Using a Model of Coordinated Interaction for Estimation of Troops Joint Missions Effectiveness

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Abstract

The paper is dedicated to the possibility of using interaction model, based on idea of troops efforts coordination, which considers the interests not only of control subsystems (command center), but also the interests of active subsystems (combat elements), for their effectiveness estimation and optimal air defense system structure choosing. To achieve the interaction process harmonization the study of control subsystems stimulating impacts is required to compensate for the loss of active elements. The additional (synergistic) effect received by the system and elements in combined interactions is studied, as well as the loss of each element while general task performing. It is shown that the implementation of coordinated interactions in the system is possible only if the additional (synergistic) effect of all its elements exceeds their losses, and if the additional (synergistic) effect is less than the losses, the interaction inside the system with certain parameters is not effective, so its elements must carry out their missions separately from each other.The theoretical basis for solving problems of coordinated interaction is the theory of active systems and set theory.

Keywords

Interaction efficiency; coordinated interaction; combat element; joint mission; stimulating effect

1. Introduction

In modern warfare, a very important role is given to the fight against the enemy aircraft, the task of which is entrusted to the air defense system (AD System). The main task of the air defense system is the destruction of enemy aircraft attack, gaining and maintaining air superiority, protection from air strikes of groups of troops (forces), arsenals, bases, warehouses, airfields, naval bases, industrial areas, administrative and political centers, etc. [3, 8].

Therefore, special attention is paid to the organization of interaction between the Air Defense Aircraft (AD Aircraft) and the Air Defense Artillery (ADA) in order to make the most complete and effective use of their combat capabilities, as well as ensuring mutual security of their troops (forces) in performing tasks [3] to repel enemy air strikes.

Interaction is a managerial activity that is able to create a cohesive and invincible force from a handful of disparate parties that is self-learning and continuously improving [4].

Interaction is one of the basic principles of martial arts. It reflects the objective pattern of mutual influence of all troops and forces involved in the operation [3].

The problem of the interaction organizing between the AD Aircraft and the ADA is very

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sophisticated, as the nature of hostilities and methods of combat use of troops are interdependent. In addition, the effectiveness of AD combat operations depends on the scale and nature of the enemy's air defenses, the operational construction of covered troops, combat composition and combat capabilities of interacting forces and means, meteorological conditions, time of day and so on. All of this must be taken into account during the organization and implementation of interaction [4].

Therefore, it is necessary to integrate the elements of the air defense system, taking into account the consistency of their interests. This question can be assessed by using the synergetic theory of systems analysis.

The integration of AD aircraft with GBAD in one zone, according to the synergetic theory, has an additional systemic effect - emergence [5]. To increase the combat effectiveness, it is necessary to increase this system effect, which is expressed in the coefficient of interaction, by choosing the optimal (in certain conditions) method ofinteraction. But it is possible to increase only what can be measured, so it is necessary to have a comparative assessment of the effectiveness of the interaction between AD Aircraft and ADA.

The task of synthesis of the interaction process is to choose individual or a set of its components from the standpoint of the criterion of efficiency of the active system, namely: the target functions of different levels elements, procedures for forming plans, mechanisms for evaluating activities. However, in real combat conditions, often the choice of only the functions of stimulation or only the change of the functioning parameters of the elements does not provide a coordinated interaction between the elements in the system.

This is due to the fact that the stimulation functions and parameters can vary in a certain limit, and this does not allow to fully reconcile the interests of the elements in the system [2, 7]. Therefore, there is a problem of simultaneous selection of such stimulus functions and values of parameters change, which provide the coordinated, and, consequently, effective system functioning.

The papers of many specialists are devoted to the issues of combat effectiveness assessing in general and interaction directly, as well as the search for effective forms of its implementation. [1, 2] But, despite the interest of many interaction researchers, the search for effective forms of its implementation and evaluation, the problem of assessing its effectiveness is not completely solved. Modern research modeling the process of interaction is mainly carried out in the field of economics [4, 7, 9, 10], in the military sphere, the process of interaction is seen as a creative process of the commander, but with increasing input data, their rapid changes and reducing the space of interaction - there is a need to support commander's decision-making process for coordination the interests of all elements of interaction. The direction of research of the active systems coordinated interaction process is insufficiently studied.

Therefore, further developing of active systems coordinated management methods is important, basing on the simultaneous definition of incentive functions and variables, the implementation of which provides each element of additional effect that compensates for possible losses in the implementation practice of the higher-level element plan in the management of real combat systems.

2. Methods

The following methods were used in the research: analysis of theoretical sources based on the organization of interaction problems, study and generalization of best practices in the organization of interaction between the elements of active systems and the method of synthesis.

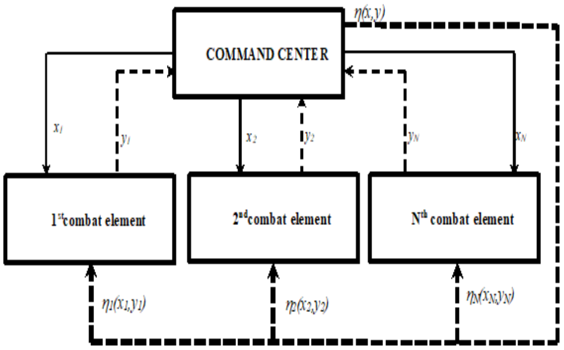

Figure 1: Interaction in an active multi-element system using stimulating effects

To analyze the costs required to reconcile the interests of the elements in the system, it is possible to develop a unified approach. The article investigates the additional (synergetic) effect that the system and its elements receive due to coordinated interaction, as well as the loss of each element while performing a common task. However, the implementation of coordinated interaction in the system is possible only if the additional (synergistic) effect of all elements of the coordinated interaction exceeds their losses. If the additional (synergetic) effect is less than the losses, then the coordinated interaction in the system at these parameters is inefficient and the elements must perform their missions separately [6].

The study of coordinated interaction is carried out on the model of a multi-element system. The model studied in the article includes the upper-level control subsystem - the command center and the lower-level controlled subsystems - active combat elements from the ADA and AD Aircraft participating in combat operations according to a single plan. The command center coordinates the work of the elements by giving them a plan, missions and incentives (comprehensive support), and active combat elements carry out the implementation of these missions, while determining the actual situation from the standpoint of their own interests (see Figure 1).

3. Results

The following concepts and designations necessary for formation of conditions of the coordinated interaction between the command center and combat elements are entered:

$x_n \in Y$– planned state of the nth combat element, $n = \overline{1,N}$;

$y_n \in Y$– the actual state of the nth combat element;

$x = (x_1, \dots, x_N) \in Y$ – the vector of combat elements planned states set by the command center;

$y = (y_1, \dots, y_N) \in Y$ – the vector of combat elements actual states;

$Y = \prod_{n=1}^{N} Y_n$ – the set of allowable values of the combat elements states;

$f_n(y_n) \in F$ – the objective function of nth combat element;

$f(y) = (f_1(y_1), \dots, f_N(y_N)) \in F$ – the vector of combat elements objective functions;

$F = \prod_{n=1}^{N} F_n$ – the set of values of the combat elements objective functions;

$P_n(f_n) = Arg\, max_{y_n \in Y} f_n(y_n)$ – the set of locally-optimal states of the nth combat element;

$P(f) = \prod_{n=1}^{N} P_n\,(f_n)$ – the set of the system locally-optimal states;

$g_n(f_n) = max_{y_n \in Y} f_n(y_n)$ – the maximum value of the objective function for the nth combat element;

$\Delta g_n(x_n) = g_n(f_n) - f_n(x_n)$ –losses of nth combat element associated with the implementation of the command center plan;

$\eta_n(x_n, y_n) \in \Theta_n$ – stimulating effect obtained by nth combat element (see Figure 1), where Θ_n – the allowable set of stimulating effects functionson nth combat element;

$\eta(x,y) = (\eta_1(x_1,y_1), \dots, \eta_N(x_N,y_N)) \in \Theta$– the vector of stimulating effects, where Θ – the set of its types;

$f_n(x_n, y_n, \eta_n) = f_n(y_n) + \Delta f_n(x_n, y_n, \eta_n)$ – the objective function of nth combat element including its stimulation (supply) in thex_n-th plan implementation;

$\Delta f_n(x_n, y_n, \eta_n)$– change in the nth combat element objective function, caused by the stimulating effect;

$\Phi(x) \in \Xi$ – the command center objective function and its possible values set Ξ;

$\Psi(\Phi) = max_{x \in Y}\, \Phi\,(x)$– maximum value of the command center objective function;

$X(\Phi) = Arg\Psi(\Phi)$– the set of the system optimal plans as a whole;

$\Psi(f) = max_{y \in P(f)}\, \Phi\,(y)$– the value of the command center objective function on the set of locally optimal states of its elements;

$\Delta\Psi(x) = \Psi(\Phi) - \Psi(f)$– additional (synergetic) effect obtained by the command center from the coordinated interaction;

$\Phi(x,y,\eta) = \Phi(x) - \Delta\Phi(x,y,\eta)$– the command center objective function, including the stimulation (supply) of combat elements;

$\Delta\Phi(x,y,\eta)$– change in the command center objective function, which arose as a result of stimulation (supply) of combat elements.

Taking into account the introduced designations, a description of the stimulating effects set which are given in the system$\Theta(x,f) = \prod_{n=1}^{N} \Theta_n(x_n, f_n)$, moreover, the set of stimulating effects that provides the maximum of the objective function of the nth combat element is expressed as:

$$\Theta_n(x_n, f_n) = \left\{ \begin{array}{l} \eta_n(x_n, y_n) \in \Theta_n \middle| \forall_{y_n} \in y_n, \\ \Delta f_n(x_n, y_n, \eta_n) \ge \Delta g_n(x_n) \end{array} \right\}, \tag{1}$$

and stimulating actions which exceed the additional effect of coordinated interaction over the command center outgoings for these actions will take the form:

$$\Theta(x, f, \Phi) = \left\{ \begin{array}{l} \eta(x,y) \in \Theta \middle| \forall_{y} \in Y, \\ \Delta\Psi(x) \ge \Delta\Phi(x,y,\eta) \end{array} \right\}. \tag{2}$$

The set of interaction mechanisms, therefore, must be selected both in terms of the command center objective function, and in terms of the combat elements objective functions. For this purpose, the intersection of the stimulating influences sets coordinated on the general plan from a position of objective functions of combat elements $\Theta(x,f)$is necessary, as well as the set of command center objective functions$\Theta(x,f,\Phi)$that is $\Theta(x,f)I\Theta(x,f,\Phi) \neq 0$.

Stimulating effects can be a comprehensive supply of troops, or stimulating actions can be implemented indirectly, by changing the various parameters of the combat elements operation models, for example, by redistributing targets between combat elements.

When used as stimulating effects, compensatory stimulation functions, the combat elements objective functions will be as follows:

$$f_n(r_n,x_n,y_n,u_n) = f_n(r_n,y_n) + u_n(x_n,y_n) \qquad (3)$$

The value

$$u_n(x_n,y_n) = \begin{cases} u_n(x_n), & if\ y_n = x_n \\ 0, if\ y_n \neq x_n \end{cases}$$

is a stimulating effect obtained by nth combat element in the case of the command center planned missions$x_n \in Y_n(r_n)$.

In this case, the set of stimulating functions $u_n(x_n)$which take into account the interests of combat elements, will be as follows:

$$F_u(x) = \left\{ \begin{matrix} u(x) | u_n(x_n) \geq \Delta g_n(x_n), \\ x_n \in Y_n(r_n) \end{matrix} \right\}. \qquad (4)$$

And a set of stimulating functions that take into account the interests of the command center will look like:

$$F_\Phi(x) = \left\{ u(x) | \Delta\Psi(x) \geq \sum_{n=1}^{N} u_n\,(x_n) \geq 0 \right\} \qquad (5)$$

For the case when the stimulation is carried out by parametric coordination, the vector of coordinating parameters for each combat element is presented as:

$$r_n(x_n,y_n) = r_n^H + \Delta r_n(x_n,y_n), \qquad (6)$$

where r_n^H – nominal value of the parameter;

$\Delta r_n(x_{n,}y_n) = \begin{cases} \Delta r_n, & if\ y_n = x_n \\ 0, & if\ y_n \neq x_n \end{cases}$ – variable component of the parameter, which is the coordinating influence of the command center on the n^th^ combat element ($\eta_n = \Delta r_n$).

Moreover

$f_n(x_n,y_n,\Delta r_n) = f_n(y_n,r_n) + \Delta f_n(x_n,y_n,\Delta\eta_n)$– the objective function of nth combat element, which takes to account parametric coordination in the implementation of various statesy_n, where

$\Delta f_n(x_{n,}y_n,\Delta r_n) = \begin{cases} \Delta f_n(x_n,\Delta r_n), if\ y_n = x_n \\ 0, if\ y_n \neq x_n \end{cases}$ – change in the objective function of the nth command element, caused by changing the parameters by the value of Δr_nduring the implementation of the combat element planned task x_n.

The set of coordinating influences $R_c(x)$, takes into account the interests of combat elements and must meet the following ratio:

$$\Delta R_c(x) = \left\{ \begin{matrix} \Delta r \in R \big| \underline{\Delta} r_n \leq \Delta r_n \leq \overline{\Delta} r_n, \\ \left(\frac{df_n(r_n,x_n)}{dr_n}, \Delta r_n \right) \geq \Delta g_n(x_n) \end{matrix} \right\}, \qquad (7)$$

where $\underline{\Delta}\mathrm{r}_\mathrm{n}$, $\overline{\Delta}\mathrm{r}_\mathrm{n}$ – the lower and upper values of changing of the coordinating parameter for the nth combat element.

And the set of coordinating influences that take into account the interests of the command center is equal:

$$\Delta R_\Phi(x) = \left\{ \begin{matrix} \Delta r \in R \big| \underline{\Delta} r_n \leq \Delta r_n \leq \overline{\Delta} r_n, \\ \Delta\Psi(x) \geq \sum_{n=1}^{N} \left(\frac{d\Phi_n(r,x)}{dr_n}, \Delta r_n \right) \end{matrix} \right\}. \qquad (8)$$

To implement coordinated interaction, it is necessary that many stimulating influences intersect, taking into account both the interests of the command center and all combat elements:

$$\Delta R_\Phi(x) I \Delta R_c(x) \neq 0 \text{ або } F_u(x) I F_\Phi(x) \neq 0$$

In the implementation of coordinated interaction by selecting the functions of stimulation and changes in the parameters of coordination at the same time as stimulating effects, a pair $\eta = (u, \Delta r)$ is selected:

$$\eta_n(x_{n,}y_n) = \begin{cases} \big(u_n(x_n), \Delta r_n(x_n)\big), & if\ y_n = x_n \\ 0, & if\ y_n \neq x_n \end{cases}. \qquad (9)$$

Then the change in the objective function of the n^{th} element, caused by stimulating effects in the implementation of the planned task $x_n$elements:

$$\Delta f_n(x_{n,}y_n,\eta_n) = \begin{cases} \Delta f_n(x_n,\Delta r_n) + u_n(x_n), \\ if\ y_n = x_n \\ 0,\ if\ y_n \neq x_n \end{cases} \qquad (10)$$

A set of stimulating effects that take into account the interests of combat elements will have the form:

$$\Omega_f(x) = \left\{ \eta = (u, \Delta r) \left| \begin{matrix} \left(\frac{df_n(r_n,x_n)}{dr_n}, \Delta r_n \right) + \\ + u_n(x_n) \end{matrix} \right. \geq \Delta g_n(x_n) \right\}, \qquad (11)$$

and the set of incentives that take into account the interests of the command center is equal to:

$$\Omega_{\Phi}(x) = \left\{ \begin{matrix} \Pi = (u, \Delta r) | \Delta\Psi(x) \geq \left(\frac{d\Phi(r,x)}{dr}, \Delta r\right) + \\ + \sum_{n=1}^{N} u_n\,(x_n) \end{matrix} \right\}. \qquad (12)$$

Implementation of the coordinated interaction mechanism in the system is possible if:

$$\Omega_f(x) I \Omega_{\Phi}(x) \neq 0 \qquad (13)$$

4. Conclusions

The choice of the coordinated interaction model will provide an opportunity to assess the excess of additional (synergistic) effect of all system elements over their losses and the ability to calculate the effectiveness of interaction for the rational choice of its methods and implementation. That gives following opportunities:

- it is possible to predict the final result of joint actions taking into account the impact of the options of the organization of interaction of troops and their combat elements, in order to choose the best option of interaction;

- the influence of control and feedback with combat elements on the result that can be achieved is determined.

Depending on the available time and the required accuracy of the results, the computing power of simulation systems, the proposed model may take into account more factors, or vice versa, may be simplified to obtain a rougher but faster forecast of the results of troops joint actions.

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