UDC 623.4


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METHOD OF DETERMINING THE PROBABILITY OF RECEIVING A COMBAT INJURY BY A SECURITY FORCE EMPLOYEE UNDER ENEMY FIRE INFLUENCE

The article addresses the issue of determining the probability of a security forces officer sustaining a combat injury under conditions of enemy fire.

An improved method for determining the probability of a security forces officer sustaining a combat injury under enemy fire has been developed. This method involves decomposing the target into elementary areas, calculating the probability of a striking element hitting each of these areas, estimating the probability of damage to each area considering the ballistic resistance diagrams of protective elements and the number of shots from a specific weapon, and determining based on this the probability of sustaining a combat injury from one or several types of weapons used simultaneously by the enemy. Unlike existing methods, this approach takes into account qualitative changes in the protection level of security forces employee provided by protective elements depending on the characteristics of the enemy's weapons and the distance at which they are used.

Using the improved method, probabilities of security forces employee sustaining combat injuries during task execution were calculated based on the protective characteristics of individual protection equipment, as well as the characteristics and number of the enemy's firearms in a developed scenario.

The calculations revealed that incorporating individual body armor in combat equipment may be impractical in situations where enemy fire conditions involve simultaneous use of multiple weapons against a single target. In certain operational conditions, individual body armor loses its significance in providing a specified level of survivability for security forces employee. To assess the survivability of security forces employee during task execution, it is essential to forecast the enemy's firearms and ammunition to identify critical distances for selecting protective elements of individual body armor with optimal protective characteristics, as well as the ratio of enemy weapons to designated targets.

Keywords: *combat trauma, bullet resistance, probability of hitting the target, protection, protective element, personal protective equipment.*

Statement of the problem. Today, security forces are entrusted with a wide range of tasks, including participation in special operations aimed at neutralizing armed criminals, suppressing illegal activities of paramilitary or armed groups, as well as organised criminal groups and groups on the territory of Ukraine. In addition, they are involved in activities aimed at countering terrorist activities and repelling armed aggression against Ukraine, which is becoming increasingly important in the context of current threats to national security [1].

The fulfilment of these tasks is inextricably linked to the potential threat of the enemy using various types of destruction means, which requires a certain level of protection that ensures an adequate level of survivability of security forces employee (SFP).

The most likely reasons for the loss of survivability of an SFP under enemy fire are combat injuries caused by various munitions. On the other hand, the survivability of the SFP is affected by other factors, including, in particular, the level of fatigue [2, 3]. Given that the protection class of personal protective equipment (PPE) affects the security of the SFP directly, and its functional properties – inversely [4, 5], there is a need to determine the rational characteristics of PPE. At the same time, there is a need to determine the probability of combat injury to the SFP under enemy fire.

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Analysis of recent research and publications. In general, domestic publications pay sufficient attention to the issue of calculating the probability of damage to manpower by various means of destruction.

Thus, work [6] considers the relevance of defeating protected enemy targets in combat operations. The interdependence of the energy and force characteristics of typical bullets of domestic and foreign manufacturers at the distance of firing from firearms (within a direct shot) was investigated in order to find the optimal effective firing distance at protected targets. The known mechanisms of target destruction are evaluated, and it is determined at what firing distance a particular mechanism of destruction dominates.

The scientific research [7] presents the results of studies of changes in the expected number of rounds required to hit a protected target depending on the type of weapon and type of cartridge at the distance of effective firearms fire. An overview of the dependence of the probability of hitting a protected target and the expected number of rounds on the class of the protective structure of the body armour is provided. The relevance of defeating enemy targets protected by personal armoured protection made of high-quality polymeric materials "Arus" and "Rusar" is considered.

The assessment of the protective capability of a target wearing SFP at a firing distance within the range of a direct shot is described in [8]. It is carried out on the basis of an assessment of the penetrating effect of the PPE bullet and the severity of injury to the serviceman equipped with this means. It also determines the change in the protective effect of PPE depending on the range of fire and the type of firearm. However, the authors of articles [6, 7, 8] consider the defeat of protected targets when firing from a single firearms type. In addition, the assumption that there is no safety margin of the body armour at the standard test distance is questionable.

Paper [9] defines the main criteria by which the effectiveness of firearms firing can be assessed, and [10] analyses and defines the indicators of firearms firing effectiveness. The authors consider the impact of scattering parameters on the probability of a hit and on the effectiveness of shooting in general. However, these works do not study the probability of hitting a target when several samples of firearms are used simultaneously.

However, these research results do not reflect approaches to calculating the probability of hitting individuals (military personnel, employees, police officers) in PPE in the event of firing at them from several firearms simultaneously. Therefore, there is a need to improve the method of calculating the probability of hitting a target, taking into account its protection, to determine the probability of combat injury to a SFP in combat equipment (CE) in the event of simultaneous use of different types of firearms by the enemy in order to ensure a certain level of protection in the face of the danger of enemy fire.

The purpose of the article is to improve the method of calculating the probability of hitting a target, taking into account its protection, to determine the probability of a combat injury to a security forces officer in conditions of danger of enemy fire.

Summary of the main material. The task of determining the probability of combat injury to a SFP under enemy fire is reduced to calculating the probability of hitting a target with firearms. To solve this problem, analytical methods for determining the probability of hitting a target are widely used [11, 12, 13]. These methods are based on mathematical analysis of physical parameters of firing, characteristics of weapons, conditions of firing and provide an acceptable accuracy of the probability of hitting the target. Therefore, in order to determine the probability of a combat injury to a security officer, it is advisable to apply an analytical method for determining the probability of hitting a target, taking into account the peculiarities of the enemy's use of weapons. Such features include the possibility of simultaneous firing at the target from several different types of firearms and the unequal degree of protection of the body parts of the security personnel.

In the case of the enemy's use of one type of firearms, the task of determining the probability of combat injury to a SFP P_{ci} is solved using a well-known method [11, 12], which involves three stages of calculations.

At the first stage, the silhouette of the SFP is divided into k elementary areas and the probability of a bullet hitting each of the k areas of the body of the P_{sbi} worker is calculated [11, 12]:

$$p_{sb_i} = \left[\frac{1}{\sqrt{2\pi}\sigma_y} \int_{Y_{i_0}}^{Y_i} e^{\frac{-(y-\bar{y})^2}{2\sigma_y^2}} dy \right] \times \left[\frac{1}{\sqrt{2\pi}\sigma_z} \int_{Z_{i_0}}^{Z_i} e^{\frac{-(z-\bar{z})^2}{2\sigma_z^2}} dz \right], \quad (1)$$

where Y_{io}, Z_{io} are the positions of the lower left corner of the i-yi section of the body of the SFP;

Y_i, Z_i are position of the upper right corner of the i-yi section of the body of the SFP;

$\dot{y}$, $\dot{z}$ are mathematical expectation of the coordinates of the hit in the target plane (SFP) in height and lateral direction, respectively;

σ_y, σ_z are root mean square deviation of the coordinates of the target plane hit points (SFP) in height and lateral direction, respectively.

At the second stage, the probability of damage to the i-yi part of the body is determined SFP p_{ci}:

$$p_{c_i} = 1 - \left(1 - \frac{p_{sb_i}}{K_i}\right)^n, \qquad (2)$$

where K_i – is the number of hits required to destroy the i-yi part of the body of the SFP;

n – the number of shots fired (striking element (SE) in ammunition with several SE).

The K_i value depends on the bullet resistance of the protective elements (PEs) that protect the body parts of the SFP. At the same time, the bullet resistance of the protective elements to a particular destruction system is affected by the firing distance. To graphically depict the distances at which qualitative jumps from "no protection to protection" occur, bullet resistance diagrams are used [14]. Therefore, to take into account the qualitative changes in the protection of the SFP by the relevant PEs depending on the characteristics of the enemy's destruction systems and the distances of their use, it is advisable to use the corresponding diagrams of the PEs bullet resistance.

At the third stage, the probability of combat injury P_{cw} of a SFP is determined in the event of the enemy's use of a certain j – type of weapon as the probability of one of the compatible events (damage to any part of the SFP body by any shot fired) [15]:

$$P_{cw_j} = 1 - \prod_{i=1}^{k}\left(1 - p_{c_i}\right). \qquad (3)$$

In the case of simultaneous use of different types of firearms by the enemy, it is proposed to carry out calculations for each type of weapon according to formulas (1), (2), (3), and then determine the probability of combat injury to a SFP P_c as the probability of at least one of the compatible equivalent events (damage to any part of the SFP body from any type of weapon) [15]:

$$P_c = 1 - \prod_{j=1}^{m}\left(1 - P_{cw_j}\right), \qquad (4)$$

where m is the number of samples of firearms used simultaneously.

The proposed approach to calculating the probability of combat injury to the P_c of a SFP under enemy fire takes into account the heterogeneity of the protection of different parts of the SFP body, the possibility of simultaneous use of different types of firearms by the enemy and their number.

Formulas (1)–(4), together with the diagrams of bullet resistance of protective elements, constitute a method for determining the probability of a combat injury to a security force member under enemy fire. The method consists in decomposing the target into elementary areas and calculating the probability of SE hitting each of them, calculating the probability of hitting each of the areas, taking into account the diagrams of bullet resistance of protective elements and the number of shots from the relevant weapon type, as well as determining on this basis the probability of a security force member receiving a combat injury from one or more weapons in the event of their simultaneous use by the enemy.

In contrast to the known methods, the presented method takes into account the presence of qualitative changes in the protection of the SFP by the corresponding protective elements depending on the characteristics of the enemy's destruction means and the distance of their use.

As an example, the probability of a combat injury to a SFP during the performance of a mission is calculated depending on the protective characteristics of PPE, as well as the characteristics and number of enemy firearms samples for the developed scenario.

Objective. To replace the security forces at the observation post in front of the enemy's front line.

Situation. The front edge of the enemy's defence runs along the hillsides between settlements. The platoon moved to the defensive and set up a system of observation posts located at distances of 900 m from our front line and 200 m from the enemy's front line. The routes to the observation posts may be subject to enemy fire.

The enemy. The enemy unit organisationally consists of three motorised infantry divisions. The enemy personnel are armed with firearms for each squad: AK 74 (PP cartridge) – 4 units; AKM (PS cartridge) – 4 units; RPK 74 (PP cartridge) – 1 unit; PK (LPS cartridge) – 1 unit.

Additional conditions of the task. The task is performed during daylight hours. The routes of advance are rocket routes with natural and artificial shelters located at a distance of 30...40 m.

Composition of combat equipment. Destruction subsystem: firearms (AK 74); ammunition for weapons (PS, PP); hand grenades (F-1, RGO). Protection subsystem: modular body armour with UARM SA3 Ranger Green main body armour [protection class (PC) III (according to

DSTU 8782:2018)]; UKR TAC side armour (PC IIaccording to DSTU 8782:2018); TOP ballistic helmet (PC I according to DSTU 8835:2019). Control subsystem: a small-sized radio station with an encrypted signal and a special headset (Motorola MotoTRBO DP4400e). Power supply subsystem: power sources (for communication, reconnaissance and surveillance equipment). Life support subsystem: medical supplies, dry rations, water.

Procedure of the task. A group of 3 security personnel moves along a defined route to the observation post. During the movement, the personnel move by running or crawling from one shelter to another.

Before making the calculations, a number of assumptions must be made that determine the scope of the calculations.

Firstly, the air defence system will be positioned in front of the enemy during firing.

Secondly, the enemy will shoot at us in short bursts.

Thirdly, the mean point of impact (MPI) corresponds to the centre of the target.

The following calculations are proposed to determine the probability of combat injury to the P_c of a SFP in conditions of danger of enemy fire:

– determining the probability of a bullet hitting a SFP at different distances for each type of enemy firearms;

– determination of the probability of combat injury to the SFP at different distances from each type of enemy firearms;

– determination of the probability of combat injury to the SFP at different distances in the event of simultaneous use by the enemy of different types of firearms.

Using formula (1), the probabilities of a bullet hitting the elementary parts of the SFP body were calculated. For this purpose, the silhouette of the SFP in the CE was divided into 38 sections (Figure 1) and the integration limits for each of them were determined.

In Figure 1, figures 17 and 22 show the body parts protected by the UARM SA3 Ranger Green, figures 1–6 by the TOP ballistic helmet, figures 8–16, 18–21, 23, 24, 25, 28, 33 by the UKR TAC side armour, and the rest of the figures show the unprotected body parts of the SFP.

Using formulas (1), (2), (3), we calculated the probability of combat injury to a SFP on the route of movement if the enemy uses one of the firearms samples at different distances (Table 1) and obtained the corresponding dependencies (Figure 2). The calculations were based on the results of studies of the impact of firing distances on the bullet resistance of PPE, in particular, the critical distances [14].

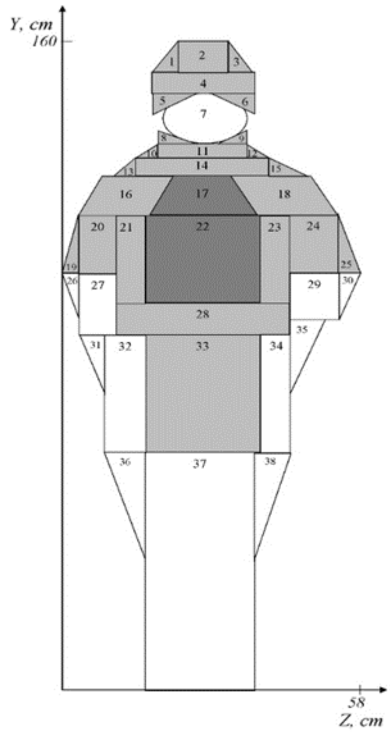


Figure 1 – Silhouette of a security officer in combat gear, which is divided into elementary sections

In this case, the distances at which qualitative jumps from "no protection to protection" are made are considered critical.

The dependencies shown in Figure 2 show that the probability of combat injury to a SFP at distances exceeding critical ones is reduced by 1.2–1.6 times. This is due to the protection of certain parts of the body of the SFP by the protective equipment.

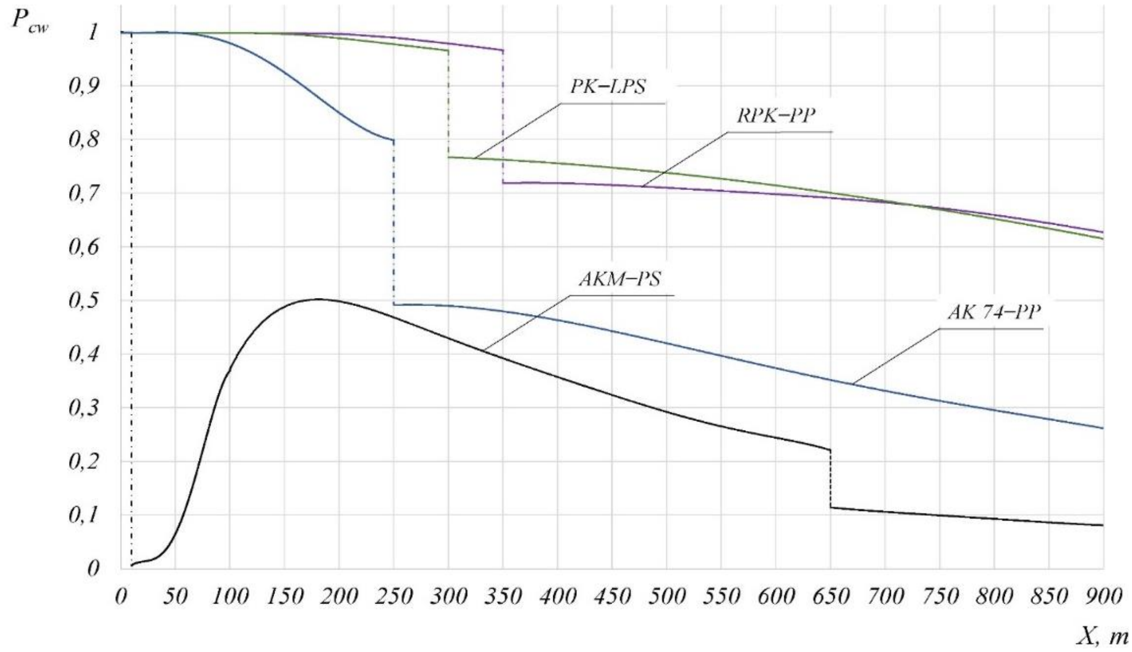
The dependence of the probability of combat injury on the AKM – PS weapon system has a certain peculiarity: at a distance of up to 170 m, it increases and then decreases. This change can be explained by the fact that when firing from the AKM – PS system at the UARM SA3 Ranger Green, the critical distance is 10 m, and the probability of hitting the target is almost equal to one, which corresponds to the maximum probability of combat injury to the SFP. In case of exceeding the distance of 10 m, due to the high accuracy of shooting, almost all hits fall within the protected area, and the PE provides reliable protection of the target, which corresponds to almost zero probability of defeat.

As the distance to the target increases, the scattering area increases and at some point extends beyond the protected area of the target. In this case, the probability of hitting the unprotected areas of the target gradually increases and then decreases due to the excessive scattering area of hits in the target plane. Thus, the probability of hitting the target first increases, reaching its maximum, and then decreases. The next jump in the P_{cw} value is observed at a distance of 650 m, which is critical when firing from the AKM – PS complex at the UKR TAC side protection devices, which have a lower protection class than the UARM SA3 Ranger Green.

To illustrate the reasons described above for the change in the probability of combat injury from the AKM – PS weapon system, a number of dependencies P_{cw} (X) were obtained for two positions MPI [the centre of the target, centre of the upper part (head) of the target] and three combinations of the average deviation of hits to the target plane in height B_h and lateral direction B_d (Figure 3).

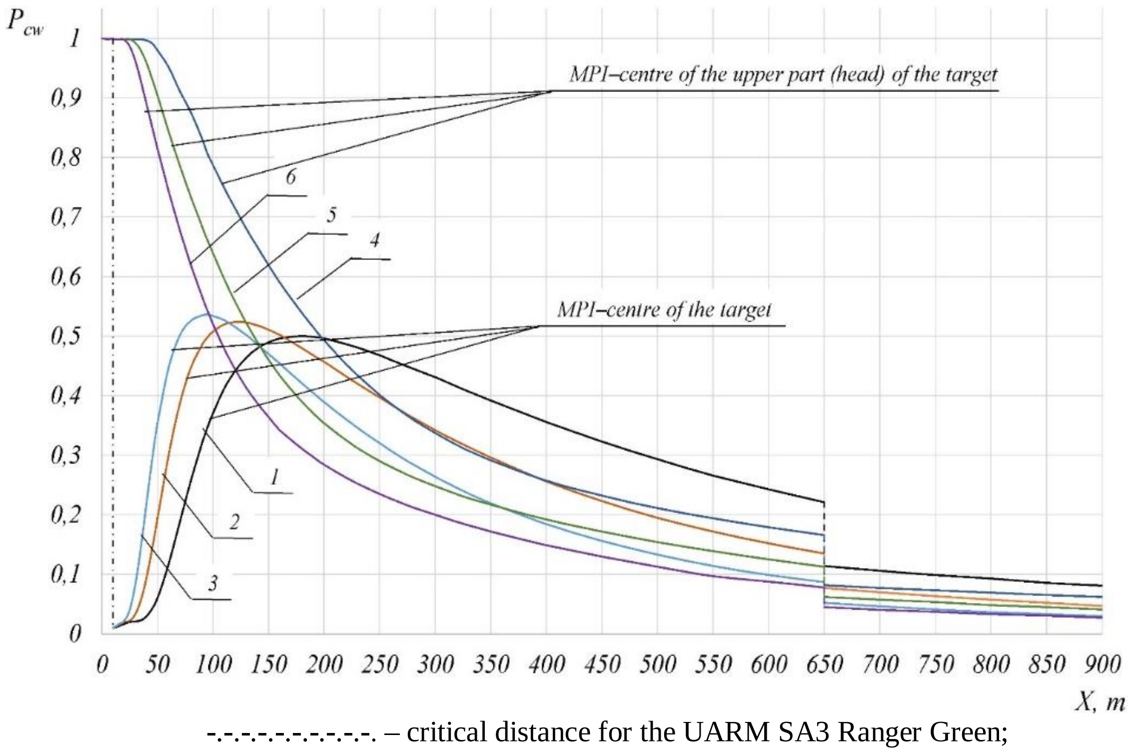
Table 1 – Probability of combat injury to a security force member in combat gear on the route of movement if the enemy uses one of the firearms at different distances

Distance to the enemy X, m	Probability of combat-related injuries to the SFP in the CE P_{cw}			
	AK 74 – PP	AKM – PS	RPK 74 – PP	PK – LPS
5	0.999	0.999	0.999	0.999
10	0.999	0.005	0.999	0.999
50	0.999	0.006	0.999	0.999
100	0.981	0.371	0.999	0.998
150	0.916	0.049	0.998	0.997
200	0.855	0.496	0.997	0.989
250	0.493	0.468	0.099	0.978
300	0.487	0.431	0.979	0.767
350	0.482	0.392	0.719	0.763
400	0.464	0.356	0.717	0.753
450	0.442	0.323	0.716	0.747
500	0.419	0.293	0.709	0.074
550	0.396	0.266	0.707	0.724
600	0.374	0.243	0.699	0.709
650	0.352	0.114	0.688	0.706
700	0.332	0.106	0.684	0.687
750	0.313	0.099	0.675	0.667
800	0.295	0.093	0.066	0.647
850	0.278	0.086	0.641	0.634
900	0.262	0.081	0.628	0.617



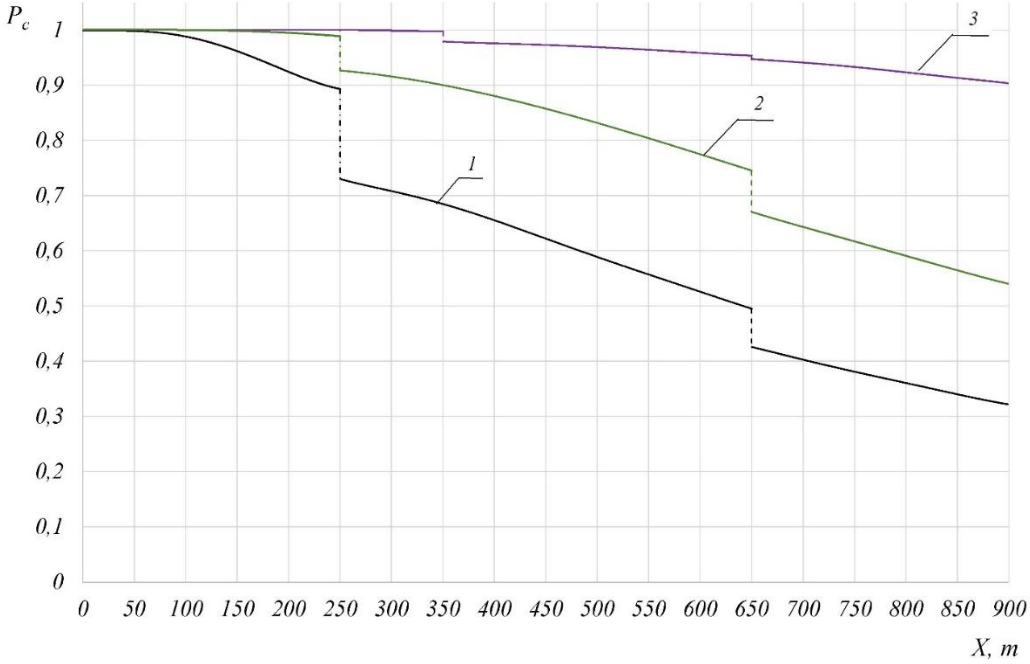
-.-.-.-.-.-.-. – critical distance for the UARM SA3 Ranger Green;
----------- – critical distance for the side munitions "UKR TAC"

Figure 2 – Dependence of the probability of combat injury to a security forces officer in combat gear on the distance to the enemy and in the case of using one type of destruction system



-.-.-.-.-.-.-.-.-.-. – critical distance for the UARM SA3 Ranger Green;
----------------- – critical distance for the side mounted "UKR TAC"

Figure 3 – Dependence of the probability of a combat injury to a security officer in combat gear on the distance to the enemy when using the AKM – PS weapon system with different indicators of the number of rounds and accuracy of fire: *1, 4* – B_h = 5 cm, B_d = 8 cm; *2, 5* – B_h = 8 cm, B_d = 11 cm; *3, 6* – B_h = 11 cm, B_d = 14 cm



-.-.-.-.-.-. – critical distance for the UARM SA3 Ranger Green;
---------- – critical distance for the side mounted "UKR TAC"

Figure 4 – Dependence of the probability of a combat trauma to a security force member in combat gear on the distance to the enemy and in the case of simultaneous use of several types of destruction systems: *1* – AK 74 – PP (1 unit), AKM – PS (1 unit); *2* – AK 74 – PP (2 units), AKM – PS (2 units); *3* – AK 74 – PP (4 units), AKM – PS (4 units), RPK 74 – PP (1 unit), PK – LPS (1 unit)

The obtained dependences (Figure 3) show that at distances of 10...50 m, the value of P_{cw} is significantly affected by the position of the centre of the upper part of the target. This is due to the fact that in the centre of the target almost all hits fall within the protected area, but in the top position of the target, they fall within the unprotected area. At distances greater than 200 m, the effect of the centre of the top of the target on the P_{cw} value decreases. At the same time, the influence of firing rate increases. Thus, in the case of defeating a protected target, the probability of its defeat at short distances depends mainly on the accuracy of firing, and at medium and long distances – on the rate of fire.

For the cases of simultaneous use of several firearms by the enemy, which are given in the scenario, the probability of combat injury to the SFP on the route of movement was calculated using formula (4) and the corresponding dependencies were obtained (Figure 4).

Figure 4 shows that with an increase in the number of samples of the engagement system, the impact of PPE on reducing the likelihood of combat injury to the SFP decreases, and if the enemy uses all available firearms (according to the scenario), the effect of PPE practically disappears.

The results of the calculations (dependence 3 in Figure 4) suggest that in conditions when the enemy uses a large number of samples of the destruction system against one target, the expediency of using PPE is not indisputable. At the same time, reducing the likelihood of combat injury is possible by increasing the manoeuvrability of the SFP by reducing the total weight of the CE (for example, by excluding PPE, which can make up up to 50 % of the total CE weight) [2]. This approach can be justified in cases where the time for preparing the first shot or for firing subsequent shots is comparable to the target exposure time [16, 17], which inversely depends on the maneuverability properties of the SFP.

Consequently:

– the use of PPE as part of combat equipment may not be appropriate in cases where the conditions of fire from the enemy provide for the simultaneous use of several types of weapons against the same target;

– in some conditions of performing assigned tasks, personal armour protection means lose their significance for ensuring a certain level of survivability of the SFP;

– in order to assess the survivability of the SFP during the performance of assigned tasks, it is necessary to predict the enemy's firearms and ammunition in order to determine the critical distances for the selection of protective elements of PPE with rational protective characteristics, as well as the ratio of the number of enemy weapons and the targets intended for it.

Conclusions

1. The method for determining the probability of a combat injury by a security officer under enemy fire has been improved.

2. This method makes it possible to increase the reliability of the forecast of combat trauma by a security officer under enemy fire by taking into account qualitative changes in the security officer's protection by appropriate protective elements, depending on the characteristics of the enemy's means of destruction and the distance of their use.

3. In the conditions of simultaneous use of several types of weapons by the enemy against the same target, the importance of personal armour protection can be significantly reduced. In such cases, the indicators of security and maneuverability of a security officer become significantly contradictory, which requires a separate study.

The direction of further research is to develop a methodology for determining the survivability of a security officer under enemy fire.

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The article was submitted to the editorial office on 27 February 2025

УДК 623.4

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МЕТОД ВИЗНАЧЕННЯ ЙМОВІРНОСТІ ОТРИМАННЯ БОЙОВОЇ ТРАВМИ ПРАЦІВНИКОМ СИЛ БЕЗПЕКИ В УМОВАХ ВОГНЕВОГО ВПЛИВУ ПРОТИВНИКА

Розглянуто питання визначення ймовірності отримання бойової травми працівником сил безпеки в умовах вогневого впливу противника.

Удосконалено метод визначення ймовірності отримання бойової травми працівником сил безпеки в умовах вогневого впливу противника. Цей метод полягає у декомпозиції цілі на елементарні ділянки і розрахунку ймовірності влучення поражаючого елемента в кожну з них, обчисленні ймовірності ураження кожної ділянки з урахуванням діаграм кулестійкості захисних елементів та кількості пострілів з відповідного зразка зброї, а також у визначенні на цій основі ймовірності отримання бойової травми працівником сил безпеки від одного та кількох зразків зброї у разі їх одночасного застосування противником. На відміну від відомих методів зазначений метод ураховує наявність *якісних змін захищеності працівника сил безпеки відповідними захисними елементами залежно від характеристик засобів ураження противника та відстані їх застосування.*

За допомогою вдосконаленого методу розраховано ймовірності отримання бойової травми працівником сил безпеки під час виконання завдання за призначенням залежно від захисних характеристик засобів індивідуального захисту та характеристик і кількості зразків стрілецької зброї противника для розробленого сценарію.

За результатами проведених розрахунків установлено, що використання у складі бойового екіпірування засобів індивідуального бронезахисту може бути недоцільним у випадках, коли умови вогневого впливу з боку противника передбачають одночасне застосування кількох зразків зброї по одній цілі; у деяких умовах виконання завдань за призначенням засоби індивідуального бронезахисту втрачають свою значущість для забезпечення певного рівня живучості працівника сил безпеки. Для оцінювання живучості працівника сил безпеки під час виконання завдань за призначенням необхідним є прогнозування наявної у противника стрілецької зброї та боєприпасів з метою визначення критичних відстаней для вибору захисних елементів засобів індивідуального бронезахисту з раціональними захисними характеристиками, а також співвідношення кількості зброї противника та призначених для неї цілей.

Ключові слова: *бойова травма, кулестійкість, імовірність ураження цілі, захищеність, захисний елемент, засоби індивідуального бронезахисту.*

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