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INDICATORS AND CRITERIA OF SURVIVABILITY FOR SECURITY FORCE PERSONNEL UNDER CONDITIONS OF ENEMY FIRE IMPACT

It has been established that the conditions under which security force units perform their tasks during a full-scale war have undergone significant changes, leading to a decrease in the survivability of security force personnel both during combat operations and while carrying out law enforcement tasks. The main factors influencing the likelihood of a security officer sustaining a combat injury have been identified, and a comprehensive set of survivability indicators for security force personnel under enemy fire conditions has been developed. Based on these indicators, a list of criteria for the survivability of security force personnel has been proposed.

Keywords: *survivability, maneuverability, concealment, protection, combat injury.*

Statement of the problem. In contemporary conditions, security forces are tasked with a wide range of responsibilities, including participation in special operations to neutralize armed criminals, halt the activities of unauthorized paramilitary or armed formations (groups), organized groups, and criminal organizations within Ukraine, as well as activities related to countering terrorism [1, 2]. The execution of these tasks implies the possibility of the offender (enemy) employing means of destruction, thereby necessitating the provision of a certain level of survivability for security force personnel (SFP) to ensure their life and combat effectiveness.

In the modern world, there is a trend towards minimizing losses among personnel during the execution of their duties by increasing the survivability of units [3]. The negative changes that have occurred in society during the full-scale war have affected the conditions under which security force units perform their tasks. A large amount of various types of weapons has entered the population, a significant portion of the population has gained combat experience, and these weapons can be used against SFP during criminal activities. Additionally, security forces have been extensively involved in tasks traditionally associated with defense units, which increases the likelihood of encountering powerful combat weapons. These circumstances lead to a decrease in the survivability of SFP both during combat operations and while performing law enforcement tasks. Therefore, enhancing the survivability of SFP is a pressing issue.

Currently, survivability is understood as the set of properties that enable maintaining and sustaining combat effectiveness at the required level in various situations and performing combat tasks under conditions of active enemy opposition.

The study of the survivability of SFP under enemy fire hazard conditions reveals that survivability depends on the concealment and maneuverability of the SFP in potentially dangerous zones, as well as their protection from enemy weaponry. Given this, enhancing the survivability of SFP can be achieved by improving their maneuverability, camouflage, and protective properties. However, increasing any of these properties often negatively affects the others. For instance, enhancing protection from weapons by increasing the area and level of combat body armour (CBA) also increases its weight and size, which negatively impacts the personnel's maneuverability. The need to improve maneuverability, which involves reducing the weight of combat equipment, leads to a decrease in the carried supplies (ammunition, water, food), thereby diminishing the degree of protection, among other factors. Therefore, to quantitatively and qualitatively characterize these properties, a comprehensive set of indicators and corresponding criteria is necessary. Such a system of indicators and criteria for SFP survivability is essential and represents the first step towards forming requirements for the characteristics of combat equipment and its individual elements to ensure the specified level of personnel survivability.

Analysis of recent research and publications. The issue of enhancing the survivability of troops (forces), units, and weapon and military equipment samples has recently received considerable attention in domestic scientific publications.

For instance, the authors of the article [4] proposed approaches to selecting criteria for evaluating the effectiveness of camouflage and imitation measures to enhance the survivability of Ukrainian Air Force assets.

In the scientific article [5], improving the survivability of troops and achieving the element of surprise in their actions is suggested through the refinement of measures and methods of operational (tactical) camouflage.

To enhance the survivability of troops against enemy unmanned aerial vehicles (UAVs), the article [6] developed a methodological approach for evaluating the effectiveness of troop protection from UAVs. This approach considers the most important indicators of troop protection from UAVs, the values that numerically characterize the main parameters of UAV combat use, as well as the conditions for implementing fortification and camouflage measures using standard camouflage kits, which significantly impact the effectiveness of engineering protection.

In the scientific article [7], a set of indicators for assessing the effectiveness (quality) of camouflaging military objects to enhance their survivability has been developed. In [8], a set of indicators for evaluating the predicted effectiveness of the use of camouflage forces and means to protect military objects from enemy aerial reconnaissance and targeting has been proposed.

The authors of the article [9] suggested a methodology for evaluating the results of a technical and economic comparison of camouflage options for combat armored vehicles to improve their survivability against enemy technical reconnaissance means.

In the scientific work [10], the main factors affecting the likelihood of combat damage to armored wheeled vehicles have been identified, and a set of indicators and criteria for the combat survivability of such vehicles has been developed.

The authors in the scientific sources [11, 12] address the issue of enhancing the survivability of military personnel by improving their protection systems through the establishment of justified requirements for the CBA. These requirements include a high protection class with superior ballistic resistance and maximum protection area, yet with relatively low weight.

The authors of publication [13] associate the enhancement of military personnel survivability under the influence of firearms with the development of new or improvement of existing protective materials and designs for individual body armor.

Survivability of military personnel is also addressed in article [14], which suggests reducing the optical visibility of military personnel by improving the camouflage properties of their equipment.

However, the mentioned research results do not reflect the indicators and criteria for the survivability of individual personnel (military personnel, employees, police officers) during task execution. Therefore, there is a need to develop a system of indicators and criteria for the survivability of SFP to ensure a certain level of survivability in conditions of enemy fire hazard.

The purpose of the article is to develop a set of indicators and criteria of the survival of a security forces personnel under conditions of enemy fire impact.

Summary of the main material. During the execution of assigned tasks, SFP may lose their combat effectiveness due to sustaining combat injuries. Combat injury is defined as an event that impairs the operational capability of an individual as a result of the influence of any type of weapon or other injurious factor, while performing assigned tasks.

The probability of a SFP sustaining a combat injury P_{ci} in the event of the enemy employing a specific type of weapon can be calculated using the formula:

$$P_{ci} = 1 - \left(1 - \frac{P}{K}\right)^n, \qquad (1)$$

where P – the probability of a weapon hitting a SFP;

K – the number of hits required to impair the operational capability of a SFP;

n – the number of shots fired (or fragments hitting the SFP).

In that case, the survivability of SFP under the danger of enemy fire influence P_s is represented as the probability of them not sustaining combat injury:

$$P_s = 1 - \left[1 - \left(1 - \frac{P}{K}\right)^n\right] = \left(1 - \frac{P}{K}\right)^n. \qquad (2)$$

Thus, by the survivability of security force personnel, we understand the probability that they will not sustain combat injury as a result of the enemy employing a specific type of weapon.

The probability of a weapon hitting a SFP will be determined by the sum of the probabilities of hits on specific elementary areas of their body P_{ABi}:

$$P = \sum_{P_{ab}=1}^{i} P_{ab}. \qquad (3)$$

The probability of hitting a rectangular area of a person's body P_{ABi} is calculated using the following formula [10, 15]:

$$P_{ab_i} = \left[\frac{1}{\sqrt{2\pi}\sigma_y}\int_{Y_i}^{y_i} e^{\frac{-(Y-\dot{y})^2}{2\sigma_Y^2}} dY\right] \times \left[\frac{1}{\sqrt{2\pi}\sigma_z}\int_{Z_i}^{z_i} e^{\frac{-(Z-\dot{z})^2}{2\sigma_Z^2}} dZ\right], \quad (4)$$

where Y, Z – the height and width of the projection of the body of the SFP;

y_i, z_i – the height and width of the i^{th} segment of the projection of the body of the SFP;

Y_i, Z_i – the position of the bottom left corner of the i^{th} segment of the projection of the body of the SFP relative to its height and width;

$\dot{y}$, $\dot{z}$ – the mathematical expectation of the coordinates of hitting in the target plane (SP) along the height and lateral direction;

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

The number of shots fired n within a certain time t depends on the firing rate of the weapon model η which is determined by the formula:

$$\eta = \frac{60}{\frac{t_a}{s}+t_c+\frac{t_l}{\varepsilon}}, \quad (5)$$

where t_a – the aiming (targeting) time of the weapon on the target;

t_l – the weapon loading time;

t_c – the cycle time of the weapon's mechanism;

ε – the magazine or strip capacity;

s – the length of the queue.

The time required for the adversary to inflict combat injury on the SFP will be determined as the average expected time to complete the firing task t_{ft} [16]:

$$t_{ft} = t_1 + \frac{n_r}{\eta}, \quad (6)$$

where t_1 – the time taken to prepare for the first shot;

n_r – the required number of shots;

η – the rate of fire of the weapon model.

Analysis of formulas (2)–(6) allows us to conclude that the probability of SFP sustaining combat injury is influenced by:

- the dimensions of the target, which refer to the projection of the SFP on the plane perpendicular to the direction of fire;
- the number of body areas of the SFP that are not protected by body armor, as well as their areas;
- the duration of time the SFP is exposed to enemy fire (target exposure time);
- the rate of fire of the enemy weapon model;
- the accuracy of the enemy's shooting with the corresponding weapon model.

By addressing the factors mentioned above, it is possible to increase the survivability of SFP in conditions of danger from enemy fire.

The size of the target depends on the dimensions of the SFP and the CBA, but they are typically not easily adjustable, except in cases where the individual wearing the body armor changes their body position relative to the enemy (e.g., by crouching, squatting, or lying down).

Reducing the number of body areas on the SFP that are not protected by the CBA can be achieved by increasing the relative coverage area of the CBA S_{rca}. The relative coverage area of the CBA S_{rca} depends on the area protected by the CBA S_{CBA} and the surface area of the SFP S_{SFP}. However, typically, employing such an approach leads to an increase in the size and weight of the CBA, which negatively affects the functional characteristics of the SFP (speed, acceleration, change of direction, reaction time, alertness).

The hazardous zone refers to the area where the SFP may be subjected to the enemy's fire. The exposure time of the target is given by [10]:

The exposure time of the target t_{et} depends on several factors including the time it takes for the enemy to detect the SFP t_{dp} and the time for the SFP to exit the hazardous zone t_{ex}. The hazardous zone refers to the area where the SFP may be subjected to the enemy's fire. The exposure time of the target is given by [10]:

$$t_{et} = t_{ex} - t_{dp}. \quad (7)$$

Reducing the exposure time of the target can prevent it from being hit. If t_{et} does not exceed the time required for the first shot preparation, then the target will not be fired upon, and the probability of hitting the target will be zero [10].

From formula (7) it can be seen that reducing the exposure time of the target is possible by either decreasing t_{ex} or increasing t_{dp}.

The time for the SFP to exit the danger zone depends on its movement speed V_m, which, in turn, is influenced by the weight of the combat equipment m_{CE}, i.e.:

$$t_{ex} = f(V_m), \quad (8)$$

$$V_m = f(m_{CE}). \qquad (9)$$

In cases where certain parts of the SFP's body are in the danger zone and the individual is aware of this, simply changing the body's position, i.e., taking cover, will suffice to exit this zone. The speed of such actions depends on the motor response of the individual. Motor response refers to the process that begins with the perception of information that prompts action (a pre-determined signal or situation with signaling significance) and ends with the onset of the response movement. Therefore, t_{ex} will also depend on the speed of the target's motor response V_{mr}:

$$t_{ex} = f(V_{mr}, V_m). \qquad (10)$$

The time of detecting the SFP by the enemy t_{dp} can be considered as the time of visual detection of the object. Then, according to [17] t_{dp} will be equal to:

$$t_{dp} = \frac{(2\beta)^2}{C \cdot K_c{}^2 \cdot \gamma^3 \cdot L_b^{0,3}}, \qquad (11)$$

where β – the angle of the observation sector;

C – the coefficient depending on search conditions;

K_c – the contrast coefficient between the object and the background;

γ – angular dimensions of the object;

L_b – brightness of the background.

Analyzing formula (11), we can conclude that increasing the time of detecting the personnel by the enemy is possible by influencing the angular dimensions of the SFP and the contrast coefficient.

The angular dimensions of the SFP depend on its linear dimensions l (height Y_c and width Z_c), as well as the distance to the enemy X and are determined by the following formula [17]:

$$\gamma = 3440 \frac{l}{X}. \qquad (12)$$

The contrast coefficient K_c is influenced by the brightness of the object L_{ob} and the background L_b [17]:

$$K_c = \frac{L_b - L_{ob}}{L_b}. \qquad (13)$$

The scientific article [17] also notes that the higher the value of the contrast coefficient K_c, the better the object is observed. Therefore, if the value of K_c is reduced, the time of detecting the SFP by the opponent can be increased.

The presence of disruptive coloring on the equipment and the CBA reduces the visibility of the SFP by merging individual color spots with the surrounding background, visually distorting the object, and causing it to lose its correspondence to the mental image. Thus, the detection and recognition range of the SFP is decreased for both the naked eye and electronic-optical and optical devices.

The main parameters of disruptive coloring include the size of the spots, color palette, contrast, and pattern repetition [18]. Increasing the size of individual disruptive spots M_{ds} improves the silhouette deformation, but at the same time reduces the ability to merge with the color noise of the surrounding background, which is crucial at relatively short distances. Therefore, there is a need for a rational combination of large (macro pattern) and small (micro pattern) spots in a single design.

During the application of disruptive spots, multicolor coloring is commonly used, which includes both dark and light colors with a color palette close to that of the surrounding background. To describe the differences between the colors of an individual spot and the background, the color difference index ΔE_{ds} can be employed [19]. When the value of ΔE_{ds} decreases, the visibility of the object decreases, and when $\Delta E_{ds} = 0$, the object becomes visually inconspicuous.

The contrast between the main and additional colors of disruptive spots is determined by the contrast coefficient of disruptive spots K_{ds}, which depends on the brightness coefficients of the lighter color K_{L1} and the darker color K_{L2}, determined using chromatic and achromatic scales. The coefficient of contrast of disruptive spots is calculated by the formula

$$K_{ds} = \frac{K_{L1} - K_{L2}}{K_{L1}}. \qquad (14)$$

The perception of naturalness of the disruptive covering is influenced by the repetitiveness of the pattern. If unique disruptive patterns are placed in small squares that are then duplicated across the entire surface of the covering, such repetition easily catches the human eye, perceiving it as an unnatural continuity against the irregular background. The number of such squares with patterns placed on the equipment and the CBA of the personnel will henceforth be referred to as the degree of pattern repetitiveness N_p.

Thus, by exerting a certain influence on the parameters of disruptive coloring, it is possible to increase the time of detection by the adversary t_{dp}.

In the case of the adversary using thermal imaging devices, the visibility of the individual SFP also depends on the temperature contrast ΔT between the personnel and the background. The magnitude of ΔT is influenced by the object temperature T_{ob} and the background temperature T_b; if T_{ob} differs little from T_b, such an object will be inconspicuous [21]. Therefore, by influencing the temperature contrast ΔT, it is possible to reduce the visibility of the SFP and thereby increase the time of detection by the adversary t_{dp}.

The time it takes for the adversary to detect the SFP also depends on the acoustic stealthiness of the personnel, which can be increased by reducing the level of sound pressure generated by the SFP's noise p_n [22]. Therefore, to reduce the visibility of the SFP and increase t_{dp}, it is sufficient to provide a level of sound pressure p_n that is not perceptible to the adversary's auditory organs.

Influencing the accuracy of the enemy's weapon fire is possible by creating unfavorable conditions for the enemy weapon operator [10].

Such conditions include:

– frontal target movement speed V_f;
– frontal target acceleration $\tilde{V}_f$;
– rate of change of distance to the target V_x;
– presence of suppressive fire to suppress enemy fire, and so on.

According to [10] the speeds V_f, $\tilde{V}_f$ та V_x affect the accuracy of the enemy weapon's fire, and therefore, the probability of hitting the SFP. For instance, the aiming error in height Δy is influenced by V_X, while the aiming error in the lateral direction Δz is affected by V_f and $\tilde{V}_f$:

$$\Delta y = f(V_x), \quad (15)$$

$$\Delta z = f\left(V_f, \tilde{V}_f\right). \quad (16)$$

The characteristics of protective elements in the CBA, which ensure resistance to specific enemy weapons, affect the required number of hits to the SFP to inflict combat injury. In this case, the protection of the individual protective equipment will be determined by the probability of penetration of the CBA P_{pen}. Reducing the probability of the CBA penetration contributes to increased protection of the individual from the effects of enemy weapons.

In view of the above, a set of indicators is proposed to assess the survivability of the SFP under the conditions of enemy fire impact (Table 1).

Table 1 – Indicators of survivability for security force personnel under the conditions of enemy fire impact

Indicator Name	Indicator Contraction	Unit	Property Reflected by the Indicator
1. Detection Distance of the SFP	X_d	m	Concealment
2. Contrast Coefficient of the SFP	K_c	–	
3. Angular Dimensions of the SFP	γ	acr. min.	
4. Sizes of Deformation Spots	M_{ds}	m	
5. Color Difference of Deformation Spots	ΔE_{ds}	–	
6. Contrast Coefficient of Deformation Spots	K_{ds}	–	
7. Pattern Repeatability Degree	N_p	units/m	
8. Temperature Contrast of the SFP	ΔT	°C	
9. Sound Pressure Level of Noise of the SFP	P_n	Pa	
10. Motor Response Speed of the SFP	V_{mr}	s	Maneuverability
11. Movement Speed of the SFP	V_m	m/s	
12. Frontal Movement Speed of the SFP	V_f	m/s	
13. Frontal Acceleration of the SFP	$\tilde{V}_f$	m/s^2	
14. Withdrawal Speed from Enemy Fire Devices	V_x	m/s	
15. Relative Area Coverage of CBA	S_{rca}	–	Protection
16. Penetration Probability of CBA	P_{pen}	–	

For the given set of survivability indicators of SFP under conditions of enemy fire impact, the following criteria are proposed: $X_d \leq X_{d\,\max}$, $K_c \leq K_{c\,\max}$, $\gamma \leq \gamma_{\max}$, $\Delta E_{ds} \leq \Delta E_{ds\,\max}$, $N_d \leq N_{d\,\max}$, $p_n \leq p_{n\,\max}$, $P_{pen} \leq P_{pen\,\max}$, $K_{ds} \geq K_{ds\,\min}$, $\Delta T \geq \Delta T_{\min}$, $V_{mr} \geq V_{mr\,\min}$, $V_m \geq V_{m\,\min}$, $V_f \geq V_{f\,\min}$, $\tilde{V}_f \geq \tilde{V}_{f\,\min}$, $V_x \geq V_{x\,\min}$, $S_{rca} \geq S_{rca\,\min}$, $M_{ds\,\min} \leq M_{ds} \leq M_{ds\,\max}$. In the provided inequalities, the indices $_{\min}$ and $_{\max}$ represent the minimum and maximum permissible values of the SFP survivability indicators, respectively.

For a reasoned determination of the numerical characteristics of the proposed criteria, it is necessary to study the influence of the SFP survivability indicators under conditions of enemy fire impact (Table 1) on the parameters that affect the probability of receiving combat injury of the SFP (t_{ex}, t_{dp}, Δy, Δz, n, K).

Conclusions

1. Based on the analysis conducted, the main factors influencing the probability of security force personnel receiving combat injury have been identified. A complex of survivability indicators for security force personnel under the conditions of enemy fire impact has been developed. These indicators include: detection distance, angular dimensions, contrast, deformation spot sizes, color difference, color contrast of deformation spots, temperature contrast, sound pressure level, pattern repeatability degree, movement speed, motor response speed, frontal movement speed, frontal acceleration, withdrawal speed from enemy fire, relative area coverage, and penetration probability.
2. In accordance with the developed survivability indicators for personnel, a list of survivability criteria for security personnel under the conditions of enemy fire impact has been proposed.

Further research direction includes determining the impact of the proposed indicators on the survivability of security force personnel in specified mission conditions.

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ПОКАЗНИКИ І КРИТЕРІЇ ЖИВУЧОСТІ ПРАЦІВНИКА СИЛ БЕЗПЕКИ В УМОВАХ НЕБЕЗПЕКИ ВОГНЕВОГО ВПЛИВУ ПРОТИВНИКА

Установлено, що умови виконання завдань підрозділами сил безпеки під час повномасштабної війни зазнали суттєвих змін, які спричиняють зниження живучості працівника сил безпеки як у ході ведення бойових дій, так і під час виконання правоохоронних завдань підрозділами сил безпеки.

На основі аналізу наукових джерел визначено, що живучість залежить від прихованості і маневреності працівника сил безпеки у потенційно небезпечній зоні та його захисту від впливу зброї противника.

Зазначено, що на ймовірність отримання бойової травми працівником сил безпеки під час виконання завдань за призначенням впливають розміри цілі, кількість незахищених ділянок тіла цілі, час експозиції цілі, бойова швидкострільність зразка зброї противника та точність стрільби з нього.

Розроблено комплекс показників, які дають змогу оцінити живучість працівника сил безпеки в умовах небезпеки вогневого впливу противника. Такими показниками є: відстань виявлення, кутові розміри, контраст, розміри деформуючих плям, колірна різниця, колірний контраст деформуючих плям, температурний контраст, рівень звукового тиску, ступінь повторюваності візерунка, швидкість руху, швидкість рухової реакції, фронтальна швидкість руху, фронтальне прискорення, швидкість віддалення від вогневого засобу противника, відносна площа прикриття та ймовірність пробиття.

Відповідно до розроблених показників живучості працівника запропоновано перелік критеріїв живучості працівника сил безпеки в умовах небезпеки вогневого впливу противника.

Ключові слова: *живучість, маневреність, прихованість, захищеність, бойова травма.*

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