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Adaptive Military Command and Control of Units in the Modern Battlefield: an Integration Model of Tank Units, Unmanned Aerial Vehicles, and Unmanned Ground Vehicles

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Abstract. This article examines current approaches to improving the effectiveness of military command and control of units in the modern battlefield, taking into account the experience gained during the Russian-Ukrainian war. The study substantiates the necessity of transitioning to an adaptive military command and control model that ensures the timely decision-making and continuous adjustment of command decisions in response to changes in the operational and tactical environment. A conceptual model for integrating tank units, Unmanned Aerial Vehicles (UAVs), and Unmanned Ground Vehicles (UGVs) into a unified information and command-and-control framework is proposed. Furthermore, a mathematical framework for the integrated assessment of military command and control effectiveness is developed based on a system of interrelated performance criteria.
Keywords: *adaptive command and control; integrated effectiveness assessment; military command and control; modern battlefield; tank units; Unmanned Aerial Vehicles (UAVs); Unmanned Ground Vehicles (UGVs).*

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Problem Statement. The modern battlefield is characterized by significant changes in the conditions under which military command and control systems operate [1-4]. The experience gained during the Russian-Ukrainian war has demonstrated the increasing importance of information superiority, unmanned systems, electronic warfare capabilities, precision-guided weapons, and digital technologies in contemporary military operations [3; 4]. A distinctive feature of modern warfare is that changes in the operational environment may occur more rapidly than the completion of the traditional command-and-control cycle, including situation assessment, operational planning, and decision-making [5-8]. As a result, decisions that were appropriate at the time they were made may require subsequent adjustment in response to changes in the operational and tactical situation.

This challenge is particularly significant for tank units. They operate in an environment where numerous reconnaissance, surveillance, strike, and electronic warfare assets function simultaneously. Consequently, the effectiveness of tank unit employment increasingly depends not only on the combat capabilities of armored vehicles but also on the efficiency, adaptability, and resilience of the military command and control system [5; 7; 8].

Analysis of recent research and publications. Improving military command and control in modern conditions is a priority area for the development of military science [5-11]. Experience from the Russo-Ukrainian War has confirmed that the effectiveness of troop employment is determined not only by the combat capabilities of weaponry and military hardware but also by the quality of the command and control system—specifically its adaptability, decision-making speed, level of information support, and ability to integrate modern reconnaissance, surveillance, and UGVs assets into a unified information and command space [1, 5, 6].

An analysis of contemporary research and practical experience in troop employment indicates a need to further develop the scientific and methodological framework for adaptive military command and control—one that integrates modern information technologies, robotic systems, and mathematical methods for assessing the effectiveness of unit command. This study is dedicated precisely to addressing this scientific problem [5-10].

The aim of this article is to develop a conceptual and mathematical model of adaptive military command and control of units in the modern battlefield, taking into account the integration of tank units, UAVs and UGVs.

Presentation of the main material. Based on an analysis of the modern combat environment [1, 4, 5], a problem tree regarding the adaptability of military command and control of units has been formulated (fig. 1).

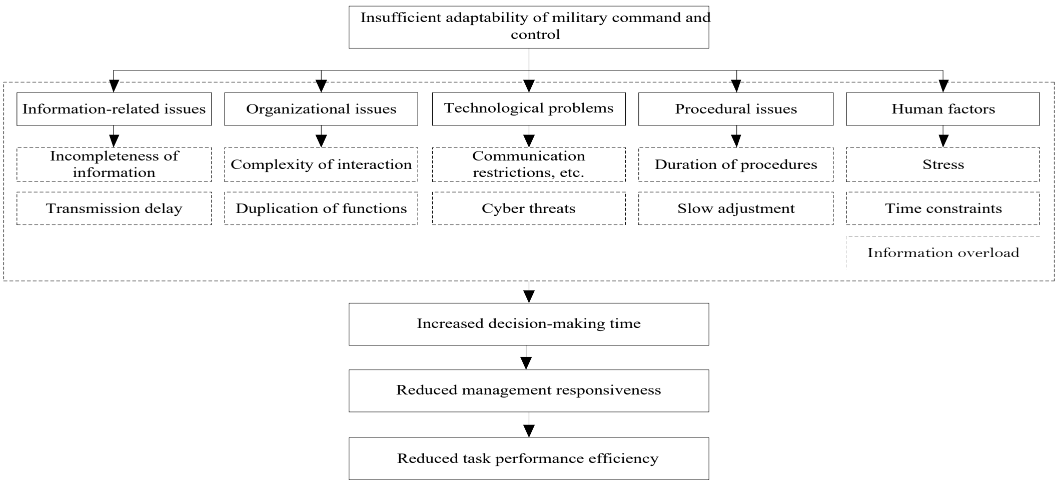

Figure 1
Problem tree regarding the adaptability of military command and control of units

Thus, the problem tree demonstrates that insufficient adaptability is the result not of a single factor, but of a combination of interconnected problems [5, 6].

Based on the problem tree, a goal tree for improving military command and control has been formulated (fig. 2).

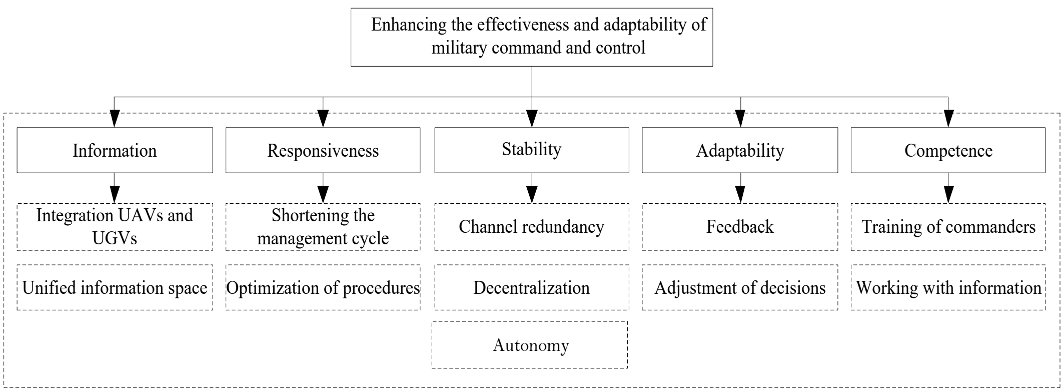

Figure 2
Goal tree for improving military command and control

A goal tree makes it possible to move from problem analysis to defining specific directions for improving the management system.

The traditional management process is often viewed as a sequence: assessment → planning → decision-making → execution.

For the modern combat environment, it is proposed to expand it into a cyclical model of adaptive military command and control (fig. 3).

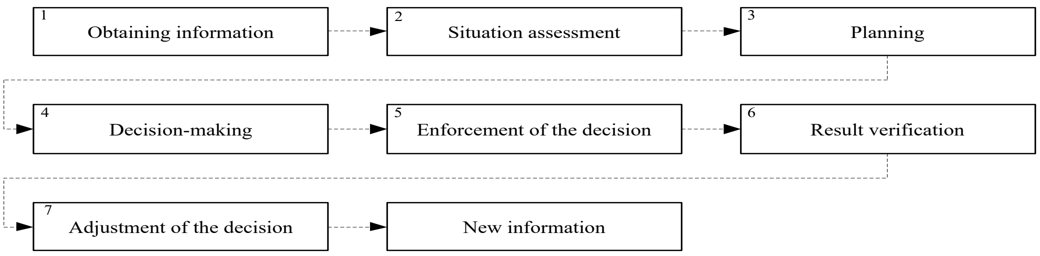

Figure 3
Cyclical model of adaptive military command and control

The scientific concept underlying the proposed approach is that a decision should not be regarded as the final stage of the command-and-control process. Instead, it should be considered an element of a continuous adaptive cycle in which the acquisition of new information may trigger a reassessment of the operational situation and the subsequent adjustment of further actions [7-10]. Modern tank units should therefore be viewed as components of an integrated command-and-control system. The conceptual model of the integrated information and command-and-control framework is presented in fig. 4.

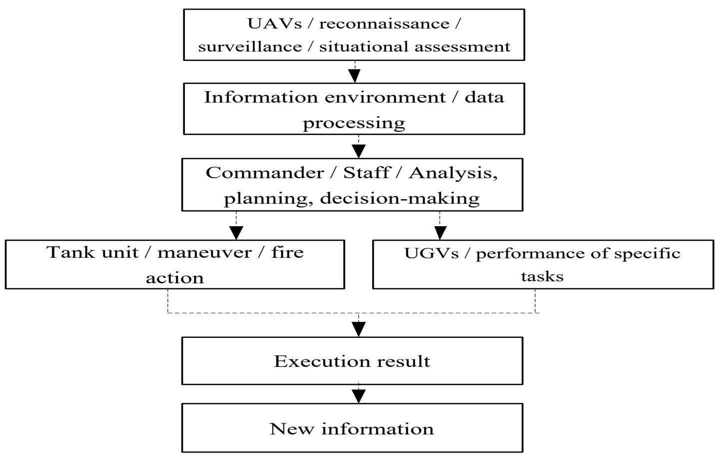

Figure 4

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Conceptual model of the integrated information and management loop

The fundamental principle is that UAVs and UGVs should not be viewed solely as separate technical assets. Their effectiveness depends on the extent to which they are integrated into the command and control system [4, 5, 8].

An integral indicator of military command and control effectiveness has been proposed for quantitative assessment:

$$E_{VU} = w_T T + w_I I + w_S S + w_A A + w_C C + w_R R, \quad (1)$$

where E_{VU} – integrated effectiveness of military command and control;

T – timeliness of the decision-making;

I – quality of information support;

S – resilience of management;

A – adaptability;

C – effectiveness of control;

R – effectiveness of interaction;

w_i – weighting coefficients.

The weighting coefficients must satisfy the condition:

$$\sum_{i=1}^{6} w_i = 1, w_i \geq 0, \quad (2)$$

The timeliness of a decision is determined by the ratio of the critical time to the actual time of the decision:

$$T_{кр} = \min\left(1; \frac{T_{кр}}{T_{ф}}\right), \quad (3)$$

where $T_{кр}$ – critical time;

$T_{ф}$ – actual time of decision-making.

If the actual time does not exceed the critical time, the indicator equals one. The information quality indicator is determined by:

$$I = q \cdot d \cdot a, \quad (4)$$

where q – completeness of information;

d – certainty;

a – topicality.

All parameters are normalized within the range:

$$0 \le q, d, a \le 1, \quad (5)$$

Using multiple sources of information can improve the quality of the situational assessment, provided the information is properly integrated.

The stability of a control system can be determined:

$$S = 1 - P_j, \quad (6)$$

where P_j – probability of control system failure.

On P_j Factors such as communication disruptions, the impact of electronic warfare (EW), the failure of individual components, and the loss of specific information sources can all have an effect. The adaptability index is determined by:

$$A = \min\left(1; \frac{T_{кр}}{T_{адапт}}\right), \quad (7)$$

where $T_{адапт}$ – the time required to adjust the decision following a change in the situation.

The shorter the adaptation time, the higher the adaptability. After defining the specific criteria, (1) is calculated, where the resulting value $0 \le E_{VU} \le 1$ can be interpreted as a normal efficiency indicator. The system of criteria and indicators for evaluating the effectiveness of military command and control is presented in table 1.

Table 1

System of criteria and indicators for evaluating the effectiveness of military command and control

Criterion	Marking	Description of the criterion	Calculated indicator
Timeliness of decision-making	T	It characterizes the speed of decision-making regarding the development of the combat situation	$T = \min\left(1; \frac{T_{кр}}{T_{ф}}\right)$
Information support	I	Reflects the completeness, reliability, and currency of the information	$I = q \cdot d \cdot a$

Table continuation 1

Criterion	Marking	Description of the criterion	Calculated indicator
Resilience of the management system	S	It characterizes the system's ability to function under the influence of destabilizing factors	$S = 1 - P_j$
Adaptability	A	It characterizes the speed at which management decisions are adjusted following a change in the situation	$A = \min\left(1; \dfrac{T_{кр}}{T_{адапт}}\right)$
Monitoring of implementation	C	Reflects the extent of control over the implementation of management decisions	Expert assessment
Interaction	R	It characterizes the coordination of actions between management bodies and units	Expert assessment

It is proposed to engage experts to determine the weighting coefficients. The assessment can be carried out using the pairwise comparison method. A matrix is constructed:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{11} & a_{1n} \\ a_{21} & a_{22} & a_{11} & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & a_{11} & a_{nn} \end{bmatrix}, \tag{8}$$

where a_{ij} – relative advantage of the criterion i on the criterion j.

To verify the consistency of expert assessments, the following is determined:

$$CI = \frac{\lambda_{max} - n}{n - 1}, \tag{9}$$

and also:

$$CR = \frac{CI}{RI}, \tag{10}$$

where CI – consistency index;
CR – consistency relation;
RI – random index;
λ_{max} – maximum eigenvalue of the matrix;
n – number of criteria.

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Provided the acceptable value is CR Weights can be used in a mathematical model of military command and control effectiveness (1) – (7).

A comparative analysis of the military command models under study is presented in Table 2.

Table 2

Comparative analysis of the military command models under study

Model	Using UAVs	Using UGVs	Integrated information field	Adaptive management cycle	Model specifications
А	-	-	-	-	Traditional unit management
Б	+	-	Part	-	Management with application UAVs
В	+	+	Part	-	Management with application UAVs and UGVs
Г	+	+	+	+	Adaptive Integrated Military Command and Control

For comparison, the following is determined: [5, 7, 8]:

$$\Delta E_i = E_i - E_A$$

where ΔE_i – increase in efficiency compared to the baseline model;

E_i – effectiveness of the corresponding model;

E_A – efficiency of the baseline model.

The proposed scientific and methodological approach enables the formalized comparison of alternative military command and control models, facilitates the identification of the most effective directions for improving the command and control of tank units, and provides a methodological basis for further mathematical modeling, expert assessment, and practical validation of the proposed solutions during military training and officer education.

Conclusions. The study analyzed the contemporary challenges affecting military command and control processes and substantiated the necessity of transitioning to an adaptive military command and control model. A problem tree and an objectives tree were developed, and a conceptual model for integrating tank units, Unmanned Aerial Vehicles (UAVs), and Unmanned Ground Vehicles (UGVs) into a unified information and command-and-control framework was proposed.

Furthermore, a mathematical framework for the integrated assessment of military command and control effectiveness was developed based on a system of interrelated criteria, including the timeliness of decision-making, information support, the resilience of the command-and-control system, adaptability, the effectiveness of control, and coordination among elements of the combat formation. The proposed model enables the quantitative comparison of alternative military command and control arrangements and provides a scientific basis for identifying the most effective directions for their further improvement.

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