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BUILDING A MODEL OF THE PROCESS OF SHOOTING A MOBILE ARMORED TARGET WITH DIRECTED FRAGMENTATION-BEAM SHELLS IN THE FORM OF A DISCRETE-CONTINUOUS STOCHASTIC SYSTEM

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This paper describes the process of shooting a mobile armored combat vehicle with directed fragmentation-beam shells as a discrete-continuous random process. Based on this approach, a stochastic model has been proposed in the form of a system of Kolmogorov-Chapman differential equations.

A universal model of the process of defeating a moving armored target with directed fragmentation-beam shells has been built, which would provide preconditions for experimental studies into the effectiveness of various variants of the components of the artillery system for three-shot firing.

The execution of an artillery task is considered as a set of certain procedures characterized by the average value of its duration. They are dependent on the firing phases involving a prospective automatic gun and the explosive destruction of fragmentation-beam shells while the explosive destruction of each shell case is characterized by the self-propagation of the reaction of explosive transformations based on tabular data on the target. An indicator of the functionality of various design options for fragmentation-beam shells is the probability of causing damage by «useful fragments» in the vulnerable compartments of a combat armored vehicle.

Devising universal models for the process of shooting a moving armored vehicle forms preconditions for further full-time experiments in accordance with the design solutions defined as a result of modeling. It is possible to use the developed discrete-continuous stochastic model in other modeling tasks to determine the optimal value of defeat.

As regards the practical application of discrete-continuous stochastic models, one can argue about the possibility of reducing the cost of performing design tasks related to weapons by 25 % and decreasing the likelihood of making mistakes at the stage of system engineering design

Keywords: discrete-continuous stochastic model, graph of states and transitions, fragmentation-beam shells

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1. Introduction

The current state of saturation of the world armies with armored vehicles and manpower in terms of protected means of individual (combat) equipment [1] did not affect the change in their product range towards reducing high-explosive fragmentation (HE-FRAG) shells that reached the limit of their capabilities [2]. However, we shall focus only on single targets in armored vehicles in the form of armored fighting vehicles (AFV). This is because shooting on manpower with a direct guide has several certain features; to understand it in full, one needs first to comprehend the essence of shooting armored vehicles.

It is known that when shooting armored fighting vehicles directly, only 15 % of the energy of explosive destruction of the hull of a high-explosive fragmentation projectile is useful. Therefore, when an AFV is hit directly, 85 % of the shell energy is wasted.

At the same time, based on the practice of wars of our time, the so-called submunitions were used [3], which should include fragmentation-beam shells (FBS). They exert not only a high impact but also a strong moral and psychological effect on an enemy with a high fire density and the rational distribution of hitting factors on the plane. However, the effectiveness of FBS is determined not only by the combat properties. A key role belongs to a set of means, which includes an intelligence tool in the form of an observation point based on a «flying platform» (hereafter, FP) and a prospective automatic gun (PAG).

Thus, according to the principle of operation, PAG can be equipped with a programmer in the form of two rings on a barrel for providing a moving FBS with the working time of the receiver to «illuminate» a target from an FP and enabling its remote detonation at a fixed distance to it. Accordingly, electronic suppression means would not be able to affect the FBS flight to the target (unlike the AR-5 type radio blaster). Reloading shells in a series of three shots, flying the FBS along a trajectory, capturing the laser beam by FBS detonators, and further initiating the detonation of explosives of shells no more than 3 seconds in the queue. However, it takes some time and financial resources to implement the plan. After all, there is a significant period from the design of a sample to its industrial production. Therefore, there is reason to believe that it is the step-by-step stages in various tests of the prototype that are likely the most expensive period in the scientific activities of developers. For example, any field tests involving promising samples of weapons and military equipment (WME) have always been and will be extremely burdensome in terms of financial costs for the economies of the overwhelming number of countries in the world. After all, it is a full-time experiment that requires a significant number of repetitions of the process to acquire the statistics of failures. Therefore, in order to reduce costs, one should apply the toolset of system engineering design. It provides an opportunity to identify and reject inappropriate variants of technical solutions long before implementation in test samples.

At the present stage of the rapid development of military equipment, it is important to check the adequacy of the samples to the requirements put forward for them. This is a time-consuming and financially-intensive process where additional components are significant costs of the scientific enterprise. We believe that fragmentation-beam shells can effectively handle an enemy's armored fighting vehicles. Constructing universal models for the process of shooting a moving armored vehicle by directed fragmentation-beam shells would form preconditions for further experimental research. This could help save money and obtain practical results, which renders relevance to this task.

Available world practice of searching for adequate procedures of theoretical assessment of the parameters of shell fragmentation is concentrated in two areas: computer simulation of processes of explosive destruction of shells' hulls and full-scale research. These areas are closely related to practical studies of the explosion process. It is their use that makes it possible to reasonably approach the optimal choice of ammunition form; material of the splintering component, and the location of the point of initiation of explosives.

However, the practical implementation of HE-FRAG shells in modern wars limits their capabilities. For example, in local wars of our time that belong to the «hybrid» ones, there is a risk of colossal civilian casualties and the destruction of vital infrastructure. Therefore, in recent decades, there has been a call by world communities to refrain (restrict) from the use of HE-FRAG shells, on the one hand. However, on the other hand, there is an absence in the military units of most states of a sufficient amount of alternative ammunition of this type. Therefore, the current development of promising means of destruction is aimed at reducing their mortality by designing fragmentation-beam shells. However, it should be noted that up to now there are no HE-FRAG shells in the world with a controlled fragmentation field. Therefore, the analysis of areas in the development of the theory and practice of fragmentation shells would outline top priorities for reviewing the role and capabilities of high-explosive fragmentation projectiles in world military practice. The advent of the so-called «smart» ABM (Air Burst Munition) FBS prompted the further development of means of armed struggle and firepower.

2. Literature review and problem statement

Study [4] reports the results of shooting with such shells but did not offer ways to simulate shooting. These shells are detonated at a given point of the trajectory, which is the closest to the target and exert a fragmentation effect on it, as indicated in [5]. Although the cited paper [5] describes elements of simulation of the shooting phase, there is no information on the specificity of the strike by a series of shots. A striking example, and the first in its class, was the AHEAD family of shells by the Swiss company Oerlikon Contraves [6]. Their characteristic feature, according to world analysts, is the minimal equipment of a separate body with ready-made elements of destruction. However, the authors disregarded their calculated or practically obtained evaluation capabilities. Only certain parameters are presented that do not give a complete picture of the capabilities of ammunition. After all, there is a significant number of works whose authors make attempts to implement the physical properties of the explosion and the fragmentation of materials in the practical aspect.

For example, paper [7] reports the results of mathematical research whose purpose was to determine the size of the dangerous zone of fragmentation damage of an explosive device. To that end, the calculation was performed in the form of the spatial distribution of fragmentation mass and the speed of its movement for two fragmentation disks of variable thickness. And work [8] modeled only the process of influence of the explosive load on metal plates. Studies [7, 8] are quite interesting but their purpose is not related to the practical implementation in the fight against an enemy's armored vehicles. After all, the process of shooting a tank-type AFV, despite their rapid quantitative growth, is limited to a list of anti-tank missile systems and single samples of anti-tank guns. It should be noted that work [9] attempted to justify ways to calculate the effectiveness of direct damage to armored fighting vehicles from promising anti-tank means but without taking into consideration the shooting in response.

A very significant impact on a single small-sized target is exerted by HE-FRAG shell with a remotely directed fragmentation field [10] – a fragmentation-beam shell; however, no universal model of FBS action is proposed. Paper [11] examined the level of damage to targets with fragmentation-beam shells but did not address the use of a series of shots whose execution, according to the authors, could contribute to the effectiveness of the action.

Study [12] proposed a finite-ballistic model for artillery high-explosive fragmentation projectiles. However, the experiments showed a satisfactory accuracy of the results compared to the ones predicted using the model.

To investigate the correlation of damage and the effectiveness of damage related to the distribution of shell fragments for a target in space, work [13] proposed the simulation of the calculation of damage to the shell and the intersection of the target. However, the correlation model built is not correct for use in the analysis of directed shells.

Our review of appropriate studies [7–13] has revealed an urgent need to devise a universal model of the process of shooting a mobile armored target (AFV) with fragmentation-beam shells of direct action. Such a model, in terms of its capabilities, would create preconditions for experimental studies into the effectiveness of various options for the implementation of components in the artillery system that fires FBS in the series of shots.

3. The study materials and methods

The object of this study is a generalized process of shooting a moving armored target. This process is a set of interrelated processes of «illumination» of mobile AFV by means of reconnaissance, failure-free fire from a prospective automatic gun, and controlled remote detonation of fragmentation-beam shells.

The purpose of this study is to find adequate methods for the theoretical assessment of the fragmentation parameters of fragmentation-beam shells based on discrete-continuous stochastic models of fragmentation-beam shells. Devising a universal model for the process of shooting a mobile armored target with directed fragmentation-beam shells would form preconditions for experimental research into the effectiveness of various options for the implementation of components in an artillery system for firing a series of shots. This could reduce the cost of design work for weapons and decrease the likelihood of errors at the system design stage.

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

– to devise a verbal model of the process of shooting a moving armored target with a series of directed fragmentation-beam shells;

– to analyze the model devised as the object of research as a discrete-continuous random process;

– to determine the parameters for the shooting process;

– to propose an approach to the construction of a discrete-continuous stochastic model that would provide for determining basic events;

– to represent the shooting of a moving armored target with a series of directed fragmentation-beam shells by a discrete-continuous random process.

4. The study materials and methods

This study was conducted using methods of system analysis, induction, and deduction, in order to devise a verbal model of the process of shooting a moving armored target in a series of three directed fragmentation-beam shells. The model was then used to build discrete-continuous stochastic models based on the Kolmogorov-Chapman differential equations using grouping and systematization methods. Such models contribute to determining the statistical reliability indicators.

By adapting the solution to problems on synthesizing technical objects and systems resistant to failure, we have proposed the reliability indicators to determine the optimal options for the structure of the shooting process involving the specified type of weapon.

5. Results of studying the process of shooting and devising a universal process model

5. 1. The verbal model of the process of shooting a moving armored target with a series of fragmentation-beam shells

The emphasis is on reproducing a statistical pattern of the process of shooting a moving armored target with directed fragmentation-beam shells (based on the hypotheses of the system functionality). This provides the possibility of conducting a model experiment of system operation, taking into consideration the possible failures of its components. Next, based on the designed algorithm of system behavior, it is possible to investigate the relationship of its components in the form of an intelligence tool such as AV. In addition, it is possible to determine each fragmentation-beam shell in a series of three shots, as well as a prospective automatic gun, as observations of the average values of shooting results (Fig. 1).

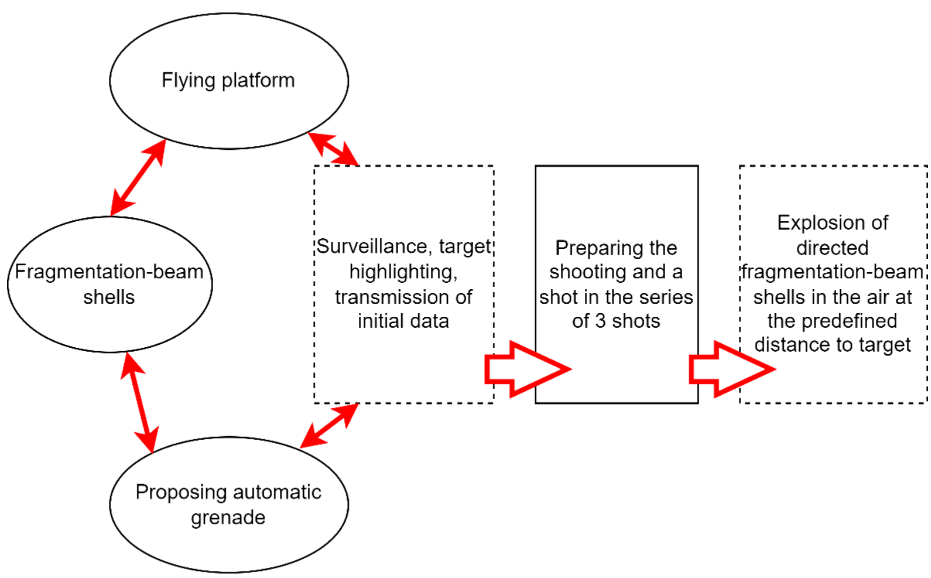

Fig. 1. Scheme of interaction between subsystems of the system for hitting an armored fighting vehicle with fragmentation-beam shells in a series of three shots

Thus, the actual possibility to predict possible moments arising in the process of firing from a prospective automatic gun (PAG) is achieved. Accordingly, the probability of performing the functions by the components of the system created by functionality indicators would be less than unity.

Direct reloading of shells in a series of three shots during PAG firing, the flight of FBS along a trajectory, the capture of a laser beam by fragmentation-beam shell detonators, and the subsequent initiation of shell detonation may take the following form:

– is the transmitted information about the nature of a target to PAG enough for FBS to fire or not?

– does the capturing of a hypothetical beam by a remote FBS detonator satisfy the «illumination» of the target or not?

– functioning and remote detonation of the 1st, 2nd, 3rd fragmentation-beam shells at a distance of n meters from a moving AFV, remote detonation, or failure to enable a remote detonator so detonation to impact, or an error;

– the total extent of damage caused by «useful fragments» to vulnerable AFV compartments in a series of three shots by FBS would reflect the degree of combat mission execution.

Thus, the verbal model of the process of shooting a moving armored target by the FBS in series is based on the algorithm of the behavior of the examined object in the form of a prospective automatic gun, FP, and fragmentation-beam shells, which are considered by a series of three shots.

Step-by-step consideration of all possible variants of the examined object behavior from the moment of detecting a moving armored target to the refusal of the AFV crew to perform tasks for its intended purpose can be described by a discretely continuous random process.

5. 2. The verbal model for representing the shooting process as the object of research by a discrete-continuous random process

We did not aim to consider the traditional assessment of the effectiveness of shells in the form of hitting, destruction, suppression of a single target with artillery means of destruction. The main goal is to investigate the process of causing damage by the «useful fragments» from FBS to vulnerable compartments in an armored target with each shot in a series of three. Having experienced such damage, the AFV crew would be forced to abandon the combat mission.

In the case the HE-FRAG shells miss the target, accounting for the characteristics of total errors in their deviation from the moving target (changing the range to the target and the projection of its vulnerable compartments) and the depth of the fragment field can be carried out using the following expression:

$$R_h = H_t \cdot 100/\theta_s,$$

where R_h is the range of hitting; H_t is the target height; θ_s is the angle of a shell approaching the target.

The depth of the fragment field is characterized by a space of destruction.

The tabular value of the hitting space for tanks and antitank guns at a range of 1,500–1,300 m and with the angles of the shell's approach to the target θ_s=(11–19) thousand, which, within R_h=246–300 m, is determined according to general rules [14].

It is known that in modern conditions of combat use of promising means of destruction, it becomes important to reduce the time for preparing the first shot. This allows us to put forward the requirements to increase the PAG rate of fire at least several times compared to existing weaponry. To this end, it is necessary to define the requirements for stating research tasks whose solution should ensure the justification of the effectiveness of the model built. However, the effectiveness of the increased PAG rate of fire would make sense only if all components are interconnected in the form of consistent processes:

1) the so-called «illumination» with a hypothetical beam of mobile AFV by means of reconnaissance;

2) PAG failure-free shooting;

3) controlled remote detonation of fragmentation-beam shells. Such a model of the process of defeating the enemy's AFV could make it possible to investigate the effectiveness of various options for building promising means of destruction. However, to organize the values of performance indicators of the planned damage process, the following steps must be taken:

– choose performance indicators for the components of the research object for the mathematical model of the shooting process;

– gradually substantiate the component of the vector of states of the shooting process with a series of promising means of fire influence;

– develop a body model of the process of hitting FBS at the predefined distance to a moving target in the form of a graph of states and transitions notating it as a system of differential equations.

5. 3. Parameters of the process of shooting a moving armored target in a series of three fragmentation-beam shells

To consider the components of causing damage, it is necessary to define the parameters of the process of shooting a moving armored object in a series of three directed fragmentation-beam shells in the form of so-called procedures. A signal is transferred from FP to the PAG receiving device to detect and accompany the movement of AFV. Then the loading and guidance of the gun are carried out in accordance with the further support of the reconnaissance vehicle in the range and direction to the movable AFV. The shot in a series of three FBS is carried out in accordance with the established reference range to the target (without taking into consideration its range). In this case, the rupture occurs with the flight of the FBS to the object at a fixed distance to cause damage to its vulnerable compartments.

Depending on the change in the coordinates of the moving AFV, the programmator on the barrel cut introduces adjustments not only to settings for shooting but also the points of initiation of the explosive substance of the following two shells. It is logical that in accordance with the change in the position of the target, the cross-country terrain with invisibility zones, as well as vulnerable compartments, the 3rd shot is fired. Under an automatic mode, the choice of the point of initiation of explosives is carried out. The total value of the damages would be determined by the performance indicators of the process, which affects the implementation (non-fulfillment) of the PAG fire task.

Thus, the execution of a fire task by a prospective automatic gun is considered by us as a set of certain procedures characterized by the average value of its duration. They are dependent on the so-called phases of PAG firing and the explosive destruction of the shell of a fragmentation-beam projectile. At the same time, explosive destruction of the hull is characterized directly by self-propagation of the reaction of explosive transformations [14] based on tabular data on the following:

– range to the target (R_t);

– the angle of the FBS approach to the target (θ_{FBS});

– depth of AFV damage space (l);

– the visual dimensions of the target (m);

– the approximate size of vulnerable target compartments (m').

5. 4. Approach to the construction of a discrete-continuous stochastic model that defines basic events

Directly, the process of modeling the shooting of FBS of a mobile AFV is based on well-known approaches to building discrete-continuous stochastic models. The ultimate form of these models is the representation of the process under study in the form of a system of Kolmogorov-Chapman equations. However, the difficulty of this process is the specificity of the procedures for shooting the PAG target. Therefore, the task as a whole depends on the course of events, which are affected by the probability of damage to vulnerable compartments of the AFV with «useful fragments» from FBS. So-called events are inherent in the procedures for completing a fire task. The main property of events is the ability to describe the procedure from its beginning to the end. In turn, the events that represent the end of the procedure are considered to be basic events (BE) [15]. In a given case, BEs in the algorithm for the moving AFV shooting process are the input data for determining the components of the target shooting with the construction of a reference state graph describing all possible situations. Accordingly, the formalized notation depends on the detection of situations in which each BE can occur. To identify situations, all possible emerging (formed) states are selected after BE1, taking into consideration all alternative extensions of the AFV shooting process.

Therefore, according to the predicted process, causing damage to vulnerable compartments of the target with «useful fragments» can be represented in the form of a graph of states and transitions, as well as possible options for the completion of the components of the process involving the degree of damage.

Thus, a given model creates an opportunity to determine the effectiveness of both defeat systems and the interaction between them [15]. The applied procedure of synthesis of fire impact on moving armored objects makes it possible to substantiate the values for the main indicators of the effectiveness of the components of the set of causing damage to AFV. A high degree of adequacy of a given model can be ensured by representing the duration of procedures and the intervals of time between adjacent events in the event flows by the law of distribution of Erlang instead of the exponential distribution law. Then staying in states ensures the distribution of functions between the components of the process of shooting AFV with directed fragmentation-beam shells in a series of three shots in the form of a graph of states and transitions (Fig. 2).

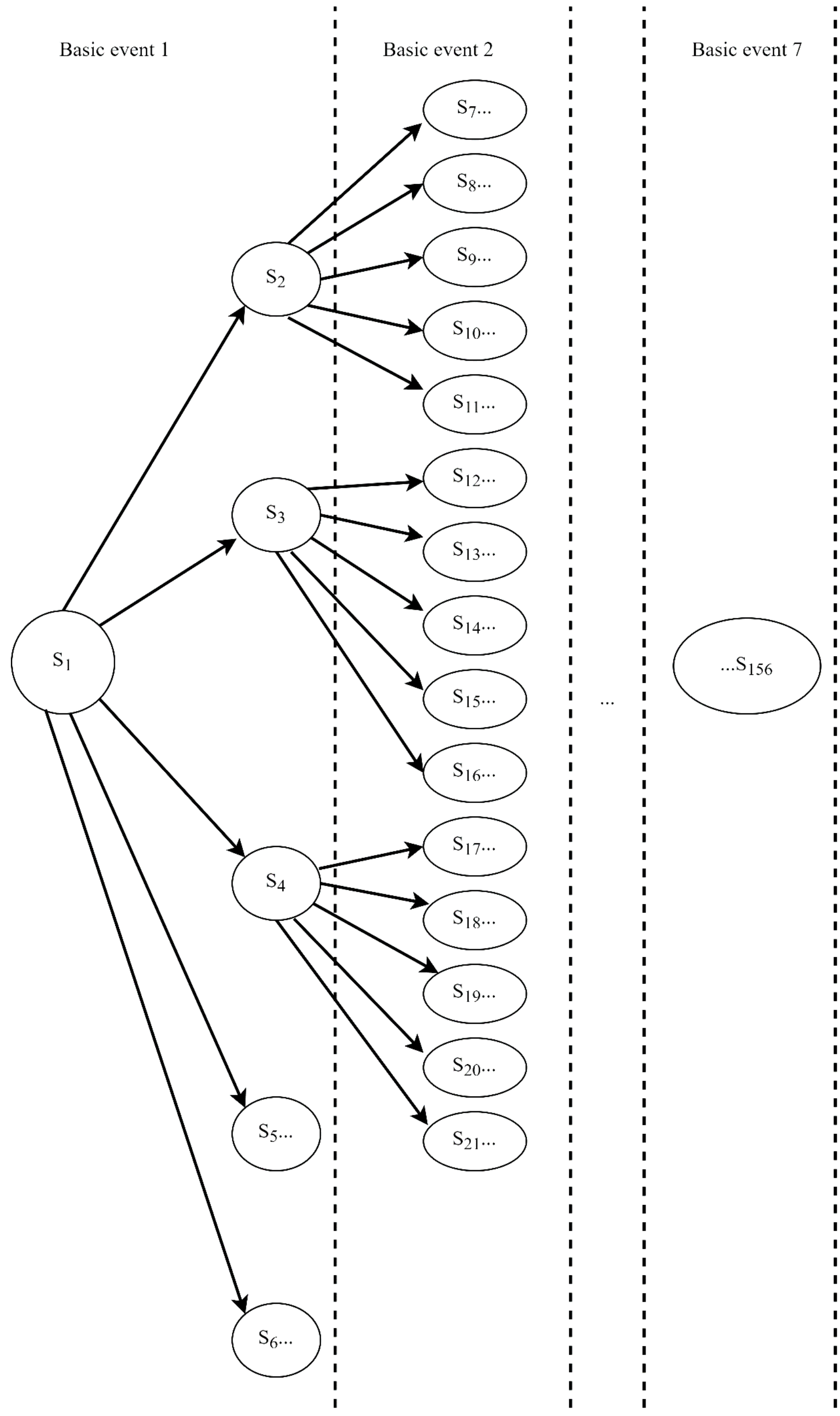

Fig. 2. Fragment of the model of causing damage by «useful fragments» to the vulnerable compartments of an armored fighting vehicle with directed fragmentation-beam shells in a series of three shots in the form of a graph of states and transitions of the process

To complete the construction of the model of shooting a mobile AFV, we use the method of state space [15]. To this end, based on the generalized experience of shooting AFV, it is quite logical that the stage of its detection and its shooting with FBS is a key one.

Therefore, the direct description of the states provides the ability to reproduce the shooting of a moving AFV in the range for perception.

Thus, the principle of modeling the process of shooting AFV is as follows:

– represent the process of reloading the FBS; explosion of the FBS at the predefined distance to AFV;

– determine the extent of damage caused by «useful fragments» from each FBS in a series of three shots;

– build a model of the object of research in the form of a graph of states and transitions;

– accept the assumptions and requirements that can be implemented in the model.

5. 5. Representing the shooting of a moving armored target by a series of fragmentation-beam shells in the form of a discrete-continuous random process

Solving universal problems of synthesis of fault-tolerable software and technical systems can be adapted to obtain reliability indicators for a significant number of options in implementing the structure of the AFV shooting process with prospective automatic guns. In turn, discrete-continuous stochastic models of functional behavior make it possible to determine statistical indicators of their effectiveness.

Therefore, devising a model of the process of shooting a moving AFV with a series of FBS as an object of research in the form of a state graph is a stage in the technology of constructing the discrete-continuous stochastic behavioral models, underlying which is the method of state space. Therefore, a generalized statistical picture of the results of observation involving a large number of shots, which is based on the process of firing on a moving armored target by a series of FBS with a possible set of options for transitions from state to state. That would be reflected by a specific algorithm for the behavior of the object of research but the number of options for its implementation could be much greater. Consequently, the duration of the stay of the object of study in each state is considered by us as a random value. The discrete-continuous random process of successful completion of all phases of the process of detecting and causing damage to a moving armored object with directed fragmentation-beam shells in a series of three shots has a set of random values.

The events taking place in the process of shooting an armored combat target with a prospective automatic gun with FBS in a series of three shots are given in Tables 1–3.

The graph of a discrete-continuous random process of causing damage to a moving armored object with directed fragmentation-beam shells in accordance with Table 1 is shown in Fig. 3.

The chart of a discrete continuous random process of causing damage to a moving armored object with directed fragmentation-beam shells in accordance with Table 2 is shown in Fig. 4.

The chart of a discrete-continuous random process of causing damage to a moving armored object with directed fragmentation-beam shells in accordance with Table 3 is shown in Fig. 5.

Table 1

The first, second, and third events taking place in the process of shooting a fighting armored target with a prospective automatic gun using FBS in a series of three shots

Event sequence	Event onset attribute	Event end attribute
ONE	The appearance of the target in the «backlight» zone and the start of the flying platform to transmit the target coordinates for the first shot	Receiving a message with the target coordinates from FP about the source data for the first shot
TWO	Start of FBS 1 transfer from the ammunition rack to the charging storage	Completion of FBS 1 transfer from the ammunition rack to the charging storage
THREE	FBS shot 1 to moving AFV	Explosion of FBS 1 at the predefined distance to moving target

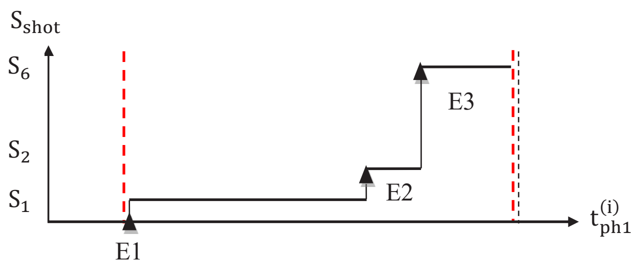

Fig. 3. Chart of the discrete-continuous random process from the first to the third procedure of causing damage to a moving armored object with directed fragmentation-beam shells

Table 2

The fourth, fifth, and sixth events taking place in the process of shooting an armored fighting target with a prospective automatic gun using FBS in a series of three shots

Event sequence	Event onset attribute	Event end attribute
FOUR	Start passing the target coordinates for shot 2	Receiving a message with the target coordinates from FP about the source data for shot 2
FIVE	Start the FBS 2 transfer from the ammunition rack to the charging storage	Complete the FBS 2 transfer from the ammunition rack to the charging storage
SIX	FBS shot 2 to moving AFV	Explosion of FBS 2 at the predefined distance to moving target

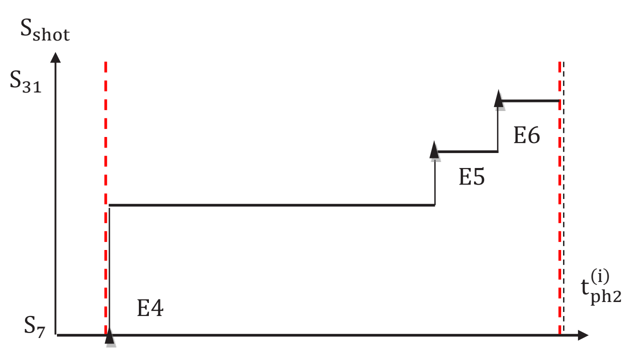

Fig. 4. Chart of the discrete-continuous random process from the fourth to the sixth procedure of causing damage to a moving armored fighting vehicle with fragmentation-beam shells

Table 3

The seventh, eighth, and ninth events taking place in the process of shooting an armored fighting target with a prospective automatic gun using FBS in a series of three shots

Event sequence	Event onset attribute	Event end attribute
SEVEN	Start passing the target coordinates for the third shot	Receiving a message with the coordinates of the target from FP about the source data for the third shot
EIGHT	Start the FBS 3 transfer from the ammunition rack to the charging storage	Complete the FBS 3 transfer from the ammunition rack to the charging storage
NINE	FBS shot 3 to moving AFV	Explosion of FBS 3 at the predefined distance to moving target

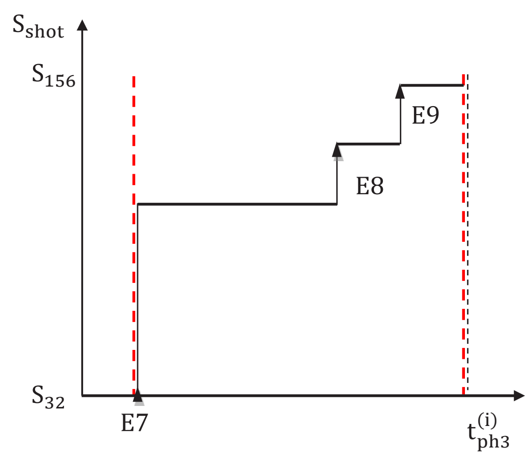

Fig. 5. Chart of the discrete-continuous random process from the seventh to the ninth procedure for causing damage to a moving armored fighting vehicle with fragmentation-beam shells

Thus, in a general form, the discrete-continuous random process of successful phases of the procedure for detecting and causing damage to a mobile AFV in a series of three shots is shown in Fig. 6.

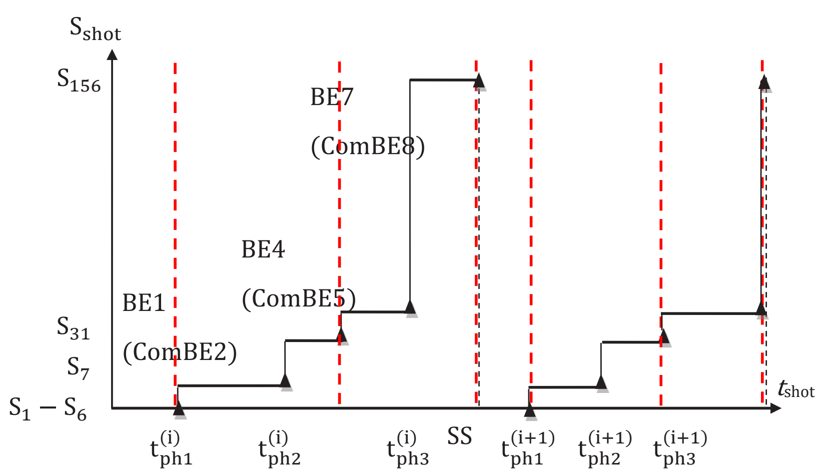

Fig. 6. Chart of the discrete-continuous random process of successful completion of all phases of the procedure for detecting and causing damage to a moving armored fighting vehicle in a series of three shots

These graphical dependences describe the chains of events in the process of creating a product before it was created, allowing the forecasting of its basic characteristics. The chain of events, taking into consideration their probability, makes it possible to construct a matrix of events. Chart elements that represent discrete-continuous random processes are represented in the logical correspondence without regard to scale. This is due to the fact that the charts are qualitative, not quantitative, and aim to reflect the patterns and trends of events in general.

The process of «illumination» of targets by means of reconnaissance to correct the trajectory of the shell when flying to the target is quite common in modern conditions. However, the possibility of detonating a shell on a trajectory at a certain distance to the target to obtain an effective fragment field creates prerequisites for determining the appropriate distance. While the internal content of the indicator «efficiency of fragmentation-beam fields» P_{FBF} depends on the following:

– the reliability of detonator and the initiation of explosives of the shell;

– the stability of an internal explosion process;

– the mass-dimensional characteristics of fragments and their punching properties.

Further, the shooting of a moving armored fighting vehicle with a change in the appropriate range to the target in the second, third, and fourth phases should be taken into consideration as average.

The process of pointing a promising anti-tank automatic gun on a moving armored fighting vehicle is executed according to established rules [15]. This takes into consideration both the linear dimensions of the moving armored target, the peculiarities of FBS trajectory at the appropriate range to the target, and the angles of shell flight directly to the point of its explosion relative to the AFV itself. Therefore, changing the amount of space for damaging an armored fighting vehicle with a shell of this type would affect the extent of damage to the vulnerable compartments of the target.

For the specified parameters of the depth of the space causing damage, the angle of FBS approach creates prerequisites for the further formation of meridional angles of the spread of «useful fragments». This can be taken into consideration when calculating directly the process of explosive destruction of the case of a fragmentation-beam shell. Note that the values for the specified parameters of the random process of changing the visual dimensions of the target would differ for the configuration of the target and directly visible dimensions of the target. These values would differ at the reconnaissance and target «illumination» stage before and during the first shot with a fragmentation-beam shell in a series of three shots. Terrain, as well as camouflage signs of armored fighting vehicles, create the need for careful exploration of the moving target. This would affect both the time before the readiness of the «backlight» and the remote detonator capture of the signal of the specified power for the initiation of explosives of fragmentation-beam shells. At the same time, the number of «useful fragments» capable of striking vulnerable compartments of a moving AFV with the wrong initiation of an explosive could be much lower compared to ideal conditions.

To assess the inflicted damage to the vulnerable AFV compartments, it is possible to conditionally divide them into two groups, namely:

– the first group should include the failure of each of them to make it impossible for the crew of this armored fighting vehicle to perform the task;

– the second group should include compartments that, together in one combination or another, would provide for the predefined extent of damage to AFV.

Consequently, the presence of the two groups of compartments in the target would lead to the accumulation of losses. However, the distribution of vulnerable compartments to the direction of PAG firing with each time value is variable. Therefore, when detonating a fragmentation-beam shell, the probability of hitting a compartment is the probability of a complex event, the value of which for a discretely continuous random process of changing the approximate vulnerable dimensions of the target changes in the state in each phase of shooting. The exception is the first phase, which is taken by the average value.

The random duration of phases is characterized by constant changes in the conditions of the combat mission. After all, the presence of closed input systems such as FP, PAG, fragmentation-beam shells, and a mobile armored fighting vehicle can directly, and in combination, affect the results of the study. And the presence of an existing number of conditions and factors considered as the limitation would unquestionably affect the result of shooting a moving armored target. After all, with an infinitely large number of practical shots, the projected duration of four phases (Table 3) can be increased by 3–4 times, which is quite acceptable for average values of discrete-continuous stochastic models.

Thus, the main advantage of FBS is the effectiveness of its fragmentation-beam fields. In the process of shell explosions in a series of three shots, the products of shell destruction and detonation fill some plane in the surrounding space. This can be described by the probability of failure of the vulnerable units of AFV with the following indicators of the effectiveness of its components: turret, hull, and running gear. The required degree of adequacy of the mathematical models of the remote denotation of FBS will be based on the optimal distance from the target.

To build a model for causing damage, the above-mentioned basic events are used. Note that the process of shooting a moving AFV in the model itself can be considered as firing a prospective automatic gun with fragmentation-beam shells in a series of three shots [15, 16]. Determining basic events is characterized by accounting for the processes and procedures that are included in the algorithm of behavior of the process of shooting a moving armored target with a series of directed fragmentation-beam shells.

Therefore, based on the above, using the model for determining the probabilities of causing damage to a mobile AFV, it is possible to create preconditions for further calculations on the spatial-high-speed distribution of fragments in the environment. However, for this study, there is a need to describe causing damage in the form of specific phases (Table 4): target reconnaissance measures, shooting preparation, as well as remote detonation of fragmentation-beam shells in a series of three shots. Reconnaissance measures, «illumination» of the target, and causing the expected damage to AFV with useful fragments of the first shot of FBS are represented by phase I. Logical completion of this phase is a basic event (BE1). The end of Phase 2 is the departure from the barrel of a promising automatic anti-tank gun of the next FBS (BE4). The third phase corresponds to the shot and explosion of the third fragmentation-beam shell (BE7).

Thus, the specified phases of shooting a mobile armored fighting vehicle with promising fragmentation-beam shells in a series of three are determined in accordance with the main aspects of causing damage to the vulnerable compartments of armored vehicles with «useful fragments». Note that in order to determine their basic events, it is necessary to take into consideration all the processes of shooting a moving armored fighting vehicle with a series of three shots with a prospective automatic gun included in the behavior algorithm.

For joint coordination of actions and interaction between FP and a prospective automatic gun, events that represent their beginning and end with an average value of its duration are inherent. Events representing the end of the procedure are considered basic [15].

However, the analysis of studies that examine the process of firing on mobile armored fighting vehicles reveals the existence of a significant number of conditions and factors affecting the result. Therefore, the study of the FBS influence on moving armored objects would not be complete without considering the algorithm of behavior in the form of phases of the process of detecting and causing damage to them.

Table 4

Events that represent the process of shooting a moving armored fighting vehicle with a series of fragmentation-beam shells

Phase No.	Event that corresponds to the onset of the procedure in the phase	Event that corresponds to the end of the procedure in the phase (basic and summary basic events)
Phase I	The appearance of the target in the «backlight» zone and the beginning of FP work on the transfer of the target coordinates for the first shot	BE1: Receiving a message with the target coordinates from FP about the source data for the first shot
	Start the FBS 1 transfer from the ammunition rack to the charging storage	BE2: Complete the FBS 1 transfer from the ammunition rack to the charging storage
	FBS shot 1 to moving AFV	BE3: Explosion of FBS 1 at the predefined distance to moving target – n, m
Phase II	Start passing the target coordinates for the second shot	BE4: Receiving a message with the target coordinates from FP about the source data for the second shot
	Start the FBS 2 transfer from the ammunition rack to the charging storage	BE5: Complete the FBS 2 transfer from the ammunition rack to the charging storage
	FBS shot 2 to moving AFV	BE6: Explosion of FBS 2 at the predefined distance to moving target – n, m
Phase III	Start passing the target coordinates for the third shot	BE7: Receiving a message with the coordinates of the target from FP about the source data for the third shot
	Start the FBS 3 transfer from the ammunition rack to the charging storage	BE8: Complete the FBS 3 transfer from the ammunition rack to the charging storage
	FBS shot 3 to moving AFV	BE9: Explosion of FBS 3 at the predefined distance to moving target – n, m

The process of detecting and causing damage to a moving armored object can be set out in the interpretation given in Table 4.

Thus, the corresponding phases, which are the beginning and end of the procedure for shooting the armored fighting vehicle with directed FBS, are a prerequisite for the construction of a discrete-continuous stochastic model. This makes it possible to derive the value of a statistical indicator of the effectiveness of the target damage and to study alternative options for the process of causing damage to the vulnerable compartments of armored fighting vehicles.

An important component of the study is to determine the structure of the vector of the state of the process of shooting a mobile AFV with a series of three shots using FBS. Therefore, the presence of a minimum set of determinative components characterizes the object of research at each moment of the process of hitting vulnerable compartments with «useful fragments» (causing damage to the target). Additionally, these components form the initial values of the moment of transmission of AFV data from the FP intelligence tool, the «highlighting» of the target to the change in the range of values of each of the specified components. Also determined is the remote explosion of each at the predefined distance in a series of three shots and hitting the vulnerable compartments of AFV with «useful fragments». Therefore, according to the above, components of the vector of states, which the system «reconnaissance tool – automatic gun – FBS in a series of three shots» can enter, have the following interpretation:

– $V1$ – receiving messages with the coordinates and characteristics of the target for FBS 1;

– $V2$ – a variant of initiation of explosive destruction of the hull (EDH) of the first fragmentation-beam shell at the predefined distance to the target;

– $V3$ – the option of causing damage with «useful fragments» of the first FBS to vulnerable AFV compartments;

– $V4$ – receiving messages with the coordinates and characteristics of the target for FBS 2;

– $V5$ – a variant of initiation of the second fragmentation-beam shell at the predefined distance to the target;

– $V6$ – the option of causing damage with «useful fragments» of the second FBS to vulnerable AFV compartments;

– $V7$ – receiving messages with the coordinates and characteristics of the target for FBS 3;

– $V8$ – a variant of initiation of the EDH of the third fragmentation-beam shell at the predefined distance to the target;

– $V9$ – an option of causing damage with «useful fragments» of the third FBS to vulnerable AFV compartments.

Component $V1$ characterizes the result of receiving a message about the state of the target during the «target highlighting» for the first shot:

– initial value $V1=0$;

– $V1=1$ indicates that the target status message was successfully received during the «target highlighting» for the first shot;

– $V1=2$ indicates that the target status message was unsuccessful during «target highlighting» for the first shot.

Component $V4$ characterizes the result of receiving a message about the state of the target during the «target highlighting» for the second shot:

– initial value $V4=0$;

– $V4=1$ indicates that the target status message was successfully received during the «target highlighting» for the second shot;

– $V4=2$ indicates that the target status message was unsuccessful during target highlighting for the second shot.

The $V7$ component characterizes the result of receiving a message about the state of the target during the «target highlighting» for the third shot:

– initial value $V7=0$;

– $V7=1$ indicates that the target status message was successfully received during the «target highlighting» for the third shot;

– $V7=2$ indicates that the target status message was unsuccessful when «highlighting the target» for the third shot.

Component $V2$ reveals the variant of EDH initiation of the first fragmentation-beam shell at the predefined distance from the target:

– initial value $V2=0$;

– $V2=1$ indicates a successful explosion of the first FBS at the predefined distance to the target;

– $V2=2$ indicates the unsuccessful explosion of the first FBS at the predefined distance to the target.

Component $V5$ reveals the variant of EDH initiation of the second fragmentation-beam shell at the predefined distance to AFV:

– initial value $V5=0$;

– $V5=1$ indicates a successful explosion of the second FBS at the predefined distance to AFV;

– $V5=2$ indicates an unsuccessful explosion of the second FBS at the predefined distance to AFV.

Component $V8$ reveals the variant of EDH initiation of the third fragmentation-beam shell at the predefined distance to AFV:

– initial value $V8=0$;

– $V8=1$ indicates a successful explosion of the third FBS at the predefined distance to AFV;

– $V8=2$ indicates an unsuccessful explosion of the third FBS at the predefined distance to AFV.

Component $V3$ characterizes the extent of damage to the vulnerable compartments of mobile AFV by the first FBS:

– the initial value of the absence of damage to the vulnerable compartments of mobile AFV $V3=0$;

– $V3=1$ indicates successful damage with «useful fragments» to the vulnerable AFV compartments by the first FBS;

– $V3=2$ indicates unsuccessful damage with «useful fragments» to the vulnerable compartments of AFV by the first FBS.

Component $V6$ characterizes the extent of damage to the vulnerable compartments of movable AFV by the second FBS:

– the initial value of the absence of damage to the vulnerable compartments of mobile AFV $V6=0$;

– $V6=1$ indicates successful damage with useful fragments to the vulnerable AFV compartments by the second FBS;

– $V6=2$ indicates unsuccessful damage with «useful fragments» to the vulnerable AFV compartments by the second FBS.

Component $V9$ characterizes the extent of damage to the vulnerable compartments of mobile AFV by the third FBS:

– the initial value of the absence of damage to the vulnerable compartments of mobile AFV $V9=0$;

– $V9=1$ indicates successful damage with «useful fragments» to the vulnerable AFV compartments by the third FBS;

– $V9=2$ indicates unsuccessful damage with «useful fragments» to the vulnerable AFV compartments by the third FBS.

Thus, determining the structure of the vector of the state of damage to the vulnerable AFV compartments is characterized by a minimum set of components of the system «FP – PAG – FBS» in a series of three shots and further integration into the model of shooting a moving armored fighting vehicle with directed fragmentation-beam shells.

It is known that any stochastic model is based on a clear algorithm of events that can be described by the so-called state and transition graph. However, the process of its design is associated with the clear establishment of some key input values. Such values can include basic events, a state vector, the indicators of functionality of components of the object of research, and the average duration of procedures in a behavioral algorithm [15, 16]. Underlying the method of constructing the state and transition graph is the basic events of the process of shooting a moving armored target with a series of directed fragmentation-beam shells using a prospective automatic gun with the help of FP.

The number of components determines the degree of adequacy of the model while the initial values of the components of the state vector represent the vector of the first state (the first state of the graph) [15]. For each basic event and its alternative continuation, changes are made to the values of the components of the state vector, which forms vectors of new states with additional checking for repetitions of the sequence numbers of previous state vectors. Determining the intensity of the transition and the rule of modification of components of the state vector are described by formulas. To design a state and transition graph, its tabular representation is convenient.

Thus, the model includes the following indicators of the functionality of the execution of individual procedures of the shooting process in the form of a probability:

– successful reception of messages by PAG with the coordinates and characteristics of the target for the first, second, and third FBS (P_{SR1}, P_{SR2}, P_{SR3});

– successful remote detonation of the first, second, third FBS (P_{rd1}, P_{rd2}, P_{rd3});

– causing damage with «useful fragments» of the first, second, third FBS to the vulnerable compartments of AFV (P_{cd1}, P_{cd2}, P_{cd3});

– successful loading of the first, second, third FBS, that is, the FBS transfer from the ammunition rack to the PAG charging storage (P_{SL1}, P_{SL2}, P_{SL3}).

The average duration of the flight duration of fragmentation-beam shells is also represented: the first $\bar{t}_{1F}$ (s), the second $\bar{t}_{2F}$ (s), and, accordingly, the third $\bar{t}_{3F}$ (s).

The model of the shooting process in the form of a graph of states and transitions is given in Table 5.

Preliminary assumptions regarding determining the events were obtained empirically. Modeling of discrete continuous stochastic systems was implemented in the ASNA software module. Working with this software module involves preliminary development of structural and automatic models, which are the chosen configuration of the fault-tolerant system and its behavior. In the ASNA system, diagrams of the relationship between high-explosive fragmentation projectiles and fragmentation-beam shells were created on large data sets for which the confidence interval was selected. A detailed description of the methodology is to be included in our future papers.

The resulting graph of states and transitions makes it possible to build a discrete-continuous stochastic model in the form of a system of Kolmogorov-Chapman differential equations ((1) to (9), given in abbreviated form):

$$\frac{dP_2(t)}{dt}=\left(\frac{1}{t_{1F}}P_{SR1}P_{RD1}P_{CD1}\right)P_1(t)-$$
$$-\begin{pmatrix}\frac{1}{t_{2F}}P_{SR2}P_{RD2}P_{CD2}+\frac{1}{t_{2D}}(1-P_{SR2})+\\ +\frac{1}{t_{2F}}P_{SR2}(1-P_{RD2})P_{CD2}+\\ +\frac{1}{t_{2F}}P_{SR2}P_{RD2}(1-P_{CD2})+\\ +\frac{1}{t_{2F}}P_{SR2}(1-P_{RD2})(1-P_{CD2})\end{pmatrix}P_2(t), \quad (1)$$

$$\frac{dP_3(t)}{dt}=\left(\frac{1}{t_{1F}}(1-P_{SR1})\right)P_1(t)-$$
$$-\begin{pmatrix}\frac{1}{t_{2F}}P_{SR2}P_{RD2}P_{CD2}+\frac{1}{t_{2F}}(1-P_{SR2})+\\ +\frac{1}{t_{2F}}P_{SR2}(1-P_{RD2})P_{CD2}+\\ +\frac{1}{t_{2F}}P_{SR2}P_{RD2}(1-P_{CD2})+\\ +\frac{1}{t_{2F}}P_{SR2}(1-P_{RD2})(1-P_{CD2})\end{pmatrix}P_3(t), \quad (2)$$

Table 5

Model of the shooting process in the form of a state and transition graph

Step number	Considered state and actual basic events	Probabilities of alternative process extensions	State vector									State number	Transition	Formulas for calculating the intensity of the transition
			V1	*V2*	*V3*	*V4*	*V5*	*V6*	*V7*	*V8*	*V9*			
1	Initial state	–	0	0	0	0	0	0	0	0	0	1	–	–
2	1BE1 ComBE2 ComBE3	$P_{SR1}P_{RD1}P_{CD1}$	**1**	**1**	**1**	0	0	0	0	0	0	2	1→2	$P_{SR1}P_{RD1}P_{CD1}/t_{3F}$
3		$1-P_{SR1}$	**2**	**0**	**0**	0	0	0	0	0	0	3	1→4	$1-P_{SR1}/t_{3F}$
4		$P_{SR1}(1-P_{SR1})\times P_{CD1}$	**1**	**2**	**1**	0	0	0	0	0	0	4	1→4	$P_{SR1}(1-P_{RD1})\times P_{CD1}/t_{3F}$
5		$P_{SR1}P_{RD1}\times(1-P_{CD1})$	**1**	**1**	**2**	0	0	0	0	0	0	5	1→5	$P_{SR1}P_{RD1}\times(1-P_{CD1})/t_{3F}$
6		$P_{SR1}(1-P_{RD1})\times(1-P_{CD1})$	**1**	**2**	**2**	0	0	0	0	0	0	6	1→5	$P_{SR1}(1-P_{RD1})\times(1-P_{CD1})/t_{3F}$
...														
152	31BE7 ComBE8 ComBE9	$P_{SR3}P_{RD3}P_{CD3}$	1	2	2	1	2	2	**1**	**1**	**1**	152	31→152	$P_{SR3}P_{RD3}P_{CD3}/t_{3F}$
153		$1-P_{SR3}$	1	2	2	1	2	2	**2**	**0**	**0**	153	31→153	$1-P_{SR3}/t_{3F}$
154		$P_{SR3}(1-P_{RD3})\times P_{CD3}$	1	2	2	1	2	2	**1**	**2**	**1**	154	31→154	$P_{SR3}(1-P_{RD3})\times P_{CD3}/t_{3F}$
155		$P_{SR3}\ P_{RD3}\times(1-P_{CD3})$	1	2	2	1	2	2	**1**	**1**	**2**	155	31→155	$P_{SR3}P_{RD3}\times(1-P_{CD3})/t_{3F}$
156		$P_{SR3}(1-P_{RD3})\times(1-P_{CD3})$	1	2	2	1	2	2	**1**	**2**	**2**	156	31→156	$P_{SR3}(1-P_{RD3})\times(1-P_{CD3})/t_{3F}$

$$\frac{dP_4(t)}{dt}=\left(\frac{1}{t_{1\mathrm{F}}}P_{\mathrm{SR1}}\left(1-P_{\mathrm{RD1}}\right)P_{\mathrm{CD1}}\right)P_1(t)-$$
$$-\left(\begin{array}{l}\frac{1}{t_{2\mathrm{F}}}P_{\mathrm{SR2}}P_{\mathrm{RD2}}P_{=72}+\frac{1}{t_{2\mathrm{F}}}\left(1-P_{\mathrm{SR2}}\right)+\\ +\frac{1}{t_{2\mathrm{F}}}P_{\mathrm{SR2}}\left(1-P_{\mathrm{RD2}}\right)P_{\mathrm{CD2}}+\\ +\frac{1}{t_{2\mathrm{F}}}P_{\mathrm{SR2}}P_{\mathrm{RD2}}\left(1-P_{\mathrm{CD2}}\right)+\\ +\frac{1}{t_{2\mathrm{F}}}P_{\mathrm{SR2}}\left(1-P_{\mathrm{RD2}}\right)\left(1-P_{\mathrm{CD2}}\right)\end{array}\right)P_4(t), \tag{3}$$

$$\frac{dP_5(t)}{dt}=\left(\frac{1}{t_{1\mathrm{F}}}P_{\mathrm{SR1}}P_{\mathrm{RD1}}\left(1-P_{\mathrm{CD1}}\right)\right)P_1(t)-$$
$$-\left(\begin{array}{l}\frac{1}{t_{2\mathrm{F}}}P_{\mathrm{SR2}}P_{\mathrm{RD2}}P_{\mathrm{CD2}}+\frac{1}{t_{2\mathrm{F}}}\left(1-P_{\mathrm{SR2}}\right)+\\ +\frac{1}{t_{2\mathrm{F}}}P_{\mathrm{SR2}}\left(1-P_{\mathrm{RD2}}\right)P_{\mathrm{CD2}}+\\ +\frac{1}{t_{2\mathrm{F}}}P_{\mathrm{SR2}}P_{\mathrm{RD2}}\left(1-P_{\mathrm{CD2}}\right)+\\ +\frac{1}{t_{2\mathrm{F}}}P_{\mathrm{SR2}}\left(1-P_{\mathrm{RD2}}\right)\left(1-P_{\mathrm{CD2}}\right)\end{array}\right)P_5(t). \tag{4}$$

Similarly, there is a conversion for other steps, for example:

$$\frac{dP_{87}(t)}{dt}=\left(\frac{1}{t_{3\mathrm{D}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}P_{\mathrm{CD3}}\right)P_{18}(t)-$$
$$-\left(\begin{array}{l}\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}P_{\mathrm{CD3}}+\frac{1}{t_{3\mathrm{F}}}\left(1-P_{\mathrm{SR3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}\left(1-P_{\mathrm{CD3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)\left(1-P_{\mathrm{CD3}}\right)\end{array}\right)P_{87}(t), \tag{5}$$

$$\frac{dP_{88}(t)}{dt}=\left(\frac{1}{t_{3\mathrm{F}}}\left(1-P_{\mathrm{SR3}}\right)\right)P_{18}(t)-$$
$$-\left(\begin{array}{l}\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{C?3}}P_{\mathrm{RD3}}P_{\mathrm{CD3}}+\frac{1}{t_{3\mathrm{F}}}\left(1-P_{\mathrm{SR3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)P_{\mathrm{CD3}}+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}\left(1-P_{\mathrm{CD3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)\left(1-P_{\mathrm{CD3}}\right)\end{array}\right)P_{88}(t), \tag{6}$$

$$\frac{dP_{89}(t)}{dt}=\left(\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)P_{\mathrm{CD3}}\right)P_{18}(t)-$$
$$-\left(\begin{array}{l}\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}P_{\mathrm{CD3}}+\frac{1}{t_{3\mathrm{F}}}\left(1-P_{\mathrm{SR3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)P_{\mathrm{CD3}}+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}\left(1-P_{\mathrm{CD3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)\left(1-P_{\mathrm{CD3}}\right)\end{array}\right)P_{89}(t), \tag{7}$$

$$\frac{dP_{155}(t)}{dt}=\left(\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}\left(1-P_{\mathrm{CD3}}\right)\right)P_{31}(t)-$$
$$-\left(\begin{array}{l}\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}P_{\mathrm{CD3}}+\frac{1}{t_{3\mathrm{F}}}\left(1-P_{\mathrm{SR3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)P_{\mathrm{CD3}}+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}\left(1-P_{\mathrm{CD3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)\left(1-P_{\mathrm{CD3}}\right)\end{array}\right)P_{155}(t), \tag{8}$$

$$\frac{dP_{156}(t)}{dt}=\left(\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)\left(1-P_{\mathrm{CD3}}\right)\right)P_{31}(t)-$$
$$-\left(\begin{array}{l}\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}P_{\mathrm{CD3}}+\frac{1}{t_{3\mathrm{F}}}\left(1-P_{\mathrm{SR3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)P_{\mathrm{CD3}}+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}P_{\mathrm{RD3}}\left(1-P_{\mathrm{CD3}}\right)+\\ +\frac{1}{t_{3\mathrm{F}}}P_{\mathrm{SR3}}\left(1-P_{\mathrm{RD3}}\right)\left(1-P_{\mathrm{CD3}}\right)\end{array}\right)P_{156}(t). \tag{9}$$

The calculations that we carried out using the proposed model for fragmentation-beam shells produced results close to those reported in work [17]. A positive difference compared to existing procedures is the speed of such calculations since it is 25 % lower on average due to the possibility of solving the multivariant analysis problem. The specified value of time win is achieved by the fact that the greater the number of events laid in the model, the more accurate the calculation results. Although the introduction of additional events takes time, the results do not require clarification, which leads to a decrease in the time of design work.

6. Discussion of results of studying the construction of a model of the shooting process

Determining the generalized process of shooting a moving armored target in the form of interrelated processes of the components of the system involves a step-by-step consideration of all possible options for its behavior. These options arise from the moment the AFV is detected to the refusal of its crew to perform tasks for its intended purpose. This is described in this paper by a discretely continuous random process, which is represented by the diagrams of the process of causing damage to a moving armored object (Fig. 3–6).

The peculiarity of the proposed approach to devising a model of the shooting process is the use of verbal-to-describe procedures, the application of basic events taking into consideration various processes and procedures that are included in the algorithm of behavior of the shooting process. At the same time, indicators of the functionality of the execution of certain procedures of the shooting process are represented in the form of probability and are continuation of the research reported in [9].

Although this study is limited to the process of shooting, consisting of a series of three shots, this approach is justified because it is predetermined by the need to quickly perform the task of hitting a target before being detected by the enemy.

The model itself can be expanded and modified for other parameters of shooting.

The area of further investigation is to determine the components of the structural-automatic model of single target shooting in armor protection with directed fragmentation-beam shells in a series of three shots based on the reference graph of states. There is reason to believe that the procedures for shooting a single target in armor protection should be formalized to form preconditions for obtaining the value for a statistical indicator of the effectiveness of damage to a target and to study further alternatives to this process.

7. Conclusions

1. A verbal model of the process of shooting a moving armored target with a series of directed fragmentation-beam shells has been built by highlighting certain procedures and their verbal descriptions. This model is based on the algorithm of behavior of the research object in the form of a prospective automatic gun, an observation point, and fragmentation-beam shells, which are in a series of three shots.

2. The proposed verbal model was analyzed as the object of research by a discrete-continuous random process. The analysis was carried out in terms of causing damage to the vulnerable compartments of an armored target with «useful fragments» using FBS with each shot in a series of three. The process of shooting is considered to be a set of interrelated processes of «illumination» of a mobile AFV by means of reconnaissance, failure-free firing from a prospective automatic gun, and controlled remote detonation of fragmentation-beam shells.

3. As parameters of the shooting process, the range to the target, the angle of FBS approach to the target, the depth of the space of damage to AFV, the visual dimensions of the target, the approximate dimensions of the vulnerable target compartments were chosen. This makes it possible to formalize the description of the process and its individual procedures.

4. The construction of a discrete-continuous stochastic model providing for determining basic events is proposed to be carried out based on the state and transition graph. This creates an opportunity to determine the effectiveness of both defeat systems and the interaction between them. The components of the states chosen were receiving the messages with the coordinates and characteristics of the target, initiating the explosive destruction of the fragmentation-beam shell hull, and inflicting damage with «useful fragments» of FBS to the vulnerable AFV compartments. Transitions, which mean moving an object from one state to another, depending on the step number, determine the formula for calculating the intensity of the transition.

5. Shooting a moving armored target by a series of directed fragmentation-beam shells is proposed to be represented in the form of a discrete-continuous random process. For this purpose, the basic events of the attack were determined, a component of the state vector of the object of research was established, and a model was represented in the form of a state and transition graph. The stochastic model built is represented in the form of a system of Kolmogorov-Chapman differential equations. This makes it possible to derive the value of a statistical indicator of the effectiveness of damage to the target and to study alternative options for the process of causing damage to the vulnerable compartments of armored fighting vehicles.

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