Development of an optimal restructuring model for the Croatia armed forces officer personnel

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Abstract. *The system dynamics model of restructuring officer personnel is presented as part of a wider problem of restructuring the overall armed forces of the Republic of Croatia. Optimal restructuring of the existing officer personnel implies a shift from the present, relatively non-homogeneous officer structure (based on rank and age categories), to the planned structure at the end of the restructuring period. The officer personnel is disaggregated according to rank and age category, while the exogenous control variables are defined through the speed of training i.e. the speed of occupying the lowest officer personnel rank, as well as the speed of transition from rank to rank. The optimization problem has been formulated in the form of the minimization of deviation of the system position variables from the set position at the end of the time interval, according to the speed of transition with set limitations to the speed of transition. Genetic algorithms have been used to resolve the defined problem while scatter diagrams were used to analyze the sensitivity of the obtained solution.*

Key words: *system dynamics modeling, dynamic optimization, genetic algorithm, sensitivity analysis, armed forces restructuring*

1. Introduction

One of important tasks of the Ministry of Defense of the Republic of Croatia in the near future will be the restructuring of the Armed Forces aimed at its rationalization and adjustment to NATO standards. This is a significantly complex problem which cannot be treated efficiently without the use of modern organizational theories - Strategic Management, Human Resources Management, Resource System Management, etc.

One must stress the importance of the Resources System Management (RSM) [1] which enables a direct and elegant formalization of the problem in the shape of the system dynamics simulation model and in that sense it enables a formal

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analitical treatment of a complex dynamic organizational system like the Ministry of Defense of the Republic of Croatia.

The RSM examines and describe differences in performance of the organization as a complex system, in order to avoid delays in building staff skills, misperceptions of productivity and goal conflict. According to the Resource System Management, organization are represented as an interlocking network of resources embedded in closed feedback loops while resource management is represented in terms of operating policies, goals and feedback loops that control the building-up and retention of the key resources. The staff presents only one tangible resource in this model. As it can be seen, this managerial view shifts attention from the quasi-static comparison of resource endowments [2] to the dynamic analysis of resource accumulations and the policies, dominant logic and feedback processes that control them.

It is important to stress that resource accumulation presents a fundamental part of any dynamic resource system [3]. The idea of resource accumulation was introduced for the first time into the strategy literature by Dierickx and Cool [4]. In order to understand competitive advantage, one has to recognize the inertia of resource accumulation - asset stock accumulation. They said: “While flows can be adjusted instantaneously, stock cannot. It takes a consistent pattern of resource flows to accumulate a desired change in strategic asset stock”. According to Heene and Sanchez’s theory of competence-based management [5], an organization can be viewed as a system of tangible and intangible assets organized under a strategic logic for achieving its goals. The resulting conceptual model shows a hierarchy of system elements for managing an organization’s assets and capabilities, ranging from higher-order cognitive elements to lower-order operating elements.

The System Dynamics method [6], [7] provides an ideal tool for this purpose, providing a rigorous means of formulating the mathematical integration underlying the accumulation and depletion of resources. Furthermore, it can capture the dynamics interdependencies between resources, leading to powerful models of an organization’s performance through time, as a function of effectiveness of this dynamic resource system. The second contribution of system dynamics to understanding the time-path of strategy arises from its ability to capture the interdependence (complementary) between strategic resources. This is achieved by recognizing that managers use resources they already have to develop their other needs. In other words, the current rate of change of a resource is a function of the current level of all resources in the system, including that resource itself.

The aforementioned justifies the use of Resource System Management and System Dynamics when treating problems in the process of restructuring of the Armed Forces. The Armed Forces resources (accumulation, level, stock) are weapons, infrastructural objects, personnel of various ranking and education, etc. Growth or decline of resources (rate, flow) are also well defined. For example, accumulation of weapons increases with purchase and production of new weapons and decreases with writing off as scrap weapons after their lifespan. This paper presents a limited aspect of overall restructuring problem of the armed forces - the restructuring of the officer corps. The problem is how to implement the process of restructuring officer personnel within the set period of time and accomplish the staff structure suitable for the needs of the armed forces. In other words, the question is which means and instruments would enable the shift of the existing relatively heterogenous officer structure (according to rank and age category) to the target structure by the end of the period of restructuring. This is a presentation of a simple model with certain basic initial suppositions that subsequently could be elaborated in proportion to the needs and the particular area of problems taken into consideration, so that the model could be adjusted as much as possible to the real situation. These suppositions stem from a regular system free of all significant perturbations during a sufficiently long time span.

This paper is organized as follows. *Section 2* presents system dynamics formulation of the problem. In the *Section 3* is presented a simulation example. In the *Section 4* is formulated optimization problem where is presented solution using the genetic algorithm, i.e. scatter diagrams. Finally, the conclusions are emphasizes by *Section 5*.

2. Model formulation

The total number of officers will be disaggregated according to their ranks and age categories. Generally speaking, there is number of officer ranks N and number of age categories per rank M. This means that we have $P_1(t)$ officers of the lowest rank, $P_2(t)$ officers of the next higher rank, etc., to $P_N(t)$ officers of the highest rank. Then, the number of officers per rank could be disaggregated by introducing age categories. This means that there are $P_{11}(t)$ youngest officers with the lowest rank, $P_{12}(t)$ officers with the lowest rank but in the next age category, etc., to $P_{NM}(t)$ officers with the highest rank in the highest age category.

We start with the following basic model assumptions:

- the total number of officers in the system is to be increased only by personnel who have completed the adequate military training and who occupy the formation post with the lowest rank (and the lowest age category) provided for the adequate training level,
- the total number of officers in the system is to be decreased by retirement only following the legally prescribed number of years, irrespective of the officer's rank,
- the instruments for regulating the dynamics of changing the officer personnel is the speed of promotion from rank to rank and the speed of training.

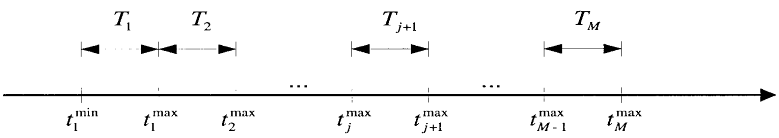

Figure 1. *Time scale with times of duration of age categories*

We are introducing the following notation:

- $P_{i,j}(t)$ - the number of officers of i-th rank in the j-th age category, $i = 1, ..., N$, $j = 1, ..., M$,
- $P_{i,j}(0)$ - the initial structure of the officer personnel,
- $\widehat{P}_{i,j}(t_f)$ - the target structure at the end of the process of restructuring t_f,
- w_i - the speed of promotion from i-th to $i+1$ rank, $P_i \overset{w_i}{\rightarrow} P_{i+1}$,
- τ_i - the average time of promotion from i-th to $i+1$ rank,
- w_{ij} - the speed of promotion from i-th rank, j-th age category, to $i+1$ rank, $P_{i,j} \overset{w_{ij}}{\rightarrow} P_{i+1}$,
- $w_{i,i+1}^{j,j}$ - the speed of promotion from i-th rank to $i+1$ rank in j-th age category,
- $w_{i,i}^{j,j+1}$ - the speed of promotion of i-th rank of the j-th age category to a $j+1$ age category,
- $w_{i,i+1}^{j,j+1}$ - the speed of promotion of i-th to $i+1$ rank from the j-th age category to $j+1$ age category,
- $w_{i,i}^{M,M+1}$ - the speed of retirement of i-th officer rank of M-th age category,
- u_{11} - the speed of training of the officer personnel (the lowest rank, the youngest age category),
- T_j - time interval of j-th age category (*Figure 1*),
- Δt - the period of discretisation.

The next denomination we are introducing is the speed of promotion from one rank to the following higher rank. If we consider this problem by taking into consideration the total number of officers of a certain rank (without disaggregation according to age categories), then the denomination w_i presents the number of officers of i-th rank promoted to $i+1$ rank during the time period (annually), as it is illustrated in the *Figure 2. a.*

If we would like to "increase the resolution" of the problem and to introduce age categories, then the outcome will be the situation illustrated in the *Figure 2. b.* In this case the w_{ij} denomination stands for the number of officers of i-th rank of the same j-th age category promoted to $i+1$ rank in the time period. The link between the w_{ij} and w_i can be expressed by the following equation:

$$w_{ij} = \frac{T_j}{\sum_{k=1}^{M} T_k} w_i. \tag{1}$$

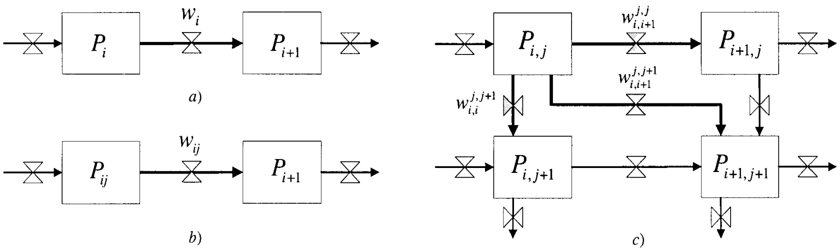

Figure 2. *The flow diagrams:* *a) promotion from i-th rank to $i+1$ rank,*
b) promotion from i-th rank of the j-th age category to $i+1$ rank,
c) completely disaggregated promotions from i-th rank of the j-th age category

Finally, when the total disaggregation of all ranks according to age categories is concerned, as it is illustrated in the *Figure 2. c* there are three types of promotion of i-th rank of the same j-th age category (the term 'promotion' means moving from one category to another and not necessarily to the next officer rank):

- $P_{i,j} \to P_{i+1,j}$ with the following speed of promotion $w^{j,j}_{i,i+1}$,
- $P_{i,j} \to P_{i,j+1}$ with the following speed of promotion $w^{j,j+1}_{i,i}$,
- $P_{i,j} \to P_{i+1,j+1}$ with the following speed of promotion $w^{j,j+1}_{i,i+1}$.

Now, we can expressed the system dynamics formulation of the change of the variables depending on the speed of promotion:

$$P_{i,j}(t+1) = P_{i,j}(t) + \Delta t(Inflow(i,j) - Outflow(i,j)), \tag{2}$$

where

$$Inflow(i,j) = w^{j-1,j}_{i-1,i} + w^{j-1,j}_{i,i} + w^{j,j}_{i-1,i}, \tag{3}$$

is the inflow in the level variable $P_{i,j}(t)$, while

$$Outflow(i,j) = w^{j,j+1}_{i,i+i} + w^{j,j}_{i,i+1} + w^{j,j+1}_{i,i}, \tag{4}$$

is the outflow from the level variable $P_{i,j}(t)$.

By taking into consideration non-negativity of variables $P_{i,j}(t)$, we can find out the speeds of promotion as it is demonstrated in the *Figure 3*

$$w^{j,j+1}_{i,i+1} = \frac{w_{ij}\Delta t}{T_j}, \tag{5}$$

$$w^{j,j}_{i,i+1} = \frac{T_j - \Delta t}{T_j} w_{ij}, \tag{6}$$

$$w_{i,i}^{j,j+1} = \frac{P_{i,j} - w_{ij}\Delta t}{T_j}, \tag{7}$$

for $i = 1, ..., N-1$, $j = 1, ..., M-1$. Furthermore,

$$w_{i,i}^{M,M+1} = \frac{P_{i,M}}{T_M}, \quad w_{i,i+1}^{M,M} = w_{iM}, \quad i = 1, ..., N-1, \tag{8}$$

$$w_{N,N}^{j,j+1} = \frac{P_{N,j}}{T_j}, \quad j = 1, ..., M. \tag{9}$$

The afore stated ways of denoting the speed are valid when $P_{i,j}(t) > 0$, otherwise they disappear. By taking into consideration the fact that the speed of promotion is legally defined with the minimum number of years an officer should remain in the same rank before being promoted into the next higher rank, the speed of promotion depends on the average time spent in the same rank

$$w_i = \frac{1}{\tau_i}\sum_{j=1}^{M} P_{i,j}. \tag{10}$$

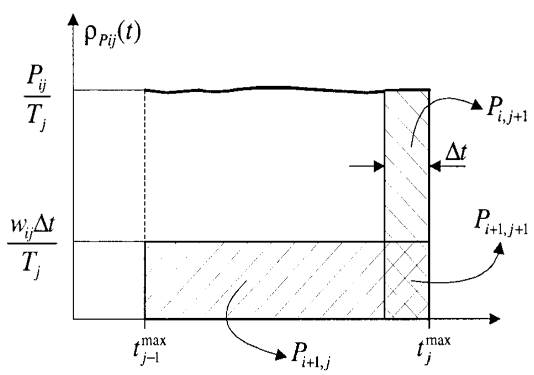

Figure 3. *Density of the number of officers of i-th rank and the same j-th age category according to time*

Since equations (2)-(4) are in general applied to the level variables $P_{i,j}$ for $1 < i < N$, $1 < j < M$, we must add special "boundary" type equations for the level variable $P_{i,j}$. Including this "boundary" type equations we obtained

$$\begin{aligned} P_{i,j}(t+1) &= P_{i,j}(t) + \Delta t\{[1 - H(i-1)H(j-1)]u_{11} - \\ &- [H(i-1) + H(j-1)]w_{i-1,i}^{j-1,j} + H(j-1)w_{i,i}^{j-1,j} + H(i-1)w_{i-1,i}^{j,j} - \\ &- [H(N-i) + H(M-j)]w_{i,i+i}^{j,j+1} - w_{i,i}^{j,j+1} - H(N-i)w_{i,i+1}^{j,j}\}, \end{aligned} \tag{11}$$

where an additional function is introduced

$$H(k) = \begin{cases} 0; k = 0 \\ 1; k > 0 \end{cases} \tag{12}$$

In this model the speed of dismissing officers q_{ij} is not included, as well as the speed of the premature retirement r_{ij}. If one would like to include these rates in the model, one would simply have to add $-\Delta t(q_{ij} + r_{ij})$ on the right side of the equation (11).

However, by introducing the premature retirement and dismissal, we have to take into consideration the total costs of the stated measures in the form of the longterm expenses of the pension fund and social security and that is an issue that falls beyond the scope of this article.

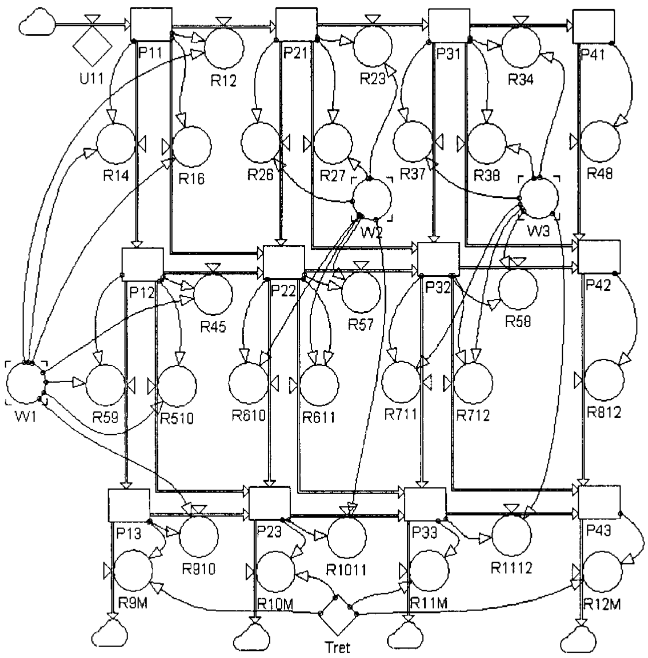

Figure 4. *System dynamic simulation model for $N = 4$, $M = 3$*

3. Simulation results for $N = 4$ and $M = 3$

Simulation of the model could be conducted in various ways depending on the selection of exogenous variables. The natural choice for exogenous variables in this model is - 1) taking w_i as an exogenous variable, or 2) taking τ_i as an exogenous variable. The first case is appropriate when we consider the consequences of the legal pre-condition that the promotion to higher rank is possible only if there is an empty structural position. The second case is interesting since the mean time of promotion to higher rank is one of the key stimulation factors when planning a military career.

Figure 4 shows the system dynamics simulation model that we analyze for the case $N = 4$, $M = 3$. Such dimensions of the problem imply that at least some variables P_i represent aggregate variables of several ranks. We have taken for the initial allocation of the number of officers by ranks and age categories

$$\mathbf{P} = \begin{pmatrix} 600 & 250 & 50 & 5 \\ 400 & 250 & 80 & 5 \\ 200 & 100 & 50 & 10 \end{pmatrix} \tag{13}$$

Further, for mean times of promotion to higher rank we have taken $\tau_1 = \tau_2 = 16$, which would correspond with the mean time by rank of approximately 8 years and for the promotion time to the highest rank we have taken $\tau_3 = 40$, which would be correspondent with the standard barrier for promotions to highest ranks. For the speed of training we have taken $u_{11} = 40$ what is approximately correspondent with the total speed of retiring of all officers. *Figure 5* shows temporal dependence of variables P_{ij}.

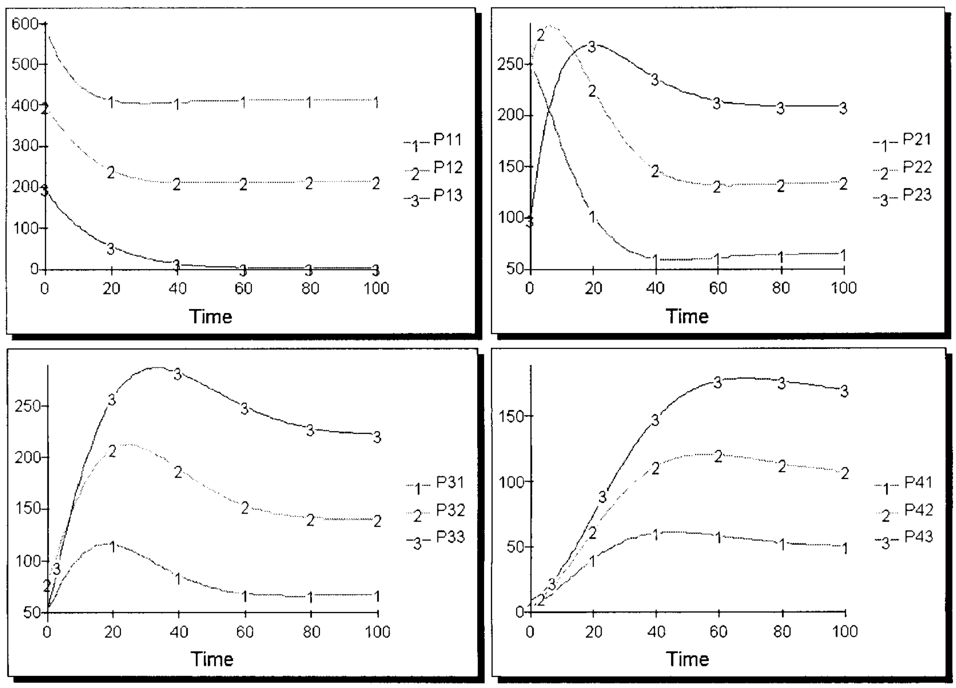

Figure 5. *Temporal dependence of variables* P_{ij}

One could reach following conclusions from conducted simulations with respect to some general characteristics of the analyzed system:

- the system has the tendency of degenerating the initial hierarchical structure - the decrease of the number of officers of lower ranks and the increase of the number of officers of higher ranks.

- such a conduct of the system is insensitive to the modification of the mean time of promotion to higher rank as well as to the number of officers who enter the system,
- the time of establishing stable state is relatively long (over 30 years),
- the age structure of officers by ranks can be regulated naturally with no additional external interventions.

It is essential to keep these general dynamic characteristics of the analyzed system in mind prior to formulating the problem. Of course, such a degeneration of hierarchical structure would not be allowed in real system, where a promotion is possible only if there is an empty structural position. However, the results of simulation in that case demonstrate very large mean times of promotion to higher rank - so that this means that a large part of officers would spend an entire active career in the same rank.

4. Optimization problem formulation

The next problem is determining the speed of transitions w_i (or the average speed of promotion in higher rank τ_i) as well as speed of training of officer personnel u_{11} with the aim to transform the initial structure of officer personnel $P_{i,j}(0)$ into the final target structure of officer personnel $\widehat{P}_{i,j}(t_f)$, (that is, the structure closest to the desired structure) within a given restructuring period t_f.

In mathematical terms we can formulate this in the following way:

$$F = \min_{\mathbf{w},u} \sum_{i=1}^{N} \sum_{j=1}^{M} \omega_{ij} \left(P_{i,j}(t_f) - \widehat{P}_{i,j}(t_f) \right)^2 . \tag{14}$$

If the value of the function for the obtained optimum solution is $F = 0$, then such an obtained optimum solution leads to the target structure of the officer personnel $\widehat{P}_{i,j}(t_f)$. If $F > 0$,then we cannot reach the target structure of officer personnel within given time for restructuring t_f and the obtained solution represents "the closest" solution to the target solution. The weight coefficients ω_{ij} enable us in this case to ensure that particular variables of interest $P_{i,j}$ are closer to the target solution than others (so that the correspondent weight coefficients are put higher than others). Also, if we are unable to reach the target structure of officer personnel within the given restructuring time t_f, then we can rephrase the problem in finding the minimum time within which that could be possible. Of course, in order for previous conceptions to make sense, the constraints to the speed of transitions and the speed of training of officer personnel must be given

$$w_i^{\min} \le w_i \le w_i^{\max}, \tag{15}$$

$$u_{11}^{\min} \le u_{11} \le u_{11}^{\max}. \tag{16}$$

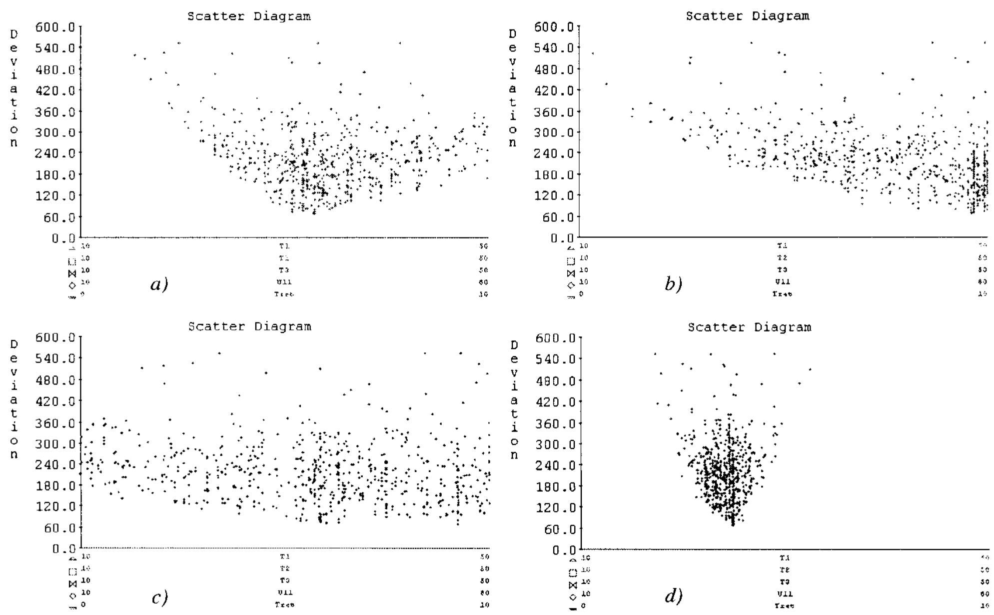

Figure 6. *Scatter diagrams for a) τ_1, b) τ_2, c) τ_3, d) u_{11}*

For the above mentioned optimization problem we used a genetic algorithms (100 generations with 40 genes per generation). *Figure 6* shows scatter diagrams which are useful for detecting a possible pattern in the relation between free variable (the speed of promotion) and target variable (performance criteria (14)). The scatter diagram shows which values of the free variable lead to a good results. The values of the different free variables are shown along the x-axis, while the deviations between the related results and desired result (in our case - the value of the performance criteria) are shown along the y-axis. Each dot represents a value of the performance criteria. In the interest of not showing the poorest genes, we have reduced the scaling of the scatter diagram. This means that a scatter diagram, besides showing the area of the optimal value of the free variables, illustrates a sensitivity of the optimal solution that originates from a changes of the free variables.

The scatter diagrams in *Figure 6* shows that the average speed τ_1 and the speed of training u_{11} have significant impact within the relative narrow area and values defined by constraints (15), (16). Variable τ_2 has a significant impact on a performance criteria not earlier than a higher limit defined by constraints, while the variable τ_3 has a constant impact on a performance criteria during the whole interval defined by constraints.

In other words, reaching the target structure of the officer personnel at the end of the restructuring process mostly depends at the right selection of the speed of promotion of the officer personnel u_{11}, the average speeds of promotion τ_1 and τ_2, and the average speed of promotion τ_3.

5. Conclusions

The key problem that could be identified from the results of model simulation is the conflict between the aspiration towards favourable conditions for promotion of officer personnel over their entire military career and simultaneous maintenance of the hierarchical structure. The aforementioned conflict cannot be overcome by presently existing, relatively small number of legally defined instruments, that are available for regulating current officer's structure. Therefore, introduction of additional regulating instruments into the model is necessary with the aim of increasing controllability of the perceived system as for instance: (1) early or graded retirement, (2) stimulating leaving the military forces, that is introducing a contract on temporary employment, (3) including the length of service in the salaries of the officers as stimulation measure which would compensate too long mean time of stay in the same rank, (4) introducing of additional ranks of lower level with the aim of decreasing mean time of stay in the same rank.

Undoubtedly, by introducing the aforementioned instruments the entire cost of all alternatives should be taken into consideration as an additional criterion in choosing the optimal combination of the mentioned instruments.

In conducted simulations, we were using the constant values of the speed of transition and training over time. The next step is analyzing this issue from the point of view of optimal control by introducing temporal control variables, which would enable improvement of transitional performances of the system and faster establishment of a stable state. Also, one should emphasise that such a model is applicable to all organizational systems with strictly defined hierarchical structure (functional) as f.i. Ministry of the Interior and Ministry of Science and Technology.

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