

Methods for Description, Analysis and Evaluation of Command and Control Systems (C2)

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Abstract- Every organization needs a clear understanding of its own processes, capabilities, products, technologies and relationships to effectively deliver its objectives in response to a changing environment. A clear understanding of the nature of management systems requires an integrated abstract representation of their multifaceted aspects through organisational modelling methods. When the system is complex, an approach that can provide a unified medium for representing all major functional and system perspectives is necessary for its comprehensive modelling. The purpose of this publication is to present an approach that provides an integration into one environment of organizational goals; policies, concepts, and doctrines; management systems; decision-making procedures; organizational structures, processes, information flows, and data; resources, capabilities, and technologies. In this approach, architecture refers to the fundamental organization of a system, which includes the system components, their relationships with each other and with the environment, and the principles that underlie system design and its development.

Keywords- Modelling and analysis methods, Modelling, Simulation, Analysis, Evaluation.

I. INTRODUCTION

Command and control systems are complex systems, of the "system of systems" type, whose integrity is a determinant of their overall effectiveness. Their specific characteristics determine the need to establish a clear basis, uniform standards and full integration of all activities and tasks to achieve the set objectives. Ensuring this explicit necessity requires encompassing the entire Command and control system in a single cognitive paradigm. An approach where individual fragments of the 'big picture' are modelled and analysed with different, purpose-built tools is possible. However, achieving compatibility of the respective models may be

problematic, given the complex and heterogeneous nature of these systems, including their elements and system relationships. A universal approach is needed to provide a common, integrating basis for system modelling in security and defence [1].

The architectural approach is precisely the means by which the following can be integrated into an environment: 1) objectives; 2) policies, concepts and doctrines; 3) leadership, Command and control systems; 4) planning systems; 5) decision-making procedures; 6) organizational structures, processes, information flows and data; 7) resources, capabilities and technologies [1].

In this approach, architecture is understood as the fundamental organization of a system, which includes the system design with its components, the interrelationships among the components, and the relationships with external organizational systems that correspond to the subject matter of the system under study. Organizational architecture (OA) provides the mechanism that accomplishes the communication between the elements of the organization and its functioning [2].

The conceptual difference in approaches to building organizational architectures is materialized in the way each architecture is formalized. The relevant formalisation tool is the so-called Architecture Framework (AF). The AF provides a single formalized model containing the requirements of C2 systems. The AF is a specification of how to organize and represent the structure of a system, its processes, the capabilities it must have, the technologies, etc. It is a meta-model that ensures compatibility of the models being developed by defining rules, guidelines and product descriptions for their development, representation and communication.

Historically, the first AF is that of Zachman. According to Zachmann, the model for describing systems is built at

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the contextual, conceptual and logical levels and illustrated with a matrix. The framework requires answering the questions "what", "how", "where", "who", "when" and "why" from different perspectives to describe the same process. Zachman pulsed a rapid and productive process of developing different AFs and powerful software packages to support them. The type and choice of a particular framework depends on the goals and characteristics of the organization [3].

There are other AFs. In 2003, the U.S. Department of Defence approved the DODAF Architecture Framework, which provides a common integrative approach for modelling and analysis across the U.S. armed forces. The UK MODAF and NATO NAF AFs have been developed based on it [4].

Several AFs incorporate description methods and techniques to assist analysts in reaching an optimal or near-optimal solution to a complex problem. These techniques may include, for example, the Computer Integrated Open Systems Architecture (CIMOSA), the Integrated Definition Engine (IDEF) methodology, Petri nets and their variations, the Unified Modelling Language (UML), organizational function diagrams (EFD), etc. Using these techniques, a clear representation of the processes is achieved through a set of decomposed activities with corresponding inputs, outputs and actors. Some description methods can also represent process dynamics.

Formal description and analysis methods can be conventionally classified into three groups: 1) state machine methods; 2) languages for programming and specification; and 3) combined methods.

State machines. Methods in this group are based on sets of states, performing processing in response to events leading to a state change. These models are a convenient and natural way of describing interactions, but when described in sufficient detail lead to an unacceptably large number of states. These include Petri nets, finite automata, state diagrams, formal grammars, etc.

Languages of description and specification. Methods from the group of programming and specification languages view an interaction as an algorithm and are used to describe it precisely. Their main drawback is that nonessential details can mask important aspects of the interaction of system elements. Algorithm graphschemes, logic schemas, parallel logic schemas, matrix schemas, parallel algorithm matrix schemas, canonical schemas, etc. belong to this group of methods.

Combined methods. The methods of this group integrate the first two groups. The interaction is represented as a machine with a small number of states reflecting the basic features of the interface. This machine is augmented with additional "context" variables and procedures to handle them in each state. The functioning of the machine is determined by the input events, the values of the 'context' variables and the procedures for processing them in the

current state. Examples of combination methods are E-networks, Keller's Model, etc.

II. MATERIALS AND METHODS

For the research of a complex Command and control system it is also necessary to define the goals and objectives of the research, to choose the methodological tools for the optimal solution of the set tasks. The toolkit should include quantitative methods, tools for formal description of models, and software products for modelling and simulation. Next, the objective function of the study should be defined. An analytical expression should be chosen to find the overall performance of the system, including the performance indicators. A detailed list of the factors affecting the study object should be prepared. After analysis, the factors essential for modelling shall be identified. The consistency of the selected essential factors with the necessary requirements for the objectives of the study shall be established in order to determine the critical success factors. After these activities, the model/architecture of the existing (As-Is) system is formed. The formed model is subjected to a model controllability check. The activity model (OV-5) has to verification of the adequacy, completeness and inconsistency. The performance of the model is simulated using specialised software tools. The performance of the (As-Is) model is evaluated using the specified objective function. Conclusions and recommendations from the analysis are formed.

The recommendations made are applied to create an advanced model of the desired/future (To-Be) state of the studied system. The new model is again checked for adequacy, completeness and inconsistency where changes have occurred. The performance of the (To-Be) model shall be assessed using a selected modelling and simulation software or appropriate mathematical apparatus. The experiment is usually associated with the influence of critical success factors on the output parameter values. On this basis, the performance of the (To-Be) model is evaluated. The effect of changes is calculated. Conclusions and recommendations are formed.

The results of the study can be interpreted in a specific software application. Usually, specialized modelling software automatically generates an outline of a logical model based on the data (OV-7) for the creation of a future information system of the studied model. Next, descriptions of system interfaces (SV-1) and system functionality (SV-4) are prepared, an overview of the subsystems comprising the information system is provided, and a profile of technical standards (TV-1) is developed. A prototype of the system is developed and tested using a separate methodology.

The presented sequence of abstract steps by stages forms a methodology for modelling, analysis and development of complex organizational systems. The proposed methodology is presented schematically in

Fig.1. Depending on the purpose to be pursued, only Stage 1

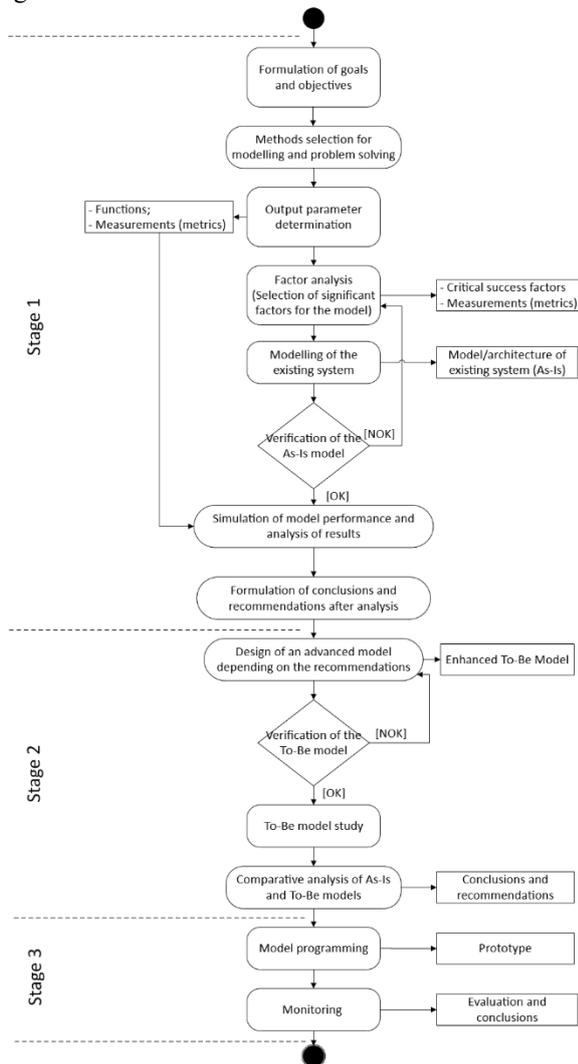


Fig. 1. Methodology for modelling and analysis of complex organizational systems.

for the description of the current system, Stages 1, 2, and 3 or Stages 1 and 3 for the improvement of the existing system can be executed successively.

III. RESULTS AND DISCUSSION

This application is an example of the use of the description and analysis methods described below in the section on the proposed methodology. The research object is the typical C2 system. This is current Capability Planning Subsystem, which is part of the Defence Planning System of the Bulgarian Army. The objective of the study is to increase its effectiveness. The research is a practical expression of the described ideology of the architectural approach. The case study is a sample from the Strategic Defence Review completed in 2020 and

presents the status of the Defence Planning System for the period November 2018 to March 2019.

The following approaches were used to find realistic solutions: 1) Architecture Approach with technology of operation described as architecture products as required by the DoD Architecture Framework, Ver. 1.5 document; 2) Process approach, which is based on the concept of Business Process Management (BPM).

The following methods were also used: 1) Scientific Abstraction; 2) Analysis and Synthesis; 3) Modelling; 4) Decomposition; 5) Factor Analysis; 6) Activity Based Costing (ABC); 7) Statistical Modelling and Optimisation Methods.

IDEF0 diagrams were used for the formal description and analysis of the model. Simulation of the model performance was performed using the Ultimius Process Designer Ver. 6.0 software application.

The presented study was performed under the following constraints:

- The creation of the model is based on available normative, regulatory, and reference documents covering the period November 2018 - March 2019;

- Due to the large amount of information, only Stage 1 of the proposed methodology is considered in this paper;

- Information from explicit sources has been used.

In order to simplify the model without significantly changing the modelled environment, the following assumptions are made:

- For the purpose of the study, an approximate accuracy of the results satisfying the analysis is adopted;

- The study is oriented towards increasing the efficiency of the alternatives considered at a given cost - seeking maximum effect;

- It is conventionally assumed that about 300 people are involved in the execution of one cycle of the work of the system, of which about 4% (12 people) are full-time staff, the remaining 288 people are non-regular staff.

- The non-regular staff use about 20% of their working time to carry out planning activities. As a result, for an equivalent full-time workload on an annual basis, about 70 staff work on the implementation of capability planning activities.

Objective function selection

Within the study, performance measurement is oriented towards improving the cost and cycle time performance of the processes at the study site.

Given this, the generalized objective function Y is formed from three output parameters.

$$Y = \phi(y_1, y_2, y_3), \quad (1)$$

where: Y - subsystem efficiency.

In Tab. 1 are shown the selected output parameters with the relevant outcome indicators and their measures.

TABLE 1 OUTPUT PARAMETERS

Y Parameters	Performance Indicator	Metrics
y_1	Costs of staff involved in the processes	Euro
y_2	Timeout period (Inactivity time)	Days
y_3	Processing time per task	Hours

The generalized function of the form (1) is sufficiently complex and can be given in the following form [5]:

$$Y = \sum_{v=1}^u a_v \cdot y_v, \quad u = 2,3 \quad (2)$$

where a_v are weighting factors that account for the role of individual parameters in the quantitative characterization of the target. They can be positive quantities (when an increase in the corresponding parameter corresponds to the target) and negative quantities (when an increase in the corresponding parameter leads to a move away from the goal).

Because the individual parameters y_1, y_2, y_3 have different physical natures, different dimensions and intervals of definition, the coefficients a_v must also have different dimensions and intervals of variation so that the generalized output parameter has some chosen dimensionality. It is therefore more convenient to proceed to form Y in the form of a dimensionless and bounded in the interval $[-1, +1]$ quantity.

For this purpose, the three parameters y_1, y_2, y_3 are transformed into new parameters $\theta_1, \theta_2, \theta_3$ by the formula [5]:

$$\theta_v = \frac{y_v - \bar{y}_v}{\frac{y_{v,max} - y_{v,min}}{2} \cdot u}, \quad v = 1,2,3, u \leq n, \quad (3)$$

where \bar{y}_v is the average value of y_v , which can be estimated by:

$$\bar{y}_v = \frac{y_{v,max} + y_{v,min}}{2}, \quad (4)$$

The quantities $y_{v,max}$ и $y_{v,min}$ are the maximum and minimum values of y_v , and $u=3$ is the number of parameters that are involved in the formation of the generalized objective function. Then considering (3) and (4) we obtain [5]:

$$Y = \sum_{v=1}^u \alpha_v \cdot \theta_v = \frac{1}{3} \sum_{v=1}^3 \alpha_v \frac{2y_v - (y_{v,max} + y_{v,min})}{(y_{v,max} - y_{v,min})} \quad (5)$$

In such a transformation of the individual output parameters, the coefficients α_v can be dimensionless if they are also chosen in the interval $[-1, +1]$, i.e.

$$-1 \leq \alpha_v \leq 1, \quad (6)$$

the generalized objective function Y in will be a dimensionless quantity whose values are constrained:

$$-1 \leq Y \leq 1, \quad (7)$$

Selection of modelling factors

From a modelling perspective, the Capability Planning Subsystem under study is a multifactorial object incorporating material, human and information resources that is impacted by a number of factors. In order for the model of the studied object to be adequate, the most significant factors determining the functioning of the model must be included in the model. That is, the task of selecting the factors in modelling boils down to identifying the essential factors and eliminating the non-essential factors. In practice, this involves:

1. Preparation of a detailed list of factors impacting the performance of the subsystem under study;
2. Selecting the essential factors and eliminating the non-essential ones;
3. Establishing the compliance of the selected essential factors with the necessary requirements from a modelling perspective.

To facilitate the selection of the significant factors that affect model performance, the factor space is divided into three areas: planning, organizing, and execution. For each of these, a complete list of candidate factors (F_i) (20 in total) required for the formation of the model of the object under study was determined by brainstorming. The selection of the significant factors for the model was performed by the rank correlation method through a survey of 15 highly qualified experts with years of experience in defence planning. After the data processing, the degree of agreement between the experts' opinions was determined using the concordance coefficient (W). The consistency of the opinions was done by formula (8) since the ranking contains matching ranks:

$$W = \frac{S_d}{\frac{1}{12} m^2 \cdot n(n^2-1) - m \cdot \sum_{j=1}^m U_j}, \quad (8)$$

$$\text{where } S_d = \sum_{i=1}^n \left[\sum_{j=1}^m x_{ij} - \frac{1}{2} m(n+1) \right]^2. \quad (9)$$

After performing the appropriate calculations, a high degree of probability was obtained in the consistency of the experts' opinions on the influence of the factors under study. This gives confidence that the selected factors can be used for modelling purposes.

In the following, the factors are presented in a histogram of summary ranks from which the significant factors are separated. Three of the most significant factors are identified from the histogram. These are listed in Table 2. These are identified as the critical factors of the modelling. Once the factors have been selected, their respective metrics and the measurement units by which each should be scaled are established.

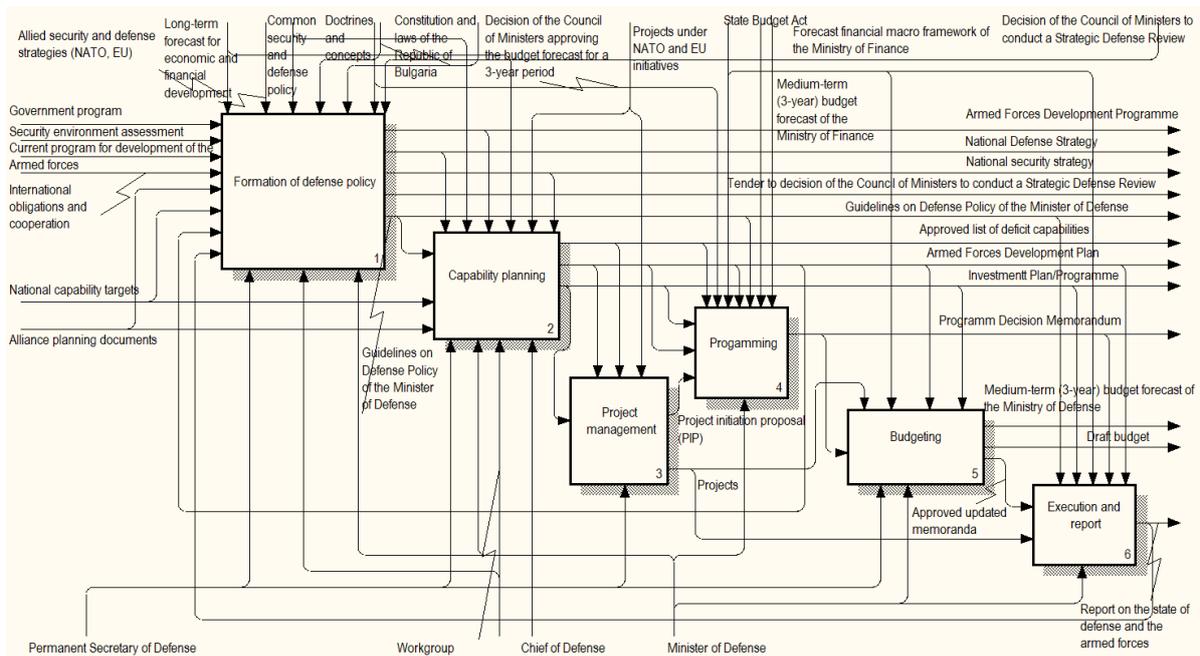


Fig. 2. A0 Defence planning model in the Bulgarian Armed Forces (BAF)

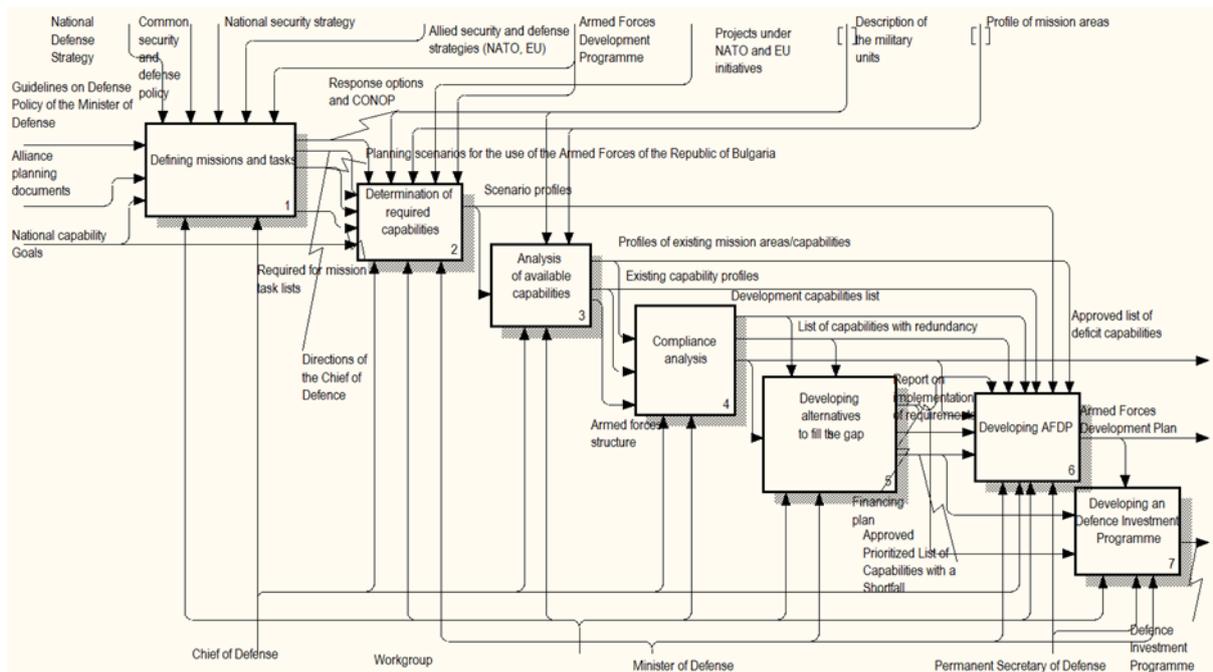


Fig. 3. A2 Capability planning sub model

It is characteristic for the selection of the factors that they must meet the following basic requirements: 1) each individual factor must allow for quantification; 2) they must be controllable; 3) they must be independent, i.e., no two factors are functionally related in the set; 4) they

must be consistent, i.e., it must be possible to realize all possible combinations of factor values within their domains of definition [5, 6].

TABLE 2 MOST SIGNIFICANT FACTORS

Factor	Essence of the Factor	Indicator	Metrics
F1	Performance of the participants	Time for completion of individual activities	Hour
F2	Process resourcing, including the human resources (full time and non-full time officials, management staff) of the management and executive structures involved in the processes	Amount of personnel	Number
F3	Funding of activities	Participants' labour costs	Euro/hour

Activity Model (OV-5)

After determining the objective function and critical factors for the modelling, the As-Is model of the study object is formed.

The activity model is presented in Fig. 2 using CASE system (Computer-aided software engineering) according to IDEF0 standard. To demonstrate the described methodology, the activity diagrams are decomposed to the level two (Fig. 3).

Verification of the adequacy, completeness and inconsistency of the OV-5 activity model

Checking for adequacy, inconsistency and completeness of the model presented in Fig. 3. is the next step that the researcher has to do. The verification is performed using an E-network model of the interaction and matrix properties of the algorithm, see [Radulov I., "Modelling of capability-based defence planning processes, 2024"]. Similarly, the A2 Capability planning submodel presented in Fig. 3 was checked for adequacy. From the verification of transition management and reachability of E-network states, it turns out that all A2 model states are reachable. The consistency and completeness check of A2 was performed using a matrix scheme of the algorithm as described in [7, 8]. The formed model of the capability planning subsystem is proved to be adequate, consistent and complete. The operation as a set of subnetworks was simulated using the Visual Object Net++ Evaluation Version 2.0a software product.

Evaluation of the controllability of the model

At this stage, the impact of the controlled factors on the model output parameter values is evaluated. It is characteristic of multifactor objects, such as the Capability Planning Subsystem under study, that the generalized output parameter Y changes significantly under the influence of the factors selected for the study. In some cases, however, the changes in Y are insignificant, and it is difficult to determine whether they are due to changes in the controlled factors or to

confounding factors. If the influence of the controlled factors is insignificant, the study of the model with them becomes pointless. It is therefore necessary to assess the appropriateness of modelling the process with the selected factors at the outset of the study.

Verification of the controllability of the model was carried out prior to conducting the overall experiment. In this regard, the evaluation was performed for one process state of the As-Is model for a certain number of experiments (n) with different values of the input factors. After each experiment, the values of the objective function parameters were recorded, and their estimates and variance were calculated using the following formulas [5]:

$$\bar{y}_u = \frac{1}{n} \sum_{i=1}^n y_{i_u}, u=1...3 \tag{10}$$

$$S_{y_u}^2 = \frac{1}{n-1} \sum_{i=1}^n (y_{i_u} - \bar{y}_u)^2, \tag{11}$$

where \bar{y}_u is the average value of the parameter, and $S_{y_u}^2$ is its dispersion.

The Fisher criterion (F-criterion) was used to compare the dispersion estimates $S_{y_u}^2$ and the dispersion estimate of the equivalent disturbance $S_{\epsilon_u}^2$ for each parameter separately [5].

$$F_u = \frac{S_{y_u}^2}{S_{\epsilon_u}^2} \tag{12}$$

The verification of the considered process was performed under five different combinations of values of the critical factors for which the values of the parameters of the generalized objective function were measured. In order to analyse whether the controlled factors have a significant influence on the model output parameter, the experimental data for \bar{y}_1 and $S_{y_1}^2$ are obtained as: $\bar{y}_1=103038,67$ и $S_{y_1}^2= 883889512,25$. The experimental results for the remaining parameters are plotted in Table 3.

TABLE 3 THE EXPERIMENTAL RESULTS

i	1	2	3	4	5
y_1	120097,34	145090	91567	89465	68974
y_2	9724,32	8124,02	5534,33	11632,17	4544,53
y_3	17,50	12,00	7,00	5,50	10,50

i	\bar{y}_j	$S_{y_j}^2$
y_1	103038,67	26591,57
y_2	7911,87	2613,90
y_3	10,50	4,21

From ten other observations conducted with constant factor values, the estimate of the single dispersion was determined $S_{\epsilon_1}^2 = 883889512,3$. The calculated F-coefficient is: $F_1 = \frac{S_{y_1}^2}{S_{\epsilon_1}^2} = \frac{26591,57}{2769,96} = 9,6$.

From a table of reference, the tabular value of the significance of Fisher's criterion was determined. At a significance level of $\alpha=0,05$ and freedom degrees of

$v_1=5-1=4$ and $v_2=10-1=9$, for the single dispersion S_{y1}^2 and the dispersion of the equivalent disturbance $S_{\varepsilon 1}^2$, obtained with N observations, respectively, the tabular value of Fisher's criterion is $F_{t1} = F_{t2} = F_{t3} = 6,00$. Similarly, $F_2 = \frac{S_{y2}^2}{S_{\varepsilon 2}^2} = \frac{2613,90}{348,52} = 7,5$ and $F_3 = \frac{S_{y3}^2}{S_{\varepsilon 3}^2} = \frac{4,21}{0,5} = 8,4$. Since $F_1 > F_{t1}$, $F_2 > F_{t2}$ и $F_3 > F_{t3}$, the input factors are assumed to significantly affect the parameters of the objective function. Therefore, constructing the model with these factors is reasonable.

Model performance

To find the overall efficiency of the model in (1), it is necessary to determine the cost of the outputs of the capability planning process. For this purpose, the Activity Based Costing method is used. The method gives a more accurate picture of the cost of process outputs by allocating costs based on the activities performed to produce them, rather than the traditional linear cost allocation [9, 10].

In this particular example, after describing the activities in Fig. 3, we proceed to divide the costs by categories of personnel in order to make the metrics (cost drivers) more understandable and accurate.

TABLE 4 AVERAGE DAILY RATE BY CATEGORY OF ACTORS

Average Daily Rate by Category in Euros	MoD		BAF	
	Civilian	Officers	Civilian	Officers
By professional relationship	71,42			
Under an employment contract	45,23		40	
Under the Armed Forces Act		100		90,47

In this case, labour costs are grouped by the categories of officials involved in the implementation of the planning activities. These are shown in Table 4. In addition to the category of actors involved in the process, the table also contains the cost per actor in EUR. The cost of the actors involved in the process has been determined on the basis of indicative values for the average gross monthly remuneration for the Bulgarian Armed Forces (BAF) and the Ministry of Defence (MoD). Labour costs are for an 8-hour working day with an average of 21 days worked per month.

For each activity-cost relationship, the level of relationship, i.e. the costs that are generated by the specific activity, is determined. The allocation of costs to activities is based on the participation of each of the experts in the relevant activities at the relevant rate per day. The number of participants for each activity and the days worked by each participant are also determined. The results are plotted in Table 5.

TABLE 5 LABOUR COSTS

Activity	Staff Category	Rate per Day	Number of Staff	Days Worked	Total (Euro)
A2					109931,19
A21 Defining missions and tasks	Officers MoD	100	2	10	2000
	Officers BAF	90,47	12	10	10856,4
	Civilian 1 MoD	71,42	1	10	714,2
	Civilian 2 MoD	45,23	2	10	904,6
	Civilian BAF	40	7	10	2800
					19705,56
A22 Determination of required capabilities	Officers MoD	100	3	14	4200
	Officers BAF	90,47	10	14	12665,8
	Civilian 1 MoD	71,42	2	14	1999,76
	Civilian 2 MoD	45,23	0	10	0
	Civilian BAF	40	3	7	840
					14565,8
A23 Analysis of available capabilities	Officers MoD	100	3	5	1500
	Officers BAF	90,47	12	10	10856,4
	Civilian 1 MoD	71,42	1	5	357,1
	Civilian 2 MoD	45,23	2	5	452,3
	Civilian BAF	40	7	5	1400
					10447
A24 Compliance analysis	Officers MoD	100	2	10	2000
	Officers BAF	90,47	12	5	5428,2
	Civilian 1 MoD	71,42	1	10	714,2
	Civilian 2 MoD	45,23	2	10	904,6
	Civilian BAF	40	7	5	1400
					15570,48
A25 Developing alternatives to fill the gaps	Officers MoD	100	2	12	2400
	Officers BAF	90,47	10	12	10856,4
	Civilian 1 MoD	71,42	2	12	1714,08
	Civilian 2 MoD	45,23	0	0	0
	Civilian BAF	40	3	5	600
A26					18463,35

Developing AFDP	Officers MoD	100	3	15	4500
	Officers BAF	90,47	6	15	8142,3
	Civilian 1 MoD	71,42	2	15	2142,6
	Civilian 2 MoD	45,23	1	15	678,45
	Civilian BAF	40	5	15	3000
					13903,8
A27 Developing an Defence Investment Programme	Officers MoD	100	1	20	2000
	Officers BAF	90,47	5	20	9047
	Civilian 1 MoD	71,42	2	20	2856,8
	Civilian 2 MoD	45,23	0	0	0
	Civilian BAF	40	0	0	0

Performance evaluation of the As-Is model

The results of the model performance study were validated using the Ultimus Process Designer, Ver. 6.0. software under the following experimental assumptions:

1. Incoming task norm. For the purpose of the study, it is assumed that a new task appears every 4 hours with a standard deviation of +/-1 hour.

2. An acceptable number of tasks to quantify the process. A value of "100" is assumed for better representativeness of the selection.

3. Preload the system. Determines how many tasks will flow through the system, after the process is initiated, before their normal execution flow level is reached. For this example, a value of "20" is assumed, which means that the first 20 tasks will be excluded since the system has not been previously loaded. The execution of these 20 tasks will not reflect the normal workload of the system. This necessitates that only tasks 21 through 120 be included in the sample of the current statistical model.

4. Resources available to execute the tasks at each stage. Contains the number of participants in the process and the cost of each participant in Euros. The sample data used are shown in Table 4.

5. Time required to complete each task and the deviation from this time. These assumptions are specified individually for each process participant and are embedded in the model work.

6. Type of distribution of incoming tasks in the system. The central limit theorem states that the distribution of a sum of a large number of independent, uniformly distributed random variables tends to a normal distribution. Therefore, it can be assumed that the distribution of flows in statistical models obeys some normal distribution. This determines the choice of the normal distribution of the problems in the present model.

The results obtained for the parameters of the generalized objective function (y_1, y_2, y_3) are presented in Table 6, after simulating the model performance with Ultimus Process Designer, Ver. 6.0.

TABLE 6 THE RESULTS FOR THE PARAMETERS OF THE GENERALIZED OBJECTIVE FUNCTION

Generalized Objective Function Parameters	Min Value	Max Value	Average	Standard Deviation
y_1 – Costs for staff involved in the processes (€)	68974,00	145090,00	104187,42	24410,20
y_2 – Timeout period (Inactivity time) (Days)	4544,53	11632,17	7595,23	2488,98
y_3 – Processing time per task (Hours)	5,50	17,50	10,00	4,00

The evaluation of the model effectiveness is performed using the defined analytical expression (5). The values of the weighting coefficients are determined using expert estimation: $\alpha_1 = -1$; $\alpha_2 = -0,5$; $\alpha_3 = -0,7$. They are substituted in (5), where the value of the generalized output parameter $Y = 0.106$ characterizing the system performance is obtained.

Conclusions and recommendations from the analysis

This example demonstrates a process improvement approach to the Defence Resource Management System. The approach integrates methodologies for describing, implementing and controlling processes and technologies for their implementation. The recommendations, in the order in which they are proposed, improve the output parameter values.

This approach is applied to improve the processes in the formation of the To-Be model and contributes to increase the overall efficiency of the model. The measures that can be applied to improve the performance of the object of study are:

1. *Reducing support functions.* The reduction of support functions, of actors in the Command and control system is associated with the removal from the scheme of operational nodes of actors with little or no contribution to the system. Reducing redundant links between operational nodes, without compromising system reliability, can be accomplished by linking them, for example, from a hierarchical structure to a topology of another type. A possible solution is the use of a star-type structure. In this case, this type of topology can be implemented with organisational changes or with the adoption of information technology, including an information system and facilities for communication.

2. *Improving the process by reducing the waiting time.* From the simulation with the software, it is found that some of the activities are bottlenecked which slows down the overall process execution in the system. The frequency with which tasks are generated and arrive for

processing from lower levels is too high for the teams at the next levels to handle the workload. To overcome the slowdown, the following measures can be implemented:

- Assign additional staff to carry out the various activities;
- Reduce the number of tasks by changing the rules and specifying that not every task is enforceable;
- Increase the speed of implementation.

The appointment of additional personnel has a significant impact on defence spending, which is not an acceptable solution.

Reducing the number of tasks performed is also not an adequate solution due to the fact that all activities of the model are performed according to The Classic Waterfall Development Model, i.e. they are interdependent and are directly or indirectly linked to each other, since the outputs of one activity are the input for the next. Such an approach to work is normal in a complex process, but there is a risk that if the work of one of the working groups is delayed or if the quality of the outputs is low, these negatives may accumulate in the work of the following groups. On the one hand, ignoring or failing to complete tasks can slow down the work of all subsequent groups, and on the other hand, poor quality intermediate results can "distort" the final results.

Of the following options, the only viable alternative is the third, to increase the processing speed. Without changing the work rules and the number of staff, increasing the speed of processing can be done by introducing a complex of measures, including: 1) increasing the qualification of the staff; 2) increasing the methodological guidance of the staff; 3) ensuring the interchangeability of staff; 4) creating additional conditions for parallel work; 5) reducing the time documents stay in the registry system and the time they take to reach the final recipient.

3. Improving the process by reducing the waiting time.

From the simulation, it can be seen that the values of waiting time in the execution of some activities is too high. This can be explained by the following: 1) the process participants were inactive for some steps in the process; 2) the model did not fully account for the specifics of the employment of non-essential personnel. The assumption that non-essential staff use about 20% of their working time for planning activities implies that the waiting time for these staff is presumably used to perform activities related to their other job duties.

The process could also be improved with a cost change by making the following changes:

In one of the tabular reports of the study, it is shown that for a large part of the stages, more than 70% of the total time is used for waiting. In this respect, process improvements can be made through changes in the teams involved in planning activities in the Ministry of Defence, the Bulgarian Army and the structures subordinate to the Minister of Defence. In these teams,

where possible, the same staff may be involved for several tasks. This practice is not new, but is currently applied on a limited basis.

4. Improving the process by increasing resources.

The application of this approach may be associated with:

- Eliminating some of the activities in the process.
- Introducing new technologies to reduce the cost and/or speed of completing each stage of the process.
- Changing the rules governing the process.
- Improving the process by acquiring new capabilities from the participants.

5. Objective refinement of the model

In order to achieve the set objective, it is necessary to reduce the value of the standard deviation. The standard deviation of the whole process is a function of the standard deviations of each stage. Using the process time table, it can be seen that certain stages affect the standard deviation the most. In order to reduce the overall value of standard deviation, the possibilities of reducing the deviation for these stages should be considered.

6. Additional recommendations by the analysis:

- Personnel costs are greatest for the implementation of "A22 Determination of Required Capabilities". Additional measures are needed to reduce these costs.

- A lack of analytical tools and information technology to support system operations has been documented. This makes the interaction and exchange of information between organisational units and the work of officials and non-official bodies difficult. There is a need to compensate for the lack of real-time monitoring by management decision-makers, for example, by setting up an appropriate information system.

- There are tendencies to ignore risk as an element of governance, which reduces the quality and effectiveness of the functioning of the system. A clear risk management policy needs to be formulated.

IV. CONCLUSION

In accordance with the objectives, the following major contributions were obtained by the author:

1. A methodological toolkit with application of quantitative methods and simulation tools with proven usefulness in practice is proposed.

2. The processes of the current capability-based defence planning system are defined and documented.

3. A generalized research objective function (1) is defined. An analytical expression for finding the overall effectiveness of the system is presented.

4. The outcome indicators and their units of measurement are defined. These are used as measurement criteria.

5. Critical success factors have been identified through rank correlation.

6. An architecture of the current BA defence planning system has been developed.

7. A verification of the model's controllability with respect to the selected factors is made.

8. The formed activity model is checked for adequacy, consistency and completeness.

9. The performance of the system is simulated using specialized software tools.

10. The effectiveness of the system is evaluated.

11. Conclusions from the analysis are drawn. The conclusions are formulated on the basis of the results of the model analysis and are aimed at identifying opportunities for its improvement.

Exploring options to address the defined C2 performance issues is aimed at developing a future, improved system model and its implementation to address existing weaknesses.

In this paper, only Stage 1 of the proposed methodology for modeling and analyzing complex organizational systems is demonstrated. Following the recommendations from the analysis, according to the presented research methodology, a model of the desired state (To-Be) of the system still needs to be formed. It is an advanced model of the presented (As-Is) defence planning system. The perceived weaknesses in the (To-Be) model should be corrected. This can be done through a series of events, including the insertion or elimination of activities, the incorporation of analytical tools and new information technologies, and the reduction of supporting processes in the system. The model of the future state formed, similar to the (As-Is) model, shall be checked for adequacy, consistency, and completeness. Its efficiency shall be found. Using the described mathematical apparatus, the performance evaluation of the (To-Be) model shall be determined. A comparative analysis shall be made with the (As-Is) model to find the 'value added' after the changes made. In this way, all the activities identified in Step 2 of the methodology are performed.

In Stage 3, the programming implementation of a planning information system shall be presented. The stage should cover all activities and process actors. This includes: 1) the logical data model; 2) the descriptions of the system interfaces; 3) the description of the system communication tools; 4) the description of the system functionality; 5) the profile of the technical standards; 6) the programming sources as well as other specifics of the information system.

The study demonstrates the capabilities of an approach for evaluating alternatives to C2 systems. The approach generally involves modelling, analysis, and selection of advanced process solutions within a Defence Planning

System. The results are the basis for activities to create an effective C2 system. The proposed approach has demonstrated applicability to all areas of management where capabilities and resources are involved.

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REFERENCES

- [1] A. Lazarov, I. Radulov, and P. Andreeva P, Organisational-architectural modelling and transformational processes in defence, *Military Journal*, issue 6, Sofia, 2009, pp. 25-33, ISBN 0861-7392.
- [2] J. Schekkerman, *The Economic Benefits of Enterprise Architecture*, Trafford Publ, 2005, ISBN 1-4120-6729-4.
- [3] J. A. Zachman, A framework for information systems architecture, *IBM Systems Journal*, vol. 26, no 3, Reprint vol. 38, NOS 3&3, 1999, pp. 454-470.
- [4] Architecture Capability Team Consultation, Command & Control Board, NATO ARCHITECTURE FRAMEWORK, Version 4, January 2018 Document Version 2020.07, https://www.nato.int/nato_static_fl2014/assets/pdf/2020/9/pdf/NA_Fv4_2020.07.pdf, [Accessed: April. 07, 2024].
- [5] E. Bozhinov and I. Vuchkov, *Statistical methods for modelling or optimization of multifactorial objects*: DI Technika, Sofia, 1973, UDC 519.2:62-52.
- [6] Y. Yanakiev, T. Georgieva and T. Grozdanova, *Methodology for assessing the organizational climate in the formations and structures of the Armed Forces of the Republic of Bulgaria*: published by Military Academy "G. C. Rakovski", 2019, ISBN 978-619-7478-27-3.
- [7] I. Radulov, Modelling of capability-based defence planning processes, National Scientific Program "Security and Defense", RTA 15th International Scientific and Practical Conference "ENVIRONMENT. TECHNOLOGY. RESOURCES", June 27-28, 2024, Vol. 4 (2024) page 218-223, <https://journals.rta.lv/index.php/ETR/article/view/8214/6524> [Accessed: April. 07, 2024].
- [8] Z. Zdravkov, E-network model for session protection in distributed relational databases, "Scientific Session 2001" with International Participation", Shumen 2001, ISBN 954-9681, pp. 212-219.
- [9] R. S. Kaplan, S. Robert and R. Cooper, *Process Costing as a Management Instrument*, Frankfurt/Main, 1999.
- [10] F. Melese, J. Blandin and S. O'Keefe, A New Management Model for Government: Integrating Activity-Based Costing, the Balanced Scorecard and Total Quality Management, *The International Public Management Review* 5:2, 2004: 103-30.