EVALUATION METHOD OF THE ARTILLERY'S EFFECTIVENESS AGAINST UNITARY TARGET

МЕТОД ЗА ОЦЕНКА НА ЕФЕКТИВНОСТТА НА АРТИЛЕРИЯТА СРЕЩУ ОТДЕЛНА ЦЕЛ

M.Sc. Ing. Katsev I., Assistant
Faculty of “Artillery, air defense and CIS” –National Military University “Vasil Levski”, Veliko Tarnovo, the Bulgarian Republic

katsev.i@abg.bg

Abstract: *Artillery is major land forces' combat element, which enforces firepower against enemy units in operations. Artillery’s effectiveness heavily depends on how accurate will be weapon delivery, which is a function of dependent and independent errors related to weapon-target interaction and how much will be artillery shell's lethality.*

Keywords: Damage probability, Carleton damage function, Unitary target.

1 Introduction

Artillery is a major combat element of the land component for engaging various enemy targets located in the area of operation. The main content of the combat use of artillery formations is fire support. Fire support is one of the main battle functions and represents firepower enforcement by using the fire of weapon systems in artillery formations. The main job of the artillery is to minimize the combat potential of the enemy group and to limit its capabilities in battle. The success of operation depends heavily on the effectiveness of fire support, which in turn depends on the effectiveness of the forces involved in the fire support. As the primary tool of the ground component involved in fire support, artillery plays a vital role in achieving and retaining fire superiority in the operation.

Artillery formations conduct fire tasks against different enemy targets and objects. Targets and objects in the opposing force in operations can be generally divided into unitary and area targets. To fulfill the purpose of this study, we will focus on the unitary targets and an evaluation method of the artillery's effectiveness against unitary targets.

The efficiency of artillery fire against unitary target depends mainly on the probability that the target will be damaged or destroyed. This probability changes as a result of the deviation in the distance and direction of the mean point of impact from the target center (aiming point). Deviations in distance and direction are caused by a number of random errors associated with the specificity of the work of the artillery formations in the preparation of fire data, such as miscalculation of latitude, longitude, distance, wind effect, or uncertainty in target's locating . Random errors are typically divided into two groups. First ones are the repetitive errors. They are repeatable for all shots and these errors are associated with inaccuracies in the targeting due to errors in the calculation of the fire position, observation post and target locations, errors in aiming the weapon systems, errors in determining the meteorological and ballistic conditions, and others. The second type of random errors are the non-repetitive errors, which refers to ballistic projectile errors caused by variations in the shape of the ammunition, the angle of projectile discharge, the amount of gunpowder used in the shells and others.

2. Artillery fire effectiveness determination.

2.1. **Purpose:** Presenting a theoretical evaluation method for the artillery's effectiveness against unitary target.

2.2. Objectives:

- to determine standard deviation of random errors regarding weapon systems accuracy;

- to determine the weapon lethal area and damage function;

- to determine artillery fire effectiveness against unitary target.

The model for assessing the efficiency of damage from fire systems is based on determination of a precision function and a damage function.

The accuracy function depends on the repetitive errors in the fire data preparation. These errors can be represented by a range error probable and deflection error probable as a quantum of random errors. Those random errors are normally distributed and independent from each other.

$$(1)\quad E_x = \sum_{i=1}^{n} E_{x_i}$$
$$(2)\quad E_y = \sum_{i=1}^{n} E_{y_i}$$

where E_{x_i} and E_{y_i} - random error of i-th element, i - elements involved in the fire data preparation, E_x and E_y – repetitive errors in range and defection direction.

Errors due to ballistic dispersion occur for each round fired from weapon systems and may be denoted by E_{d_x} for random dispersion error in range and E_{d_y} random dispersion error in deflection.

In order to determine the efficiency of artillery fire from closed fire positions against unitary observable ground targets, standard deviation of errors is used and according to the normal distribution law, the standard deviation is calculated by following formulas:

$$(3)\quad \sigma_{mpi_x} = \frac{E_x}{0.6745}$$
$$(4)\quad \sigma_{mpi_y} = \frac{E_y}{0.6745}$$
$$(5)\quad \sigma_{d_x} = \frac{E_{d_x}}{0.6745}$$
$$(6)\quad \sigma_{d_y} = \frac{E_{d_y}}{0.6745}$$
$$(7)\quad \sigma_x = \sqrt{\sigma_{mpi_x}{}^2 + \sigma_{d_x}{}^2}$$
$$(8)\quad \sigma_y = \sqrt{\sigma_{mpi_y}{}^2 + \sigma_{d_y}{}^2}$$

where σ_{mpi_x} and σ_{mpi_y} – standard deviations or repetitive errors in preparation of fire data, σ_{d_x} and σ_{d_y} – standard deviations or non-repetitive errors due to ballistic dispersion, σ_x and σ_y – standard deviations of the sum of standard deviations of errors due to normal distribution law.

The damage function determination depends on the power of the weapon systems, the artillery shells and type of the target. The damage function of a fragmentation projectile is represented by the Carleton damage function. To determine the power of the weapon systems and the impact of the projectiles on the target, we calculate the lethal area of the target from a single round by:

Carleton damage function is used for calculating fragmentation lethal area of an artillery shell with basic data considered for projectile mass, caliber and amount of shrapnel. The damage function also consider impact angle and output data is effective weapon area:

$$(9)\quad a = 1 - 0.8 * cos\,\theta$$
$$(10)\; S_r = \sqrt{AL * a}$$
$$(11)\; S_d = \frac{S_r}{a}$$

where a - impact angle coefficient, θ - impact angle, AL - target lethal area, S_r - effective weapon length,S_d - effective weapon width.

In some cases, unitary targets require a hit by single shot to be destroyed, that demands the single sortie probability of damage to be determine. This probability is calculated by using the cumulative function of the normal distribution by the formulas:

$$(12)\; P_x = 2 * \left(normcdf\left(\frac{S_r}{2}, 0, \sigma_x\right) - 0.5\right)$$
$$(13)\; P_y = 2 * \left(normcdf\left(\frac{S_d}{2}, 0, \sigma_y\right) - 0.5\right)$$
$$(14)\; P_{hit} = P_x * P_y$$

where P_x - probability of damage in range direction, P_y - probability of damage in deflection direction, P_{hit} - single sortie probability of damage.

The probability of damage due to the number of shots, fired from weapon systems is determined by the formula:

$$(15)\; P_{=1}^{k} = 1 - (1 - P_{hit})^n$$

where $P_{=1}^{k}$ - the probability of damage after firing the n shots, n - number of shots fired.

Some targets require more than one hit to be damaged, such targets must be struck by a certain number of shots to be destroyed, so we have to determine the probability of the target being hit by the minimum number of rounds necessary for its destruction. For this purpose we use the cumulative function of binomial distribution:

$$(16)\; P_{\geq 1}^{k} = 1 - binocdf(u - 1, n, P_{hit})$$

where $P_{\geq 1}^{k}$ - probability of damage, u - number of hits required for target destruction.

3. Results and discussion;

In this section we are going to examine an example of a case study of artillery engaging unitary target and the effectiveness of artillery fire against that target.

Example: We are given - random errors in range $E_x = 20m$ and deflection $E_y = 10m$, ballistic dispersion in range $E_{d_x} = 20m$ and deflection $E_{d_y} = 10m$, target lethal area $AL = 300m^2$, impact angle $\theta = 45^o$ and number of shots fired $n = 20$.

The solution of the task is initialized by calculating the quadratic deviations of the random errors due to the errors in the preparation and the dispersion.

$$\sigma_{mpi\,x} = \frac{E_x}{0.6745} = \frac{20}{0.6745} = 29.7m$$

$$\sigma_{mpi\,y} = \frac{E_y}{0.6745} = \frac{10}{0.6745} = 14.8m$$

$$\sigma_{d_x} = \frac{E_{d_x}}{0.6745} = \frac{20}{0.6745} = 29.7m$$

$$\sigma_{d_y} = \frac{E_{d_y}}{0.6745} = \frac{10}{0.6745} = 14.8m$$

$$\sigma_x = \sqrt{{\sigma_{mpi\,x}}^2 + {\sigma_{d_x}}^2} = 41.9m$$

$$\sigma_y = \sqrt{{\sigma_{mpi\,y}}^2 + {\sigma_{d_y}}^2} = 20.9m$$

After calculating the accuracy, the damage effect of weapon systems needs to be determined. Fragmentation lethal area calculations results in the following:

$$a = 1 - 0.8 * \cos\theta = 0.58$$

$$S_r = \sqrt{AL * a} = 13.2m$$

$$S_d = \frac{S_r}{a} = 22.7m$$

The probability of damage due to mistakes in preparation and dispersion will be determined by the formulas:

$$P_x = 2 * \left(normcdf\left(\frac{S_r}{2}, 0, \sigma_x\right) - 0.5\right) = 0.125$$

$$P_y = 2 * \left(normcdf\left(\frac{S_d}{2}, 0, \sigma_y\right) - 0.5\right) = 0.413$$

$$P_{hit} = P_x * P_y = 0.052$$

From the calculations above, it is clear that the single shot has $\mathbf{5.2}\%$ probability to damage the target.

$$P_k = 1 - (1 - P_{hit})^n = 0.653$$

$$P_{\geq 1}^{k} = 1 - binocdf(u - 1, n, P_{hit}) = 0.276$$

20 shots fired results in $\mathbf{65,3}\%$ probability that a single shot hits the target, while the probability of two shots hits the target is $\mathbf{27.6}\%$.

Table 1: *Case studies for different occasions, which shows probability of damage changing due to errors, rounds and lethal area parameters change.*

PARAMETERS	CASE STUDY				
	1 base line	2	3	4	5
#Rounds	20	**10**	20	20	**30**
Random errors in range, m	20	20	**40**	20	**30**
Random errors in deflection, m	10	10	**20**	10	**15**
Ballistic dispersion in range, m	20	20	**40**	20	**30**
Ballistic dispersion in deflection, m	10	10	**20**	10	**15**
Target lethal area, m^2	300	300	300	**600**	**450**
Probability of damage, %	65.3	41.1	23.6	87.3	65.6
Probability of two hits, %	27.6	9.1	3	59.7	28.3

Table 1 show how the probability of damage changes because of variation of random errors in preparation, dispersion errors, number of rounds and target lethal area. Knowledge about evaluation method characteristics and probability of damage alteration plays a significant role in achieving firepower enforcement against unitary target.

4. *Conclusion*

Probability of damage is primary factor to be taken into account when evaluating artillery formations' combat effectiveness. There also can be calculated inverse task, determining artillery shells expenditure for achieving certain amount of probability for damaging opposing forces' targets and objects.

Determining probability of damage against enemy targets in operation is a major factor in planning the forces' battle actions in combat domain. The ratio of forces and resources, expenditure of munitions and the efficiency of fire support are essential elements to be taken into account by the commander when deciding combat operation scenario.

REFERENCES:

1. Chusilp, P., Charubhun, W., Koanantachai, P., Monte Carlo Simulations of Weapon Effectiveness Using Pk Matrix and Carleton Damage Function, International Journal of Applied Physics and Mathematics, vol4, pp 280-285, 2014.

2. . Driels, M., Weaponeering: Conventional Weapon System Effectiveness - 2nd Edition, American Institute of Aeronautics and Astronautics (AIAA), Education Series, Reston, 2014.

3. Eckler A., Burr S., Mathematical models of target coverage and missile allocation, Military operations research society, 1972.

4. Klopcic J., "A comparison of damage functions for use in artillery effectiveness codes", Technical report, Ballistic research laboratory Aberdeen proving ground, Maryland, 1990.

5. Washbur A., Notes on firing theory, Naval postgraduate school, Monterey, California, 2002. Washburn A., Diffuse-Gaussian multiple shot patterns, Military operations research, vol8, n3, 2003.