to supply our organization subsequently we move to virtual source 2 when we reach the maximum flow capacity of the arc out of virtual source 1 to supply this node.

Figure 4 illustrates the connection of three virtual sources to two different nodes. We assume that node2 represents a more important job position than node1, therefore, $C11 < C12$. We consider that this relative importance is true until a certain defined limit. This limit is used for the flow capacity of the arc from virtual source1 to node1. In order to flip the importance between nodes beyond this limit, we set $C12 < C21$. This will push the solver to supply the organization from virtual source1 towards node2. We can switch again the importance between the nodes by defining a maximum flow capacity for the arc going from virtual source1 to node2 and putting $C21 < C22$. The same case applies to virtual source3.

For the integer program, we need extra inequalities to define the flow capacities of the arcs

connected to virtual nodes.

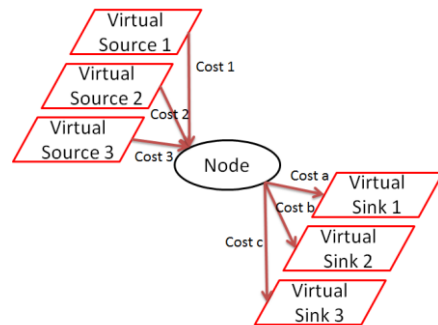


Figure 3 : The connection of three virtual nodes couples to one node.

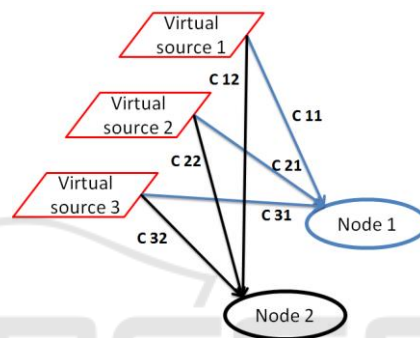


Figure 4 : The connection of three virtual sources to two nodes.

4.3 Goal Programming Solution

The main challenge of the integer programming solution is to define all the costs which influence the optimal solution. Another solution approach is the use of a goal programming approach with different goals that express the different targets of the organization. The goal programming approach defines for every objective a numeric goal, and then it targets the minimization of the deviations from these goals (Hillier, 2010).

For our case, some of the constraints are rigid constraints and cannot be deviated from, for instance the constraints related to the model. Additionally, we have other constraints which are soft constraint and they can be considered as goals for the organization. The constraints which are considered as rigid ones are the models' constraints (initial workforce conditions, the transshipment conditions) and the recruitment capacity, because it is impossible for the organization to afford extra training. On the other hand, the soft constraints or the goals are the requirements, both statutory demand and competence demand. Also, we add to these the goal

of reducing the undesirable movements.

Each goal constraint generates deviation variables which are used in the objective function with different priorities. These priorities have to be determined by a human resources manager.

4.4 Illustration

To study the different reactions of the model, we perform simulations. In this article we illustrate a simulation scenario for the previously defined example in table 1 using the goal programming solution. The simulation involves an initial workforce sized 880 soldiers distributed over the different ranks and job position of the organization as illustrated in table 2. The organization has a defined statutory logic target as shown in table 3 and a competence logic target as in table 1. We perform a 30-year simulation in order to see the evolution of our organization both on the statutory level and the competence level.

Table 2: Available initial manpower in the organization.

Job Position	Recruit	R1	R2	R3	Total
Skill 1	-	120	75	50	710
Skill 2	-	120	75	50	
Competence	-	90	80	50	
Training	30	90	50	-	170
Total	30	420	280	150	880

Table 3: Statutory logic demand of the simulated example.

Rank	Rank 1	Rank 2	Rank 3
Demand	390	350	210

Figure 5 shows the statutory view of the obtained results. The graph illustrates the number of personnel in each rank through the 30 years of simulation. The dashed lines represent the targeted number by the organization. The competence view of the results is represented in figure 6. It shows for every year of the simulation the total number of active personnel (i.e. personnel number on a job position and not on training). It shows also the required number of active personnel and the personnel number on training.

The results show that the model could converge to a solution where both statutory and competence logics are satisfied. Figure 5 demonstrates that the statutory goal is attained after 11 years of simulation. The required statutory goal is maintained after that until the end of the simulation which demonstrates that we have a steady state situation. As for the competence goal, the total number of active personnel is met after 7 years of simulation. However, the fact that the total number is met, does

not guarantee that the optimal competence distribution is met. Therefore, we illustrate in figure 7 the detailed distribution of the manpower on a competence level. We present the personnel number in each requirement. The graph shows that we could fulfill the competence distribution within 7 years and keep this optimal distribution until the end of the simulation.

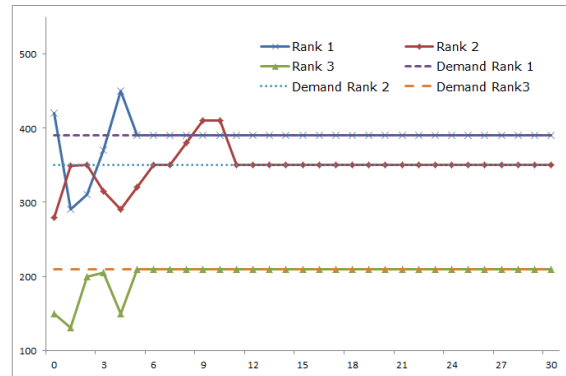


Figure 5: Statutory view of the obtained results out of the simulation.

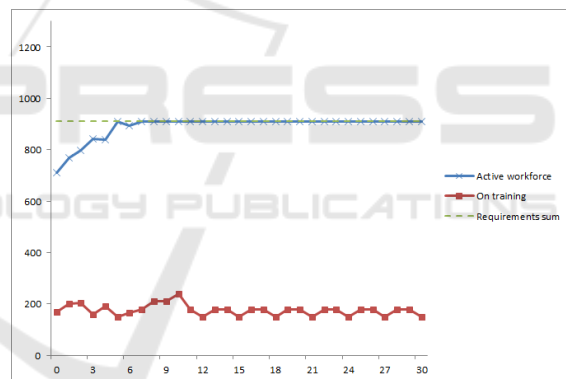


Figure 6: Competence view of the obtained results out of the simulation.

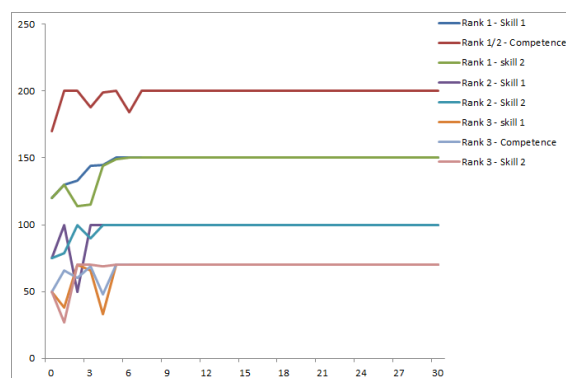


Figure 7: Detailed competence view of the obtained results out of the simulation.

This illustration shows that our model is able to mimic the manpower behavior on both statutory and competence levels. It allows us the prediction of the feasibility of our goals. Having attained and maintained the statutory objective and fulfilled the required operational distribution, our goals are feasible within 11 years.

5 CONCLUSIONS

This article gives a brief description of the military manpower system and its specificities. It tackles the problem faced by military human resources managers to strike the balance between the statutory and the competence logics when they are modeled separately. Therefore, we develop a way to model the military manpower system for both logics simultaneously. In order to find the optimal solution, we illustrate the use of mathematical programming methods, namely integer programming and goal programming.

The developed model permits the military human resources managers to study the impact of the used policies on the strategic level as well as the operational level. Used in a military human resource management department, the model gives detailed plans for the future actions to be taken. The provided actions are linked to job transfers, promotions, the yearly recruitment and the retirement policy.

As future works, we will use the developed model in a real study case scenario in collaboration with the human resources management department to have a better idea of the impact of their policies on the manpower structure in the future. Furthermore, due to the shortcoming of population based methods which is the non-consideration of soldiers' preferences and satisfaction each soldier can express, a future modeling approach for the military manpower system is to consider a fully entity based model. Such modeling approach allows the computation and incorporation of individual attrition probabilities depending on the individual satisfaction. Entity based model permits the consideration of additional information about the manpower, for example age and preferred geographic region.

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