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Quantification of Command and Control Approaches – Model-Based Evaluation

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Abstract:

The Post-Information Age brings new challenges into the military operational environment. The current approach of the extreme hierarchical command and control cannot be sustained in this complex and dynamic environment. Thus, making the search for new command and control approaches is a critical activity. The description and classification of command and control approaches is expressed in a very abstract way. The article describes a unique, quantification technique of command and control approaches. The quantification is demonstrated by Use Case with self-synchronization as the selected command and control approach. In the Use Case, the deterministic dynamic model is implemented. The results achieved from the model demonstrate a variance of a single parameter, on which the quality of the selected Command and Control approach in the given operational scenario quantifies.

Keywords:

deterministic model-based evaluation, military command and control system, self-synchronization

1. Introduction

The era of the Information Age supersedes the Industrial Age of the 20th century, when the economic value was rooted in information and communication networks. The right information in the right place in the right moment is critical for the decision-making process. The information's users are not only human beings, but also machines. The speed of the information exchange is faster than the physical movement during the Information Age. The key enablers of the Information Age are the collection, organization

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and distribution of information within a given time and space [1]. We are stepping into the post-Information Age, where production is no longer the key objective; creativity and innovation are the main drives. Knowledge and ideas are more important than information. The primary focus is on collaboration and knowledge sharing [2].

Such changes will be reflected in the military domain with the objective to share and exploit data, information, knowledge and wisdom [3]; to design an open, scalable, robust and secured communication environment; to move interoperability to the conceptual level [4]; to eliminate the burden of the omnipresent digitalization of operation execution; and finally to fully integrate cyber domain into the other military domains [5]. These changes and new factors in the Post-Information Age formulate new requirements for the command and control approaches in the military domain, mainly real time simulation support and the semi-automated, decision making process within all military domains [6-9].

Military Command and Control (C2) is based on organisational and technical attributes and processes that employ human, physical and information resources to solve problems and accomplish missions [10, 11]. The current Command and Control architectures are based on a hierarchical approach. It means that units are strictly controlled, hierarchically with low levels of autonomy. This approach is not flexible to sustain the pace of the Post-Information Age. The rigid method of connection between subordinated units does not reflect the complexity of the current, or near future, operational and security environment. It is impossible to reach a common understanding following the C2 hierarchical approach when using a very high and heterogeneous number of participants in the operational environment. The new design of the C2 architecture is based on the idea of self-synchronization, where all players in the operational environment are represented by Nodes with a given capacity and ability to share the mission objective [12].

The traditional method of expressing the quality of C2 approaches is based on value metrics, which are easy to measure and evaluate the speed of communication, correctness of information, precision of information or combat effectiveness [13]. However, this approach is not applicable in more complex and dynamic operational environments. Better value metrics do not ensure that the quality of C2 is increased.

Another approach to express the quality of C2 is based on formulating functions that should be executed in the C2 architecture. Moffat at al. [14] stated that three functions, the Collective Decision Rights, the Levels of Interaction and the Distributed Information, express the quality of C2. It creates the latest approved classification of C2 approaches. Baroutsi [15] defined the soft technique, defining quality of C2 by expressing strengths, weaknesses and trends for each specified category in the C2 functions. The C2 classification or soft technique methods, without any analytical tool, create only a theoretical and exceedingly abstract way to express the quality of command and control.

The article proposed a new quantification technique of C2 approaches, using self-synchronization tenets as the Use Case. The theoretical background of command and control classification is given in section 2. Further, in section 3, self-synchronization is introduced as a candidate for the future of command and control approach. Section 4 introduces the model that is used to evaluate the quality of command and control. Afterwards, in section 5, the results obtained from the deterministic model are discussed and compared to justify the use of single *Qn* function as a C2 quality demonstrator. Finally, the conclusion is presented in section 6.

2. Command and Control Classification

An effective command and control approach is fundamental in the military operation. The classification of command and control approaches enables the better understanding of the current state of the art and the way ahead for this domain.

The latest classification of C2 approaches mixed three abstract factors, the first one being Collective Rights. The rights to make decision are moving from the individual C2 system level to the collective level, where all players made dynamic synchronized collective decision-making process. The Level of Collective Decision Rights (LCDR) differs from None up to Dynamic. The second factor is Interaction. It differs based on the volume and constrains in interaction among all players in the battlefield and defines Levels of Interaction (LI) from None up to Unlimited. The last factor is the Distributed Information that describes the type and information exchange constrains among all entities. It varies from Organic information up to All information available of the Level of Distributed Information (LDI).

Tab. 1 Classification of C2 approaches

C2 approach	LCDR	LI	LDI
Edge C2	Dynamic	Unlimited	All available
Collaborative C2	Collaborative Process and Shared Plan	Broad	Collaborative Areas Information
Coordinated C2	Coordinated Process and Linked Plan	Focused	Coordinated Areas Information
Deconflicted C2	Constraints	Limited	Constraints Information
Conflicted C2	None	None	Organic Information

The level of each factor classifies C2 approaches into five classes. The first one is Conflicted C2. In this approach, standalone operations are conducted when each participant exclusively focuses on their own resources and capabilities to reach their own objectives without considering other participants. Conflicts of interest among participants are present and very visible. The objectives of individual players are mutually exclusive. Design and execution of plans compete against each other.

The second approach is Deconflicted C2. In this approach, operations are carried out in a way as not to interfere among the entities present in the battlefield. The orchestration among the players is supported by liaison officers and it is technically limited to the synchronization of operations in space and time, using phase lines or synchronization points. The Hierarchical C2 approach is still very present and active. However, decision rights are well-defined and connected to the responsibility sections.

The third approach is Coordinated C2. In this approach, operations drive joint planning procedures with the intent shared by all players. Planning synchronization allows for decision making on the lower levels in the C2 hierarchy to occur. There are mainly horizontal connections among the players at the same level of command. Each player is still acting on their own behalf. The responsibility to execute the plan remains with the players. The operations are coordinated and require a common intent and a common awareness of the battlefield situation, supported by shared sensors and a shared common picture.

The next approach is Collaboration C2. In this approach, the prerequisite is not only the shared planning process, but also the shared execution process. Sharing is executed in both directions, vertically and horizontally. The shared situational awareness is supported by joint common operational pictures, built upon an integrated, heterogeneous infrastructure shared by all players.

The last approach is Edge C2, which is anchored in rapid and agile decision-making processes based on seamless and transparent information sharing. All information for the decision-making process is available proactively or on demand. The distribution of information is time, space and role independent.

3. Self-Synchronization

An idea of a new implementation of command and control that is moving towards the Edge C2 approaches is based on self-synchronization, where all the players in the operational environment are represented by Nodes with capacity and capability being minimally given.

Self-synchronization is the ability of a force to act in a manner coordinated in intent, time, and space with other battlespace entities, both civilian and military, without being specifically ordered to do so.

Nodes represent all the players that work in the operational environment, not including the enemy. It covers its own, white and green and all governmental and nongovernmental players as well. A Node can be an individual or a team representing military or civilian actors who may contribute to the Coalition mission and objective. A military Node may comprise of a company or a platoon. The level of individuals is not considered, because it is not able to bring an effect alone to the operational environment.

In the context of the paper, the self-synchronization of Nodes is enabled by the following tenets of trusting others, the ability to adapt and awareness for the operational environment.

The proposed method of evaluation for self-synchronization is founded in the idea of maximizing all three tenets. Therefore, the maximum quality of self-synchronization is reached when one's trust in others, one's ability to adapt and one's awareness of the operational environment is at maximum. To demonstrate this approach the deterministic model founded in these 3 tenets is implemented.

To get a single function to evaluate the quality of command and control approach, the model of self-synchronization tenets must be part of the scenario, which describes the operational environment.

3.1. Scenario Design

The overall scenario in the operational environment is described by the Number of Nodes (*NON*) and the *Complexity* factor. *NON* is the total Number of Nodes playing a role in the operational environment.

The *Complexity* factor describes the level of difficulties to describe and understand the operational environment through all domains; Political (*P*), Military (*M*), Environment (*E*), Social (*S*), Infrastructure (*I*), Information (*In*) (PMESII) classification [16], where each domain is classified by the value from intervals between 0 and 1.

The Minimum Complexity represented by the value of 0 in the Political Domain means the political situation in the operational environment is crystal clear and all relations and coalition are explicitly defined; all parties have clear and understandable ambitions and an objective. A maximum value 1 in the Political Domain represents an absolutely, non-readable political situation with no clear objective and no defined relationship among the parties. The *Complexity* factor varies between 0 and 6 and it is calculated for the scenario as

$$Complexity = \sum \left(P + M + E + S + I + In \right), \tag{1}$$

$$P, M, E, S, I, In \in \langle 0,1 \rangle . \tag{2}$$

3.2. The Self-Synchronization Tenets Model

Nodes represent Coalition military and non-military actors. Each Node demonstrates the Level of Capability (*LOC*) which varies from squad (*LOC* = 1), platoon (*LOC* = 2), company (*LOC* = 3), battalion (*LOC* = 4) up to brigade (*LOC* = 5). The *LOC* does not reflect only Node size, but also the ability to exhibit effect in the operational environment. Furthermore, each Node is described by the time functions of the Ability to Adapt (*ATA*), the Awareness of Operational Environment (*AOE*) and Trust in Others (*TRUST)*.

The *ATA* describes Node ability to adapt to the dynamically changing operational environment, at the given time. It is a function of time, the *Complexity* factor and the *LOC*, given by

$$ATA = 6 - LOC + 1 - \exp\left(-\frac{t}{T_{\mathrm{LOC}} LOC \cdot Compexity} \right). \tag{3}$$

where T_{LOC} is a time constant.

Fig. 1 shows the variance of the *ATA* based on the value of the *LOC*, where the lowest orange curve corresponds to the *LOC* = brigade and the highest brown curve corresponds to the *LOC* = squad. In between these two curves, the light green colour represents a battalion, the blue colour represents a company and the green colour represents a platoon. The colours of the curves are the same for the other time functions of the *AOE* and *TRUST* as well. Therefore, these colours express the same value of the *LOC* in Figs 2 and 3. The *ATA*, the *AOE* and *TRUST* are expressed as dimensionless variables (dmnl) and are visualized as the y-axis in Figs 1, 2 and 3. The time value corresponds with the x-axis in Figs 1, 2, 3 and 6 and it is limited to 50 units in all cases, meaning the 50 days of the executed mission in the operational environment

The *AOE* describes the level of single Node awareness of the operational environment and its function of time, the *Complexity* factor, the *NON*, the *LOC*, *b* – amplitude of oscillation and $\omega(t)$ – variable frequency of oscillation, given as

$$AOE = LOC + 1 - \exp\left(-\frac{LOC}{T_{\mathrm{AOE}} \cdot Compexity} t \right) + b \frac{\sin\left[t \cdot \omega(t) \right]}{\log NON}, \tag{4}$$

where T_{AOE} is a time constant.

The oscillations defined by parameters *b* and $\omega(t)$ create a random variance of the *AOE*. In the specific case of self-sync as a theoretic approach to C2 it is not important to have explicit equation, it is more about philosophical approach that *AOE* after reaching saturation limit will likely oscillate in given interval reflecting dynamic character of the operational environment. Therefore, *AOE* and following *TRUST* will depend on the current operational environment that is not stable after defined period. The best approach is to model this situation by random oscillation.

Fig. 2 shows the variance of the *AOE* based on the value of the *LOC*. The highest red curve corresponds to the *LOC* = brigade. The brigade can reach a faster and higher *AOE* comparing to the squad or the platoon (brown and green colours respectively).

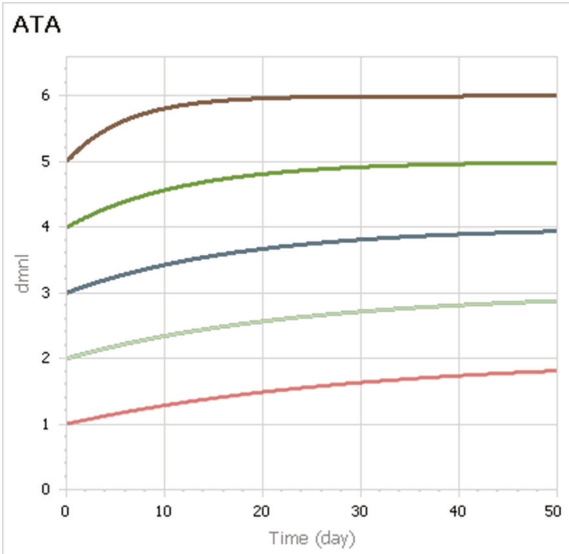

Fig. 1 The ability to adapt function in different LOCs

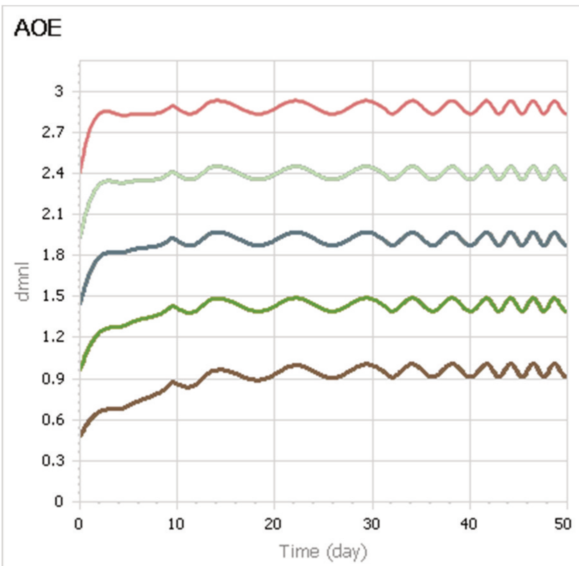

Fig. 2 Awareness of operational environment function in different LOCs

Node's *TRUST* in other factors are the function of time, the *Complexity* factor, the *NON*, the *LOC* and the *AOE*, given by

$$TRUST = AOE \cdot LOC + \frac{1}{T_1 \cdot Compexity \cdot \log NON} t \cdot \exp\left(-\frac{Compexity}{T_2} t \right), \qquad (5)$$

where T_1 and T_2 are time constants. All time constants in expressions (3) – (5) were set to 1 during simulation runs.

Node's *TRUST* grows linearly with the *AOE* function. It reflects reality, where the higher understanding of a complex situation increases one's trust in others. Fig. 3 shows the variance of *TRUST* based on different values of the *LOC*. The highest curve corresponds to the brigade *LOC* = 5. The brigade can reach a faster and higher *AOE*, compared to the lower hierarchic levels.

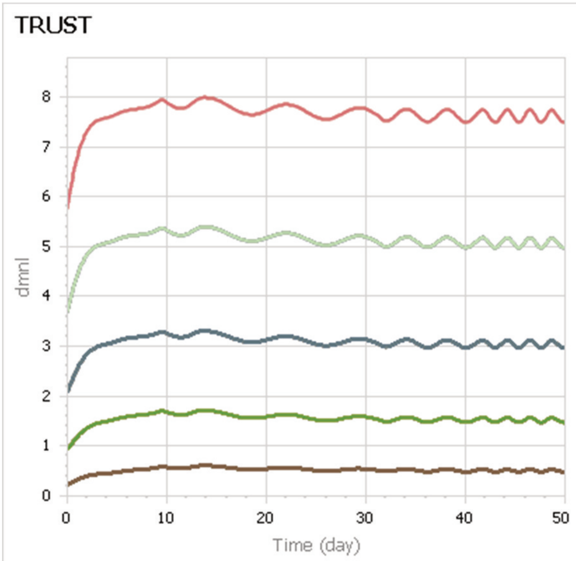

Fig. 3 TRUST in other actors, function in different LOCs

3.3. Model-Based Quantification

The quantification method of self-synchronization quality by the single function, *Qn*, is founded on the idea of adding *TRUST*, the *ATA* and the *AOE* together, given by

$$Qn = \frac{Q}{t}; \quad t > 0, \qquad (6)$$

$$\sum_{1}^{NON} \int_{0}^{t} TRUST(\tau) \mathrm{d}\tau + \sum_{1}^{NON} \int_{0}^{t} ATA(\tau) \mathrm{d}\tau + \sum_{1}^{NON} \int_{0}^{t} AOE(\tau) \mathrm{d}\tau \,. \qquad (7)$$

The *Qn* function can be then used to compare C2 approaches and express the quality of individual cases by the quantitative parameter. *Qn* is expressed as a time function, therefore even the quality of the C2 approach may be studied in given time.

3.4. Model Implementation

The model defined by Eqs (1)-(5), was implemented in the Ventity application, which is based on the system dynamics paradigm [17]. An individual Node is modelled as an entity, see Fig. 4, where the Node Collection Count represents the *NON* and Omega represents $\omega(t)$ variable respectively.

The overall characteristics are computed in the Infospace entity, see Fig. 5. The *Complexity* factor is used in the Node *AOE*, the *ATA* and *TRUST* calculations. The *Node Collection Sum AOE*, the *Node Collection Sum ATA* and the *Node Collection Sum TRUST* are aggregated variables summarizing corresponding functions for all Nodes. These variables are inputs to the *AOE In*, the *ATA In* and the *TRUST In* inflows. The integration of inflows takes place in the *AOE Level*, the *ATA Level* and the *TRUST Level* variables, which accumulate inflows. Finally, *Q* and *Qn* are computed according to Eq. (6) and Eq. (7).

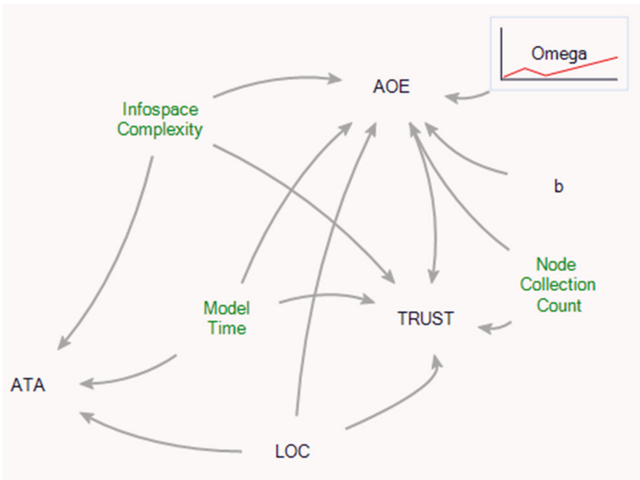

Fig. 4 Implementation of single node characteristics

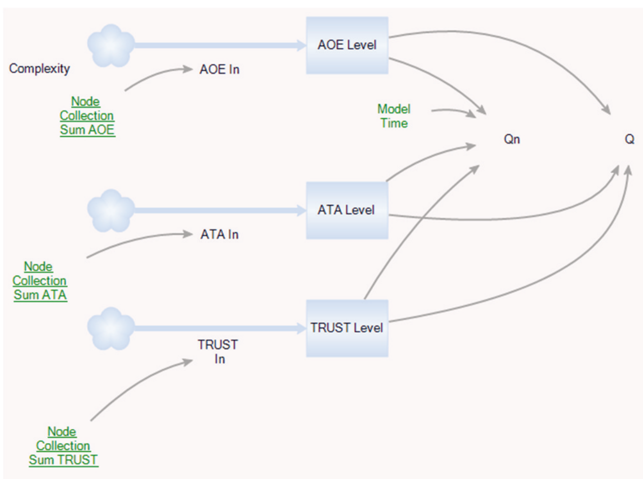

Fig. 5 Diagram of Infospace entity

4. Results and Discussion

The Infospace of the experiment – operational environment – was populated by all Nodes generated from input data, where the *LOC* for each Node was specified. The Full Factorial Design of Experiment combining values of the C2 structure and the *Complexity* factor, with the same conditions of the Number of Nodes in the scenario, was implemented to demonstrate the use of parameter *Qn*. The C2 structure factor varies between two values: Hierarchical and Flat. The *Complexity* factor varies among three values 1, 3 and 6. The Conditions of the experiment were defined by the constant value of *NON* = 121 which was constant for all the experiment runs. Therefore, in total, six runs of the deterministic model were used. Both the Hierarchical and the Flat C2 structures describe only the variation of Nodes at different levels. The Hierarchical in this context does not mean the rigid hierarchical way of command. It just describes the level of units being deployed. In both cases, self-synchronization tenets are implemented.

Fig. 6 shows the results of four experiment runs, comparing the pure, Hierarchical C2 structure, consisting of 1 brigade (*LOC* = 5), 3 battalions (*LOC* = 4), 9 companies (*LOC* = 3), 27 platoons (*LOC* = 2) and 81 squads (*LOC* = 1), making in total *NON* = 121 with the pure, Flat C2 structure consisting of 121 squads with the *LOC* = 1, combined by the highest *Complexity* factor = 6 and by the lowest *Complexity* factor = 0.1.

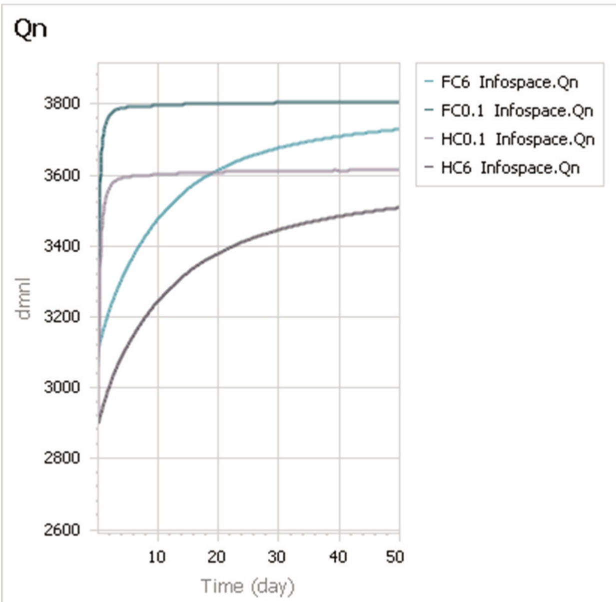

Fig 6 Four experiment runs with the Hierarchical and the Flat C2 structure and the highest and lowest Complexity factor

Based on the experiment results, the Quality of the C2 built upon the self-synchronization tenets is significantly higher when the pure, flat C2 structure of the Nodes is used in comparison to the Hierarchical C2 structure with the same *Complexity* factor. The growth of the Quality of C2 is steeper in the case of the low *Complexity* factor. It demonstrates that the Quality of C2 is higher even when the Quality of the Hierarchical C2 structure with low *Complexity* is steeper in the beginning of the operation than the

Flat C2 structure with a higher Complexity factor. However, in definite time of operation, Quality of C2 is higher in the case of the Flat C2 structure, even in a very complex environment.

5. Conclusion

The article proposed using the single quantitative function that expresses the quality of a C2 approach. In our Test Case, the tenets of self-synchronization were used to implement a deterministic model based on the variation of the Complexity, the Number of Nodes and the Level of Capability of each Node. The main advantage of this quantification is an added value to the current abstract method of the classification for C2 architectures. Previously, the C2 quality was expressed as the estimates of experts of the abstract C2 factors. The new method of specifying the C2 quality is based on the explicit definition of the fundamental functions that are executed in evaluating the C2 architecture. The main application of these results is in the military domain, when new C2 architectures are introduced and military experts must be able to compare proposed architectures with each other. With the proposed quantitative parameter Qn, produced by the model execution as a single time function, key military leaders can make decisions on approval of a new C2 concept. Furthermore, Qn as a time function can express the time needed to reach the expected level of the C2 quality. It helps to better prepare the mission execution in the operational context. Further work will be focused on selecting two C2 architectures, specifying basic functions that are executed in each C2 architecture and the Qn function will be used as the C2 quality comparative tool.

In conclusion, model-based evaluations of the quality of C2 approaches add value to the current, significantly abstract method of the C2 classification description.

References

[1] ALBERTS, D.S. and HAYES, R.E. *Power to the Edge: Command, Control in the Information Age*. Washington: CCRP Publication Series, 2003. 303 p. ISBN 1-893723-13-5.

[2] FJELDSTAD, O., SNOW, C., MILES R. and LETTL, C. The Architecture of Collaboration. *Strategic Management Journal*, 2012, vol. 33, no. 6, p. 734-750. DOI 10.1002/smj.1968.

[3] MALIK, Z., HASHMI, K., NAJMI, E. and REZGUI, A. Wisdom Extraction in Knowledge-Based Information Systems. *Journal of Knowledge Management*, 2019, vol. 23, no. 1, p. 23-45. DOI 10.1108/JKM-05-2018-0288.

[4] TOLK, A. Modeling and Simulation Interoperability Concepts for Multidisciplinarity, Interdisciplinarity, and Transdisciplinarity – Implications for Computational Intelligence Enabling Autonomous Systems. In *Proceedings of Modelling and Simulation for Autonomous Systems.* Cham: Springer, 2015, p. 60-74. DOI 10.1007/978-3-319-22383-4_5.

[5] ORMROD, D. and TUSNRBULL, B. Developing a Military Cyber Maturity Model for Multi-Domain Battle Mission Resilience and Success. *International Journal of Cyber Warfare and Terrorism*, 2017 vol. 7, no. 4, p. 1-13. DOI 10.4018/IJCWT.2017100101.

[6] LOUVIERIS, P., GREGORIADES, A. and GARN, V. Assessing Critical Success Factors for Military Decision Support. *Expert Systems with Applications*, 2010, vol. 37, no. 12, p. 8229-8241. DOI 10.1016/j.eswa.2010.05.062.

[7] FARLIK, J. Conceptual Operational Architecture of the Air Force Simulator: Simulation of Air Defense. In *Proceedings of the International Conference on Military Technology*. Brno: University of Defence, 2015, p. 675-679. DOI 10.1109/MILTECHS.2015.7153723.

[8] BISHT, S., BHARATI, H.S., TANEJA, S.B. and BEDI, P. Command Agent Belief Architecture to Support Commander Decision Making in Military Simulation. *Defence Science Journal*, 2018, vol. 68, no. 1, p. 46-53. DOI 10.14429/dsj.68.11375.

[9] STARÝ, V., KŘIVÁNEK, V., ŠTEFEK, A.. Optical Detection Methods for Laser Guided Unmanned Devices. *Journal of Communications and Networks*, 2018, vol. 20, no. 5, p. 464-472. ISSN 1229-2370. DOI 10.1109/JCN.2018.000071.

[10] HAYES, R.E. and ALBERTS, D.S. *Understanding Command and Control*. Washington: CCRP Publications, 2011. 222 p. ISBN 1-893723-17-8.

[11] SHENOY, R. Command, Control, Communication and Intelligence Systems A Review. *Defence Science Journal*, 2014, vol. 37, no. 4, p. 423-431. DOI 10.14429/dsj.37.5929.

[12] DEKKER, A.H. C2, Networks, and Self-Synchronization. *Network Topology in Command and Control: Organization, Operation, and Evolution*. Eds Grant, T.J., Janssen, R.H.P. and Monsuur, H. IGI Global, 2014, p. 191-215. DOI 10.4018/978-1-4666-6058-8.ch009.

[13] LEE, Y., and LEE, T. Network-Based Metric for Measuring Combat Effectiveness. *Defence Science Journal*, 2014, vol. 64, no. 2, p. 115-122. DOI 10.14429/dsj.64.5534.

[14] HUBER, R., MOFFAT, J. and ALBERTS, D. Achieving Agile C2 by Adopting Higher Levels of C2 Maturity. [on-line]. In *Proceedings of the International Command and Control Research and Technology Symposium,* 2012, p. 1-19. [cited 2008-02-12]. Available from http://www.dodccrp.org/events/17th_iccrts_2012/post_conference/papers/021.pdf.

[15] BAROUTSI, N.A. Practitioner's Guide for C2 Evaluations: Quantitative Measurements of Performance and Effectiveness. In *Proceedings of the International ISCRAM Conference*. Rochester: Rochester Institute of Technology, 2018, p. 170-189. ISBN 978-0-692-12760-5.

[16] HARTLEY, D.S. Comparing Validation Results for Two DIME/PMESII Models: Understanding Coverage Profiles. In *Proceedings of the 2010 Winter Simulation Conference*. Baltimore: IEEE, 2010, p. 420-440. DOI 10.1109/WSC.2010.5679141.

[17] *Ventana System*, *Inc.* Ventity Software [on-line]. [cited 2019-03-2019]. Available from https://ventity.biz.