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MODEL FOR EXECUTING A FIRE MISSION BY A SECURITY FORCES SNIPER WITH RESTRICTIONS ON COLLATERAL INJURY TO BYSTANDERS

To take into account the specifics of use of weapon by security forces, a model of execution a fire mission with restrictions on harming bystanders by a security forces sniper has been developed. This model links the parameters of the weapon, the target and the fire mission conditions with indicators of firing effectiveness, specifically the probabilities of hitting the target and a bystander and the probabilities of damaging the target and a bystander, and the probability of execution the fire mission in general. The proposed model is intended for calculating the indicators of execution fire mission by a security forces sniper, to determine the indicators of execution fire mission that ensure a predetermined or maximum probability of success, and assessing the suitability of specific weapon samples for execution corresponding fire mission with a given probability.

Keywords: *fire mission, the probability of execution, firing effectiveness, security forces, sniper, bystanders.*

Statement of the problem. In recent times, the significance of the security forces (SF) has increased; they are tasked with a variety of missions, including those involving the use of weapons. Thus, the security forces are expected to conduct operations to stop the illegal activities of armed or paramilitary formations not provided for by law, criminal groups and organizations, and armed criminals; participate in measures to stop unlawful actions of groups of persons who are convicted or in custody; restore law and order during inter-confessional and inter-ethnic conflicts; halt unlawful actions in cases where particularly important state facilities are seized and unblock them; and conduct counter-terrorist and other activities that involve the use of firearms.

At the same time, the specifics of SF missions impose certain restrictions on the results of their activity. In particular, when firearms are used in the presence of hostages or bystanders (BS) in the firing direction, SF personnel must maximize their safety.

Thus, while executing SF missions, situations arise in which it is necessary to damage the target with much higher reliability than is anticipated by typical defense missions. Such situations include neutralizing armed terrorists who have taken hostages and offenders who attack protected persons in the presence of bystanders in their surroundings. In this case, injuring BS surrounding the offender or located in the likely line of fire is not allowed. Therefore, there is a need to perform fire missions with high indicators of firing effectiveness. Specifically, the probability of damaging the target should approach unity as closely as possible, while the probability of damaging BS should be minimized.

Analysis of recent research and publications. Currently, the issue of firing effectiveness has received attention in a significant number of scientific works.

The authors of [1] focus on the experimental evaluation of aiming error, considering its contribution to overall dispersion when firing from different positions at ranges of 100–500 m. They show that changing the shooter's position can lead to increased dispersion due to increased aiming error, which becomes particularly critical at greater distances.

According to the study [2], a methodological approach for assessing accuracy using simulation models is proposed. This approach makes it possible to simultaneously account for the random nature of deviations of impacts from the control point, changes in firing rate and their influence on the distribution of impacts, as well as the individual variability of the shooter between series and exercises.

Extending the ideas of using simulation models for assessing accuracy, [3] transfers the analysis from the "exercise" level to interpreting shooting data in the context of combat application. The article presents the advantages of combat modelling for evaluating and explaining the results of shooting exercises. A model of "small arms combat" is proposed, regarded as a tool that translates shooting results into more applied indicators and allows the data to be interpreted not only as a fact of "hit/not hit" but as a probabilistic characteristic of firing effectiveness for a set of conditions.

The author of [4] proposes an approach in which the distribution of impact points is formed by introducing random components and repeatedly simulating the firing scenario for given conditions. The practical value of that work lies in the fact that the model allows the probability of damaging the target to be evaluated depending on distance, type and size of the target and shooting conditions, and it can be used as a basic module for further complexity of input data.

Using statistical control charts for monitoring and controlling the quality of sniper training is proposed in [5]. The idea is to regard firing results as a process that should remain statistically stable over time. The control limits allow one to distinguish random fluctuations from significant changes associated with systematic causes, enabling the detection of indicator "drift" and timely adjustment of training.

The monograph [6] systematizes statistical models of dispersion (two-dimensional distributions, parameter estimation, interpretation of spread) in external ballistics. It summarizes approaches to describing dispersion as a random process on a plane, introduces and explains typical characteristics, and considers principles for estimating parameters from experimental data.

In the articles [7, 8], the need to increase the safety of using small arms by law-enforcement forces is substantiated and ways to solve this problem are identified. Criteria for assessing the safety of firearm use are developed; it is established that effective ways to improve the safety of weapon use are reducing the energy characteristics of the bullet to minimally sufficient levels and minimizing the distance at which it retains lethal effect.

In [9], an algorithm is developed to justify rational values of the technical characteristics of kinetic weapons with a limited range, allowing the necessary tactical characteristics to be ensured – specifically, the specified effect of the damaging element on the target with given parameters within a specified distance range, with reliability and safety not lower than required.

The problem of ensuring a given muzzle velocity of damaging elements for non-lethal kinetic weapons is considered in [10]. A method is proposed to increase the stability of the muzzle velocity of damaging elements that is not associated with tightening tolerances for the manufacture of cartridge components, enabling increased reliability of executing a fire mission.

By the authors of the articles [11, 12, 13] highlight the peculiarities of fire missions performed by a law-enforcement sniper and identify ways to improve their effectiveness, in particular by determining the rational magnification of the optical sight and reducing the bullet launch angle and coordinating its magnitude with the sight's field-of-view angle.

In the study [14], a list of technical characteristics of weapons and functional characteristics of the shooter that jointly and significantly affect fire mission results is identified, as well as the structure of the connections between them. Tasks are formulated whose solution will allow achieving specified firing effectiveness by formulating requirements for the weapon's technical characteristics while accounting for the shooter's functional characteristics.

However, the cited works do not consider models of executing fire missions that account for the impact of protecting bystanders on firing effectiveness. Thus, there is a problem: a contradiction between the need to evaluate the effectiveness of sniper fire missions with consideration for bystander safety and the absence of appropriate models.

The purpose of the article is to develop a model for executing a fire mission by a security-forces sniper with a restriction on injuring bystanders.

Summary of the main material. The use of firearms by security forces personnel can take place within quite diverse fire missions – from eliminating armed offenders detected during search operations in areas outside settlements and other crowded places to neutralizing dangerous offenders in the presence of BS in the firing direction. The most difficult fire missions can be considered those requiring neutralizing an offender who shields himself with a hostage. In this case, the size of the target is minimal and the hostage's position is the least convenient for the sniper.

To evaluate the effectiveness of executing such fire missions there are specific indicators and criteria – namely, the probability of executing the fire mission W_{fm} and the minimum permissible value of this indicator W_{min} [15]:

$$W_{fm} = W_d \cdot W_{pndb} \cdot \left(1 - P_{pndb}\right) \cdot \left(1 - P_{pdee}\right) = \\ = \left[1 - \left(1 - \frac{P_d}{K_{nhd}}\right)^n\right] \cdot \left(1 - \frac{P_{pdb}}{K_{nhd}}\right)^n \cdot (1 - P) \cdot \left(1 - P_{pdee}\right), \quad (1)$$

$$W_p \geq W_{p\,min}, \quad (2)$$

where W_d is the probability of damaging the target;

W_{pndb} is the probability of not damaging a bystander;

P_{pdei} is the probability that the effect of the damaging element on the target will be insufficient;

P_{pdee} is the probability that the effect of the damaging element on the target will be excessive;

P_d is the probability of damaging the target;

P_{pdb} is the probability of damaging a bystander;

K_{nhd} is the the number of hits on the target that to its damage;

K_{nhb} is the the number of hits on a bystander that lead to their injury;

$W_{p\,min}$ is the minimum permissible probability of not damaging a bystander.

The quantities P_{pdee} i P_{pdei} are important in cases involving the use of kinetic non-lethal weapons, which is not typical for a sniper fire mission. Therefore, formula (1) can be simplified:

$$W_{fm} = W_d \cdot W_{pndb} = \left(1 - \left(1 - \frac{P_d}{K_{nhd}}\right)^n\right) \cdot \left(1 - \frac{P_{pdb}}{K_{nhb}}\right)^n. \quad (3)$$

The quantities K_{nhd} i K_{nhb} are meaningful in cases involving weapons with multiple damaging elements or where the target is protected by individual amour. If such circumstances are absent, then formula takes the following form:

$$W_{fm} = W_d \cdot W_{pndb} = (1 - (1 - P_d)^n) \cdot \left(1 - P_{pdb}\right)^n. \quad (4)$$

The probabilities P_d and P_{pdb} are calculated according to the well-know formula [16]:

$$P = \left[\frac{1}{\sqrt{2\pi}\sigma_y}\int_0^Y e^{\frac{-(y-M_y)^2}{2\sigma_y^2}} dy\right] \times \\ \times \left[\frac{1}{\sqrt{2\pi}\sigma_z}\int_0^Z e^{\frac{-(z-M_z)^2}{2\sigma_z^2}} dz\right], \quad (5)$$

where P is the probability of hitting the target;

σ_y is the root mean square deviation of the coordinates of the impact points from the dispersion axis in height;

σ_z is the root mean square deviation of the coordinates of the impact points from the dispersion axis in the lateral direction;

M_y is the mathematical expectation of the vertical coordinates of the bullet impact points;

M_z is the mathematical expectation of the coordinates of the bullet impact points in the lateral direction;

Y is the height of the target;

Z is the width of the target.

From this follows:

$$P_d = \left[\frac{1}{\sqrt{2\pi}\sigma_{yd}}\int_0^{Y_d} e^{\frac{-(y-M_{yd})^2}{2\sigma_{yd}^2}} dy\right] \times \\ \times \left[\frac{1}{\sqrt{2\pi}\sigma_{zd}}\int_0^{Z_d} e^{\frac{-(y-M_{zd})^2}{2\sigma_{zd}^2}} dz\right], \quad (6)$$

$$P_{db} = \left[\frac{1}{\sqrt{2\pi}\sigma_{ypdb}}\int_0^{Y_{pdb}} e^{\frac{-(y-M_{ypdb})^2}{2\sigma_{ypdb}^2}} dy\right] \times \\ \times \left[\frac{1}{\sqrt{2\pi}\sigma_{zpdb}}\int_0^{Z_{pdb}} e^{\frac{-(y-M_{zpdb})^2}{2\sigma_{zpdb}^2}} dz\right]. \quad (7)$$

The probabilities of damaging the target W_d and the bystander W_{pndb} depend on the probabilities of hitting P_d and P_{pdb}, which in turn depend on the target dimensions Y_d and Z_d the bystander-zone dimensions Y_{pdb} and Z_{pdb}, the distances to them X_d and X_{pdb}, the coordinates of the mean point of impact M_{yd}, M_{zd}, M_{ypdb}, M_{zpdb} and the dispersion parameters of impacts in the plane of the target σ_{yd}, σ_{zd} and σ_{ypdb}, σ_{zpdb}. Furthermore, the probability of damaging the target depends on the number of shots at the target n, whether fired sequentially by a single sniper or simultaneously by several snipers on command.

During shooting with sniper rifles equipped with modern optical sights, the aiming point usually coincides with the position of the control point and the ideal position of the mean point of impact. However, there are always errors in aiming the weapon at the target, caused by the peculiarities of the sight, the shooter's skills, the quality of zeroing the weapon, the accuracy of taking into account the firing conditions (distance to the target, wind direction and speed, etc.), and other factors. These errors are random, so they are appropriately regarded as a source of reduced shot grouping, characterized by the quantities σ_{yd}, σ_{zd}, σ_{ypdb}, σ_{zpdb}. Each corresponding root mean square deviation σ is calculated using the following formula [16]:

$$\sigma = \sqrt{\sigma_t^2 + \sigma_p^2}\,, \tag{8}$$

where σ_t is the root mean square deviation of the coordinates of the impact points attributable to the technical shot grouping;

σ_p is the root mean square deviation of the coordinates of the impact points attributable to the error in aiming the weapon at the target.

So:

$$\sigma_{yd} = \sqrt{\sigma_{tyd}^2 + \sigma_{pyd}^2}\,, \tag{9}$$

$$\sigma_{zd} = \sqrt{\sigma_{tzd}^2 + \sigma_{pzd}^2}\,, \tag{10}$$

$$\sigma_{ypdb} = \sqrt{\sigma_{typdb}^2 + \sigma_{pypdb}^2}\,, \tag{11}$$

$$\sigma_{zpdb} = \sqrt{\sigma_{tzpdb}^2 + \sigma_{pzpdb}^2}\,. \tag{12}$$

It is obvious that within the scope of the single fire mission under consideration, $\sigma_{yd} = \sigma_{ydpb}$, and $\sigma_{zd} = \sigma_{zpdb}$. However, there may be cases when several targets are present at different distances in the line of fire. Then the equalities mentioned above will no longer hold. In the context of performing a fire mission with restrictions on injuring a bystander SF, it is not always appropriate to aim at the centre of the target, because in such cases the probability of not damaging the target may exceed the specified minimum value $W_{p\,min}$. To reduce $W_{p\,min}$ corrections can be introduced in the aiming point along the vertical axis ΔY_d and the lateral axis ΔZ_d relative to the target centre. In this case, the expected-value positions of the impacts in the target plane will not coincide with its center, but instead will be calculated by the following formulas:

$$M_{yd} = \frac{Y_d}{2} + \Delta Y_d\,, \tag{13}$$

$$M_{zd} = \frac{Z_d}{2} + \Delta Z_d\,, \tag{14}$$

$$M_{ypdb} = Y_{dd} - Y_{dpdb} + \frac{Y_{pdb}}{2} + \Delta Y_d\,, \tag{15}$$

$$M_{zpdb} = Z_{dd} - Z_{dpdb} + \frac{Z_{pdb}}{2} + \Delta Z_d\,, \tag{16}$$

where Y_{dd} i Z_{dd} are the coordinates of the centre of the target in height and in the lateral direction, respectively;

Y_{dpdb} i Z_{dpdb} are the coordinates of the centre of the SF in height and in the lateral direction, respectively.

It is worth noting that all the considerations presented above apply to targets of rectangular shape. For targets of complex shape, shape coefficients should be used (for typical targets), or the target should be divided into rectangular elements (for atypical targets). In the latter case, the probability of hitting the target will be equal to:

$$P = \textstyle\sum_{i=1}^{k} P_i\,, \tag{17}$$

where P_i is the probability of hitting in i-th rectangular section of the target.

For ease of reducing the amount of preliminary calculations and simplifying the input of source data, it is advisable to use the angular dispersion parameters of impact points during firing, σ'_Y and σ'_Z while calculating the corresponding linear values as a function of the distances to the target X_d and to the bystander X_{pdb} using the following formulas:

$$\sigma_{yd} = tg\left(\frac{\pi\sigma'_{yd}}{180^\circ \cdot 60'}\right) X_d, \tag{18}$$

$$\sigma_{zd} = tg\left(\frac{\pi\sigma'_{zd}}{180^\circ \cdot 60'}\right) X_d, \tag{19}$$

$$\sigma_{ypdb} = tg\left(\frac{\pi\sigma'_{ypdb}}{180^\circ \cdot 60'}\right) X_{pdb}, \tag{20}$$

$$\sigma_{zpdb} = tg\left(\frac{\pi\sigma'_{zpdb}}{180^\circ \cdot 60'}\right) X_{pdb}\,. \tag{21}$$

Therefore, a model for executing a fire mission with restrictions on harming bystanders by a security forces sniper has been developed. This model consists of the input data [Y_d, Z_d, Y_{pdb}, Z_{pdb}, X_d, X_{pdb}, Y_{dd}, Z_{dd}, Y_{dpdb}, Z_{dpdb}, ΔY_d, ΔZ_d, K_d, K_{pdb}, n, σ_{yd}, σ_{zd}, σ_{ypdb}, σ_{zpdb} (σ_{tyd}, σ_{tzd}, σ_{typdb}, σ_{tzpdb}, σ_{pyd}, σ_{pzd}, σ_{pypdb}, σ_{pzpdb}) σ'_y та σ'_z (σ'_{ty}, σ'_{tz}, σ'_{py}, σ'_{pz})] and expressions (3), (6), (7), (9)–(16), and, for specific cases, additionally expressions (17)–(21).

The model links the above input data with the indicators of firing effectiveness, namely the probabilities of hitting the target P_d and the bystander P_{pdb} the probabilities of damaging the target W_d and the bystander W_{pdb} as well as the overall probability of executing the fire mission W_{fm}.

A specific feature of the model is the presence of formulas that relate M_{yd}, M_{zd} and to the target dimensions Y_d, Z_d, the coordinates of its centre

Y_{dd}, and Z_{dd} and the deviations ΔY_d, ΔZ_d, while M_{ypdb}, M_{zpdb} – are related to the dimensions of the bystander damage zone Y_{pdb}, Z_{pdb}, are related to the dimensions of SF damage zone Y_{dpdb}, Z_{dpdb} and target Y_{dd}, Z_{dd} and the deviations ΔY_d, ΔZ_d. As a result, the input of source data is substantially simplified, their number is reduced, and the probability if errors caused by additional calculations if decreased.

In addition, in order to reduce the amount of preliminary calculations and the number of input data to be entered, the possibility of using angular dispersion parameters of impacts during firing is provided, while the corresponding linear values are calculated automatically depending on the distance to the target.

The application of the proposed model may be advisable for such cases as:

– calculating the probability of executing a fire mission by a security forces sniper with restrictions on harming bystanders, corresponding to given input data;

– determining the parameters of fire mission execution that ensure a specified or maximum probability of its successful execution;

– assessing the suitability of weapon samples for executing the corresponding fire mission with a specified probability, as well as for other similar tasks.

Conclusions

1. Known models of firing effectiveness, due to their insensitivity to the factors that determine the safety of weapon use for bystanders, prove to be unsuitable for assessing the effectiveness of fire mission execution by security forces.

2. To account for the specifics of weapon use by security forces, a model of execution a fire mission with restrictions on harming bystanders by a security forces sniper has been developed. This model links the parameters of the weapon, the target and the fire mission conditions with indicators of firing effectiveness. Unlike known models, the proposed model takes into account not only the parameters affecting the probabilities of hitting the target and damaging the target, but also those determining the probabilities of hitting a bystander and damaging a bystander. This makes it possible to study the influence of the weapon parameters, the target parameters and the fire mission conditions on the probability of execution the fire mission with restrictions on harming a bystander in general.

3. The developed model is advisable to use for calculating the indicators of execution a fire mission by a security forces sniper, for determining the fire mission parameters that ensure a predetermined or maximum probability of success, and for assessing the suitability of specific weapon samples for execution the corresponding fire mission with a given probability.

The direction of further research is to determine the influence of individual parameters of the security forces sniper's fire task on the indicators of the effectiveness of its execution.

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МОДЕЛЬ ВИКОНАННЯ ВОГНЕВОГО ЗАВДАННЯ СНАЙПЕРОМ СИЛ БЕЗПЕКИ З ОБМЕЖЕННЯМ ЩОДО УРАЖЕННЯ СТОРОННІХ ОСІБ

Процес гуманізації суспільства накладає суттєві обмеження на припустимі результати дій сил безпеки. Під час застосування зброї у населених пунктах, у ході визволення заручників та виконання інших завдань безпосередньо близько до сторонніх осіб сили охорони правопорядку мають враховувати інтереси цих осіб і максимально їх убезпечувати.

Під час виконання завдань силами безпеки виникають ситуації, коли необхідно уразити ціль з виключно високою надійністю. До таких ситуацій слід віднести знешкодження озброєних терористів, що утримують заручників, та правопорушників, що здійснюють замах на осіб, які охороняються, за наявності в їхньому оточенні сторонніх осіб тощо. При цьому накладаються обмеження щодо недопущення ураження заручників і сторонніх осіб, які оточують правопорушника або знаходяться у напрямку ймовірної стрільби. Отже, виникає необхідність у виконанні вогневих завдань з високими показниками ефективності. Зокрема, ймовірність ураження цілі при цьому має максимально наближатися до одиниці, а ймовірність ураження сторонніх осіб – мінімізуватися.

Відомі моделі ефективності виконання вогневого завдання здебільшого не придатні для оцінювання ефективності виконання специфічних вогневих завдань силами безпеки через нечутливість до безпечності застосування зброї для сторонніх осіб.

Для врахування специфіки застосування зброї силами безпеки розроблено модель виконання вогневого завдання з обмеженням щодо ураження сторонніх осіб снайпером сил безпеки. Модель зв’язує параметри зброї, цілі та умов виконання вогневого завдання з показниками ефективності стрільби, зокрема, ймовірностями влучення у ціль та сторонню особу, ймовірностями ураження цілі та сторонньої особи, а також імовірністю виконання вогневого завдання в цілому.

Запропоновану модель можливо використовувати для розрахунку показників виконання вогневого завдання снайпером сил безпеки, для визначення параметрів виконання вогневого завдання, які забезпечують задану або максимальну ймовірність його виконання, а також для оцінювання придатності зразків зброї до виконання відповідного вогневого завдання із заданою ймовірністю.

Ключові слова: *вогневе завдання, ймовірність ураження, ефективність стрільби, сили безпеки, снайпер, сторонні особи.*

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