DEVELOPMENT AND APPLICATION OF HUMAN RESOURCES TRANSITION SIMULATION MODEL IN SLOVENIAN ARMED FORCES

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Abstract

Present paper describes development of continuous and discrete simulation models of human resources transitions in Slovenian Armed Forces. The model is developed in order to: a) Forecast the future manpower requirements, b) Perform the analysis of the impact of proposed changes in policy, c) Test different historical policies, d) Perform the feasibility analysis, e) Understand the structure and the dynamics of the system, f) Optimize the system performance. In the development phase, the comparison of both models was performed with the purpose of structural and quantitative validity. Both models were developed in MATLAB/Simulink/SimEvents and included eight different ranks providing important information about structural dynamics. The calibration of the model was performed where the historical data was used to determine time constants of transitions and fluctuations. Simulation runs were performed in order to complete predictive validation of the model. Target response of the system was determined for five ranks. Optimization according to the stated criteria functions by the application of pattern search algorithm was performed. Here the key parameters of transitions and fluctuations with boundaries were considered. By this means the target strategy of the system could be determined. The models enable the user to identify potential manpower shortfall and determine the impact of a chosen policy and examine possible corrective policies or rationalizations by simulating the operations in a real-world system. System dynamics methodology proved to be appropriate tool for initial development of the model and structural validation reference. Hybrid approach to the problem provided higher level of confidence.

Keywords: system dynamics, manpower, optimization, strategy, HRM

Presenting Author's Biography

Andrej Škraba obtained his Ph.D. in the field of Organizational Sciences from the University of Maribor. He works as a researcher at the Faculty of Organizational Sciences in Cybernetics and Decision Support Systems Laboratory. His research interest covers modelling and simulation, decision processes and system theory. His work is focused on experiments with decision groups applying system dynamics simulators in experimental and real environments. As a coauthor he has published papers in the following journals: Simulation, System Dynamics Review and Group Decision and Negotiation.

1 Introduction

Human Resource Management (HRM) in a large and complex organization is a challenging and continuing process. Concept of anticipation plays an important role at the system control [1, 2, 3, 4, 5, 6, 7], and is a prerequisite for efficient management of complex systems. Dynamics of human resources could be simulated with continuous and event based models. By applying both methodologies, additional validation of developed models could be performed by comparison of the results and structure. Each of the approaches has its own advantages which should be considered. Different structure of the input data for continuous and discrete model should provide the same results which is important validation step. While simulating the manpower dynamics event based simulation is more accurate. On the other hand, preparation of the data for discrete model is time consuming due to the application of analytical methods and data-mining. Comparison of discrete and continuous model allows structural and quantitative validation. Main objective of present study is development of a simulation model, which would provide information about structural dynamics and enable forecasting of fluctuation between individual ranks in a large and complex organizational structure; in our case Slovenian Armed Forces. Due to the restructuring the addressed problem is of significant importance. The structure best adapted to the purposes of considered organization changes with time, and planning has to take account of changing circumstances, to arrive at a structure most appropriate in it own time, at leas as nearly as possible [8]. Some parts of a manpower system are suject to control by management action; for example the number and points of entry of recruits [9]. Here the object of the control theory is to provide the strategies which would ensure that the change takes place in the right direction. The study is based on a system simulation method, where continuous and Discrete Event Simulation (DES) are used. Continuous simulation with application of System Dynamics (SD) [10] procedure is more aggregated. SD methodology is transparent to the users due to significant aggregation, while DES assures higher accuracy of gained results. Two differently aggregated SD models were developed, based on averages, median and empirical distributions of transitions between ranks. The SD model was built out of the common entities of system dynamics; levels and rates. Individual level represents number of rank members (a number of persons positioned in a rank) and are labeled as A, B, C, ... while rate represents the number of persons who enter or leave each rank in one time unit. Dynamical model is developed in a numerical computing environment and programming language `MATLAB`. Time unit of simulation run in a continuous model is chosen as one month. Calibration of continuous model was performed using a historical data, where simulation results matched with the anticipations. Simulation was performed for a period of 10 and 15 years. Besides accuracy, discrete event model also includes more detailed data, as it also considers duration of training and education, which individual spends in a rank before the transition to the next level. Model is in a stage of evaluation where complexity *Vs* benefit ratio is considered. There have been significant efforts put to the development of the user friendly interface. One should note, that the system should be used "in the field" therefore transparency and ease of use is of primary importance.

2 Methodology

Long-term HR planning has an important strategic role due to the involvement of resources and costs which should be optimized. These entities are a part of a complex social system, where we can expect desired results only on within longer time frame due to the large time constants and delays in feedback loops [11]. Behaviour of such systems is very sensitive to small perturbances from environment and different decision policy proceedings. This means that the developed model must enable a simulation (prediction) of personnel structure dynamics, considering transitions between different ranks and fluctuation out of the system boundaries. The model should allow the user to [12]: a) Forecast the future manpower requirements that will be satisfied by the current number of the personal, b) Perform the analysis of the impact of proposed changes in policy, such as changes in promotion or retirement rules and changes in transfers into and out of the organization, c) Test the rationale of historical policy for consistency and establish the relations among operating rules of thumb, d) Explore regions of possible policy changes and allow a planner to experiment with and perhaps discover new policies, e) Understand the basic flow process and thus aid in assessing the relative operational problems, f) Design the system that balance the flow of manpower and requirements, g) Structure the manpower information system in a manner suitable for policy analysis and planning. The development of continuous model was based on the system dynamics methodology [10]. There are many examples of system dynamics methodology implementation in the field of workforce management [13, 14, 15]. The main purpose of the system developed within our research framework is to perform and support a process of complex decision making concerning human resources management by man-machine interaction. Developed simulation model incorporates the flows of personnel through various ranks showing the dynamic response of the system. Here different input resources could be considered. This means, that user can identify potential manpower shortfall and calculate financial impacts for a chosen policy and examine possible corrective policies or rationalizations by simulating the operations in a real-world system. However, this can only be achieved, if one develops a validated simulation model, which would take into consideration system feedback loops, dependencies and key parameters, especially time constants which define human resources dynamics. Transitions in the system are dependant on demand for particular rank and training capacity which is basically hierarchical. In terms of system dynamics this would mean causal dependance of each particular rank. Number of members in each rank depends on the demand which determines the training human resource capacity. This

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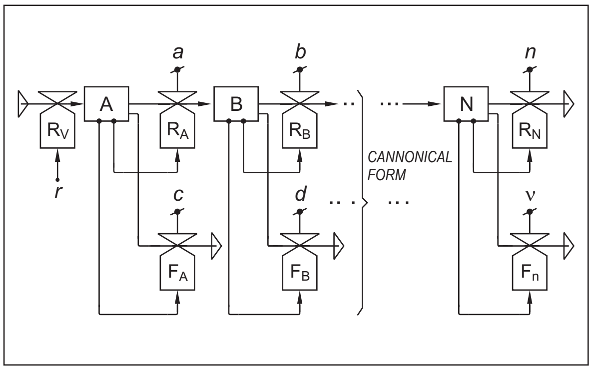

Fig. 1 Structure of system dynamics model of rank transitions in the cannonical form. Shown structure represents delay chain of first order delay elements.

positively influences number of instructors as well as number of rank members. On the other hand, the instructors diminish the number of members in particular rank since these instructors work with higher rank. The instructor effort is supported by new technologies in military training. While the structure is repetitive representing a chain of negative feedback loops, the task to achieve the target function, meaning a particular dynamic of particular rank members is main issue addressed in the research. Particular rank is also determined by discharge rate and retention rate. Figure 1 represents the stock and flow diagram of an SD model, which represents transitions of manpower between individual ranks. The structure shows that a closed labor force system is examined in a way where individual workforce type is produced within the system rather than imported from the outside or in a strictly hierarchical system, where i.e. higher rank manpower must be from next subordinate rank. This also means that the change at one rank can create chain demand in other ranks. Stock variables (levels) describe the state of the system, such as the number of manpower in rank A and rank B, while flow variables (rates) represent the rates of change of stocks, such as fluctuation and transition rates, as stated below:

R_V is an element of change of stock, denoted by value r, which tells the ratio of transitions from a preceding rank (in this case out of the system boundaries) to a rank A,

R_A is an element of change of stock, denoted by value a, which tells the ratio of transitions from a rank A to a rank B,

R_B is an element of change of stock, denoted by value b, which tells the ratio of transitions from a rank B to a next rank (in this case out of system boundaries),

F_A is an element of change of stock, denoted by value c, which tells the fluctuation out of the system from a rank A,

F_B is an element of change of stock, denoted by value d, which tells the fluctuation out of the system from a rank B. Variable a, which represents ratio of a successful transitions into rank B should be determined with regard to the historical data. This rate is determined on a basis of evaluations of monthly transitions from rank A to rank B and is defined as:

$$a = \frac{m}{A_0}\tau^{-1} \quad (1)$$

where m is the expected number of members moving from rank A to rank B in one time-step, A_0 is the initial size of a rank A ($k = 0$) and τ represents a time unit (it tells if transitions are done yearly, monthly or even in shorter period of time). The next equation in this case is:

$$a = \frac{\eta}{\tau} \quad (2)$$

where η being the transition probability and τ a time needed for rank A recruitment. Equation 3 depicts the following ratio d, which in our model represents fluctuation ratio from rank B, where $m = 15$, $S_0 = 375$ and $\tau = 12$:

$$d = \frac{15}{375}\frac{1}{12} = \frac{1}{300} \quad (3)$$

All other ratios (a, b, c and r) can now be calculated in a same manner. Results gathered depend on the accuracy and quality of data, used for calculations. This means that the appropriate way is to combine the data about yearly transitions between individual ranks with expectations of how long individuals stay in each rank. Model in figure 1 can also be represented as a system of difference equations [16, 17]:

$$\begin{aligned}
A(k+1) &= A(k) + \Delta t(R_v(k) - R_A(k) - F_A(k)) \\
R_A(k) &= a\,A(k) \\
F_A(k) &= c\,A(k) \\
B(k+1) &= B(k) + \Delta t(R_A(k) - R_B(k) - F_B(k)) \\
R_B(k) &= b\,B(k) \\
F_B(k) &= d\,B(k) \\
&\ldots \\
N(k+1) &= N(k) + \Delta t(R_x(k) - R_N(k) - F_N(k)) \\
R_N(k) &= n\,N(k) \\
F_N(k) &= \nu\,N(k)
\end{aligned}$$

The states of the considered system are gathered in discrete time points. However, the individual decisions are actually taken in continuous time. This is also one of the rationale that the applied methodology should consider both, discrete and continuous time. The general form of the System Dynamics model definition in continuous time is:

$$L(t) = \int_{t_0}^{t} [R_{in}(t) - R_{out}(t)]\mathrm{d}t + L(t_0) \quad (4)$$

$$\frac{\mathrm{d}(L)}{\mathrm{d}t} = \text{L net change} = R_{in}(t) - R_{out}(t) \quad (5)$$

Applied System Dynamics models is in our case a set of cascaded level elements L which represent ranks, where one levels outflow is the inflow to a second level, and the second levels outflow is the inflow to a third, etc.

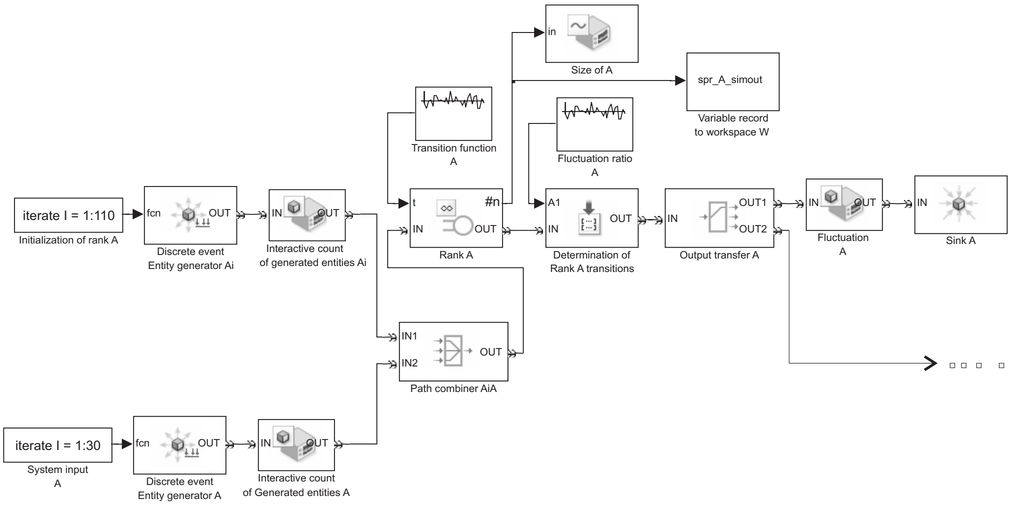

Fig. 2 Model of rank transition developed by Discrete Event Methodology in MATLAB/SimEvents.

Figure 2 represents a model of transitions between ranks, developed by principles of DES constructed by `MATLAB/SimEvents`. Element *Rank A* represent a server entity initialized by the size of a rank A. Here we use event based generator of entities. The *Rank A* ele-

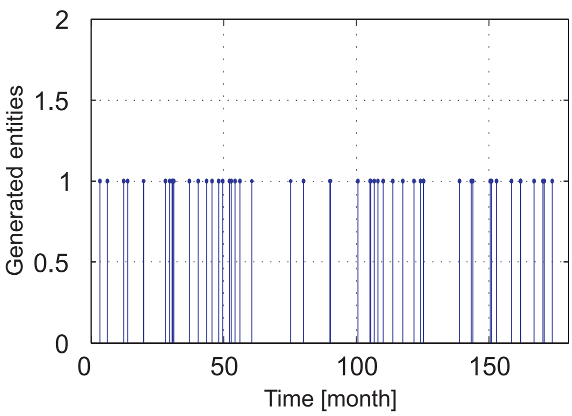

Fig. 3 Generated entities as rank fluctuation

ment is controlled by a step function, which represents an input of a system. Variation of transitions of entities from *Rank A* to the next rank is presented as frequency distribution of entity stay time in *Rank A*, which was acquired by analysis of historical data concerning dynamics and transitions between individual ranks. Fluctuation ratios are also presented as user-defined functions, gained by analysis of historical data concerning fluctuations. This is then followed as an output to the next level, which is *Rank B*. Structure of the discrete model is identical to the structure of continuous model. In a discrete model the transitions between ranks are represented as stochastic distribution functions. This means that duration that each entity spends in individual rank is represented as a distribution function gathered from a data base. Model enables the variation of discrete transitions by principles of Monte Carlo simulation and is by that more accurate than the continuous one. Figure 3 shows the dynamics of entity generation, which in our case represents fluctuations from element *Rank A*. All individual entities are generated according to the given fluctuation process distribution. Each point represents fluctuation of one rank member i.e. the entity of *Rank A*. While developing simulation models, where modelling of complex systems in addressed, implementation of hybrid simulation in simulation tool plays an important role [18]. In our case, combination of continuous and discrete simulation was performed using `MATLAB`. This functionality was build in a position to participate in the process of predictive, replicative, structural and pragmatical validation. Examples of simulation results from continuous and discrete model are shown in a figure 4. Group of curves from a dis-

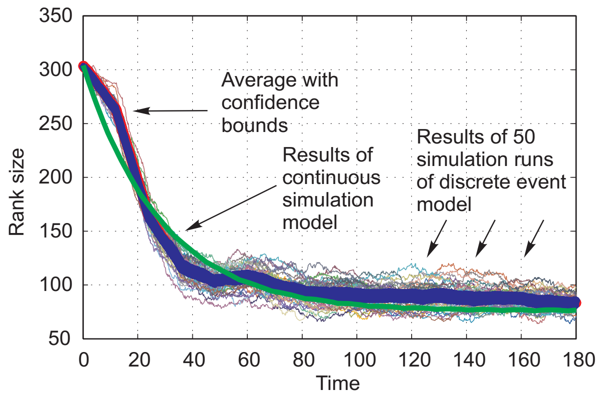

Fig. 4 Comparison of continuous and discrete simulation model results. (confidence level $\alpha = 0.05$ with average of fifty simulation runs.

crete model results represent 50 simulation runs in a 15 years simulation duration (180 months). Because of the scale of time constants, represented in models, a longer period of simulation time is required. As we can see in this figure, considering given parameter limitations, in 5 year duration of simulation target conditions could

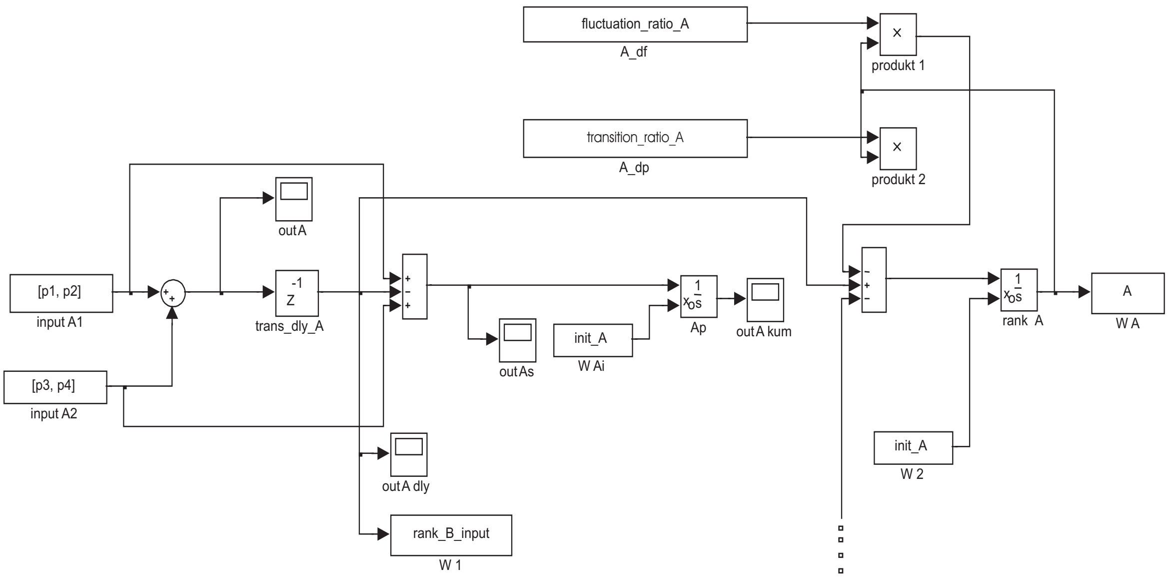

Fig. 5 Rank transition model developed by the principles of continuous simulation developed in MATLAB/Simulink.

not be met. In a process of model validation, results from continuous and discrete model should match. This form of procedure is of significant importance, especially with regard to parameters hypersensitivity. Statistical *t-test* can be performed, to confirm if results could be accepted, by confirmation of parameter adequacy. Model of transitions, developed by principles of continuous simulation using `MATLAB/Simulink` is presented on a figure 5. Step with discrete time delay function Z^{-1} is realized as input to a *Rank A*. Parameter values and simulation results are rendered through `MATLAB` *Workspace*. Level of element *Rank A* depends on initialization value *init A* and the difference of $\frac{1}{s}$ integrator inputs, presented by parameters *fluctuation A ratio* and *transition A ratio*. According to discrete model, main difference is, that here transition ratio is defined only by parameter *transition A ratio*, which is the critical element in definition of model.

3 Definition of strategy according to target functions

The core of the optimization system is Rank Structure, where different ranks hierarchically interact with each other. The system is driven by the Desired Rank Structure Dynamics. In our case target functions were determined. Depending on the Rank Structure Adequacy the Optimization Algorithm determines the Parameter Set Values according to the Parameter Boundaries. Response of the Rank structure is in the next cycle compared to the Desired Rank Structure Dynamics where the procedure repeats until the satisfactory Rank Structure is reached. Definition of the strategy was defined as an optimization problem. Optimization problem is a process of finding the best solution from all feasible solutions. Figure 6 describes the dynamics of criteria function value variation trough 600 iterations of simulation. Iteration is presented as calculation of the criteria function which is minimized:

$$\min_{u \in U} J = \sum_{n=1}^{r} \sum_{i=0}^{t_k} \sqrt{\Big(C(i)_n - X(i)_n\Big)^2} \tag{6}$$

where u is a set of input parameters with some value limitations, n is the number of optimized ranks and by that a number of known criteria functions C_n. We need to specify target function for each observed rank and calculate the mean square error from the value of observed parameter X_n. t_k is a discrete time. Sum of mean square error from the values of criteria functions are then summed again according to the set of target functions [19]. If the init values of ranks are known as $x_1(0), x_2(0), x_3(0), ..., x_n(0)$, we are able to manage the control functions in a following manner:

$$\begin{aligned}
\frac{dx_1}{dt} &= f_1(x_1, x_2, x_3, ..., x_n, u_1, u_2, u_3, ..., u_n) \\
\frac{dx_2}{dt} &= f_2(x_1, x_2, x_3, ..., x_n, u_1, u_2, u_3, ..., u_n) \\
\frac{dx_3}{dt} &= f_3(x_1, x_2, x_3, ..., x_n, u_1, u_2, u_3, ..., u_n) \\
&... \\
\frac{dx_n}{dt} &= f_n(x_1, x_2, x_3, ..., x_n, u_1, u_2, u_3, ..., u_n)
\end{aligned}$$

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where u_n are time dependant control variables. In our scenario, the primary objective is to define the values of u_n variables in a such way, that values of rates are brought from their init values:

$$x_1(0), x_2(0), x_3(0), ..., x_n(0) \quad (7)$$

to their target values:

$$x_1(t_k), x_2(t_k), x_3(t_k), ..., x_n(t_k) \quad (8)$$

For minimization of criteria function expressed by equation 6, a numerical method was used. Since the empirical functions are considered in stated optimization problem, the analytical solution to the optimization problem could not be easily defined. It is questionable whether the analytical solution of such case could be determined. In the search for the optimum or in our case definition of best strategy, according to target functions, application of pattern search algorithm was performed. Figure 7 represents attainability of target functions for

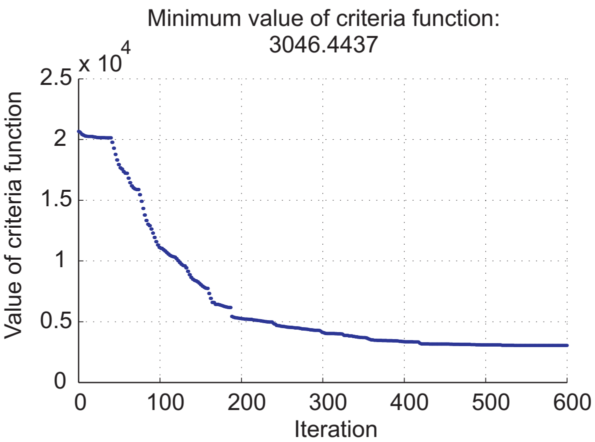

Fig. 6 Value of criteria function with respect to algorithm iteration. Application of pattern search algorithm for determination of optimal strategy (600 iterations).

observed ranks *A*, *B*, *C* and *D*. Target function should be expressed for each and every rank, which is to be observed. According to given target and criteria functions expressed by equation 6 our goal is to aim for minimal deviations considering the limitations of key parameters. The dashed curves on a figure 7 denote the target functions of individual ranks, while solid lines denote system response or in our case the actual number of manpower in a rank. As a result, the system calculates an optimal strategy for achieving target functions within a set of parameter limitations. The example of parameter variation according to the stated target function is shown in Figure 8. The dynamics of the parameter variation is not convenient for a decision maker to draw a conclusion about the computed strategy. Therefore the tabular results are more convenient for representation. Table 1 (*values are altered due the security reasons) shows the strategy determination for particular rank. The number of officers in rank is shown, the inputs to particular rank, transitions to the next rank and Fluctuation. In the last two rows the parameter values

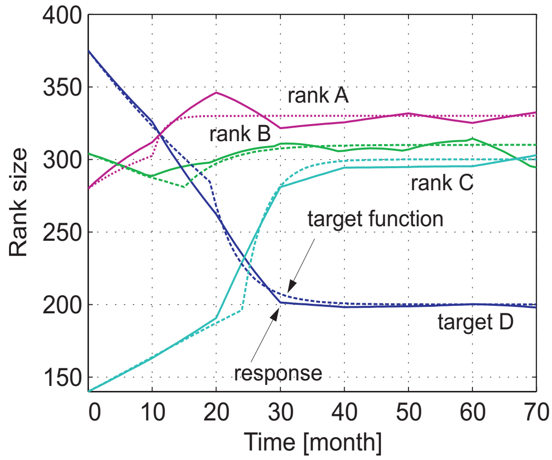

Fig. 7 Target function approximation (dashed lines) for ranks *A*, *B*, *C* in *D* (full lines)

for Transitions to the next rank and Fluctuation parameters are shown. Table 1 is one of the possible solutions automatically computed by developed system and provided to the decision maker. Here the methods of group decision making play an important role [20]. Depending on the parameter constraints, feasibility and government policy the possible acceptable strategy could be selected and implemented. Important consideration at the application of optimization techniques is user interaction. Methods applied are relatively advanced however, the system should enable user-friendly manipulation of input variables. In our case, the target functions as well as the parameter boundary values are stated as the time vectors. This means, that the user has to state at least *15* vectors in order to perform particular optimiza-

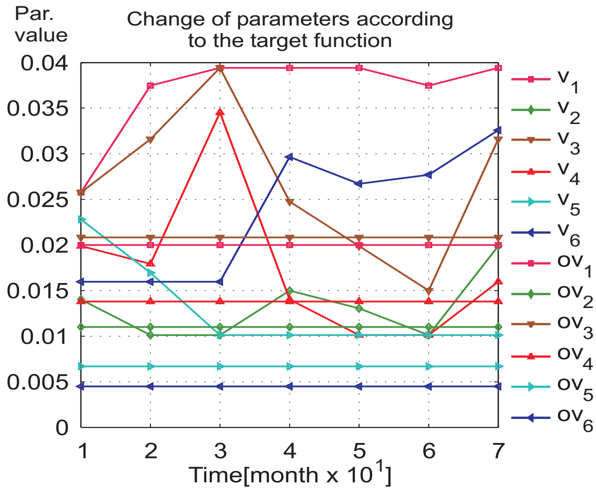

Fig. 8 Example of parameter variation according to the target function.

tion run. In our case the system for data manipulation was developed where the input of the parameter values was made by application of a spreadsheet. Each spreadsheet with defined input vectors represented particular simulation/optimization scenario with description. For each scenario stated goal functions were represented in order to quickly characterize particular scenario. User interface also showed lower and upper boundaries of variational parameters of stated optimization problem.

Tab. 1 Strategy determination for particular rank*

month	0	10	20	30
No. in rank	4620	4633	4627	4598
Rank inputs	86	58	23	34
Trans. next	59	49	44	38
Fluctuation	14	15	8	4
Trans. par.	0.0328	0.025	0.0101	0.0152
Fluct. par.	0.0098	0.0098	0.0061	0.0032
month	40	50	60	70
No. in rank	4590	4604	4593	4607
Rank inputs	56	28	56	×
Trans. next	38	39	30	×
Fluctuation	4	0	12	×
Trans. par.	0.025	0.0128	0.025	0
Fluct. par.	0.0037	0	0.0098	0

4 Conclusion

The main conclusion after performed development phase and initial validation is, that continuous simulation with system dynamics approach contributes to the main development cycle with its transparency. The structures developed by system dynamics approach were referential during the entire development process. One of the important advantage of the continuous models is the possibility to perform the optimization and target function strategy search. In this regard the Markov chain approach is less suitable [21]. Hybrid approach was almost mandatory in order to provide the appropriate level of validation confidence. Due to the importance of the problem addressed, the validation was the crucial methodological topic. Presented approach incorporating system dynamics methodology is structured in a way that the prediction of what will happen in a system if current policies are kept is enabled. Optimization problem solving technique on the other hand provides answers to the question what kind of policies should be implemented to fulfil given goals. Developed system based on MATLAB provides a computational engine which provides the dynamical strategy according to the stated target function. Stated optimization problem represents significant computational task which could be effectively addressed by the means of parallel computing. On the example of Slovenian Armed Forces, the determination of proper human resource strategy is of primary importance on account of ongoing restructuring process. Presented approach provides effective algorithm to provide the strategy for management of large scale HRM problem with high importance on the national level. Future research process will include model testing actions and comparison analysis. Another aspect of future research will include the development of sophisticated simulation graphical user interface (GUI) and introduction of feedback information in human resources management process. Final tool will generate a list of possible strategies how to deploy human resources management policies in a large and complex organizational system according to given target functions. Such tool could be applicable in different types of complex workforce planning processes like in Slovenian army and other large organizations.

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