MODELLING OF ARTILLERY FIRE AND SIMULATION OF ITS EFFICIENCY

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Abstract: *The aim of the paper is to describe the basic principles of the solution of one of the most difficult military issue. Those are the theoretical and practical issues of the firing activities on various objects. In both, in general and specific point of view, it has a fruitful reference not only for artillery specialist, but also for wider group of another branches and specialization officers.*

Keywords: modelling, simulation, fire efficiency

1. Introduction

Modelling of artillery fire seems to be much specialised issue, but it is not. Concrete results of artillery fire modelling intervene and certainly affect the whole range of artillery firing issues. It contains evaluation of the importance of the targets in the enemy formation, evaluation of the artillery ammunition effectiveness, determining the effects of the artillery fire, and determining the number of artillery ammunition for the target.

Constant changes in the security situation have an impact on security and defense strategies. Of course, economic effects also affect these processes. This results in changes in the organization of ground forces, which are fully reflected in the organizational structures and principles of the use of artillery units. Because of these changes, it is necessary to review the theory of fire and fire control, the methods of evaluating the effectiveness of effective firing and the determination of ammunition consumption standards.

Modeling artillery fire and simulating its efficiency with the use of computers creates new qualitative conditions for the

assessment of artillery fire and all related processes. Last but not least, the issues of military-economic efficiency, economy, but also the environmental issues of the armed forces need to be taken into account.

2. The background of the issue

The idea of modelling a certain part of the reality of the material world for the purpose of its knowledge is not new at all. It has its beginnings at a time when a man started trying to understand the world. From the available literature that deals with the history of modelling and models, it can be concluded that modelling has begun to be used in the military first.

Models as they were and are: war games, exercises on maps, field exercises, and so on are known tools of the armies of the world. Their beginning dates back to the years before our birth (e.g. Egypt), through chess-like games (16th century), to the Prussian model of battle (19th century). During World War II, war games were used on both sides as a tool for verifying the plans before their practical realization.

The emergence and development of computers and new mathematical methods

penetrating into advanced armies in the post war period and allowing them to solve many existing difficult military problems, has triggered an interest in these possibilities even in the former Czechoslovak army. As with other types of troops, as well as in artillery, modelling and simulation was mainly used for the training of individuals, troops and units, for the preparation of commanders and staffs, as well as for scientific work to address the current and prospective problems of the theory of shooting and control of land artillery fire.

One of the basic problems of the theory of shooting is a detailed analysis of artillery fire, which can be understood as a complex stochastic system. In its implementation, it is necessary to proceed first of all from the detailed analysis of the basic characteristic of the artillery firing, which is its effectiveness.

If different definitions of firing effectiveness of artillery fire were to be paraphrased, then this evaluation can be understood as a process whose outcome is determination of expected results of each performed fire. In the process of evaluating the fire performance it is necessary to solve a number of tasks, which include the selection of objective characteristics of the efficiency of the fire, the elaboration of methods for their calculation, the determination of all the causes that affect the efficiency of the fire and the analysis of the effects of different shooting conditions on the efficiency of fire.

To solve these problems, it was and is necessary to use the mathematical methods of the operational analysis. One of the oldest parts of the operational analysis is the theory of combat effectiveness, which forms part of a common basis of other disciplines and operational analysis methods that deal with exploring and solving military problems, including the artillery.

It has historically been confirmed that artillery firing systems are characterized by

their activity under conditions of incomplete information, the operation of random processes, the random nature of phenomena and system states. Because of this, the course and result of the activity (fire and its effect) are random and can only be rationally described using probabilistic characteristics. It is clear from this that the main mathematical apparatus of the theory of shooting (and the theory of combat effectiveness) is the theory of probability and mathematical statistics.

To evaluate the effectiveness of the artillery fire, a number of accurate analytical and approximate methods have been developed to make it possible to assess the firing efficiency, in particular from a quantitative point of view. At present, the method is called "evaluation of firing efficiency at parabolic density of firing", the basis of which, the theoretical basis and the mathematical apparatus were laid in the 70s of the last century by Jirsák [2].

Two mathematical models of artillery fireworks were developed for exploration and experimentation. The first, elemental artillery firearm model was created for the simplest case of fire when the fire is guided by single cannon. The second, a general artillery firearm model, was created for more complex cases of fire when the fire was guided by a group of cannons (platoon, a battery, a section, or a group of sections). The general artillery firearm model is based on the reduction of all possible errors into two groups of errors. The first group consists of reduced errors in the preparation of elements in the distance and in the direction. The second group consists of reduced errors of dispersion in the distance and in the direction.

As any analytical method, also the method of assessing the firing efficiency of the parabolic firing density is usable under certain conditions that must be met in order to be applicable. The most essential and indispensable condition for using a fire performance evaluation method for parabolic sampling density is that probable

reduced errors in the preparation of elements in the distance and in the direction must be greater than probable reduced errors of dispersion in the distance and in the direction. Here we see at present the biggest pitfalls for the use of the mentioned method.

The role of artillery (fire support) is to support the operational (maneuvering) land forces by the required fire [1]. Artillery activity is concentrated in the operating area to fulfill the main task of firing the enemy objects. It can be: live force, combat and other techniques, and various constructions. Firing impact on these objects is realized by artillery firing. Artillery fire is a means of ground fire support [3]. Efficiency of fire is conditioned by timeliness, efficiency, high accuracy, moment of surprise, and suitability of fire control depending on the nature of the target.

The assessment of the effectiveness of artillery firing and the determination of ammunition consumption standards has a dominant role in assessing the main role of artillery (on the professional level). These two characteristics represent the main problems of the theory of shooting and the practical handling of fire control issues. The heterogeneity of artillery fire-fighting systems, the principles of deployment of fire units in firing positions [4], and the results of research [5] have shown that used analytical methods to evaluate fire efficiency, which are only approximate, often do not meet basic input requirements.

Problem research begins with the modelling of artillery firing systems of basic tactical and fire units and the construction of mathematical models of the system of fire defects, modelling of possible objects (targets) and ending with the determination of the numerical characteristics of the fire and the standards of ammunition consumption.

Finding these values by real experimental shooting is very demanding, economically expensive, environmentally unbearable, and

in the full extent almost impossible to achieve in peace conditions. For these reasons, it is more appropriate to apply, instead of direct methods, method of mediated research, based on mathematical modelling, simulation and statistical evaluation of fire using computing.

2. Modelling of the artillery firing system

When creating a model using a computer program, we distinguish two stages of its design. The first one can be characterized as the creation of a conceptual model that specifies the behaviour of the studied system by means of a verbal or mathematical apparatus. The second stage is the design and implementation of a computer model for which the transformation of the mathematical model into a program product is characteristic [6].

A model of artillery firing system, designed specifically for the purpose of solving the theory of fire and fire control, is determined by the organizational structure of the artillery unit, its place and role in the ground force firing system. At present, it is necessary to consider at least three independent artillery system models, independent of each other in such way as it is with the help of the gross organizational scheme shown in Figure 1.

When creating a model of the artillery fire system, it is necessary to consider the type of artillery weapon. It can be a mortar, tube artillery weapon and rocket launcher (MLRS).

The basic fire unit (artillery battery) can have 6 to 8 pieces of artillery weapons. The battalion can have two or three batteries. Batteries can be deployed in a firing position, spread in a platoon or as a whole. In the current period, mining units are organized in platoons or sections (a pair of mines). These integrated facts determine the quantitative side of creating a mathematical model of a system of fire defects.

Figure 1: Scheme of model of artillery fire system (Source: own work)

Mathematical models of the system of errors are used to determine the numerical characteristics of artillery fire, most often for the conditions of complete preparation, which is the basic way of determining elements for conducting effective firing [1]. The analysis of these data makes it possible to determine the conditions for selecting the appropriate method for determining numerical characteristics of fire

performance [4]. It is clear from the scheme of the artillery fire system model that the use of the analytical method depends on the ratio of the probable reduced errors in the preparation of the elements in the distance and in the direction (Ex_o , Ez_o , $Ex_{\check{c}}$, $Ez_{\check{c}}$) and probable reduced dispersion of errors (odo , $o\check{s}o$, $od\check{c}$, $o\check{s}\check{c}$). The indicated inequality is a necessary condition (SINE QUA NON).

In the research work, it makes it possible to optimize the requirements for firearms preparation and fire control, as well as to lay down the basic technical requirements for newly developed means of exploration, connection of elements of the combat group and identification of directional poles, meteorological and ballistic training and methods for identifying elements for shooting.

Verification and validation of the model are necessary steps before using the model in stages of experimentation itself. The conditions for behaviours of the simulation model in the process of verification, validation, and self-experimentation are typically defined in simulation experiments. Under the verification of the simulation model of artillery firing efficiency is meant verification of the logical correctness of the program. There is no general procedure for model validation. However, the most common method is to prepare several simulation experiments that can be used to test the model under certain standard conditions.

The reality of the results obtained from the simulation experiments is possible and necessary to be verified by comparison with values mentioned in the consumption of norms of consumption of shots, or in certain conditions with the values obtained by the analytical methods, as well as by firing tests in tactical exercises and control of fire fighting with a sharp fire, even if only with a limited number of shots.

3. Simulation method of evaluating firing efficiency

Changing the qualitative aspect of the numerical characteristics of system of errors of artillery fire systems evoked the need to deal very seriously with modelling and simulation. Not just as a modern method of studying the behaviour of a real model of artillery fire. Not only as a modern method of studying the behaviour of a real model of artillery fire.

It is necessary, because already known

analytical methods of evaluating fire efficiency and assigning of norms of shot consumption are under current conditions nearly unusable. Real values are proved by numerical characteristics of set of errors systems of fire of weapon systems, comprehensively computed and listed in the work [4].

The entire simulation procedure is useful to divide into separate but interdependent operations. The first is the modelling of a firing system that has been described in rough terms in the previous section. The input variables are the type and calibre of the artillery weapon set, the size of the firing unit and the way it is deployed in the firing position, the type of missile, the lighter and its setting.

The second operation is to create a symbolic object model (target). Its main variables are the dimensions of the target (width and depth), the number and type of elementary targets, their dimensions, expressed by the altered area of the fragmented or combined effect of the ammunition used, and their distribution on the shot section.

Another operation is statistical modelling of fire, which exploits knowledge from the theory of fire and fire control, from theory of probability and simulation on the PC. The results of the modelling of the firing system are fully used, with input data.

Input data are the distance of the firing and the numerical characteristics of the fire fault system defined by the possible remote and directional errors of the preparation of the elements of the battalion (Exo, Ezo), the batteries (Exb, Ezb), the platoons (ExčEzč), sections (Exse, Ezse), cannons (Exd, Ezd) and likely distances and directional scatter errors (from, oš) that are in the database. Other input data characterizing the method of firing, or effective firing, is the number of distances and directions, the length of the jump in the distance, interval of fan and the ammunition consumption per cannon, distance and direction.

These operations are followed by modelling

of random deviations using random number generators, the calculation of the co-ordinates of explosions, and finally the calculation of the firing effect. A comprehensive description of the operations is given in the work [5]. Here are just some of the peculiarities of the application.

For simulation of life fire, random modelled deviations standardized in a normally spread random variable x , which has a zero expected value $M(x) = 0$ and a unit probable deviation $E(x) = 1$. If by random selection a sequence of deviations of the special values a_i and b_i of this random variable from its expected value are obtained, it can be converted by transformation into random deviations ξ_i and ψ_i of special values of random variables. The transformation equations are valid [6]:

$$\xi_i = a_i \cdot E\xi \quad (1)$$

$$\psi_i = b_i \cdot E\psi \quad (2)$$

In order to find random deviations a_i and b_i , one of the commonly used methods, based on the Lindenberg-Lévy limit sentence, can be applied. For most practical needs, $n = 12$ is sufficient for good approximation. This option leads to a simple procedure because what is valid is:

$$a_i = \sum_{n=1}^{12} r_n - 6 \quad (3)$$

where: r_n are random numbers and a_i values can be considered as random values of quantity with normal distribution. In analogy this also applies to b_i values.

The entire process of modelling random deviations consists of the sequential generation of 12 random numbers, each of which is evenly distributed over the interval (0,1) and their fitting into relation (3) a random deviation a_i is obtained (b_i) standardized in a normally spread random variable from its expected values. The

results can be further transformed according to relations (1) and (2) and used to calculate random co-ordinates of explosion.

In general, the shooting of the artillery section with classical fragmented blasting missiles, with three distances and one direction, a suitably modified fan, may be random co-ordinates of explosions in distance and direction written in this form:

$$\xi = \xi_o + \xi_b + \xi_c + h\xi_d + \xi_d + \xi_r \quad (4)$$

$$\psi = \psi_o + \psi_b + \psi_c + I_v\psi_d + \psi_d + \psi_r \quad (5)$$

For the practical calculation of the co-ordinates of explosions are used standard random deviations in the distance a_i and in direction b_i . There are used transformation equations (1) and (2) applied with each partial random error of the numerical characteristics of the section system of the fire errors. They can be written in the form:

$$\xi = a_o \cdot Ex_o + a_b \cdot Ex_b + a_c \cdot Ex_c + h\xi_d + a_d \cdot Ex_d + a_r \cdot od \quad (6)$$

$$\psi = b_o \cdot Ez_o + b_b \cdot Ez_b + b_c \cdot Ez_c + I_v\psi_d + b_d \cdot Ez_d + b_r \cdot oš \quad (7)$$

where: $h\xi_d$ is size of jump in a distance, $I_v\psi_d$ is size of interval fan.

The final computational operation of the applied simulation method is the statistical processing of the obtained firing effects of simulated fire. The expected firing effect R is given by:

$$R = \frac{1}{q} \cdot \sum_{r=1}^q u_r \quad (8)$$

where: u_r are the firing effects achieved in individual simulations, and q is the number of simulations performed.

The advantage of applying the simulation method is that it is possible to find out the dispersion of the expected firing effect, which is given by:

$$D = \frac{1}{q-1} \cdot \sum_{r=1}^q (u_r - R)^2 \quad (9)$$

Reliability of the results obtained can be achieved by the number of simulations repeated $q \geq 25$.

4. Conclusions

Presentation of a complete artillery firearm model and simulating fire performance is not an objective of this text. There is presented the possibility but also the necessity of a wide application of simulation methods and models in the theory of shooting and solving practical problems of using artillery units. The almost limitless usability and variability of

a suitably processed and implemented program product offers its wide use in scientific work and in dealing with practical issues of fire control. Simulation experiments can be performed in different tasks depending on which questions we would like to answer. For example, determining requirements for the prospective (or even hypothetical) technical means of preparation of fire and fire control it is possible to perform factor or optimization experiments.

Appreciation of a complete program product, especially a simulation of fire performance, will be judged after it has been incorporated into the complex fire firing modeling system on various terrain targets within the ground forces or its application in integrated automated command and control systems, in particular in the preparation and execution of fire fighting support for operational (maneuvering) forces.

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