Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 15th International Scientific and Practical Conference. Volume II, 127-131

A Generalized Net Model of Command and Control System

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Abstract. **The relevance of the topic is related to the search for ways to support management in the military field by improving the command and control system (C2-system) of the armed forces. The purpose of the paper is to present an original generalized net model (GN-model) of a command and control system for the needs of the armed forces, including three main elements - personnel, structure and equipment, procedures. Through the integration of these three elements in the created GN-model to provide an opportunity for more detailed testing of different implementation options of the C2-system, even before its implementation in the process of managing the armed forces. To verify the GN-model, a simulation was performed in the GN IDE simulation environment and some results are presented. Some possible applications of the GN-model for the analysis and improvement of the C2-system of the armed forces are described.**

Keywords: Generalized net, modeling, command and control systems, armed forces.

I. INTRODUCTION

The command and control system (C2) supports the process of managing troops and forces by ensuring comprehensive and covert preparation of combat actions and operations, timely response to changes in the situation and successful performance of assigned tasks under any conditions.

A command and control system is a unity of personnel, infrastructure, equipment, and procedures that enables commanders and their staffs to exercise command and control. It includes the following elements [13]:

- Personnel – of the command and headquarters implementing the planning and management processes, as well as of the personnel ensuring their activity;
- Infrastructure and equipment – military command and control center with the relevant equipment for the work and life of the personnel;
- Procedures – standard operating procedures for staff operations in planning and directing operations developed at all levels of command and control.

The command and control system can be seen as built up of three integrated levels – the "headquarters" level, the "combat platform" level, the "soldier" level. These levels of classification were also used as the basis for the original model of a generalized net command and control system presented below. More information about the nature, tools and services used for these levels can be found in another publication by the authors [14].

II. MATERIALS AND METHODS

The generalized nets themselves are based on the Theory of generalized nets, which was defined in 1982 by K. Atanassov [1], [2], [3]. In the following years, the theory developed in two varieties – special and general, and found application for modeling a wide class of tasks, processes and phenomena. An application of other modeling nets, such as N-nets (a variation of Petri nets), has been used in [10]. Other studies related to modeling can be found in [11], [17] as well as countering various command and control system threats [6], [8], [9], [12], [15], [16].

Atanassov's theory of generalized nets was used to create the generalized network model of a command and control system presented below.

A GENERALIZED NET MODEL OF A COMMAND AND CONTROL SYSTEM

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2024vol2.8035

The operation model of the command and control system can be described by a generalized net E as follows:

E={Z1, Z2, Z3, Z4} where

Z1 – situational analysis and action at the "soldier" level

Z2 – Situation Analysis and Actions at the "Battle Platform" level

Z3 – tactical (operational) assessment and actions at the "headquarters" level

Z4 – Commander decision making and control

The schematic of the generalized net E is shown in Fig. 1.

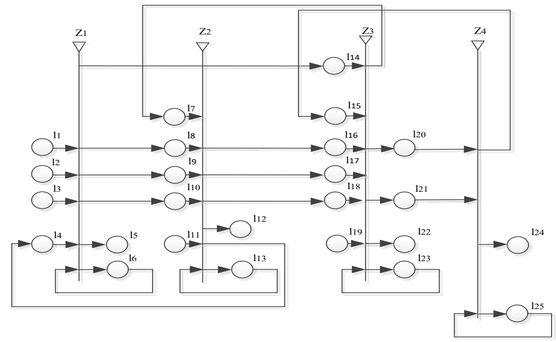

Fig.1. GN model of C2 system

The tokens of a generalized net E are:

α – personnel (soldiers, sergeants, officers, staff), with the following characteristics: $X_\alpha(e^\alpha_{p1}, e^\alpha_{p2}, \ldots, e^\alpha_{pi}, \ldots, e^\alpha_{pk})$, where e e^α_{pi} is the estimate of i-th parameter from k ($i \le k$) basic evaluation parameters for personnel;

β – infrastructure (control points, resources, etc.) necessary for the work of the headquarters, with the following characteristics: $X_\beta(e^\beta_{q1}, e^\beta_{q2}, \ldots, {}^\beta_{qi}, \ldots, e^\beta_{qm})$, where e^β_{qi} is the estimate of the ith object/resource out of n ($i \le n$) required objects/resources;

γ – procedures (sequence of actions, algorithms, information and logistics services, documentation, etc.), with the following characteristics: X_γ $(e^\gamma_{v1}, e^\gamma_{v2}, \ldots, e^\gamma_{vi}, \ldots, e^\gamma_{vs})$, where e^γ_{vi} is an evaluation of the ith type of procedure from s ($i \le s$);

δ – equipment (equipment, weaponry, tools, etc.), and δ' tokens are used for individual equipment, and δ" tokens are used for collective equipment, with the following characteristics: X_δ $(e^\delta_{w1}, e^\delta_{w2}, \ldots, e^\delta_{wi}, \ldots, e^\delta_{wt})$, where e^δ_{wi} is an estimate of the ith equipment type from t ($i \le t$);

ι – information (data, orders, orders, etc.), with the following characteristics: $X\iota(e^\iota_{h1}, e^\iota_{h2}, \ldots e^\iota_{hi}, \ldots, e^\iota_{hm})$, where e^ι_h is an estimate for the availability and usefulness of necessary information from m ($i \le m$).

e^α_p, e^β_q, e^γ_v, e^δ_w and e^ι_h are functions of the generalized net, which include estimated parameters with values in the following intervals: {0,1} – for the general case; [0,1] – for normal fuzziness, or [0,1] × [0,1] – for intuitionistic fuzziness [4].

For more flexible estimation of different parameters, intuitionistic fuzzy estimators are used.

For the generalized net model of C2-system functioning, the estimates $e_k^{\{\alpha, \beta, \gamma, \delta, \iota\}}$ look like this:

$e_j^{\{\alpha, \beta, \gamma, \delta, \iota\}} = \{<\mu_j, \nu_j> (\mu_j, \nu_j \in R \ \& \ \mu_j \ge 0 \ \& \ \nu_j \ge 0 \ \& \ \mu_j + \nu_j \le 1)\}$, for j=1, …, k, where:

μ_j – degree of certainty (certainty) about the estimation of a given parameter of the system;

ν_j – degree of uncertainty regarding the estimation of a given parameter of the system;

$\pi_j = 1 - \mu_j - \nu_j$ – degree of uncertainty about the estimation of the values of a given parameter.

The description of the individual transitions is as follows

$Z_1 = <\{l_1, l_2, l_3, l_4, l_6\}, \{l_5, l_6, l_8, l_9, l_{10}, l_{14}\}, r_1, M_1, \vee(l_1, l_2, l_3, l_4, l_6)>$,

where

l_1 – entry position into which tokens α (personal composition) with characteristics $X_\alpha(e^\alpha_{p1}, e^\alpha_{p2}, \ldots, e^\alpha_{pi}, \ldots, e^\alpha_{pk})$ enter;

l_2 – initial input position into which δ' tokens (individual equipment) enter, with characteristics: $X_{\delta'}$ $(e^{\delta'}_{w1}, e^{\delta'}_{w2}, \ldots, e^{\delta'}_{wi}, \ldots, e^{\delta'}_{wn})$;

l_3 – initial input position, where γ tokens (procedures) with characteristics X_γ $(e^\gamma_{v1}, e^\gamma_{v2}, \ldots, e^\gamma_{vi}, \ldots, e^\gamma_{vn})$ and ι (information) enter, with characteristics: $X\iota(e^\iota_{h1}, e^\iota_{h2}, \ldots e^\iota_{hi}, \ldots, e^\iota_{hm})$;

l_4 – position in which α, δ', γ and ι-tokens enter, coming from transition Z_2 (battle platform);

l_5 – position in which α-tokens (personnel) who have suffered and are unable to perform their duties enter;

l_6 – position in which tokens enter, in waiting or processing mode;

l_8 – position in which α-tokens (personnel) enter, which participate in transition Z_2 (combat platform);

l_9 – position in which δ'-tokens (individual equipment) enter, which participate in transition Z_2 (combat platform);

l_{10} – position in which γ-tokens (procedures, orders, orders, etc.) and ι-tokens (information) necessary for transition Z_2 (combat platform) enter;

l_{14} – transition position Z_3 (headquarters), into which α-tokens (personnel, staff involved in the headquarters, control points), γ-tokens (procedures, orders, orders, etc.), ι-tokens (information from sensors, etc., received directly at headquarters from the battlefield).

$r_1 =$

	l_5	l_6	l_8	l_9	l_{10}	l_{14}
l_1	F	T	$W_{1,8}$	F	F	$W_{1,14}$
l_2	F	T	F	$W_{2,9}$	F	$W_{2,14}$
l_3	F	T	F	F	$W_{3,10}$	$W_{3,14}$
l_4	F	T	F	F	F	$W_{4,14}$
l_6	$W_{6,5}$	$W_{6,6}$	$W_{6,8}$	$W_{6,9}$	$W_{6,10}$	$W_{6,14}$

T – allowed transition (True), F – forbidden transition (False)

$W_{1,8}$ – "there is an α-token involved in a combat platform (in a crew)";

$W_{1,14}$ – "there are α-tokens performing tasks directly from the headquarters (referees, persons with special missions, etc.);

$W_{2,9}$ – "individual equipment does not need further inspection" (in l_6);

$W_{2,14}$ – "there are δ'-tokens necessary for the needs of the headquarters (individual equipment – tools, technical means, etc.);

$W_{3,10}$ – "there are procedures (γ-tokens) and information (ι-tokens) that do not need further verification" (in l_6);

$W_{3,14}$ – "there are γ-tokens and ι-tokens necessary for the needs of the headquarters (primary information from the battlefield, information from sensors, reports, execution of combat orders, orders, etc.);

$W_{4,14}$ – "there are α-, γ-, δ- and ι-tokens that need to be further analyzed (personnel to occupy other combat positions, change in combat orders, need for new equipment, new information received from the combat field or headquarters, etc.);

$W_{6.5}$ – "has α- or δ-tokens (personnel or equipment) that have been analyzed as incapable of performing their duties or functions;

$W_{6,6}$ – "there are tokens in processing or waiting";

$W_{6,8}$ – "there are α-tokens after analysis or waiting for transition Z_2" (performing tasks in a combat platform or for further movement in GN);

$W_{6,9}$ – "there are δ-tokens after analysis or waiting for transition Z_2" (performing tasks in a combat platform or for further movement in GN);

$W_{6,10}$ – "have γ- or ι-tokens after analysis or waiting for Z_2 transition" (performing tasks in combat platform or for further movement in GN);

$W_{6,14}$ – "there are α- or γ- or ι-tokens which, after analysis, are needed directly for the headquarters.

M_1 =

	l_5	l_6	l_8	l_9	l_{10}	l_{14}
l_1	0	N	N	0	0	$m_{1,14}$
l_2	0	N	0	N	0	$m_{2,14}$
l_3	0	N	0	0	N	$m_{3,14}$
l_4	0	N	0	0	0	$m_{4,14}$
l_6	$m_{6,5}$	N	N	N	N	$m_{6,14}$

N – the maximum number of tokens;

$m_{1,14}$, $m_{2,14}$, $m_{3,14}$, $m_{4,14}$, $m_{6,14}$ have values from 0 to the maximum allowable number of tokens for direct transition to Z_3 (<N);

$m_{6.5}$ – from 0 to the maximum allowed number of α-tokens losses.

$Z_2 = \langle\{l_7, l_8, l_9, l_{10}, l_{11}, l_{13}\}, \{l_4, l_{12}, l_{13}, l_{16}, l_{17}, l_{18}\}, r_2, M_2, l_8 \wedge (l_7 \vee l_9 \vee l_{10} \vee l_{11} \vee l_{13})\rangle$,

where

l_7 – position in which γ and ι-tokens enter, coming from transition Z_3 (instructions, orders, etc.);

l_{11} – initial entry position into which δ" tokens enter (common, collective equipment), with characteristics: $X_{\delta''}(e^{\delta''}_{w1}, e^{\delta''}_{w2}, \ldots, e^{\delta''}_{wi}, \ldots, e^{\delta''}_{wn})$;

l_{12} – position in which δ-tokens (equipment, combat platforms, etc.) enter, which are unable to perform their functions or destroyed;

l_{13} – position in which tokens enter, in waiting or processing mode;

l_{16} – position in which α-tokens (personnel) enter, which participate in transition Z_3 (headquarters);

l_{17} – position in which δ-tokens (equipment) enter, which participate in transition Z_3 (headquarters);

l_{18} – position where γ-tokens (procedures, orders, orders, etc.) and ι-tokens (sensory, intelligence and other information) necessary for transition Z_3 (headquarters) enter.

r_2=

	l_4	l_{12}	l_{13}	l_{16}	l_{17}	l_{18}
l_7	F	F	T	F	F	F
l_8	F	F	T	F	F	F
l_9	F	F	T	F	F	F
l_{10}	F	F	T	F	F	F
l_{11}	F	F	T	F	F	F
l_{13}	$W_{13,4}$	$W_{13,12}$	$W_{13,13}$	$W_{13,16}$	$W_{13,17}$	$W_{13,18}$

$W_{13,4}$ – " there is α-, δ-, γ- or ι-tokens destined for Z_1 transition" (after processing)

$W_{13,12}$ – "there are δ-token, unable to perform their functions or destroyed";

$W_{13,13}$ – "there is a processing or waiting process"

$W_{13,16}$ – "has processed α-tokens intended for transition Z_3 (headquarters)"

$W_{13,17}$ – "has processed δ-tokens intended for transition Z_3 (HQ)"

$W_{13,18}$ – "has processed γ- and ι-tokens intended for transition Z_3 (headquarters)"

M_2 =

	l_4	l_{12}	l_{13}	l_{16}	l_{17}	l_{18}
l_7	0	0	N	0	0	0
l_8	0	0	N	0	0	0
l_9	0	0	N	0	0	0
l_{10}	0	0	N	0	0	0
l_{11}	0	0	N	0	0	0
l_{13}	$m_{13,4}$	$m_{13,12}$	$m_{13,13}$	$m_{13,16}$	$m_{13,17}$	$m_{13,18}$

$m_{13,4}$, $m_{13,13}$, $m_{13,16}$, $m_{13,17}$, $m_{13,18}$ have values from 0 to the maximum number of tokens allowed (<N);

$m_{13,12}$ – from 0 to the maximum number of δ-token losses allowed.

$Z_3 = \langle\{l_{14}, l_{15}, l_{16}, l_{17}, l_{18}, l_{19}, l_{23}\}, \{l_7, l_{20}, l_{21}, l_{22}, l_{23}\}, r_3, M_3, l_{17} \wedge (l_{14} \vee l_{15} \vee l_{16} \vee l_{18} \vee l_{19} \vee l_{23})\rangle$,

where

l_{15} – position in which tokens α_i (i = 1, …, k) enter – personnel ensuring the implementation of the information process between the headquarters and the commander;

l_{19} – initial input position in which β-tokens enter, with characteristics $X_\beta(e^\beta_{q1}, e^\beta_{q2}, \ldots, {}^\beta_{qi}, \ldots, e^\beta_{qm})$, which initiate the elements of the infrastructure;

l_{20} – position that is occupied by α-tokens (personnel), which participate in transition Z_4 (commander, command);

l_{21} – a position in which γ-tokens (reports, proposals for decisions, etc.) and ι-tokens (information from headquarters, intelligence data and other information) necessary for decision-making by the commander enter;

l_{22} – position in which γ-tokens (rejected reports, proposals, etc.) and ι-tokens (rejected false, unnecessary or useless information) enter, results of the work of the staff or commander (returned from Z_4 to Z_3 through position l_{15}) ;

l_{23} – position in which tokens enter, in waiting or processing mode.

r3=

	l_7	l_{20}	l_{21}	l_{22}	l_{23}
l_{14}	F	F	F	F	T
l_{15}	F	$W_{15,2}$	F	F	T
l_{16}	F	F	F	F	T
l_{17}	F	F	F	F	T
l_{18}	F	F	F	F	T
l_{19}	F	F	F	F	T
l_{23}	$W_{23,}$	$W_{23,2}$	$W_{23,2}$	$W_{23,2}$	$W_{23,23}$

$W_{15,20}$ – "there are α-tokens that directly participate in the commander's decision-making process"

$W_{23,7}$ – "there is γ- or ι-token" (battle orders, instructions, etc. prepared for dispatch)

$W_{23,20}$ – "there are α-tokens involved in transition Z_4" (persons of staff involved in the commander's decision-making process)

$W_{23,21}$ – "there are γ- or ι-tokens intended for the commander" (prepared decision options, draft orders, situational assessment reports, etc.)

$W_{23,22}$ – "there is γ- or ι-tokens which are unnecessary (false, useless)"

$W_{23,23}$ – "there is a processing or waiting process"

M3 =

	l_7	l_{20}	l_{21}	l_{22}	l_{23}
l_{14}	0	0	0	0	N
l_{15}	0	$m_{15,20}$	0	0	N
l_{16}	0	0	0	0	N
l_{17}	0	0	0	0	N
l_{18}	0	0	0	0	N
l_{19}	0	0	0	0	N
l_{23}	$m_{23,7}$	$m_{23,20}$	$m_{23,21}$	$m_{23,22}$	$m_{23,23}$

$m_{15,20}$, $m_{23,7}$, $m_{23,20}$, $m_{23,21}$, $m_{23,23}$ have values from 0 to the maximum number of tokens allowed (<N);

$m_{23,22}$ – from 0 to the maximum number of γ- or ι-token losses allowed.

$Z_4 = \langle\{l_{20}, l_{21}, l_{25}\},\{l_{15}, l_{24}, l_{25}\}, r_4, M_4, \vee(l_{20}, l_{21}, l_{25})\rangle$, where

l_{24} – final position in which α-tokens (staff officers), γ-tokens (generated orders and orders from the command /commander/) and ι-tokens (decisions made, results of decision implementation, control results, etc. enter);

l_{25} – position in which tokens (α and ι) enter, in waiting mode or information processing and decision making.

r4=

	l_{15}	l_{24}	l_{25}
l_{20}	$W_{20,15}$	F	$W_{20,25}$
l_{21}	F	F	T
l_{25}	$W_{25,15}$	T	$W_{25,25}$

$W_{20,15}$ – "there is α-tokens that carry out direct orders from the commander"

$W_{25.15} = \neg W_{20.15}$

$W_{20,25}$ – "there is α-tokens, γ-tokens and ι-tokens with commander's final decisions"

$W_{25,25}$ – "there is a processing or waiting process"

M4=

	l_{15}	l_{24}	l_{25}
l_{20}	$m_{20,15}$	0	$m_{20,25}$
l_{21}	0	0	N
l_{25}	$m_{25,15}$	P	$m_{25,25}$

$m_{20,15}$, $m_{2,14}$, $m_{20,25}$, $m_{25,15}$, $m_{625,25}$ have values from 0 to the maximum number of tokens allowed for this transition (<N).

MODEL SIMULATION AND RESULTS

The presented OM-model of a command and control system is simulated in the GN IDE simulation environment [5, 6]. Some of the model simulation results obtained are shown in Fig. 2 to 5.

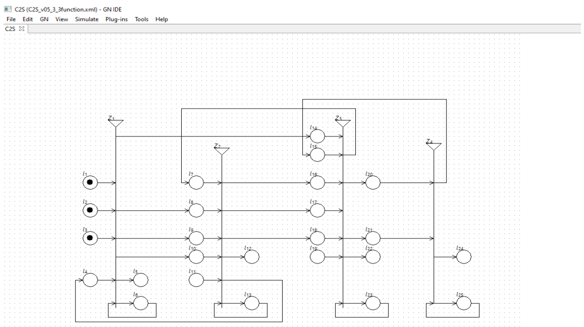

Fig.2. Simulation of the OM-model of a C2 system using the GN IDE simulation environment (step 1)

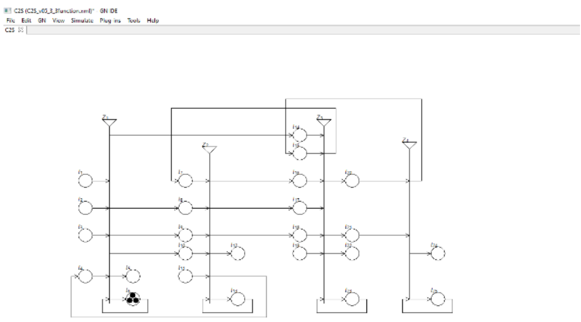

Fig.3. Simulation of the OM-model of a C2 system using the GN IDE simulation environment (step 2)

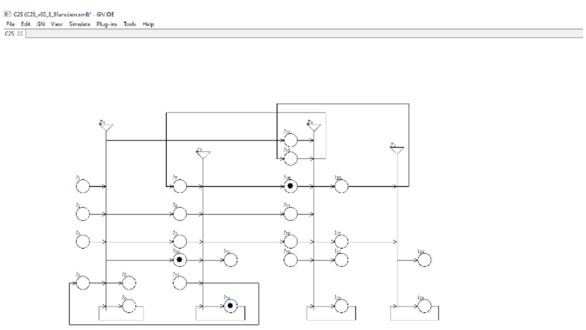

Fig.4. Simulation of the OM-model of a C2 system using the GN IDE simulation environment (step 4)

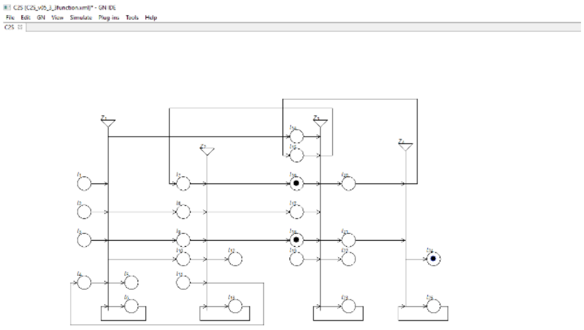

Fig. 5 Simulation of the OM-model of a C2 system using the GN IDE simulation environment (step 6)

From the simulations of the GN-model, it was established that it is a flexible tool for testing different implementation options of the C2-system, even before its implementation in the process of managing the army forces. By means of the GN-model, different implementation variants of a C2-system can be simulated. This is done by changing the individual characteristics of the main three components - personnel, structure and equipment, procedures, can only be done by setting different values of the parameters of the corresponding cores in the model (α-, β-, γ-, δ-, ι-tokens). Also, by changing the rules of interaction between these components (by changing the corresponding predicates $W_{x,y}$), one can track what the changes in the output of the model will be. All this will help to compile a more realistic assessment of the impact of one or other input factors on the output of the system, which in turn will enable the realization of a more stable and efficient C2-system.

CONCLUSION

From the research done, it was found that no other C2-system model based on the use of generalized nets has been created at the moment with which to compare it, but we undoubtedly expect other, more advanced OM-models with such a purpose to appear in the future.

The proposed OM-model of a C2-system can be successfully used to analyze and improve command and control at the tactical and operational level. By simulating different situations, the interrelationships between the main elements of the C2-system can be studied, as well as the possible ways of its optimization.

The presented generalized model of a command and control system can be refined and expanded by taking into account the influence of external and internal adverse factors, the degree of fulfillment of the set tasks – by using numerical or verbal assessments, planning the necessary resources for the functioning of the system, etc.

ACKNOWLEDGEMENTS

This work was supported by the NSP “Security and defence” program, which has received funding from the Ministry of Education and Science of the Republic of Bulgaria under the grant agreement no. Д01-74/19.05.2022.

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