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Long-Range Assets Effectivity Dependence on the Method of Their Employment

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Abstract:

The aim of the article was to determine the long-range assets effectivity dependence on the method of their employment. To achieve this goal, the mathematical model of combat employment of long-range assets based on the theory of Markov processes with continuous time and discrete states was improved. In contrast to the existing ones, the improved mathematical model includes a state in which the asset launches a second missile strike from the firing position from which the previous missile strike was launched. This provides the possibility to model the method of combat employment of the assets, the implementation of which makes it possible to increase the number of missile strikes made in a certain time by these assets. This is the essence of long-range assets effectivity employment.

Keywords:

effectiveness, fire advantage, long-range engagement assets

1 Introduction

Current trends in hostilities indicate that the main number of fire tasks for enemy engagement relies on those assets which can engage the enemy's groups and critical infrastructure to the full depth of its combat order.

This approach creates favorable conditions for the maneuver of combined-arms formations, which will perform the ultimate function of engagement and capturing key objects, lines and positions of the enemy [1-4].

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This approach has led to the development and modernization of long-range assets in the world's leading countries, which form the basis of a joint task force. The use of such approaches provides an ability to achieve a fire advantage over the enemy, the essence of which is the ability of fire assets to successfully perform fire tasks, preventing significant resistance to enemy fire assets [5-7].

However, the development and modernization of existing long-range assets requires sufficient budget expenditures, which is not always possible.

This, as well as the objective need to perform more fire tasks by units armed with long-range assets (here and after – LRA), leads to the search for ways to justify scientific and organizational decisions, the implementation of which will increase the LRA effectivity – number of missile strikes made in a certain time by these assets. To this end, there is a scientific task of search nature, which is designed to model the process of combat employment of units armed with LRA. This will provide a possibility to establish a link between the number of missile strikes made in a certain time by LRA and the method of their combat employment in order to further substantiate the relevant recommendations.

2 Definition of Research Problem

Sufficient attention has always been paid to modeling the combat employment of units armed with LRA. However, after some episodes of their effective combat employment in the current armed struggle, research on the problems of their combat employment has become even more relevant, because these units were entrusted with the largest volume of enemy engagement tasks to achieve fire advantage. The LRA should be understood as a weapon that can hit various enemy targets in a certain time at long range, for example: ATACMS, MLRS, HIMARS, SS-21, SS-26.

In [8], the scientific and methodological apparatus for determining the fire capabilities of artillery as a branch was analyzed. The article analyzes the existing approaches to identifying these opportunities. The aim of the article was to find the main ways to develop the scientific and methodological apparatus for determining the capabilities of military formations. The main part of the article reveals the contradictions in the conceptual apparatus of assessing the fire capabilities of artillery, comparative relations inconsistencies while solving the same issues in different ways. Based on the analysis of the scientific and methodological apparatus, the most promising approaches to this issue have been identified.

In [9], the influence of the effectiveness of combat employment of LRA on the achievement of fire advantage over the enemy is substantiated. According to the proposed dependence of the probability of fire advantage over the enemy on the degree of realization of firepower of the LRA involved in the fire engagement of the enemy, the ways of increasing the degree of realization of firepower of units armed with LRA are validated in the article. The main goal of the research is to estimate how many rocket (missile) strikes the LRA will be able to carry out during the most intense period of their combat employment under different variants of the initial data.

In [10], the study of the process of combat employment of reconnaissance and fire complex was carried out by modeling the method of its combat employment using the theory of Markov random processes. The results of the study have provided the possibilities to substantiate the ways to increase the survivability of the reconnaissance and fire complex during its combat employment. The main disadvantage of this model is that within this model, the LRA after the fire engagement is able to go into any state and to continue combat employment.

In [11], the study of the process of combat employment of artillery units was carried out by modeling the method of their combat employment using the theory of Markov random processes. The results of the study, according to the authors, made it possible to justify ways to increase the survivability of artillery units. The main disadvantage of this model is that within this model, artillery units after the fire engagement of the enemy are able to go into any state and to continue combat use. Another disadvantage is double accounting of probable damage of artillery units due to the probability of their damage in the appropriate state, defining the appropriate state of the damaged units

In [12], the combat employment of units covering the state border during a battle with a sabotage reconnaissance group was studied. In order to achieve the goal of the study, the method of mathematical modeling of combat operations in the class of Markov processes with continuous time and discrete states was chosen. The results of the study have enabled to build an adequate mathematical model and to evaluate the process on a specific example.

As seen, the best option for studying the effectiveness of combat employment of units, weapons systems can be an approach based on the theory of random Markov processes.

At the same time, the issue of assessing the degree of realization of LRA fire capabilities, including rocket (missile) forces and artillery, depending on the method of their combat employment, is not fully addressed in these and other publications, although such a need exists. Estimation of the degree of realization of fire capabilities of LRA can be carried out using the appropriate mathematical model of the method of their combat application. Such a model should reflect the most intense period of combat employment of LRA and include calculation formulas that allow assessing the degree of realization of their firepower in different variants of their combat employment. At the same time, the model can be based on the results of previous studies, taking into account the above improvements.

Therefore, the aim of the article is to improve the mathematical model of combat employment of LRA from the joint task force and on its basis, to assess the degree of realization of fire capabilities of LRA for different variants of their combat employment. The main goal is to estimate how many rocket (missile) strikes the LRA will be able to carry out during the most intense period of their combat employment under different variants of the initial data.

3 Research Results

3.1. A Brief Description of the Combat Employment of LRA in Modern Operations

Combat employment of LRA of the joint task force is carried out in the chosen approach. In accordance with this approach, the LRA at the initial stage of its combat employment is in a disguised state, standing by to perform a combat mission. Upon the receipt of the appropriate combat mission, the LRA increases the readiness to launch a rocket (missile), namely it gradually transfers itself into readiness №3, 2, 1 to launch a rocket (missile), and finally it launches it on the target. Let’s consider these states of readiness. To clearly describe the whole process, it is necessary to specify the activities of each state of readiness.

Readiness №3: the unit was deployed in combat order, missile inspections were carried out, LRA with missiles is in the stowed position at FP in trenches (on sites) or near them (30-50 m) masked, devices are placed, coordinates of FP and meteorological data are entered into control devices, voltage from the equipment is removed, electronical devices are switched off, management of subordinate units is organized, the senior commander has established a stable signal connection, meteorological bulletins are regularly sent to the battalion's headquarters. The missile can be launched in 16 min.

Readiness №2: the unit was deployed in combat order, LRA with missiles in trenches (on sites), hung on jacks, disguised; devices are placed, FP coordinates, missile characteristics, meteorological data and the coordinates of the targets are entered into the equipment; voltage from the equipment is removed, electronical devices are switched off; management of subordinate units is organized, the senior commander maintains a stable connection; meteorological bulletins are regularly sent to the battalion's headquarters. The missile can be launched in 6 min.

Readiness №1: the unit is deployed in combat order; LRA with missiles at FP – in the trenches (on sites), hung on jacks, disguised, data for start-up entered in equipment; missiles are ready for launch in full; voltage from the equipment is removed, electronical devices are switched off; management of subordinate units is organized, the senior commander maintains a stable connection; meteorological bulletins are regularly sent to the battalion's headquarters. The missile can be launched in 3 min.

After launching the rocket (missile), the LRA leaves firing position (FP) urgently, maneuvers to the spare FP, loads a new rocket (missile) and operates according to the scenario described above. At the same time, the LRA, which can carry two rockets (missiles) on board, is able to launch the missile for the second time both from the occupied FP and from the spare one. In each state, the LRA can be detected by the enemy and engaged. The graphic image of the described variant of combat employment of the LRA is presented on the graph of states (Fig. 1).

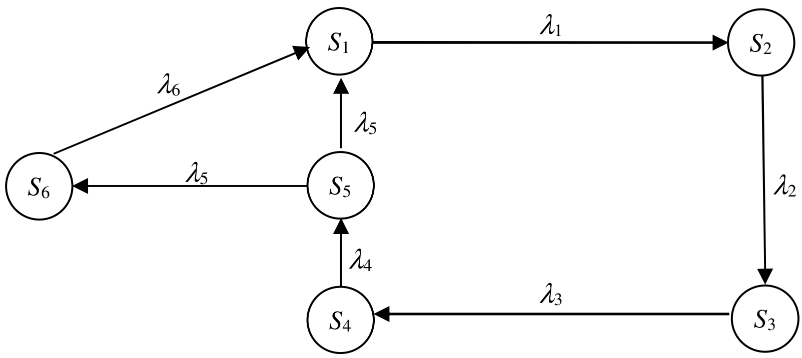

Fig. 1 LRA graph of state. S_1 – "LRA performs the maneuver after the mission accomplishment", S_2 – "LRA is on a FP, standby (readiness) №3", S_3 – "LRA is on a FP, standby (readiness) №2", S_4 – "LRA is on a FP, standby (readiness) №1", S_5 – "LRA is on a FP, launched the 1st rocket (missile) at the target", S_6 – "LRA is on a FP, launched the 2nd rocket (missile) at the target"

The transitions between the states of the graph occur with the corresponding intensities λ, which describe the properties of the combat employment of the LRA, features and subprocesses that characterize the influence of major factors on the functional state of the LRA during its combat employment.

Thus, we pass to the formalized description of the corresponding intensities.

3.2 Formalized Description of the Intensities of LRA Transitions to Different States

This section will contain a large number of formulas and symbols. In order to understand them correctly, all the following symbols are summarized in Tab. 1.

Tab. 1 Symbols of formulas

№	**Full designation**	**Reference designation**
1	Intensity of change of LRA states	λ_{ij}
2	Task setting time	t_1
3	Time of LRA's readiness №3 on the new FP	t_2
4	Time of transition of LRA from readiness №3 to readiness №2	t_3
5	Time of transition of LRA from readiness №2 to readiness №1	t_4
6	Start-up (launch) time	t_5
7	Time to leave the LRA FP after launch	t_6
8	LRA maneuver time to reserve (alternative) FP	t_{m}
9	The probability of survival of the LRA in appropriate state S_i	P_i
10	The probability of LRA engagement in appropriate condition S_i	$P_{\text{d}i}$
11	The time the LRA in the same FP	t_{sp}
12	Time of the enemy's fire in response at the LRA	t_{fr}
13	The probability of the LRA in the appropriate conditions $S_1 \dots S_6$	$P_1 \dots P_6$
14	The total time of combat employment of LRA in the operation	T_{CE}
15	Time of preparation of rocket (missile) engagement	t_{S}
16	The total number of rocket (missile) engagements	N_{MS}
17	Probability of timely retaliation by the enemy	P_{t}
18	Probabilities of engagement of the LRA by means and assets of the enemy on condition of timeliness of strike	P_{s}

The process of combat employment of the LRA begins with the receipt of the command to go into readiness №3 (transition of the LRA from state S_1 into S_2 with intensity λ_{12} in accordance with Fig. 1).

$$\lambda_{12} = \frac{1}{t_1 + t_{\text{m}} + t_2} P_i \tag{1}$$

The transition of the LRA from readiness №3 to readiness №2 occurs after receiving the next command (transition of the LRA from state S_2 into S_3 with intensity λ_{23} in accordance with Fig. 1).

$$\lambda_{23} = \frac{1}{t_1 + t_3} P_i \qquad (2)$$

The transition of the LRA from readiness №2 to readiness №1 occurs after receiving such a command (transition of the LRA from state S_3 into S_4 with intensity λ_{34} in accordance with Fig. 1).

$$\lambda_{34} = \frac{1}{t_1 + t_4} P_i \qquad (3)$$

Launch of the rocket (missile) from readiness №1 occurs after receiving the appropriate command to confirm the aim of the command and pass the Start-up (launch) mode (transition of the LRA from state S_4 into S_5 with intensity λ_{45} in accordance with Fig. 1).

$$\lambda_{45} = \frac{1}{t_1 + t_5} P_i \qquad (4)$$

After the first launch of the rocket (missile) on the target, LRA can receive the appropriate command to launch the second one, which is on the LRA, from the occupied FP (transition of the LRA from state S_5 into S_6 with intensity λ_{56} in accordance with Fig. 1).

$$\lambda_{56} = \frac{1}{t_1 + t_5} P_i \qquad (5)$$

After the first missile launch, the LRA may leave the occupied FP and maneuver to the place where the new rockets (missiles) will be loaded or to the reserve (alternative) FP for the second rocket (missile) launch (transition of the LRA from state S_5 into S_1 with intensity λ_{51} in accordance with Fig. 1).

$$\lambda_{51} = \frac{1}{t_6} P_i \qquad (6)$$

After the second launch, the LRA immediately leaves the occupied FP for maneuver (transition of the LRA from state S_6 into S_1 with intensity λ_{61} in accordance with Fig. 1).

$$\lambda_{61} = \frac{1}{t_6} P_i \qquad (7)$$

The probability of survival of LRA in the condition S_i is determined by the formula

$$P_i = 1 - P_{\mathrm{d}i} \qquad (8)$$

In turn, the probability of engagement of the LRA in the states $S_1 \ldots S_6$, respectively, will depend on the probability of timely fire in response by the enemy and the probability of engagement of the LRA by means and assets of engagement of the enemy, provided the timeliness of the strike (engagement)

$$P_{\mathrm{d}} = P_{\mathrm{t}} P_{\mathrm{s}} \qquad (9)$$

$$P_{\mathrm{t}} = \exp\left(-\frac{t_{\mathrm{sp}}}{t_{\mathrm{fr}}}\right) \tag{10}$$

3.3 Formalization of Combat Employment of the LRA

Having a formal description of the intensities of LRA transitions from state S_1 to state S_6, it is possible to proceed to a formal description of the process of combat employment of LRA in accordance with its graph of states (Fig. 1). The LRA state graph is described by the system of Kolmogorov differential equations [10, 13]:

$$\begin{cases} \dfrac{\mathrm{d}P_1(t)}{\mathrm{d}t} = -\lambda_{12}P_1(t) + \lambda_{51}P_5(t) + \lambda_{61}P_6(t) \\ \dfrac{\mathrm{d}P_2(t)}{\mathrm{d}t} = \lambda_{12}P_1(t) - \lambda_{23}P_2(t) \\ \dfrac{\mathrm{d}P_3(t)}{\mathrm{d}t} = \lambda_{23}P_2(t) - \lambda_{34}P_3(t) \\ \dfrac{\mathrm{d}P_4(t)}{\mathrm{d}t} = \lambda_{34}P_3(t) - \lambda_{45}P_4(t) \\ \dfrac{\mathrm{d}P_5(t)}{\mathrm{d}t} = \lambda_{45}P_4(t) - \lambda_{56}P_5(t) - \lambda_{51}P_5(t) \\ \dfrac{\mathrm{d}P_6(t)}{\mathrm{d}t} = \lambda_{56}P_5(t) - \lambda_{61}P_6(t) \end{cases} \tag{11}$$

under the initial conditions $P_1(0) = 0$, $P_2(0) = 0$, $P_3(0) = 0$, $P_4(0) = 0$, $P_5(0) = 0$, $P_6(0) = 0$. It is obvious that

$$\sum_i P_i(t) = 1, \ \overline{i = 0, n-1} \tag{12}$$

Preliminary studies suggest that with 3…5 cycles of LRA use, the research of their combat employment can be carried out in stationary process [10]. For a stationary application process, differential Eq. (11) is transformed into linear algebraic equations:

$$\begin{cases} P_1 = \dfrac{\lambda_{51}P_5 + \lambda_{61}P_6}{\lambda_{12}} \\ P_2 = \dfrac{\lambda_{12}P_1}{\lambda_{23}} \\ P_3 = \dfrac{\lambda_{23}P_2}{\lambda_{34}} \\ P_4 = \dfrac{\lambda_{34}P_3}{\lambda_{45}} \\ P_5 = \dfrac{\lambda_{45}P_4}{\lambda_{51} + \lambda_{56}} \\ P_6 = \dfrac{\lambda_{56}P_5}{\lambda_{61}} \\ P_1 + P_2 + P_3 + P_4 + P_5 + P_6 = 1 \end{cases} \tag{13}$$

When transforming differential Eq. (11), instead of the last equation in the system of algebraic Eq. (13), the equation that follows from condition (12) is written.

From the system of Eq. (13), the following dependences follow to determine the probability of LRA in states:

$$\begin{cases} P_1 = \dfrac{\lambda_{51}+\lambda_{56}}{\lambda_{12}} P_5 \\ P_2 = \dfrac{\lambda_{51}+\lambda_{56}}{\lambda_{23}} P_5 \\ P_3 = \dfrac{\lambda_{51}+\lambda_{56}}{\lambda_{34}} P_5 \\ P_4 = \dfrac{\lambda_{51}+\lambda_{56}}{\lambda_{45}} P_5 \\ P_6 = \dfrac{\lambda_{56} P_5}{\lambda_{61}} \\ P_1+P_2+P_3+P_4+P_5+P_6=1 \end{cases} \tag{14}$$

To simplify the above-mentioned Eq. (14), the following formula is used:

$$\lambda_{51}+\lambda_{56}=a \tag{15}$$

From the system of Eqs (14) and (15), the following dependences follow to determine the probability of LRA states:

$$P_1 = \frac{a}{\lambda_{12}} \Bigg/ \left(\frac{a}{\lambda_{12}} + \frac{a}{\lambda_{23}} + \frac{a}{\lambda_{34}} + \frac{a}{\lambda_{45}} + 1 + \frac{\lambda_{56}}{\lambda_{61}} \right) \tag{16}$$

$$P_2 = \frac{a}{\lambda_{23}} \Bigg/ \left(\frac{a}{\lambda_{12}} + \frac{a}{\lambda_{23}} + \frac{a}{\lambda_{34}} + \frac{a}{\lambda_{45}} + 1 + \frac{\lambda_{56}}{\lambda_{61}} \right) \tag{17}$$

$$P_3 = \frac{a}{\lambda_{34}} \Bigg/ \left(\frac{a}{\lambda_{12}} + \frac{a}{\lambda_{23}} + \frac{a}{\lambda_{34}} + \frac{a}{\lambda_{45}} + 1 + \frac{\lambda_{56}}{\lambda_{61}} \right) \tag{18}$$

$$P_4 = \frac{a}{\lambda_{45}} \Bigg/ \left(\frac{a}{\lambda_{12}} + \frac{a}{\lambda_{23}} + \frac{a}{\lambda_{34}} + \frac{a}{\lambda_{45}} + 1 + \frac{\lambda_{56}}{\lambda_{61}} \right) \tag{19}$$

$$P_5 = 1 \Bigg/ \left(\frac{a}{\lambda_{12}} + \frac{a}{\lambda_{23}} + \frac{a}{\lambda_{34}} + \frac{a}{\lambda_{45}} + 1 + \frac{\lambda_{56}}{\lambda_{61}} \right) \tag{20}$$

$$P_6 = 1 - (P_1 + P_2 + P_3 + P_4 + P_5) \tag{21}$$

The presence of Eqs (16)-(21) for determining the probabilities of the LRA during its combat employment in the states $S_1 \ldots S_6$ provides a possibility to determine how many rocket (missile) engagement tasks the LRA is able to perform in different approaches of its employment.

Since the LRA carries out rocket (missile) engagement in states S_5 and S_6, the total number of missile strikes can be expressed by the formula

$$N_{\mathrm{MS}} = T_{\mathrm{CE}} \frac{P_5 + P_6}{t_{\mathrm{S}}} \tag{22}$$

3.4 Calculations of a Practical Example Using the Presented Model

To assess the functionality of the proposed model and the possibility of its use in practice, it is necessary to make calculations under conditions that can be close to real.

Assume that a task force of 12 LRAs within a joint task force is designed to carry out tasks of long-range engagement of the enemy in a defensive operation of a joint task force. The most difficult option may be the need to consistently perform a large number of tasks of long-range engagement to the enemy. Own LRAs can be engaged by the enemy in response. For research purposes, the ammunition capacity of rockets (missiles) to perform tasks of long-range engagement of the enemy is not limited. Supply of rockets (missiles) for reloading LRA for subsequent missile launches is organized smoothly. The initial data, which represent the value of tactical and technical indicators of the tasks of long-range engagement of the enemy, are taken from the relevant guidelines and methods of combat training (Tab. 2) [14, 15].

Tab. 2 Time indicators of operations

№	**Type of operation**	**Duration of the operation**
1	Joint task force duration of the operation	24 h
2	Task setting time	1 min
3	Transfer of LRA to readiness №3 after start-up (launch)	30 min
4	Transfer of LRA from readiness №3 to readiness №2	4 min
5	Transfer of LRA from readiness №2 to readiness №1	2 min
6	Rocket (missile) engagement from readiness №1	2 min
7	Launching a 2$^{\mathrm{nd}}$ rocket (missile) strike from occupied FP	3 min
8	Leaving the LRA FP	16 min
9	LRA maneuver*	3.5 min/km
10	Occupation of LRA FP	4 min
11	Preparation of a rocket (missile) fire in response of the enemy	20 min

* Line 9 in Tab. 2 means that it takes 3.5 min for LRA to pass one km of the march.

The results of calculations show that under such conditions of combat employment, each LRA is capable of successively inflicting no more than 13 missile strikes.

Reducing the time to bring the LRA to readiness №3 by 5 minutes allows to increase the number of missile strikes to 15 (15 %) indicating an increase in the effectiveness of LRA employment. Putting the LRA into readiness №3, in accordance with the described method of their combat employment, involves their maneuver to a reserve (alternative) FP at a certain distance and technical operations, which are strictly limited by the time of operation of LRA means. With this method of combat employment, the reduction of time for the transfer of LRA to readiness №3 is possible either by reducing the maneuvering distance of the LRA from the main FP to the reserve (alternative) one, or by replacing the corresponding LRA units with more rapid ones.

At the same time, the second rocket (missile) strike from the same FP from which the previous strike was made must be made as soon as possible, within a period of 1 to 7 minutes. Due to the implementation of the second strike from the FP within such time, the indicators give approximately the same result of the overall increase in the number of strikes. However, increasing this time by more than 7 minutes leads to a significant reduction in the total number of strikes that can be performed by the LRA in the operation.

4 Conclusions

The article presents an improved mathematical model of combat employment of LRA, which is based on the theory of random Markov processes with discrete states and continuous time.

The mathematical model of combat employment includes the following indicators: parameters of rocket (missile) strike time, random time of detection and engagement of the LRA by the enemy, time indicators of LRA and rocket (missile) preparation for launch, time indicators of leaving the FP, maneuver between firing positions and occupying the FP. According to the results of the study, the long-range assets effectivity dependence on the method of their employment was revealed.

The presented model is multifunctional and allows to conduct research to find rational values of parameters (indicators) that determine the features of preparation and application of rocket (missile) strikes. It also allows to substantiate recommendations on the method of combat employment of LRAs in operations.

The given example of the initial data is taken from real experience of combat employment, and the received results testify the possibility of use of the model for an estimation of long-range assets effectivity depending on an approach of their combat employment.

The presence of this model with existing calculation formulas will allow to assess the possible results of combat employment on the basis of initial parameters (indicators), as well as to substantiate the operational and tactical requirements for promising LRA. Thus, the presence of this mathematical model and the obtained adequate practical results indicate the achievement of the research goal.

The content of further research in this area may be to validate the allowable time between the first and second launch of missiles from one FP in order to ensure the survivability of the LRA.

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