Development of a Human Resources Transition Simulation Model in Slovenian Armed Forces

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Abstract

The paper describes development of continuous and discrete model of human resources transitions in large organization. The model considers eight different ranks. The calibration of the model was performed where the historical data was used to determine time constants of transitions and fluctuations. Basic simulation runs were performed in order to complete predictive validation of the model. Optimization of the model was performed by application of pattern search algorithm considering the key parameters. By this means the target strategy of the system could be determined. Development and comparison of continuous and discrete event model was performed. Discrete event model was applied in the validation phase. Hybrid approach to the problem provided higher level of confidence. System dynamics methodology proved to be appropriate as the tool for initial development of the model and structural validation reference.

Keywords: simulation model, system dynamics, human resources, transitions, optimization, target function, strategy

1 Introduction

In a large and complex organizational structure, human resources management (HRM) is a demanding and on going process. From an abstract system dynamics (SD) point of view, this problem is represented as a delay chain, for which we need to determine such parameters, that the target functions will be achieved. In such case, prediction or anticipation is a very important point of view [1, 2, 3, 8, 9, 10, 11], and serves as a prerequisite for efficient management of complex systems. Problem of dynamics can be addressed by continuous or event based simulation. Applying both methodologies, additional validation of developed models can be achieved using their comparison. It is important to take advantages each of the approaches has, while considering differences amongst them, especially while preparing input data for simulation. While solving this kind of problems, event based simulation is to be more accurate. However, higher accuracy is bonded to time demanding data preparation. Comparison between discrete and continuous model provides means of structural and quantitative validation.

Main objective of present study is development of a dynamical model, which allows structural pursuit and foreseeing of fluctuation amongst individual ranks in a large and complex organizational structure; in our case Slovenian Armed Forces. Developed system should provide optimal strategy to achieve desired rank structure. The goal structure should be achieved by the consideration of parameter limits and longer time constants which determine system response. By the means of the optimization the best solution for armed forces development should be provided. Due to the restructuring the addressed problem is of significant importance. The study is based on a system simulation method, where SD and Discrete Event Simulation (DES) are used. SD procedure is more aggregated and that is why more understandable to users, while DES assures higher accuracy of gained results. In this phase we developed two differently aggregated SD models, based on averages of transitions amongst ranks. The SD model is built from 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 this model was performed using a historical data, where simulation results perfectly get along with anticipations. While time period for such simulation is free to choose in our case 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 - benefit ratio is considered.

2 Metodology

Long-term HR planning is a strategic and very important part in a process of preparation and realization of such a complex organizational system also for the sake of cost reduction. All these entities are a part of a complex social system, where we can expect results only on a longer time periods because of a large time constants and delays across feedback loops [16]. Behaviour of such systems is very sensitive to slightest initiatives from environment and different decision policy proceedings. This means that the developed model must enable a simulation (prediction) of personnel structure dynamics, considering transitions amongst different ranks and their fluctuation from inside and outside of the system.

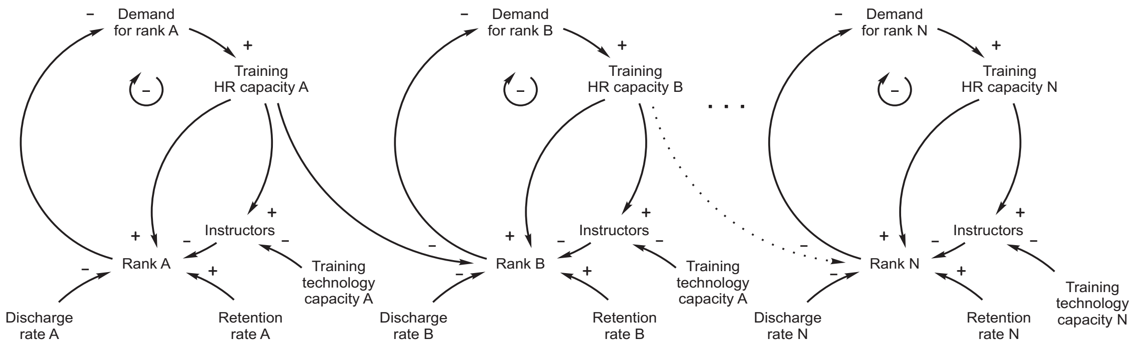

Figure 1: Causal Loop Diagram for rank transitions.

The model is based on the system dynamics methodology [13]. There are many examples of system dynamics methodology implementation in the field of workforce management [7, 5, 6]. 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. Different models designed simulate the flows of personnel through various ranks, answering to a question what would be the system behaviour like considering different input resources. This means, that user can identify potential manpower shortfall and calculate financial impacts for a chosen policy and examine possible curative policies or rationalizations only by mimicking operations of real-world system. But this can only be achieved, if we develop a validated simulation model, which will take into consideration model feedback loop dependencies and key parameters, specially time constants which define human resources dynamics. Figure 1 shows causal loop diagram of the system [4]. 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 positively influences number of instructors as well as number of rank A 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.

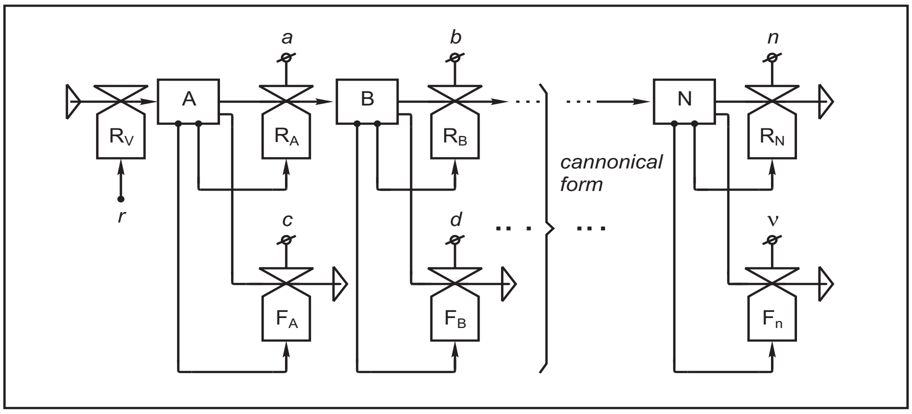

Figure 2: Structure of system dynamics model of rank transitions in the cannonical form. Shown structure represents delay chain of first order delay elements.

Such SD model, can be easily adopted in a group decision-making process [12] by realization of next activities:

1. Definition of structure, development of model, definition of goals and criteria.
2. Gathering of data and calibration of model.
3. Validation of model.
4. Preparation of simulation scenarios and what-if analysis.
5. Simulation scenario analysis system development.
6. Simulation test and initiation of a model.

Figure 2 represents the stock and flow diagram of an SD model, which represents transitions of manpower amongst individual ranks. The structure shows that a closed labour 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 bust be from next rank below. 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) illustrate 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 prior rank (in this case out of 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.

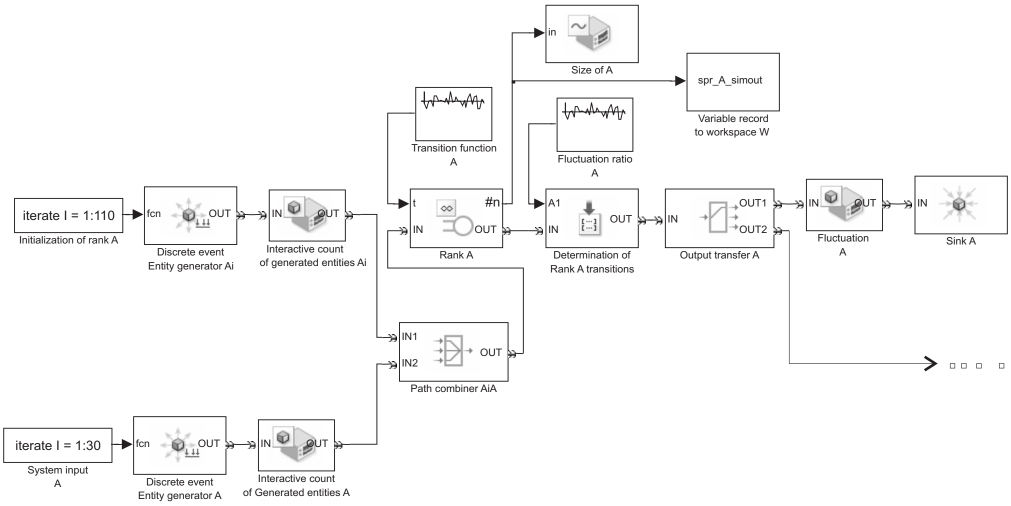

Figure 3: Model of rank transition developed by Discrete Event Methodology in MATLAB/SimEvents.

Now lets try to define variable a, which represents ratio of a successful transitions into rank B. This rate depict on a basis of evaluations of monthly transitions from rank A to rank B and can be defined as:

$$a = \frac{m}{A_0}\tau^{-1} \tag{1}$$

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

$$a = \frac{\eta}{\tau} \tag{2}$$

where η being the transition probability and τ a time needed for rank A recruitment.

Equation 3 depicts the following fictious ratio d, which in our model represents fluctuation ratio from rank B, where $m = 15$, $S_0 = 375$ and $\tau = 12$:

$$d = \frac{15}{375}\frac{1}{12} = \frac{1}{300} \tag{3}$$

All other ratios (a, b, c and r) can now be calculated in a same manner. Results gathered in such way depend on the accuracy and quality of data, used for calculations. This means that the best way is to combine data about yearly transitions amongst individual ranks with expectations of how long individuals stays in each rank.

Model on a figure 2 can also be represented as a system of difference equations [15, 14]:

$$
\begin{aligned}
A(k+1) &= A(k) + \Delta t(R_v(k) - R_A(k) - F_A(k)) \\
R_A(k) &= a\,A(k) \\
F_A(k) &= c\,A(k) \\
B(k+1) &= B(k) + \Delta t(R_A(k) - R_B(k) - F_B(k)) \\
R_B(k) &= b\,B(k) \\
F_B(k) &= d\,B(k) \\
&\ldots \\
N(k+1) &= N(k) + \Delta t(R_x(k) - R_N(k) - F_N(k)) \\
R_N(k) &= n\,N(k) \\
F_N(k) &= \nu\,N(k)
\end{aligned} \tag{4}
$$

Figure 3 represents a model of transitions amongst ranks, developed by principles of DES constructed by `MATLAB/SimEvents`. Element *Rank A* characterize a server entity in a discrete event simulation, initialized by the start size of a rank A. Here we use event based generator of entities. The level of *Rank A* element is controlled by a step function, which represents an input of a system. Variation of transitions of entities from *Rank A* to the next level is presented as frequency distribution of entity stay time in *Rank A*, which was acquired by analysis of historical data about dynamics and transitions amongst individual ranks. Fluctuation ratios are also presented as user-defined functions, gained by analysis of historical data about fluctuations. This is then followed as an output to the next level, which in our case is *Rank B*.

Structure of discrete model is identical to the structure of continuous model. In a discrete model the transitions amongst ranks are represented as stochastic distribution functions. This means that duration which entity spends in individual rank is represented as cumulative 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.

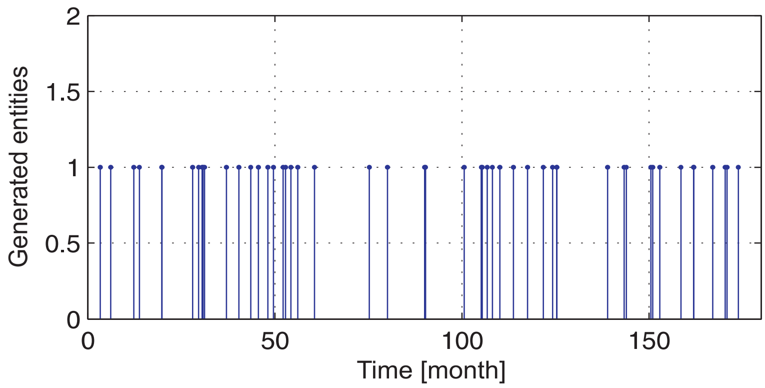

Figure 4: Generated entities as rank fluctuation

Figure 4 shows the dynamic of entity generation, which in our case represents fluctuations from element *Rank A*. All individual entities are generated according to given fluctuation process distribution. Each and every one of these points represent fluctuation of one manpower as 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 5. Group of curves from a discrete model results represent 50 simulation runs in a 15 years simulation

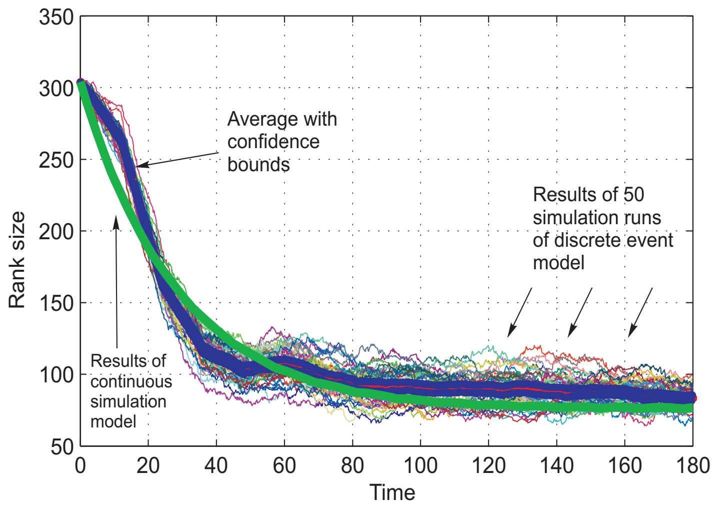

Figure 5: Comparison of continuous and discrete simulation model results. (confidence level $\alpha = 0.05$ with average of fifty simulation runs.

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 on this figure, considering given parameter limitations, in 5 year duration of simulation target conditions could not be met. In a process of model validation, results from continuous and discrete model should match. This form of procedure is very important, especially regarding parameters hypersensitivity. Statistical *t-test* can be performed, to confirm if results correspond, by confirmation or rejection of parameter adequacy.

Model of transitions, developed by principles of continuous simulation using `MATLAB/Simulink` is presented on a figure 6. Step and 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 textitRank 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

Figure 7 shows the structure of the optimization problem. The core of the 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 strategy was defined as optimization problem. Optimization problem is a process of finding the best solution from all feasible solutions. Figure 8 describes the dynamics of criteria function value variation trough 600 iterations of simulation. Iteration is presented as calculation of the value of criteria function, minimisation of which is required:

$$\min_{u \in U} J = \sum_{n=1}^{r} \sum_{i=0}^{t_k} \sqrt{\Big(C(i)_n - X(i)_n\Big)^2} \tag{5}$$

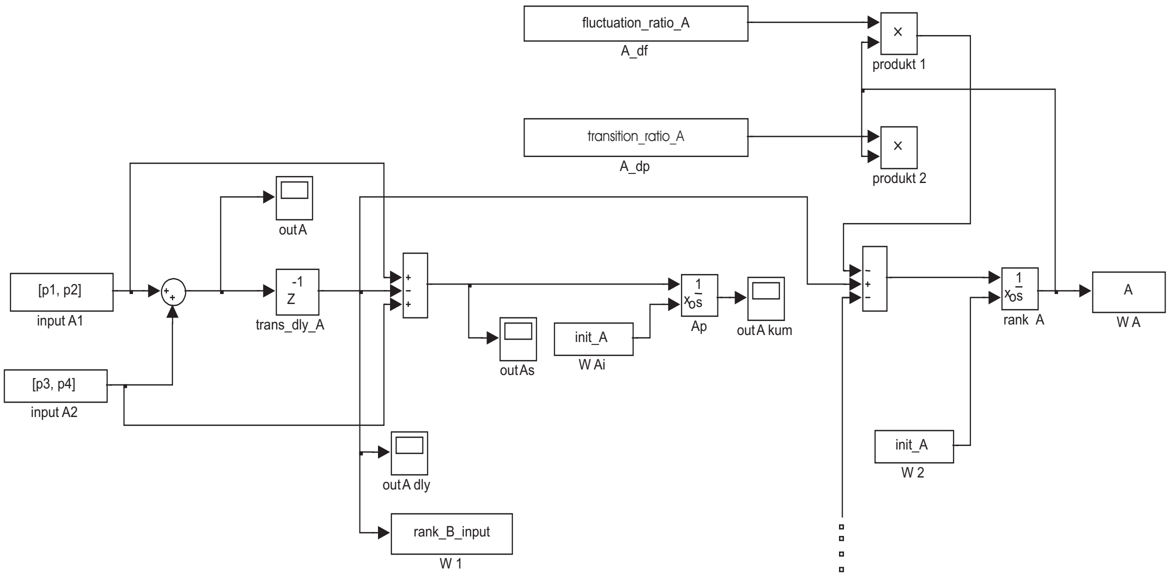

Figure 6: Rank transition model developed by the principles of continuous simulation developed in MATLAB/Simulink.

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 deviation from the value of observed parameter X_n. t_k is a discrete time. Sum of mean square deviations from the values of criteria functions are then summed again according to the set of target functions [17]. 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:

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

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:

$$x_1(0), x_2(0), x_3(0), ..., x_n(0) \tag{6}$$

to their target values:

$$x_1(t_k), x_2(t_k), x_3(t_k), ..., x_n(t_k) \tag{7}$$

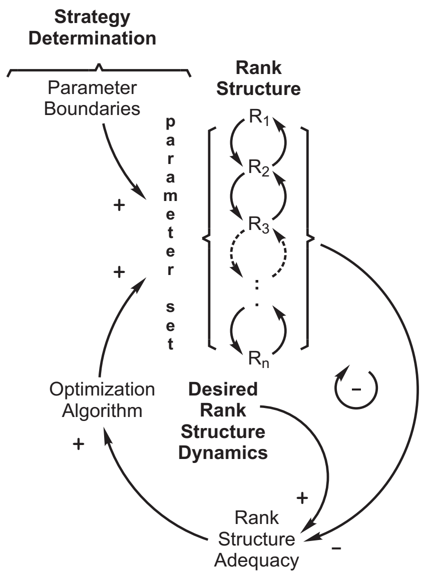

Figure 7: Optimization problem key components.

For minimisation of criteria function expressed by equation 5, a numerical method was used. Assumption of empirical functions in such optimization problems cause, that probability for determination of analytical or mathematical accession of optimum is considerably small. In our case, in search of optimum or definition of best strategy, according to target functions, application of pattern search algorithm was performed.

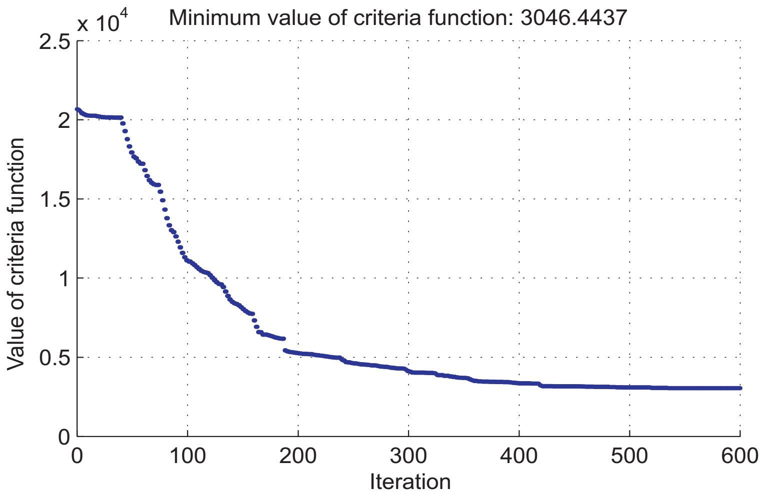

Figure 8: Value of criteria function with respect to algorithm iteration. Application of pattern search algorithm for determination of optimal strategy (600 iterations).

Figure 9 represents attainability of target functions for 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 5 our goal is to aim for minimal deviations considering the limitations of key parameters. The dashed curves on a figure 9 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 targed

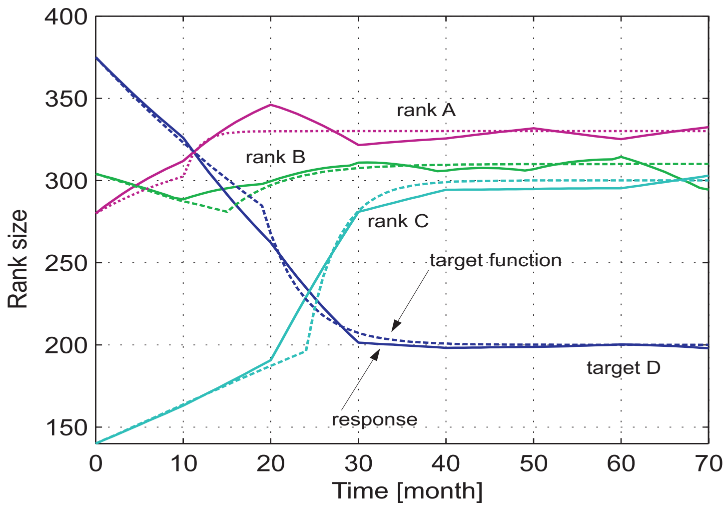

Figure 9: Target function approximation (dashed lines) for ranks A, B, C in D (full lines)

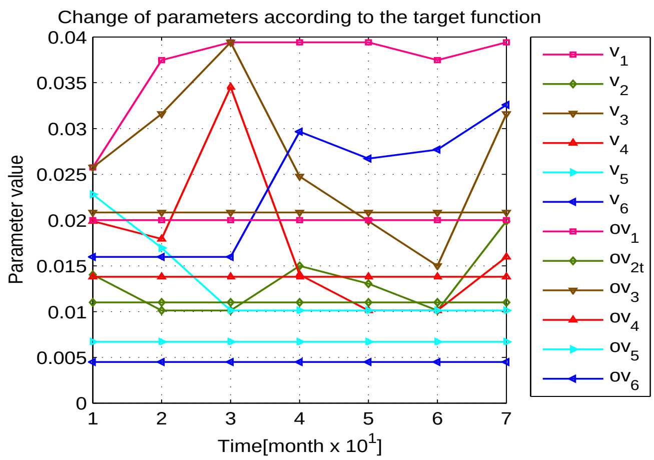

Figure 10: Example of parameter variation according to the target function.

function is shown in Figure 10.

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 confidence 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 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. Depending on the parameter constraints, feasibility and government policy the possible acceptable strategy could be selected and implemented.

4 Conclusion

The main conclusion after performed development phase is, that 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 impor-

Table 1: Strategy determination for particular rank*

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

tant 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 [4]. 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 burden which could be effectively addressed by the means of parallel computing. On the example of Slovenian Armed Forces, this 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 for state. Results of the system are applicable to the real world system almost instantaneously.

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 introducing feedback information in human resources management process. Final tool should 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 type of complex workforce planning processes like in Slovenian army and other large organizations.

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