The object of the study is the process of firing a single target with fragmentation-beam projectiles.

The problem of determining the components of the structural-automatic model is solved by creating a graph of states and transitions. The purpose of the process is to form a formalized expression of the object of study in the form of a structural-machine model of the process of firing a mobile armored vehicle with a series of three shots with fragmentation-beam projectiles of directional action. This model can be further practically implemented during the development of the latest samples of fire resistance in order to reduce errors at the stage of system design. This approach reduces the cost of design and production of prototypes by up to 25 %.

This paper considers the process involving interrelated elements of the components of a system while accounting for all possible variants of its behavior from the moment of detection to the failure of a single target in armor protection to perform tasks as intended. The execution of a fire task is considered as a set of certain procedures characterized by the average value of their duration. The explosive destruction of the hull of each fragmentation-beam projectile is characterized by the self-propagation of the reaction of explosive transformations based on tabular data on an armored combat vehicle. Appropriate procedures (phases) of firing a single target in armor protection are advisable to formalize to create preconditions for obtaining the value of a statistical indicator of the effectiveness of causing damage to the target and to study further alternative options for this process.

For the proposed structural-automatic model of the process of firing a single target in armor protection with a series of fragmentation-beam projectiles of directional action, validation and verification were carried out, which demonstrated the convergence of the results that exceeded 60 %. The use of the structural-automatic model's components proposed in this work increases the probability of performing a fire task for the first shot from 0.23 to 0.88, for the second – from 0.35 to 0.95, for the third – from 0.45 to 0.98

Keywords: structural-automatic model, single target shelling, fragmentation-beam projectiles, vulnerable compartments, basic event

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DETERMINING THE COMPONENTS OF THE STRUCTURAL-AUTOMATIC MODEL OF FIRING A SINGLE TARGET IN ARMOR PROTECTION WITH FRAGMENTATION-BEAM PROJECTILES OF DIRECTED ACTION IN A SERIES OF THREE SHOTS BASED ON THE REFERENCE GRAPH OF STATES

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1. Introduction

The analysis of military conflicts in the world reveals that the destruction of the overwhelming number of targets of different classes of protection on the battlefield (manpower, armored combat vehicles, fortifications) is achieved by firing combined-type projectiles – high-explosive fragmentation projectiles (HEFP). They are multipurpose ammunition and form the basis of ammunition kits (AK) in artillery systems of ground artillery, as well as are part of anti-tank and tank gun AK [1]. However, these projectiles have a number of key drawbacks that actually level the possibility of their successful use, namely:

– irrational use of fragmentation flows during ground blast;

– the material of the hull (C-60, 45X1-grade steel, etc.) has unsatisfactory fragmentation characteristics;

– are capable of hitting mainly only unprotected and lightly armored targets.

The analysis of the use of HEFP in local conflicts carried out by military specialists showed an insufficient level of their striking action as the main type of ammunition for single armored targets of the "tank" type. That led to an increase in ammunition consumption and increased the wear of gun barrels.

At the same time, military analysts of the aggressor country analyzed the use of the Armed Forces of the Russian Federation in the conflicts they started over the past 30 years. They identified the main disadvantages of security and communication of armored combat vehicles and manpower. This has led to the creation of new models of armored combat vehicles and individual (combat) equipment of a soldier with an increased level of protection, changes in constructive, layout, and communication solutions. The examples include the T-14 Armata tank, infantry fighting vehicle (IFV), tracked armored personnel carrier (APC) Kurganets-25. They are built on a modular principle. Combined armor of ceramics and steel in the armored wheeled vehicles "Typhoon" and "Boomerang" and the tracked combat vehicles of landing force (BMD-4M) and APCs "Rakushka" are able to withstand an explosion of 5 kg of TNT equivalent. At the same time, the armored protection of manpower of individual (combat) equipment in the form of a set of "Ratnik-3" [2] deserves attention.

It should be noted that the above examples of military equipment have significant structural solutions to increase the combat capabilities of both weapons and military equipment (WME) and a soldier on the battlefield. However, nothing in this world exists perfectly and everything has a so-called "Achilles heel" in the form of vulnerable compartments [3]. And the hypothetical arrow that hits the heel can be a technical solution in the form of HEFP with directional action called the "fragmentation-beam projectile" (FBP) [4].

The insufficient level of fragmentation impact of HEFP encourages research aimed at improving the effectiveness of use by providing a directional fragmentation spectrum of multipurpose controlled by the process of explosive destruction of the hull. In world practice, there are the following traditional ways to solve this kind of task:

– changing the loading pattern of the hull of existing projectiles and searching for new design schemes for the layout of HEFP;

– improvement of the characteristics of the fragmentation field of damage based on changes in the chemical composition of steels and their mechanical properties;

– conducting fundamental studies into the regularities of the processes of formation of fragmentation and high-explosive fields of destruction;

– purchase of high-tech weapons.

However, any solution has three key limitations: time, finances, and dependence on arms manufacturers in other states. After all, a state that does not have its production of weapons is hopelessly doomed and always dependent on the risk of spending money for its constant updating, replenishment, and repair. Therefore, it is predicted that the rational embodiment of scientific thought in metal may be the search for ways to combine the controlled explosive destruction of shell hulls and, accordingly, their fragmentation impact on single targets in armor protection.

The implementation of such a solution does not lie on the surface but hides behind global concepts in the form of the deployment of financially costly reconnaissance and strike (fire) systems. However, as the experience of military conflicts shows, the current state of affairs dictates the requirements for minimized, relatively cheap, unscientifically intensive, but effective systems such as "means of reconnaissance and guidance-gun-projectile".

Therefore, there is a need to conduct research that will provide an opportunity to design the newest examples of fire effects while reducing errors at the stage of system engineering.

2. Literature review and problem statement

Work [5] considers the features of target designation to determine the height of the target, but is more relevant for aircraft. In [6], the results of studies into the process of explosive throwing of a set of fragmentation discs are given, the same issue is addressed in [7] where special attention is paid to fragments of spherical shape. These works [5–7] can be taken into account to clarify the effectiveness of shelling with projectiles of a certain type. These studies are related to the design of ammunition of traditional models in general, the peculiarities of the physical processes associated with them, but the systematic study of issues from the beginning of planning the number of ammunitions to their direct practical application is not presented.

The damaging properties of high-explosive fragmentation projectiles are discussed in [2]. However, the main disadvantage of a high-explosive fragmentation projectile is its low armor penetration, so there is a need to increase the accuracy of projectiles hitting the area of "vulnerable compartments". The study of fragmentation properties along the axis of the metal shell under explosive load was carried out in [8]; it is valuable for understanding the principles of the formation of fragments of the warhead. In [9], the simulation of the process of mass distribution and speed of fragmentation discs in space is carried out; in [10], an attempt is made to predict the natural fragmentation of the metal shell charged by the explosion. Theoretical assessment of the parameters of fragmentation of high-explosive fragmentation projectiles was reported in work [11]. Paper [12] provides a detailed description of the ammunition and the damaging action they perform; work [13] considers the explosive effect of cylindrical projectiles. However, the issues raised in these works were not considered in a system-technical form. The combination of the results from [8–13], with appropriate changes to the firing management process, can contribute to improving the efficiency of the firing process.

In [14], a model was proposed that makes it possible to estimate the lethal radius (radius of efficiency) of artillery shells against human targets but without taking into account the impact on armored combat vehicles. The results of studies of the explosive action of a set of fragmentation discs of natural crushing are described in [15], which was advanced in [16] where the impact on biological objects was considered. However, the analysis of the protection of these objects through the use of armored technological objects was not carried out. Analysis of the results of blast wave propagation can be performed using appropriate software [17, 18].

The existing unchanging concept of creating modern armored combat vehicles (ACV) is the ability to achieve the optimal combination of crew security with fire and maneuverability capabilities. Thus, in [19], the method for determining the level of combat survivability of armored wheeled vehicles is proposed; in [20], the properties of wheeled and tracked combat vehicles are considered. Nevertheless, the approaches proposed in works [19, 20] can be expanded and supplemented.

In [21], the technological and scientific tasks faced by the developers of ACM are considered. However, for the effective fight against these ACVs, two main conditions remain unchanged:

– reliable destruction of FBP case;

– FBP fragments hit a single target in armor protection.

In this context, the defeat should be understood as damage by the products of explosive destruction of the hull (EDH) in the form of "usable fragments" of FBP, namely their entry into the reduced dimensions of vulnerable compartments of ACV [22]. For example, typical consequences of HEFP action are the detonation of the ACM ammunition and the scattering of their fragments by more than 50 m [23]. However, in conditions of highly urbanized terrain, this is absolutely not permissible. The "scalpel action" of FBP should ensure non-lethality for the civilian population and maximum disabling of components and assemblies. This is achieved by hitting the individual compartments of the armored combat vehicle in order to stop its crew from performing a combat mission.

It is known that the battle involving ACV in densely populated areas is quite difficult [24, 25], so the continuation of the search for more optimal solutions is necessary and is not limited to the issues of mechanical damage by fragments of various types of projectiles. Thus, in [26], the practical aspects of building a reconnaissance and strike network based on the development of a system of weapons and military equipment are considered. Work [27] provides a justification for the prospects for the development of general-purpose weapons warfare; [28] reports a method for assessing the quality of military equipment. Work [29] describes in detail the tactics, techniques, and order of operation of the battery of field artillery. The safety, reliability, and effectiveness of the programmable blaster system are considered in [30]. However, in the above works [26–30], the assessment of the effectiveness of the destruction is carried out by the tactics of combat and the use of special military equipment in general. The issue of developing approaches to controlling the firing process from the point of view of inflicting damage to enemy equipment remains unresolved.

Taking into account our review, one can say that shooting at a moving single target in armor protection is characterized by the following factors:

– change in the continuous position of ACV (range and direction), which encourages the solution to the problem of meeting with the definition of an amendment to the movement of the target;

– the movement of an armored combat vehicle, as a rule, is not uniform and not linear, so the calculated amendments will have a number of errors in comparison with the true values of the measured range and direction to the target;

– the influence of the human factor on the process of guidance, tracking, and firing at an armored combat vehicle.

However, the practical use of various means of destruction dictates new conditions that cause the inseparability of communication between human intelligence and the combat capabilities of weapons. World military theorists of our time [31] describe it as a "man - weapon" system. Since modern weapons and military equipment, in the overwhelming majority, are not capable of independent actions, therefore, it is customary to determine the loss of combat capability of manpower as the degree of damage to the object (target).

Theoretical assessment of the destruction of objects by a series of three shots with fragmentation-beam projectiles of directional action will provide an opportunity to form a formalized expression of the object of study (the process of shelling) in the form of a structural-automatic model of the process of firing a single target in armor protection. The number of shots is determined by the values of the tactical standards for firing anti-tank weapons to the rating "satisfactory". Thus, firing is carried out by a series of rapid fire of 2–4 projectiles per gun on one sight installation, which is a feature of the consumption of high-explosive fragmentation and fragmentation-beam projectiles.

Therefore, the development of theoretical approaches to increase the effectiveness of hitting the enemy by increasing the likelihood of HEFP and FBP hitting vulnerable compartments can be considered as a way to increase the effectiveness of the destruction and minimize the time to create new models of targets.

3. The aim and objectives of the study

The aim of this study is to search for parametric components of the structural-automatic firing model that directly affect the effectiveness of hitting objects with a series of three shots with fragmentation-beam projectiles of directional action, based on the reference graph of states. This will make it possible to form a formalized expression of the firing process in the form of a structural-automatic model of the process of firing a single target in armor protection and reduce the time for developing new samples through system-technical design.

To accomplish the aim, the following tasks have been set:

– to form conceptual solutions for the representation of the process of firing a single target in armor protection;

– to validate a discrete-continuous stochastic model of the process of firing a single target in armor protection with a series of fragmentation-beam projectiles of directional action;

– to verify the structural-automatic model of firing a single target in armored protection with fragmentation-beam projectiles of directional action in a series of three shots.

4. The study materials and methods

The object of this study is the process of firing a single target with fragmentation-beam projectiles.

The essence of the proposed approach is to determine the components of the graph of states and transitions, as well as possible options for the end of the event. An event is one of the key concepts of system-technical modeling, which describes the procedure by its beginning and end. For this study, each shot is a series of three events consisting of a defined sequence of procedures. The first event begins with the appearance of a target in the "backlight" zone and the beginning of the operation of the flying platform to transmit the coordinates of the target for the first shot and ends with the receipt of a message with the coordinates of the target. The second event is the transfer of a fragmentation-beam projectile from ammunition to a charging chamber. The third event begins with the firing of FBP shot at a moving target and ends with FBP blast at a certain distance to the moving target. The use of the graph provides the possibility of formalized expression of the object of our study in the form of a structural-automatic model of the process of firing a mobile armored vehicle with a series of three shots with fragmentation-beam projectiles of directional action. Evaluation of the effectiveness of this approach was carried out using ASNA software (Ukraine).

5. Results of investigating the process of firing a single target based on the reference graph of states

5. 1. Conceptual solutions on the representation of the process of firing a single target in armor protection

Characteristics of the damaging action of ammunition [32] are the initial data for assessing the effectiveness of their use. Thus, during the EDH of their hulls, biomechanical lesions (wounds and contusions) and psychological effects on manpower in armor protection (MPAP) are created on fragments of various fractions. After all, the instinct of self-preservation forces the enemy soldier to leave his place in the combat position, stop the opposition, and take shelter during a fire raid. However, some of the affected manpower is able to overcome stress and restore lost combat capability directly on the battlefield.

Today, the soldier's equipment has reached such values that a soldier in battle can be considered as a reconnaissance and fire system due to the presence of optoelectronic equipment of fire support equipment, which equates a unit of manpower with an armored target.

The conditions of combat operations of "medium efficiency" require the soldier to be active for three days [33, 34]. Accordingly, the weight of wearable equipment and individual (combat) equipment must be adequate to the requirements. The standard American combat equipment is 34 kg, similar to that made in Germany, within 35 kg; the Russian equipment "Warrior-3" in combination with the so-called "tactical equipment" does not exceed 24 kg [35, 36] (Table 1).

Analysis of Table 1 testifies to the efforts of the developers of individual (combat) equipment to balance between the saturation of a soldier with electronic means and the selectivity of his reservation in the form of "vital parts of the body" [33, 34]. This encourages manufacturers to develop new means of protection. After all, on the one hand, the destruction of elements of tactical equipment disorients the soldier on the battlefield, and on the other, the hit of a "usable fragment" into the so-called "non-vital part of the body" does not guarantee the survival of the serviceman [37]. Thus, in the case of penetration of a fragment-embolus through one of the walls of the lower half of a vein with blood flow, it migrates to the heart. The migration of a "usable fragment" can be affected [35] by:

– intravascular hydrostatic pressure;
– the action of gravitational forces;
– location of the soldier's body when wounded;
– vascular anatomy;
– uneven ratio of protected areas of the body to unprotected ones;
– reduction of muscle massifs and respiratory excursion of the chest after injury.

Table 1

The ratio of protective elements of individual (combat) equipment to vulnerable compartments of a soldier

No. of entry	Protective elements	Tactical equipment as vulnerable compartments
1	Armored helmet 6B47	Small arms and ammunition for them
2	Body armor 6B45	Day-night sighting complex
3	Safety glasses	Optical-electronic reconnaissance device
4	Elbow and knee joint protection kit	Unified optical and thermal sight
5	A headset with an active hearing protection system	Compact binoculars
6	–	Combat overalls

During the study, it was found that the uneven ratio of protected areas of the body of a single MPAP to unprotected ones can range from 30 % to 50 %. In the standing and lying position, the percentage of unprotected lesions is as follows: frontal projection is 20–30 %; back – 70–80 %; lateral up to 90 %.

Depending on the location of MPAP from the remote explosive destruction of the FBP hull, the fragmentation action is not homogeneous. It is characterized by the penetration capacity of vulnerable compartments, depending on the mass and speed of "usable fragments" at the time of their meeting with an obstacle to simplify calculations, vulnerable compartments are divided into two groups:

– failure of a single vulnerable compartment (musculoskeletal apparatus, limbs, body parts, equipment, etc.);
– damage to the so-called combination of vulnerable compartments leads to appropriate damage.

Therefore, the process of modeling the firing of a single target in armor protection is aimed at assessing the degree of possible damage to the vulnerable compartments of the target with "usable fragments". After all, the severity of the injury as a whole depends on the ballistic characteristics of the elements of the lesion in the form of "usable fragments" with the subsequent determination of their kinetic energy, shape, punching ability, and physical properties of damaged tissues [35] or compartments.

The process of firing a single target in armor protection is directly based on the development of a graph of states and transitions with the necessary formation of a formalized expression of the object of our study in the form of a structural-automatic model (SAM) (Table 2). Although for a compact representation of SAM it is possible to combine situations and components according to clear rules, in this work we do not see the need for appropriate manipulation.

The defined SAM components are listed in Table 2, which corresponds to the form of the dialog box of the *ASNA* software tool [38, 39].

Although for the purpose of reliable design of technical systems and systems such software tools as RELEX (USA), ITEM Software (UK), ISOGRAPH (UK) can be used, they carry out calculations based on Markov analysis [40]. To do this, the listed software contain tools appropriate analytical modules where the object under study is represented as a discrete-continuous stochastic system of the Markov type. A matrix of transition intensities of the Markov process, which is homogeneous in time, can also be applied. In both cases, the model or matrix must be represented as a graph of states and transitions, which is a complex non-formalized problem. The disadvantage of this approach is the possibility of making mistakes by the user due to lack of experience and biased assessment, as well as significant time spent.

On the other hand, ASNA software uses a structural-automatic model, which provides the ability to automate the construction of a graph of states and transitions. As a result, this leads to a significant reduction in the number of errors and time costs. That is why ASNA software was chosen for the calculations of the study. An additional advantage of this choice is the presence of a larger number of discrete options for the confidence interval.

A detailed description of the concept "basic event" (BE) and calculation formulas was given in [41]. ComBE is completing of corresponding basic event.

Table 2 formalizes the process of firing a fragmentation-beam projectile in the form of a structural-automatic model, which shows the basic events, the formulas for calculating the intensity of transitions from one state to another, and the rules for modifying the component of the state vector.

The components used in this structural-automatic model are as follows:

– receiving messages with coordinates and target characteristics for the 1st FBP (*V*1);

– the option of initiating the explosive destruction of the hull of the first fragmentation-beam projectile at a set distance to the target (*V*2);

– the option of causing damage by "usable fragments" of the first FBP to vulnerable compartments (*V*3);

– receiving messages with coordinates and target characteristics for the second FBP (*V*4);

– the option of initiating a second fragmentation-beam projectile at a set distance to the target (*V*5);

– the option of causing damage to the "usable fragments" of the second FBP to vulnerable compartments (*V*6);

– receiving messages with coordinates and target characteristics for the third FBP (*V*7);

– the option of initiating a third fragmentation-beam projectile at a set distance to the target (*V*8);

– the option of causing damage by "usable fragments" of the third FBP to vulnerable compartments (*V*9).

The hypothetical notion of the process of causing damage to a single target in armor protection in a series of three FBP shots is based on the ability to reliably predict and reflect the beginning and end of the time interval for a certain state of the system in a discrete-continuous process.

The key component of the projected process of causing damage to vulnerable compartments of the target by "usable fragments" is reproduced in the form of a graph of states and transitions, as well as possible options for the end of the event.

Table 2

Fragment of a structural-automatic model of the process of firing a single target in armor protection with fragmentation-beam projectiles of directional action in a series of three shots

Basic event	Formalized description of situations in which basic events occur	Formulas for calculating the intensity of transitions	Rules for modifying a component of a state vector
1BE1 ComBE2 ComBE3	Situation 1 for BE1 (V1=0) AND (V2=0) AND (V3=0) AND (V4=0) AND (V5=0) AND (V6=0) AND (V7=0) AND (V8=0) AND (V9=0)	$\frac{1}{t_{1F}} P_{SR1} P_{RD1} P_{CD1}$	*V*1:=1; *V*2:=1; *V*3:=1
		$\frac{1}{t_{1F}} (1 - P_{SR1})$	*V*1:=2
		$\frac{1}{t_{1F}} P_{SR1} (1 - P_{RD1}) P_{CD1}$	*V*1:=1; *V*2:=2; *V*1:=1
		$\frac{1}{t_{1F}} P_{SR1} P_{RD1} (1 - P_{CD1})$	*V*1:=1; *V*2:=1; *V*3:=2
		$\frac{1}{t_{1F}} P_{SR1} (1 - P_{RD1})(1 - P_{CD1})$	*V*1:=1; *V*2:=2; *V*3:=2
...			
31BE7 ComBE8 ComBE9	Situation 25 for BE7 (V1=1) AND (V2=2) AND (V3=2) AND (V4=1) AND (V5=2) AND (V6=2) AND (V7=0) AND (V8=0) AND (V9=0)	$\frac{1}{t_{3F}} P_{SR3} P_{RD3} P_{CD3}$	*V*7:=1; *V*8:=1; *V*9:=1
		$\frac{1}{t_{3F}} (1 - P_{SR3})$	*V*7:=2
		$\frac{1}{t_{3F}} P_{SR3} (1 - P_{RD3}) P_{CD3}$	*V*7:=1; *V*8:=2; *V*9:=1
		$\frac{1}{t_{3F}} P_{SR3} P_{RD3} (1 - P_{CD3})$	*V*7:=1; *V*8:=1; *V*9:=2
		$\frac{1}{t_{3F}} P_{SR3} (1 - P_{RD3})(1 - P_{CD3})$	*V*7:=1; *V*8:=2; *V*9:=2

The purpose of the process of creating a graph of states and transitions is the formation of a formalized expression of the object of study in the form of a structural-automatic model of the process of firing a single target in armor protection with a series of three shots with fragmentation-beam projectiles of directional action. The developed model can later be used during the development of the latest samples of fire resistance in order to reduce errors at the stage of system design.

5. 2. Validation of the proposed discrete-continuous stochastic model

The basis of the method of validation of the structural-automatic model of the process of firing at a dynamic target in armor protection by a series of fragmentation-beam projectiles of directional action is the principle of reconciliation of graphs: test and obtained on the basis of a structural-automatic model. To identify errors in the structural-automatic model, the direct comparison of both graphs is performed in three stages:

– at the first stage, the state vectors are checked directly;

– at the second stage, transitions between states are checked;

– at the third stage, the values of the intensity of transitions are checked.

The established reconciliation procedure makes it possible to speed up the localization of errors and, accordingly, reduce the time spent on their search and correction.

Fig. 1 shows a graph of states and transitions; Fig. 2 – its representation, built by the *ASNA* software on the basis of embedded input data.

As the initial data, we specified:

– the probability of successful transmission of information about ACV for firing (P_{SR});

– the probability of explosive destruction of the hull (P_{RD});

– the probability of successful damage by usable fragments (P_{CD});

– duration of phases (t_F).

The actual content of the components of vectors $V1,...,V9$ is described in detail in works [41, 43].

For ammunition, even in the process of development, it is possible to assess the effectiveness on the battlefield, which cannot be carried out in design organizations without system-technical design.

We analyzed the resulting graph of states and transitions of the process of functioning of causing damage to vulnerable compartments of a single target in armor protection by "usable fragments" of FBP in a series of three shots. The analysis showed that the resulting graph (Fig. 1) fully corresponds to the state and transitions of the graph that we developed in [41]. Thus, as a result of the reconciliation of state vectors, transitions between states, and transition intensity values, it is possible to conclude that there are no both conceptual and local errors. A detailed description of the algorithm for processing the obtained data represents a significant amount of data and will be presented in the next work, which will be the completion of the research that we reported in works [41, 43] and in this paper. Thus, in [41], the general concepts of basic events and features of constructing a graph of states and transitions for modeling the firing process are given. This paper describes events and shows how they are processed in ASNA software, and, in the next article, it is planned to present and justify the choice of optimally necessary scenarios.

Thus, the validation of a discrete-continuous stochastic model of the process of firing a single target in armor protection by a series of fragmentation-beam projectiles of directional action confirms the effectiveness of the structural-automatic model, a fragment of which is given in Table 2. Its broader description includes 153 formulas of the Kolmogorov-Chapman equations and about 140 emerging events. Such a model can be used to study the process of causing damage to vulnerable compartments of an armored combat vehicle by "usable fragments" of fragmentation-beam projectiles of directional action in a series of three shots.

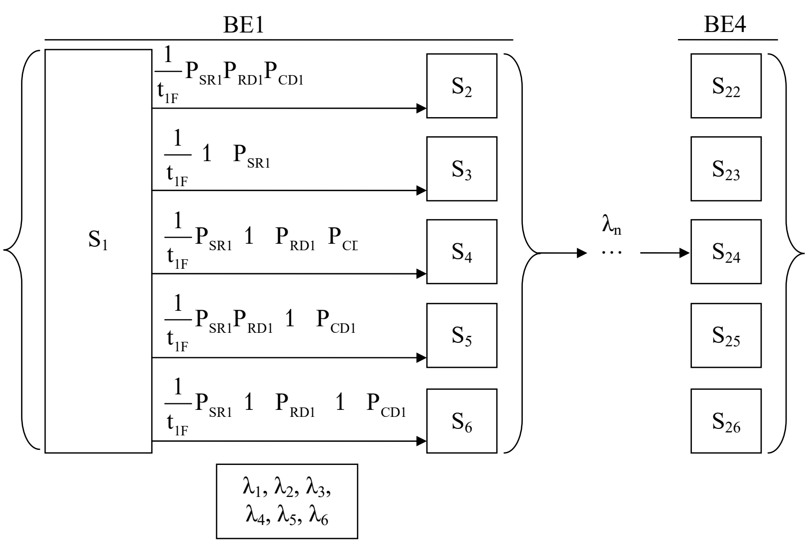


Fig. 1. Graph of states and transitions: BE – a set of basic events; S_n – basic event; P_{SR} – the probability of successfully receiving messages with coordinates and target characteristics in the gun; P_{CD} – the probability of damage by "usable fragments" of the projectile into vulnerable compartments of the target in armor protection; P_{RD} – the probability of successful remote detonation

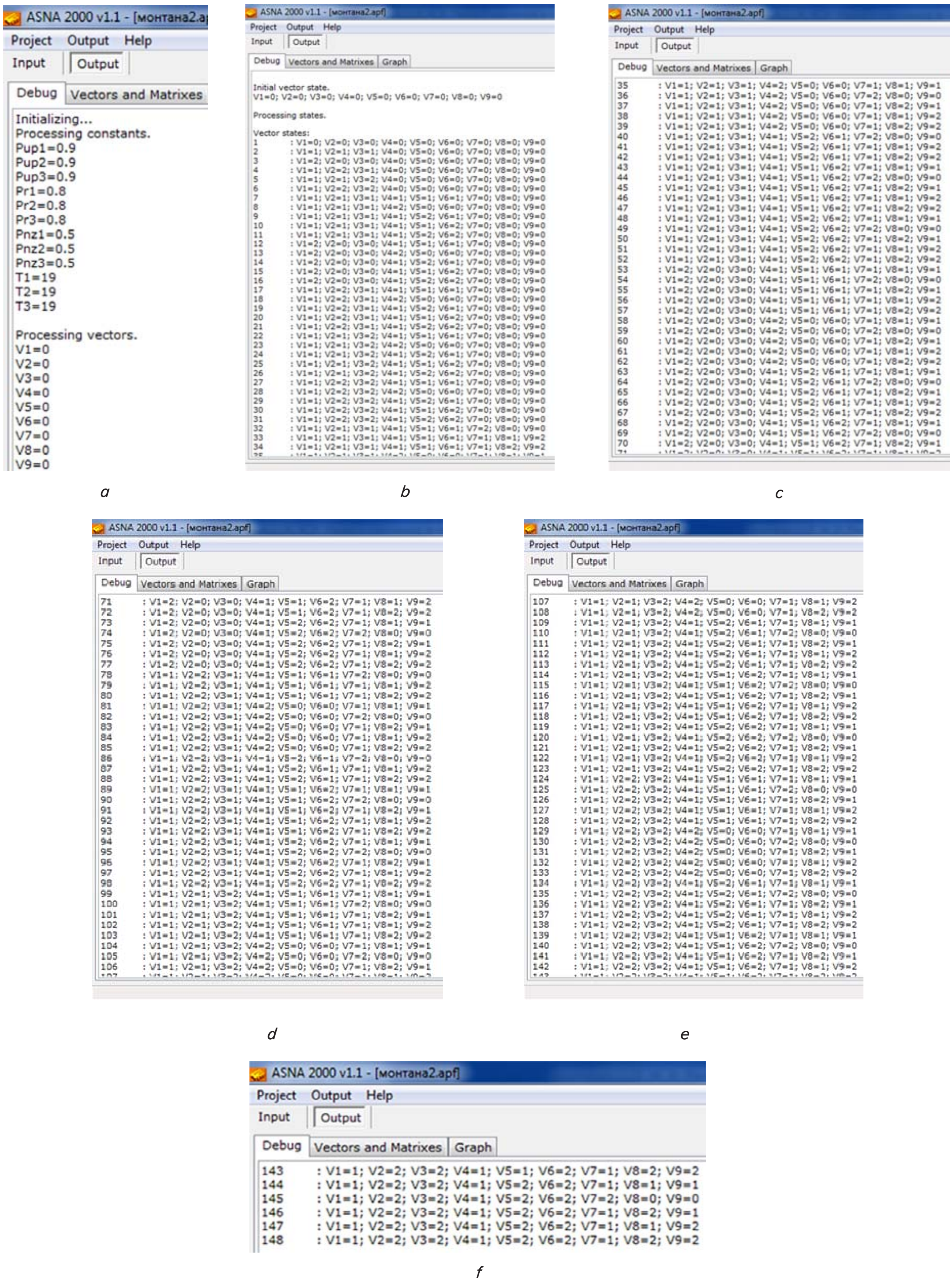


Fig. 2. Representation of the graph of states and transitions in the ASNA software (Ukraine): *a* — introduction of components of the initial state vector; *b*—*f* — determining the number of scenarios according to possible combinations of variants of component values

5. 3. Verification of the structural-automatic model of shelling

To predict the success of the model, different approaches and concepts can be used [41, 42]. In this work, the limits of the permissible possibilities of artifacts of the stochastic model have logical delineations. Namely, in the case of insufficient efficiency of subsystems [43], we predictably have a decrease in the overall probability of damage to vulnerable compartments of a single target in armor protection, which corresponds to the fulfillment of the PAG fire task.

Suppose that the input values (Fig. 3) predictably satisfy the requirements for the possible degree of damage to vulnerable compartments of a single target in armor protection by "usable fragments" of the FBP in a series of three shots.

Then the probability of performing a combat mission according to the data of the *ASNA* software will be about 10 % (Fig. 4). This result means that according to the above input values, the probability of causing damage in a series of three fragmentation-beam projectiles will be as far as possible from unity. Despite the qualitative parameters of receiving and transmitting data from the intelligence tool from the observation post, which can be quite low, the effectiveness of damage is considered sufficient at 50 %.

Suppose that in preparation for the task of causing damage to a single target in armor protection, the first fragmentation-beam projectile failed to receive a signal by a promising automatic gun (PAG) from the observation post (Fig. 4).

In the absence of a high-quality received signal about a single target in armor protection, the use of the first fragmentation-beam projectile becomes impossible and requires the use of a high-explosive fragmentation projectile instead of FBP. This leads to a decrease in the likelihood of damage to a single target in armor protection. The relevant results in the *ASNA* software are shown in Fig. 4, *a*. Subsequently, the weakness of the signal is not so important since the first shot has already been fired and a certain probability of hitting the target has been obtained. The effectiveness of the firing task by a promising automatic gun for the second (Fig. 4, *b*) and the third fragmentation-beam projectile (Fig. 4, *c*) was also determined. The probability of hitting a target when using PAG was significantly higher than for conventional guns with HEFP, and close to unity. This corresponds to the real values of the use of such means of fire exposure, despite the rest of the indicators.

The highlighted areas on the graphs correspond to cases of obtaining optimally necessary options for the results of shelling by a series of high-explosive fragmentation projectiles where there is an increase in the probability of hitting the target with conventional HEFP equipment several times. Thus, when using traditional approaches, the probability of hitting the target with the first HEFP does not exceed 0.23, the second – 0.35, the third – 0.45. The use of this method of performing a fire task increases the likelihood of damage for each of the projectiles to values exceeding 0.9, starting from the very first shot.

To verify the response of the created model to reduce the likelihood of successful reconnaissance, hitting a target, blowing up, etc. and determining the effectiveness of shooting, some changes were made to the initial data embedded in the ASNA software.

Thus, it was decided to reduce the likelihood of damage by "usable fragments" in a series of three shots [41]:

– the first FBP, to 0.5 (Fig. 5);

– the first and second fragmentation-beam projectiles, to 0.8 (Fig. 6).

As predictably, the result of the task with each shot steadily approached unity. Thus, after the blast of the first FBP, the probability of completing the task of the PAG on a single target in armor defense was 088, after the second shot – 0.95, and in a series of three shots – 0.98.

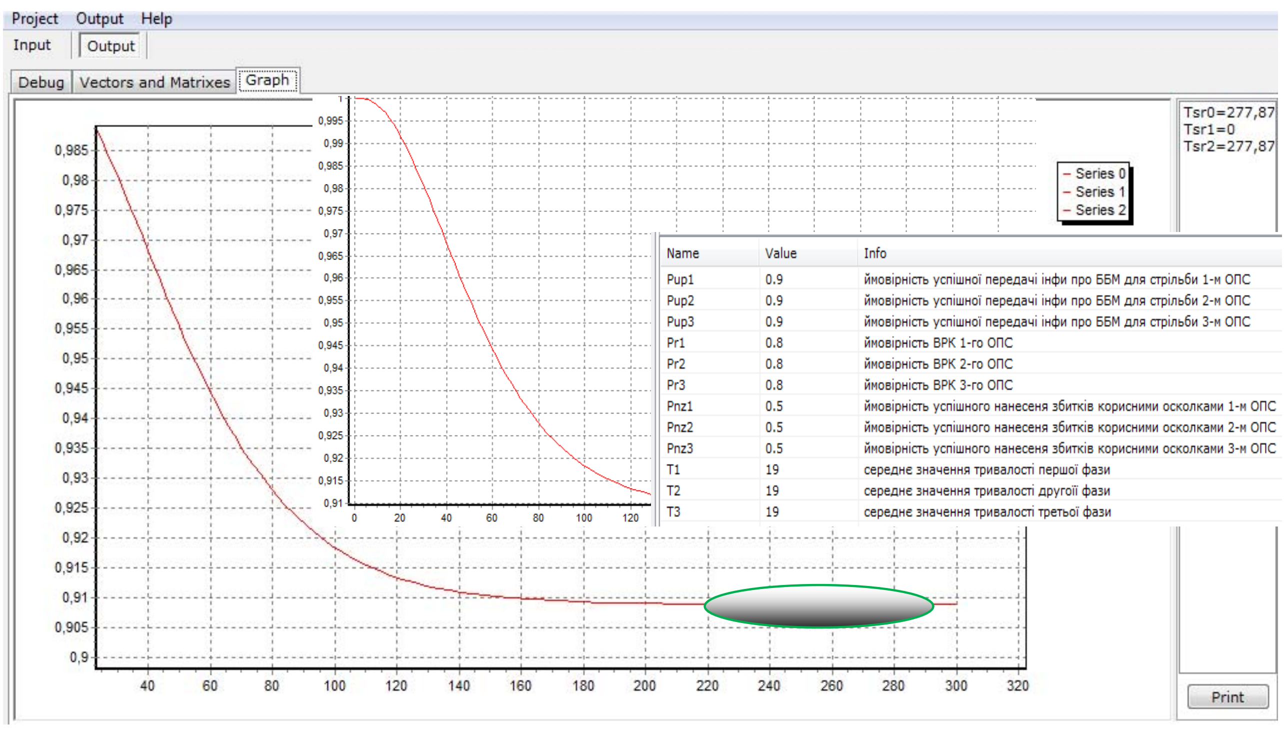
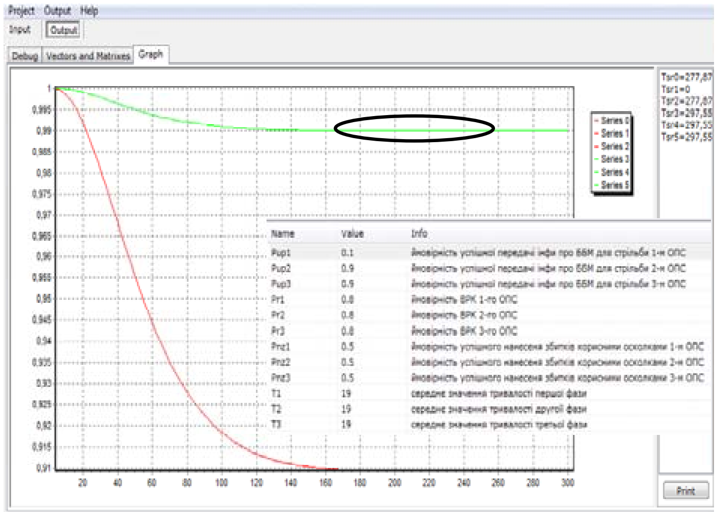
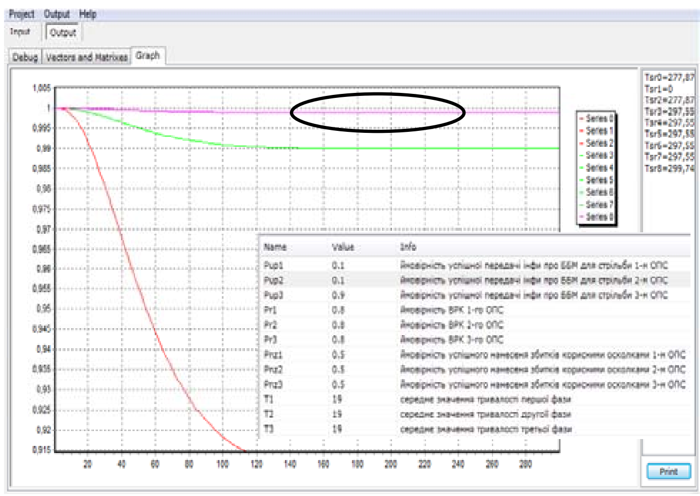


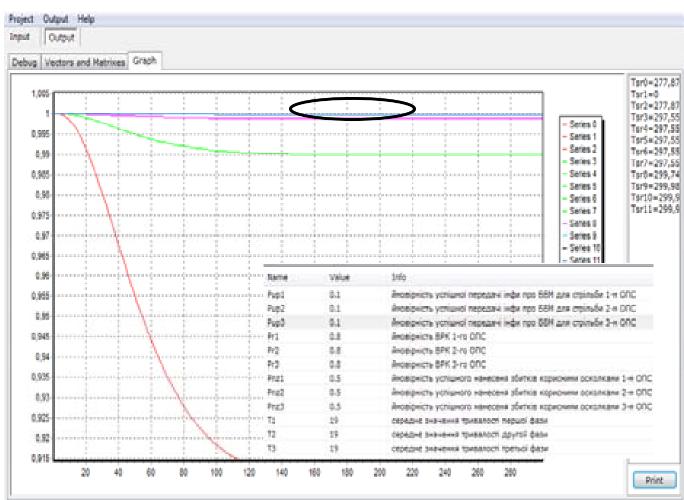
Fig. 3. The result of the *ASNA* software elaboration of the input values of the stochastic model of damage to vulnerable compartments of a single target in armor protection by "usable fragments" of fragmentation-beam projectiles in a series of three shots



a



b



c

Fig. 4. The result of processing the data of the stochastic model of damage, performed by the software ASNA: *a* – the probability of hitting the target with one projectile (red line – HEFP, fired from a conventional gun, green line – HEFP with PAG); *b* – the probability of hitting the target with two projectiles (red line – HEFP, fired from a conventional gun, green line – the first FBP with PAG; purple line – the second FBP with PAG); *c* – the probability of hitting the target with three projectiles (red line – HEFP, fired from a conventional gun, green line – the first FBP with PAG; purple line – second FBP with PAG; blue line – third FBP with PAG)

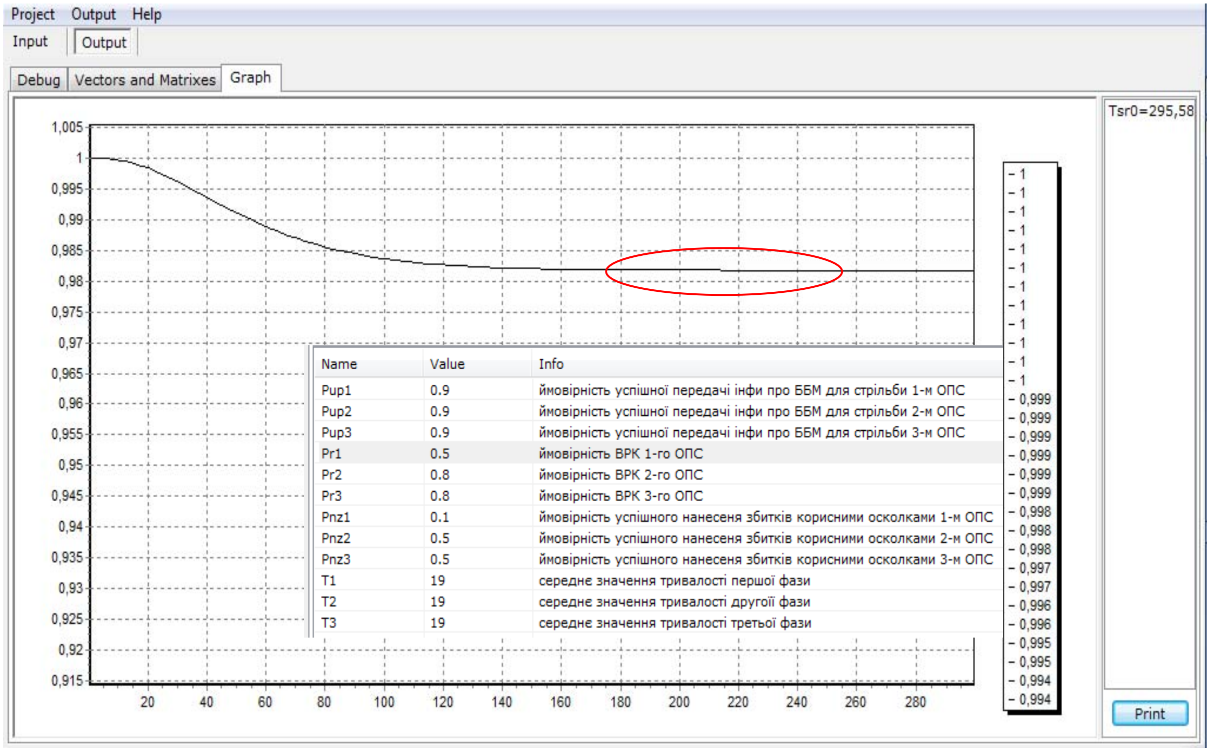


Fig. 5. Verification of the created stochastic model in the form of reducing the likelihood of damage by "usable fragments" by the first fragmentation-beam projectile

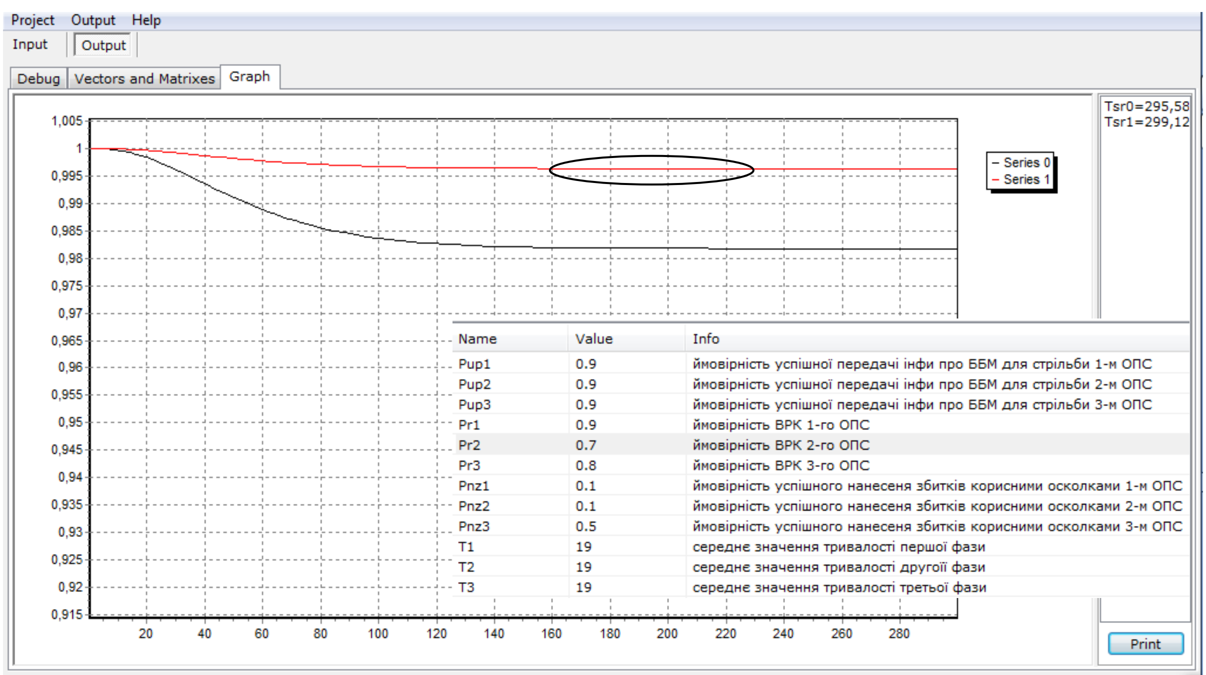


Fig. 6. Verification of the created stochastic model in the form of reducing the likelihood of damage by "usable fragments" by the first and second fragmentation-beam projectiles

Consequently, the total degree of damage caused by "usable fragments" to vulnerable compartments of a single target in armor protection in a series of three FBP shots corresponds to the failure of the fire task by a promising automatic gun [43]. We focus on the reproduction of a statistical picture of the behavior of the process of firing a movable armored target with fragmentation-beam projectiles of directional action. This approach is based on hypotheses of the functionality of the system and provides the possibility of conducting a model experiment of the system, taking into account the possible failures of their components. Then, on the basis of the created algorithm of the system's behavior, it is possible to investigate the relationship of its components in the form of a means of reconnaissance such as JV, each fragmentation-beam projectile in a series of three and a promising automatic gun. These components are defined as observations of the average values of firing results. Thus, the real ability to predict possible moments arising in the process of firing a promising automatic gun is achieved. Accordingly, the probability of performing their functions by the components of the system created by the performance indicators of functionality will be less than unity.

Reloading projectiles in a series of three shots when firing a promising automatic gun, flying an FBP on a trajectory, capturing a laser beam by FBP detonators and initiating the explosion of projectiles can take the following form:

– the transfer of information about the nature of the target to the PAG satisfies or does not satisfy the FBP for firing;

– capture of a hypothetical beam by a remote FBP blaster satisfies or does not satisfy the "backlight" of the target;

– operation and remote detonation of the first, second, and third fragmentation-beam projectiles at a distance of *n* meters from a moving armored target remote explosion or non-operation of a remote programmable blaster so detonation on impact, or miss;

– the total degree of damage caused by "usable fragments" to vulnerable ACV compartments in a series of three FBP shots will reflect the degree of performance of the combat mission.

Thus, the verbal model of the process of firing a moving armored target by a series of FBP is based on the algorithm of behavior of the experimental object in the form of a promising automatic gun, SP, and fragmentation-beam projectiles. They are seen as a series of three shots.

Phased consideration of all possible variants of the behavior of the object of study from the moment of detection of a moving armored target to the refusal of the crew of the ACV to perform tasks as intended can be described by a discrete-continuous random process. Thus, the verification of the created discrete model of causing damage to vulnerable compartments of a movable armored target by "usable fragments" of the FBP in a series of three shots corresponds to the predicted process. The latter is the shelling of an armored target with a promising automatic gun with a series of fragmentation-beam projectiles of directed action. There were no discrepancies between the results of the ASNA software and the expected results based on our empirical experience.

6. Discussion of results of the study on determining the components of the structural-automatic model of shelling

The hypothetical notion of the currently defunct process of causing damage to an armored target in a series of three FBP shots is based on the ability to reliably predict and reflect the beginning and end of the time interval. At the same time, it is believed that the system is in a certain state in a discrete-continuous process. A key component of the projected process of causing damage to vulnerable compartments of the target by "usable fragments" is reproduced in the form of a graph of states and transitions (Fig. 1), as well as possible options for the end of the event. Thus, theoretical approaches were developed to increase the effectiveness of hitting the enemy by increasing the likelihood of HEFP and FBP getting into vulnerable compartments, as evidenced by the simulation results (Fig. 5, 6).

As a result of this study, the approach proposed in [41] to create a model of the firing process based on the graph of states and transitions was advanced. The main idea is a formalized expression of the object of study in the form of a structural-automatic model of the process of firing a moving armored target with a series of three shots with fragmentation-beam projectiles of directional action. The obtained results make it possible to reduce the time of development of the latest technology by moving from a heuristic to an algorithmic approach to design. This became possible due to the specification of interpretation in the process of determining the values of the components of the structural-automatic model of the object (Table 2).

At the same time, the validation and verification of a discrete-continuous stochastic model of the process of firing a single target in armor protection by a series of fragmentation-beam projectiles of directional action only confirmed the viability and effectiveness of the modeling tools in this area. Thus, the proposed procedure for comparing graphs makes it possible to speed up the localization of errors and, accordingly, reduce the time spent on their search and correction.

This study was limited to the firing process in the form of a series of three shots, due to the peculiarities of combat operations using the PAG but can be modified to take into account other types of weapons. The disadvantage of the study is that discrepancies were found between the expected and real results of damage to vulnerable single target compartments in armor protection by "usable fragments" of FBP in a series of three shots. However, carrying out the verification procedure after validating the results increases the effectiveness of this approach.

Further practical implementation of this model is possible during the development of the latest samples of fire resistance in order to reduce errors at the stage of system engineering.

7. Conclusions

1. Conceptual solutions for representing the process of firing a single target in armor protection involve the use of parametric models of damage to such a target by fragmentation-beam projectiles of directional action in a series of three shots based on the reference graph of states. Such a representation of the process makes it possible in general to solve the problems of system-technical design of ammunition at the initial stages. The validation and verification of the use of these ammunition under modern conditions provides an opportunity to adequately respond in the process of developing ammunition to changes in their configuration, as well as changes in the configuration of their components.

2. Validation of a discrete-continuous stochastic model of the process of firing a single target in armor protection by a series of fragmentation-beam projectiles of directional action was carried out. It confirmed the effectiveness of the discrete-continuous mathematical model. Such a model can be used to study inflicting the damage to vulnerable compartments of an armored combat vehicle or other armored target by "usable fragments" of fragmentation-beam projectiles of directional action in a series of three shots. Our results, shown in Fig. 3, indicate the effectiveness of the use of a promising automatic gun and an increase in the

likelihood of hitting a target compared to conventional guns with single and serial shots.

3. Verification of the structural-automatic model of firing a single target in armor protection with fragmentation-beam projectiles of directional action in a series of three shots was carried out. The probability of hitting the target with high-explosive fragmentation projectiles from guns in conventional equipment and fragmentation-beam projectiles from promising automatic guns is calculated. It is analyzed how the understatement affects the probability of causing damage by "usable fragments" before performing a series of shots. The use of the structural-automatic model components proposed in this work increases the probability of performing a fire task for the first shot from 0.23 to 0.88, for the second – from 0.35 to 0.95, for the third – from 0.45 to 0.98. There were no discrepancies between the results of the ASNA software and the expected results obtained during the development of the structural-automatic model, there are no errors. On the basis of the data obtained, full-scale experiments can be carried out since system-technical design makes it possible to determine the results of the effectiveness of a technical sample at the modeling stage.

Conflict of interests

The authors declare that they have no conflict of interests in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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