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RESEARCH ARTICLE

Calculation Model and Method of Gain-Loss Game Distribution Mechanism on Projectile and Target Intersection Confront

YUN HAO [1] AND HANSHAN LI [2]
[1]School of Mechatronic Engineering, Xi'an Technological University, Xi'an 710021, China
[2]School of Electronic and Information Engineering, Xi'an Technological University, Xi'an 710021, China

Corresponding author: Yun Hao (yunhao1995@yeah.net)

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ABSTRACT Aiming at the problem of damage calculation under the confront game mechanism formed by the projectile and target intersection in the weapon range damage test, this paper proposes a target damage calculation model and method of gain-loss game distribution mechanism on projectile and target intersection confront based on the characteristics of the projectile and target intersection confront game. In this method, the damage of the confront game between the projectile and the target is regarded as the participants of the two-person zero-sum non-cooperative game. According to the gain-loss relationship between the participants of the projectile and the target, we establish a damage assessment calculation model with the confront game between the projectile and the target, and derive the payoff function of the attack-defense game between the projectile and the target. We also establish a target damage calculation model with value / cost index function, determine the value / cost index function of projectile attack target, and give the calculation algorithm of projectile attack target damage based on game theory, and also research the allocation method of projectile attack target based on value / cost index function, at last, give the optimized target damage evaluation system. Through quantitative calculation and analysis, it is found that the effect of target damage is different under different conditions of game strategies, especially the value of value / cost index function is different. The obtained game damage probability presents a random number of Gaussian distribution. When the optimal distribution value is satisfied, the target damage effect is the best, which verifies the scientific type and rationality of the damage calculation model proposed in this paper.

INDEX TERMS Target damage, game, projectile, gain and loss, indicator function.

I. INTRODUCTION

A. REARSEARCH BACKGROUND

Target damage effectiveness evaluation is an important content of weapon performance characterization, which involves a comprehensive evaluation system of weapon performance index, and belongs to a probabilistic evaluation system, at the same time, target damage is also an important strategic significance in the fields of aviation, aerospace, navigation, and weapons, which is roughly divided into ground-to-ground target damage, ground-to-air target damage, air-to-air target damage, ground-sea-air target damage, etc. The damage factors involved in different types of targets are also different, and the resulting damage effects vary greatly, especially in the field of ammunition damage efficiency and damage forms in the weapon industry development. No matter what kind of ammunition weapon damage effectiveness is still concerned with the dynamic parameters of projectiles and their fragments. For example, the flight speed and invasion position parameters of high-speed armor-piercing projectiles [1], [2], the dynamic dispersion parameters of warhead fragments [3], [4], [5], and the speed and position of each projectile target of various multi-barrel gun-launched weapons in the terminal trajectory. Accurate acquisition of these parameters is an important basis for effective analysis of target damage effectiveness. It is one of the important research contents of

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fuze performance evaluation for proximity damage caused by projectile and target (missile) intersection.

Because the intersection attitude of projectile and target in the air is random, the angle, position and attitude of their intersection are also uncertain with the launching state of artillery. It is difficult to accurately test the relative attitude parameters of fuze and target, and it is impossible to obtain the damage effect of fuze on projectile by direct test verification method [6], [7], [8], [9]. At present, the analysis of target damage usually uses simulation calculation or fragments formed by static fuze explosion on the ground to quantitatively calculate the damage results, and there is no comprehensive analysis of the effect of target damage under projectile and target intersection. However, in the complex war environment, in order to make full use of battlefield resources and improve combat effectiveness, it is necessary to comprehensively analyze and evaluate the lethal weapons that play a central role in the battlefield, so as to provide decision-making basis for combat command. As a part of the combat battlefield, the damage effect of the projectile fuze to the air target is directly related to the degree of the threat of the incoming target (missile) to our battlefield. How to maximize the formation of the intercept projectile in the air is an important mission of the fuze. The interception effect of the fuze is reflected in the damage result of the projectile and target intersection state [10], [11]. Therefore, the development of a gain-loss based projectile and target (missile) intersection confront game damage calculation model can provide a basis for effectively improving the scientific evaluation of ammunition damage effects.

B. RELATED WORK

For the study of target damage assessment, in the late 1970s, the United States, Britain, France, Netherlands, Sweden and other countries have carried out research and application work on battlefield damage assessment and repair [12], [13]. The U.S. military 's target damage effect assessment began with aerial bombardment, and the official definition of the U.S. military 's target damage assessment is a timely and accurate assessment of the damage caused by a lethal or non-lethal military force to a predetermined target, including air, ground, sea, and special operations weapon systems [14]. They have three training centers, the National Training Center, the Joint Operational Readiness Training Center and the Combat Maneuver Training Center, which are engaged in the collection of combat damage data. At the same time, they have also established a combat damage data analysis center in the whole army to analyze and manage the damage data, which provides rich data support for the construction of the US military target damage effect evaluation system [15]. In addition, the Army Research Laboratory (ARL) and the Ballistics Research Laboratory (BRL) of the United States have done a lot of in-depth and detailed research on the end-point damage effect and mechanism of target damage by using computer simulation technology, and developed a variety of typical target damage assessment models and procedures, and applied the research and analysis results to weapon engineering design. For example, the target damage information assessment system developed by Glenn Dickson [16], [17], which inputs the enemy's combat sequence and its own killing system in the area of interest to the database, can realize the automation of damage assessment. Ma et al. [18] studied the damage tree to analyze the target functional structure. Lu et al. [19] studied the effectiveness evaluation of weapon power field, and gave the power mechanism of weapon launching ammunition from the characteristic parameters of the weapon itself. Most of these model the damage of targets from the perspective of the power generated by weapons or ammunition itself, and do not analyze the confront characteristics generated by weapons attacking targets. Feng et al. [20] proposed a damage effect modeling method of area target based on the damage effect function since the traditional damage effect calculation method of the non-uniform area target needs to re-do the Monte-Carlo simulation after the position of sub-target changes. Xie et al. [21] established a multi-level damage assessment framework for multi-target systems based on fuzzy hierarchical analysis and cloud modeling. Zhi et al. [22] proposed a novel weapon-target assignment model based on shooting probability constraint and an improved equilibrium optimizer algorithm based on nonlinear adaptive inertia weight in which the impact of shooting probability on the effectiveness of air-defense operations was considered. For the randomness of the fragment distribution parameters of the hierarchical fragment warhead, it is difficult to directly use the existing damage evaluation method to calculate it, Xue et al. [23] put forward a target damage probability calculation model based on the hierarchical fragment dispersion characteristics and the target damage criterion. For the mixed target group of sub-targets with different destructive capacity, different importance, uneven distribution, Feng et al. [24] proposed a layer grid method for damage assessment to achieve accurate damage assessment of the whole mixed target group. Zhang et al. [25] used the target range static explosion test and numerical simulation method to establish the directional warhead power damage model under the network, and studied the fragmentation law of different initiating warheads. Most of the literature is from the perspective of the power generated by the weapon or munition itself for target damage modeling, as well as target damage modeling under fire coordination, not from the weapon attack on the target to analyze the characteristics of the confront. There are relatively few studies on target destruction based on projectile and target game confront, mainly focusing on ammunition fire allocation, AUV cooperative confront, robot cooperative confront and other aspects of the research, for example, Wang et al. [26] put forward a new turn-based confront strategy and game model, and designed a highly efficient algorithm of the exact solution. Sun et al. [27] establishes a multi-objective optimization model and a non-cooperative game model, and combined with the taboo search technology, designed an improved genetic algorithm based on Nash equilibrium search (NE-IGA) for solving. Wei and Liu [28] used the game theory of incomplete information to study the confront behavior of AUVs, and added the positional error factor, and then build an incomplete information oriented AUV confront model. Zheng et al. [29] proposed a clustering grouping-based consistent bunching algorithm (C -CBBA) for large-scale task allocation problems with time window constraints, in order to efficiently execute strategies in urban combat environments and quickly calculate acceptable sub-optimal task allocation strategies.

With the development trend of the battlefield situation, the projectile and target space confront with intelligent detection and control is becoming more and clearer. On the one hand, from the perspective of the projectile, the benefit of the fragment group formed by the explosion of the projectile on the target can objectively reflect the damage effect of the projectile on the target within a reasonable range of near-bombing control; on the other hand, from the perspective of the target side, the target should successfully avoid the damage caused by the fragment group formed by the explosion of the projectile on its own attack, in order to improve its own survivability. Therefore, how to choose a reasonable confront strategy to achieve the best damage effect of the projectile on the target is the best judgment basis for the target damage of space interception. Since the damage assessment formed by the projectile and target intersection confront involves many factors, such as the intersection position, the intersection situation of the fragment effectively attacking the target, etc., it is a more scientific evaluation method to determine the parameters of the explosive properties of the projectile by utilizing the different attitudes of the projectile and target intersection to evaluate the damage effect of the target. Therefore, this paper adopts the basic theory of two-player zero-sum non-cooperative game, and establishes the damage model and damage calculation method based on gain-loss game distribution mechanism under projectile and target intersection state.

C. CONTRIBUTION

Based on the characteristics of the projectile and target intersection confront game, this paper studied a target damage calculation model and method of gain-loss game distribution mechanism on projectile-target intersection confront from the gain situation of target damage caused by the fragment group formed by the projectile explosion, and the main work and highlights of this paper are as follows:

(1) Based on the requirement of damage assessment under the confront game mechanism formed by the intersection of projectile and target in the weapon range damage test, we proposed a new calculation model and method of gain-loss game distribution mechanism based on projectile and target intersection confront.

(2) We regarded the projectile and target intersection attack-defense adversarial game damage problem as a two-person zero-sum non-cooperative game between the two participants, and based on the gain-loss relationship between the two participants of the projectile and the target, and established a computational model of destruction assessment with the projectile and target intersection adversarial game, and derived the payoff function for the projectile-target attack-defense game.

(3) Based on the payoff function of the projectile and target attack and defense game, we established a target damage calculation model with a value/cost indicator function, determine the value/cost indicator value of the projectile attack target, and gave the game-theoretic projectile attack target destruction calculation algorithm and calculation steps.

(4) To obtain the optimal damage effect of the game, we also studied the allocation method of the projectile attack target based on the value/cost indicator function, gave the optimized target destruction evaluation system, and verified the scientific type and reasonableness of the destruction calculation model proposed in this paper through quantitative calculations and analysis.

The structure of this paper is organized as follows:

Section II states the basic game model and the set of confront strategies for the projectile and target intersection confront. Section III states the damage game calculation model of projectile and target intersection confront based on gain-loss. Section IV states the target damage algorithm based on value/cost index function. Section V gives the verification calculation and analysis. Finally, the conclusions are drawn in Section VI.

II. THE BASIC GAME MODEL AND COUNTERMEASURE STRATEGY SET OF PROJECTILE AND TARGET INTERSECTIONCONFRONT

To study the damage effect of projectile target intersection and confront in a close combat environment, this paper studies the damage evaluation method of intelligent projectile targets using projectile fuses with certain guidance and control capabilities to carry out attack and defense game confront. According to the actual relationship between the explosion position of the projectile and the target position, the attack-defense game damage of the projectile and the target intersection is regarded as a two-person zero-sum non-cooperative game, and the projectile and the target are regarded as each other's attackers and defenders, forming a game target damage assessment system for projectile and target intersection confront.

It is assumed that the detection and guidance ability of the projectile side is T, the flight attitude is Z, the target recognition ability is E, the relative target action distance of proximity explosion is R, the near-explosive fragment dispersion is ϕ, and the damaged target side has the target recognition ability E', defense ability T', and its own damage factor σ, the weight of the damage as ω, the damage level is$K$, etc. The performance parameters of the projectile side are $F_1(T, Z, E, R, \phi)$, and the performance parameters of the target side are $F_2(T', E', \sigma, \omega, K)$. The relationship between them forms the target damage effect P, P is the common correlation between the projectile side and the target side, which can be characterized as $P = f(F_1, F_2)$. Under the action of confront, F_1 and F_2 form a certain confront game income, and the effect of target damage can be analyzed from the income of the projectile side [30], [31].

The projectile (with certain attack and defense detection and guidance abilities of the projectile) and the target (with certain defense and recognition abilities) are the players 1 and 2 participating in the game [32]. The two-player zero-sum non-cooperative game model can be expressed as $G = \{A_1, A_2; B_1, B_2; Z_1, Z_2\}$, where A_1 and A_2 are the projectile and target (often referring to projectile target or aircraft, etc.) players of the game, and defining A_1 as the attacker and A_2 is the defender. B_1 is the strategy set obtained by the projectile attacking the target, B_2 is the strategy set obtained by the target effective defense projectile, Z_1 and Z_2 are the income function sets of projectile attack and target defense. For each player 1 and 2, they have their own strategy sets, which are composed of limited strategies respectively. Suppose that the strategy combination is (Z_1^l, Z_2^k), the expected payoffs of players 1 and 2 are $f_1(Z_1^l, Z_2^k)$ and $f_2(Z_1^l, Z_2^k)$, respectively, and the sum of the two payoffs is zero, because players 1 and 2 have a finite set of strategies, and the payoffs of two players to any strategy combination are zero. The random matrix game is also called the two-person finite zero-sum game [33], [34].

The attack and defense game damage problem of projectile and target intersection confront can be regarded as participant 1 and participant 2, 1 is the projectile attack party, and 2 is the target defense party. As the attacking party, the projectile intersects with the target to form an explosive power fragment field, which causes losses to the ground target. The purpose of the projectile attack is to make the effective fragments formed by itself achieve the optimal damage target. In this case, it is regarded as the projectile to obtain the optimal income. When the target finds the projectile of the incoming attack, it uses its own defense system to interfere with the projectile, so that the projectile does not explode, or the projectile explodes before exceeding the damage target, that is, the detection guidance ability and detection distance of the projectile cannot meet the predetermined detonation set value. This phenomenon is called projectile loss. Under this condition, the target can preserve its own viability, which is called target for gain. In the process of confront between the two sides, both sides are looking for the best strategy to find the Nash equilibrium point of the game matrix.

According to the above definition, it is assumed that the player 1 (the projectile side) has n projectiles, the set is $\{U_1, U_2, \cdots, U_n\}$, $x_{ij} (i = 1, 2, \cdots, n; j = 1, 2, \cdots, m)$ represents the projectile confront state, $x_{ij} = 1$ represents the i shell on the projectile square array attacked the j target position, $x_{ij} = 0$ represents the i shell failed to attack the target, which can be regarded as the projectile is in a defensive state, that is, the projectile body does not form an explosive power. When the player 2 (the target side) finds the threat of the projectile attack, it chooses whether to counterattack the projectile to protect its position by evaluating the battlefield situation. The set of the target square is $\{D_1, D_2, \cdots, D_m\}$, $y_{ij} \{i = 1, 2, \cdots, n; j = 1, 2, \cdots, m\}$ represents the confront state of the target, $y_{ij} = 1$ means that target i is effectively defending confront j, and $y_{ij} = 0$ represents that target i is not effectively defending confront j. The strategy set of the projectile is $\{x_1, x_2, \cdots, x_n\}$, and the strategy set of the target is $\{y_1, y_2, \cdots, y_n\}$.

According to the basic confront game model and definition of projectile and target intersection, the overall design of target damage calculation and evaluation method based on gain-loss mechanism is shown in Fig.1.

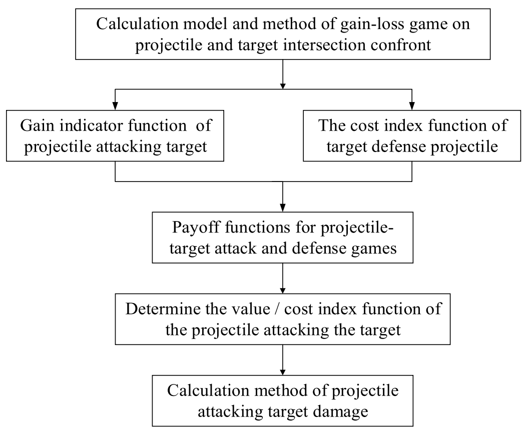

FIGURE 1. The overall design of target damage calculation and evaluation method based on gain-loss mechanism.

This paper from the two-person zero-sum non-cooperative game theory, first of all, we establish the gain index function of the projectile attacking the target and the cost index function of the target defense, so as to establish the payoff function of the projectile and the target attack and defense game. Secondly, based on the payoff function of the attack-defense game between the projectile and the target, we set up a target damage calculation model with a value / cost index function to determine the value / cost index function value of the projectile attacking the target. Thirdly, based on the selection rules of indicator function values, we search the elements of indicator function values that meet the conditions, and assign the target corresponding to that element to the attacking projectile. At last, through the attack effect of the assigned projectile on the target, the damage result of the target can be determined, and form the calculation system of projectile attack target damage assessment based on game theory.

III. DAMAGE GAME CALCULATION MODEL OF PROJECTILE AND TARGET INTERSECTION CONFRONT BASED ON GAIN-LOSS

A. REVENUE OF PROJECTILE ATTACKING TARGET

From the perspective of the profit of the projectile attacking the target, it is assumed that the target value set is $\{v_1, v_2, \cdots, v_m\}$, the projectile value is v_a, $v_{\max}$ is the maximum profit of the projectile attack, that is, $v_{\max} = \max v_j$, p_{ij} is the damage probability of the projectile i attacking the ground target j, $p_{ij} = [(p_{i\min}^1, p_{i\max}^1), (p_{i\min}^2, p_{i\max}^2), \cdots, (p_{i\min}^m, p_{i\max}^m)]$, where $(p_{i\min}^j, p_{i\max}^j)$ is the damage interval probability of the i-th projectile to the j-th ground target, and the profit index function R_{ij} is

$$R_{ij} = \frac{v_j \cdot p_{ij} - x_{ij} \cdot v_a}{v_{\max}} \tag{1}$$

If there are k projectiles attacking the target j at the same time, then the gain index function is transformed into R_{ij}^k [35].

$$R_j^k = \frac{v_j \cdot \prod_{j=1}^{k} (1 - p_{ij}) - \sum_{j=1}^{k} x_{ij} \cdot v_a}{v_{\max}} \tag{2}$$

where $x_{ij} = 1$, which means that the i-th projectile effectively attacks the j-th ground target; $x_{ij} = 0$, indicating that the i-th projectile did not attack the j-th ground target.

In the multiple projectile attack ground targets, the projectile and the target have a certain distance, if the distance between the projectile to meet the projectile's own guidance device to launch the explosion conditions, the projectile will form a certain fragmentation power to successfully attack the ground target, which is what we call the projectile effective attack on the target. If the projectile by the target's defense interference, the distance between the projectile and the ground target so that the projectile's own guidance capabilities lost or the resulting explosion has no effect on the target, that is, the projectile did not successfully attack the ground target, which is what we call the projectile did not effectively attack the target. In order to more objectively describe the game between the projectile and the target damage relationship, we introduced the cost function of the distance between the projectile and the target. Assuming that d_{ij} denotes the distance between the i-th projectile and the j-th target, $d_{\max}$ is the maximum distance of the projectile to produce an explosion, $d_{\max} = \max_{1 \le i \le n, 1 \le j \le m} d_{ij}$, then the cost function of the intersection distance of the i-th projectile to destroy the j-th target is $G_{ij} = d_{ij}/d_{\max}$. If there are k projectiles attacking the j-th target at the same time, the intersection distance cost function transforms to formula (3).

$$G_j = \frac{1}{k} \sum_{i=1}^{k} d_{ij}/d_{\max} \tag{3}$$

B. TARGET DEFENSE PROFIT

From the point of view of the target defense benefit, assuming that the projectile value set is $\{v_1', v_2', \cdots, v_n'\}$, v_i' is the value information of the i-th target, $v_{\max}'$ is the maximum value of target defense benefit, p_{ij}' is the interception probability of j-th projectile of i-th target defense, $p_{ij}' = [(p_{j\min}^1, p_{j\max}^1), (p_{j\min}^2, p_{j\max}^2), \cdots, (p_{j\min}^n, p_{j\max}^n)]$, where $(p_{j\min}^i, p_{j\max}^i)$ is the effective defense interval probability of the j-th ground target confront the i-th projectile, v_b is the target value, then the cost index function R_{ij}' of the j-th projectile being defended by the i-th target is

$$R_{ij}' = \frac{v_i' \cdot p_{ij}' - y_{ij} \cdot v_b}{v_{\max}'} \tag{4}$$

If there is an l target defending the j-th projectile at the same time, then the defense cost index function is transformed into R_{ij}' [36].

$$R_j'^l = \frac{\sum_{i=1}^{l} v_i'[1 - \prod_{i=1}^{l} (1 - p_{ij}')] - y_{ij} \cdot v_b}{l \cdot v_{\max}'} \tag{5}$$

where $y_{ij} = 1$ denotes that the i-th target effectively defends the j-th projectile; y_{ij}=0 indicates that the i-th target does not effectively defend the j-th projectile.

C. PAYOFF FUNCTION OF ATTACK-DEFENSE GAME BETWEEN PROJECTILE AND TARGET

The payoff function [37] of the damage of the i-th projectile to the j-th ground target can be expressed by formula (6).

$$F_{ij} = \omega_1 \cdot R_{ij} - \omega_2 \cdot G_{ij} - R_{ij}' \tag{6}$$

where ω_1 and ω_2 are the weight of the target value income index and the weight of the intersection distance cost index respectively, $\omega_1 + \omega_2 = 1$. Considering k projectile attacking the j-th ground target at the same time, the payoff function can be expressed by formula (7).

$$F_{ij}^k = \omega_1 \cdot R_j^k - \omega_2 \cdot G_j - R_j'^l \tag{7}$$

Due to the uncertainty of information, each element in the payoff matrix is an interval number. Each row vector of the matrix corresponds to a pure strategy of the projectile, and each column corresponds to a pure strategy of the target. The payoff matrix of the two sides of the game is F [38], it can be expressed by formula (8).

$$F = \begin{bmatrix} & y_1 & y_2 & \cdots & y_n \\ x_1 & F_{11} & F_{12} & \cdots & F_{1n} \\ x_2 & F_{21} & F_{22} & \cdots & F_{2n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ x_n & F_{n1} & F_{n2} & \cdots & F_{nn} \end{bmatrix} = \begin{bmatrix} (f_{\min}^{11}, f_{\max}^{11}) & (f_{\min}^{12}, f_{\max}^{12}) & \cdots & (f_{\min}^{1n}, f_{\max}^{1n}) \\ (f_{\min}^{21}, f_{\max}^{21}) & (f_{\min}^{22}, f_{\max}^{22}) & \cdots & (f_{\min}^{2n}, f_{\max}^{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (f_{\min}^{n1}, f_{\max}^{n1}) & (f_{\min}^{n2}, f_{\max}^{n2}) & \cdots & (f_{\min}^{nn}, f_{\max}^{nn}) \end{bmatrix} \tag{8}$$

where $x_1, x_2, \cdots, x_n$ are the strategies of projectile attack, $y_1, y_2, \cdots, y_n$ are the strategies of target defense, $F_{g1}, F_{g2}, \cdots, F_{gn}$ are the payoff values of projectile attack when the target defense party adopts $y_1, y_2, \cdots, y_n$ strategies when the projectile attack party adopts x_g-th strategy, these payoff values are interval numbers, that is, $(f_1^{g1}, f_2^{g1}), (f_1^{g2}, f_2^{g2}), \cdots, (f_1^{gn}, f_2^{gn})$.

IV. TARGET DAMAGE CALCULATION METHOD BASED ON VALUE/COST INDEX FUNCTION

A. THE DETERMINED OF VALUE / COST INDEX FUNCTION OF PROJECTILE ATTACKING TARGET

From the damage game calculation model of gain-loss projectile intersection, the result of target damage can be regarded as the value or cost of projectile attack target gain and target defense gain as the benchmark of damage assessment. The optimal decision of projectile attacking ground target damage is mainly to obtain the best single target damage effect with the least amount of ammunition. In order to achieve this goal, based on the gain-loss relationship of the damage calculation model of the projectile-target intersection confront game, it is necessary to determine the optimal value / cost ratio of both sides. Therefore, the value / cost index function of both sides must be established to avoid the repeated distribution of projectiles attacking the same target.

The value / cost matrix $D = \left(\overline{d}_{i,j}\right)_{m\times n}$ is constructed by $\overline{d}_{i,j}$, $\overline{d}_{i.j}$ is the value / cost ratio of the i-th projectile to the j-th target, $i = 1, 2, 3, \cdots, n; j = 1, 2, 3, \cdots, m$. The index function to avoid the repeated distribution of projectiles attacking the same target is constructed by formula (9).

$$J = \max \sum_{i=1}^{n} \sum_{j=1}^{m} \partial_{i,j} \times \overline{d}_{i,j} \tag{9}$$

where $\overline{d}_{i,j}$ is the value or cost of the i-th projectile attacking the j-th ground target, and $\partial_{i,j}$ is [0, 1]. When $\partial_{i,j} = 0$, it means that there is no intersection between the projectile and the target. When $\partial_{i,j} = 1$, it means that the i-th projectile attacks the j-th ground target. Their constraints function can be expressed by formula (10).

$$\begin{cases} \sum_{j=1}^{m} \partial_{i,j} \leq E_{\max}^{i}, i = 1, 2, \cdots, n \\ \sum_{i=1}^{n} \partial_{i,j} = 1, j = 1, 2, \cdots, m \end{cases} \tag{10}$$

where $E_{\max}^{i}$ is the maximum number of targets that can be attacked by the i-th projectile [39].

B. DAMAGE GAME ALGORITHM OF PROJECTILE ATTACKING TARGET BASED ON GAME THEORY

Firstly, we established the value / cost matrix of the projectile attacking the ground target. Then, according to the selection rules, searching the eligible elements, and assigned the target corresponding to the element. The damage result of the target is determined by the attack effect of the assigned projectile on the target. The calculation algorithm of projectile attacking target damage based on game theory, the specific steps are as follows:

Step 1: Establish a value / cost matrix.

$$D = \begin{bmatrix} \overline{d}_{1,1}\overline{d}_{1,2}\cdots\overline{d}_{1,m} \\ \overline{d}_{2,1}\overline{d}_{2,2}\cdots\overline{d}_{2,m} \\ \vdots \quad \vdots \quad \overline{d}_{i,j} \quad \vdots \\ \overline{d}_{n,1}\overline{d}_{n,2}\cdots\overline{d}_{n,m} \end{bmatrix}_{n\times m} \tag{11}$$

In (11), $\overline{d}_{i,j}$ is the value / cost ratio of the i-th projectile to the j-th target.

Step 2: Determine the first projectile attack object. In order to find the largest or most important target to be destroyed first, the global matrix is searched to obtain the largest element $\overline{d}_{i,j}$, and the footmarks i and j are written down. The i-th projectile is paired with the j-th target, that is, the projectile A_i attacks the target E_j, and is recorded as $A_i \to E_j$.

Step 3: Adjust the value / cost matrix to determine the target of attack A_i. According to the process of the game, after the projectile side determines the primary attack target, the defense target side will have a defensive interception. Taking the projectile side A_i as an example, the attacked target side will select the weapon with the largest damage value / cost to A_i in all its defense systems (the smallest in matrix D) to intercept. Therefore, the element $d_{i,j}$ is first multiplied by the coefficient σ, σ is the value / cost reduction coefficient, and the value [0, 1) is obtained. And $\sigma = 0$ indicates that the target is selected as the attack object and is completely damaged. Then find the smallest non-zero element in line i, and get the element $\overline{d}_{i,a}$, $a = 1, 2, 3, \cdots, m; a \neq j$, that is, the attacked target party will launch E_a to intercept A_i, denoted as $E_a \to A_i$.

Step 4: Adjust the value / cost matrix again to determine the projectile that attacking target E_a. Based on the principle of effectively eliminating ground targets, the projectile with the largest value / cost to target E_a is selected from the projectiles except A_i to attack target E_a. Therefore, the element $\overline{d}_{i,a}$ of the matrix D is multiplied by the coefficient σ, and then the largest element is searched in the a column of the matrix D to obtain the element $\overline{d}_{c,a}$, and the footmarks c and a are recorded, that is, the projectile A_c attacks the target E_a, recorded as $A_c \to E_a$.

Step 5: Determine whether the target is completely allocated. If it is not completed, the process of Step 3 and Step 4 is repeated to assign attack targets to other projectiles until all target assignments are completed.

Step 6: Taking the optimal value / cost and avoiding the repeated distribution of projectiles attacking the same target as the rules, the target allocation results are optimized, so as to obtain the target damage results of the profit-loss projectile intersection confront game. Combined with the damage calculation steps of projectile attacking target based on game theory, the processing flow chart of the algorithm is shown in Fig.2.

V. VERIFICATION CALCULATION AND ANALYSIS

According to the established game damage model and algorithm of projectile and target intersection confront, it is

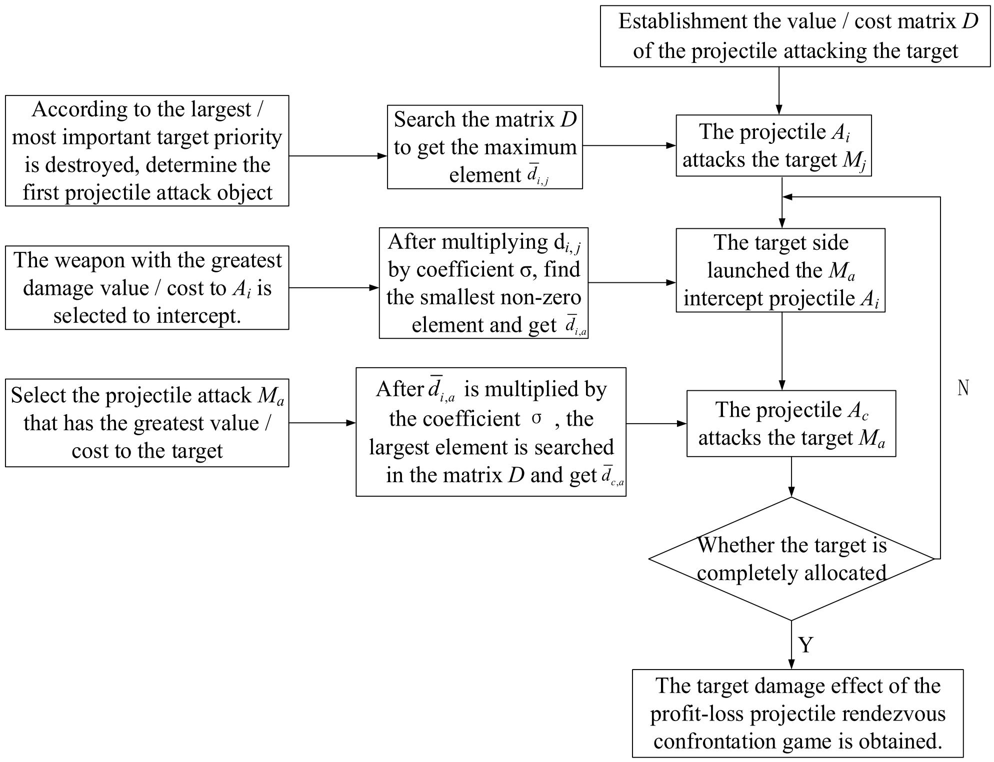

FIGURE 2. **Flow chart of damage calculation algorithm for projectile attacking target based on game theory.**

assumed that there were two projectiles attacking two ground armored targets on the ground. The probability of projectile attacking the target damage interval is shown in Table 1, and the probability of ground armored target defense is shown in Table 2.

TABLE 1. **Damage probability of projectile attacking ground target.**

	p_{ij}	Target damage probability	
		Target 1	Target 1
The ground target is in a defensive state	Projectile 1	(0.34,0.39)	(0.24,0.32)
	Projectile 2	(0.27,0.31)	(0.21,0.29)
The ground target is under attack	Projectile 1	(0.61,0.68)	(0.62,0.74)
	Projectile 2	(0.52,0.64)	(0.56,0.63)

TABLE 2. **Probability of ground target defense projectile.**

	p'_{ij}	Defense probability	
		Projectile 1	Projectile 2
State of projectile attacking ground target	Target 1	(0.23,0.31)	(0.21,0.34)
	Target 2	(0.24,0.29)	(0.16,0.23)
The projectile invalid attack target state	Target 1	(0.36,0.42)	(0.31,0.48)
	Target 2	(0.38,0.51)	(0.35,0.49)

The value matrix of the two projectiles is [21, 27], and the estimated value matrix of the target interval is [31.8, 44.7]. The projectile attack strategy set is $\{x_1, x_2, \cdots, x_n\}$, where: strategy x_1 represents that projectile 1 effectively attacks target 1, projectile 2 effectively attacks target 2; strategy x_2 indicates that the projectile 1 effectively attacks the target 1, and the projectile 2 attacks the target 2 in an invalid state; the strategy x_3 indicates that the projectile 1 attacking target 1 is in an invalid state, and the projectile 2 attacking target 2 effectively; strategy x_4 indicates that projectile 1 attacking target 1 is in an invalid state, and projectile 2 attacking target 2 is also in an invalid state. Strategy x_5 means that projectile 1 effectively attacks target 2, and projectile 2 effectively attacks target 1; the strategy x_6 indicates that the projectile 1 effectively attacks the target 2, and the projectile 2 attacks the target 1 in an invalid state; strategy x_7 indicates that projectile 1 attacking target 2 is invalid, and projectile 2 attacking target 1 effectively. Similarly, the strategy set of ground target defense projectile attack is $\{y_1, y_2, \cdots, y_n\}$, strategy y_1 indicates that target 1 effectively defends projectile 1, and target 2 effectively defends projectile 1; strategy y_2 means that target 1 effectively defends projectile 1, and target 2 ineffective defends projectile 1; strategy y_3 represents target 1 ineffective defense projectile 1, target 2 effective defense projectile 1; strategy y_4 means that target 1 effectively defends projectile 2, and target 2 effectively defends projectile 1; strategy y_5 represents the effective defense projectile 2 of target 1, and the ineffective defense projectile 1 of target 2; strategy y_6 indicates that target 1 is ineffective to defend projectile 2, and target 2 is effective to defend projectile 1; strategy y_7 represents target 1 ineffective defense projectile 2, target 2 ineffective defense projectile 1.

According to the payoff function model of both projectile and target, the game matrix of projectile and target confront can be calculated as follows: as shown in the equation at the top of the next page.

Based on the game matrix, the projectile attack strategy set is (0.106, 0, 0, 0.894, 0, 0, 0), the target strategy set is (0, 0, 0.443, 0, 0, 0.557, 0), and the projectile-target intersection attack and defense strategies adopt a mixed strategy set. The probabilities of the first strategy and the fourth strategy of the projectile are 0.281 and 0.656, respectively, and the probability of other strategies is 0. That is, the strategy probability of projectile 1 attacking target 1, projectile 2 attacking target 2 is 0.106, the strategy probability of projectile 1 attacking target 2, projectile 2 attacking target 1 is 0.894. For the target strategy set (0, 0, 0.443, 0, 0, 0.557, 0), the probability of using the third strategy and the sixth strategy for target defense is 0.443 and 0.557, respectively, and the other probability is 0.That is to say, the probability of selecting the target 1 ineffective defense projectile 1 and the target 2 effective defense projectile 1 is 0.443, and the probability of selecting the target 1 ineffective defense projectile 2 and the target 2 effective defense projectile 1 is 0.557.

Considering the value / cost index function, we use quantitative calculation and analysis to verify the target damage effect. Based on the calculation method of table 1 and table 2, according to the early enough index function, and considering the gain-loss mode of both sides of the projectile-target intersection game, the damage under the target allocation criterion of projectile attack can be obtained by using the established value / cost matrix and the allocation algorithm of projectile attack target based on game theory. Assuming that 10 projectiles attack 7 ground targets, then $n = 10$, $m = 7$. The normalized value of the ground target is [0.224,0.235,0.029,0.256,0.171,0.028,0.057], and the damage probability of the projectile to the ground target is shown in table 3.

TABLE 3. The probability of 10 projectiles being defended by 7 targets.

Type	E_1	E_2	E_3	E_4	E_5	E_6	E_7
A_1	0.885	0.411	0.326	0.617	0.348	0.129	0.263
A_2	0.783	0.676	0.932	0.687	0.556	0.165	0.643
A_3	0.921	0.186	0.042	0.768	0.225	0.261	0.492
A_4	0.672	0.712	0.047	0.283	0.696	0.851	0.287
A_5	0.039	0.0337	0.395	0.668	0.265	0.271	0.886
A_6	0.867	0.288	0.775	0.687	0.553	0.825	0.597
A_7	0.928	0.049	0.802	0.174	0.708	0.238	0.564
A_8	0.687	0.097	0.194	0.132	0.906	0.911	0.905
A_9	0.783	0.854	0.429	0.443	0.949	0.261	0.298
A_{10}	0.763	0.709	0.653	0.912	0.556	0.218	0.765

The normalized value of the projectile is [0.074,0.155,0.158, 0.042,0.188, 0.128,0.068,0.129,0.213.0.013]. The probability of the projectile being defended by the ground target is shown in Table 4, and the median of the table is a random number that obeys the Gaussian distribution.

TABLE 4. Allocation effect of 10 projectiles on 7 targets.

Type	E_1	E_2	E_3	E_4	E_5	E_6	E_7
A_1	0.778	0.496	0.659	0.987	0.403	0.556	0.176
A_2	0.412	0.012	0.667	0.086	0.267	0.559	0.181
A_3	0.587	0.422	0.767	0.482	0.887	0.153	0.296
A_4	0.084	0.218	0.765	0.112	0.453	0.876	0.445
A_5	0.076	0.819	0.085	0.926	0.937	0.654	0.067
A_6	0.654	0.298	0.226	0.012	0.231	0.423	0.944
A_7	0.863	0.556	0.967	0.784	0.276	0.498	0.952
A_8	0.974	0.158	0.155	0.854	0.179	0.076	0.511
A_9	0.143	0.675	0.873	0.892	0.149	0.081	0.522
A_{10}	0.608	0.277	0.231	0.096	0.887	0.312	0.343

Table 5 is the value / cost matrix D of the projectile. According to the index function and the constraint term, the target allocation algorithm based on game theory is used. The value / cost reduction coefficient is set to 0, and $E^i_{\max} = n$ is taken. After calculation, Table 6 is the optimal result.

TABLE 5. Allocation result of 10 projectiles on 7 targets.

Type	E_1	E_2	E_3	E_4	E_5	E_6	E_7
A_1	3.172	2.833	0.207	1.689	1.721	0.049	1.718
A_2	2.984	86.971	0.299	14.942	2.780	0.051	1682
A_3	2.487	0.877	0.005	2.876	0.328	0.337	0.977
A_4	76.863	43.092	0.484	23.788	12.309	1.443	3.086
A_5	1.084	0.059	1.176	1.298	0.412	0.078	9.111
A_6	2.476	1.780	0.807	217.083	3.871	0.480	0.407
A_7	3.652	0.264	0.398	0.669	5.932	0.213	0.632
A_8	1.321	1.098	0.424	0.312	9.097	5.567	1.276
A_9	57.023	13.564	0.897	6.874	54.974	3.451	2.088
A_{10}	4.769	10.427	1.342	43.808	1.675	0.387	2.652

TABLE 6. Probability of damage of 10 projectiles to 7 targets.

Projectile	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
Target	0	E_2	0	E_1	E_7	E_4	0	E_6	E_5	E_3

From the results of table 6, it can be seen that according to the index function established by the principle of optimal value / cost and avoiding repeated allocation, the projectile-target allocation algorithm based on game theory can obtain reasonable and feasible damage to the target.

This paper introduces the value/cost index function of the projectile attacking the target through the game mechanism of projectile and target attack and defense. On the basis of the index function, the damage algorithm of projectile-target intersection confront game is formed. The algorithm is evaluated based on the Nash equilibrium result of the game.

$$\begin{bmatrix} (21.3, 57.2) & (28.7, 56.9) & (36.4, 57.1) & (20.5, 48.2) & (23.4, 39.7) & (36.4, 53.5) & (48.6, 60.1) \\ (3.4, 13.8) & (4.2, 15.7) & (8.4, 18.2) & (8.8, 19.3) & (1.2, 15.2) & (0.9, 13.2) & (4.8, 13.5) \\ (12.8, 27.3) & (10.2, 22.7) & (18.3, 29.5) & (18.1, 22.8) & (19.8, 24.7) & (9.1, 17.6) & (22.6, 31.6) \\ (4.1, 13.5) & (6.0, 26.2) & (2.9, 13.7) & (8.6, 21.1) & (1.2, 29.6) & (9.5, 13.8) & (5.8, 8.9) \\ (18.8, 21.5) & (18.2, 33.6) & (21.8, 30.8) & (21.4, 45.8) & (12.6, 30.1) & (20.4, 35.2) & (36.6, 47.8) \\ (11.2, 28.6) & (14.5, 27.8) & (17.8, 21.5) & (21.8, 40.7) & (17.3, 29.9) & (31.4, 45.8) & (27.7, 35.5) \\ (11.6, 18.9) & (7.215.6) & (1.23, 5.84) & (0.44, 12.9) & (3.47, 19.2) & (16.8, 29.8) & (7.21, 28.4) \end{bmatrix}$$

In addition, it is the core highlight of this paper to study the target damage calculation and evaluation method under the target value / cost index function system of projectile attack targets. The theoretical model and calculation method of this paper mainly evaluate the target damage based on the specific state and characteristic parameters of space projectile-target intersection. On the one hand, it is reflected in the optimal decision-making damage of projectile attacking ground targets under the state of projectile-target intersection confront game. On the other hand, the calculation model of the paper fully considers the value / cost index function value of both sides, and forms a damage assessment system for projectile attack targets based on game theory. Through quantitative calculation and analysis, it is found that when the projectile-target intersection attack and defense strategy changes, the damage effect of the target formation has an essential change, especially when multiple projectiles attack the same target on the ground. The greater the gain of projectile attack, the more obvious the target damage effect.

VI. CONCLUSION

Aiming at the damage problem of the attack-defense game of projectile-target intersection confront, based on the basic principle of two-person zero-sum non-cooperative game, this paper takes the projectile and the target as the player 1 and player 2 of the game, and develops a gain-loss target damage calculation model and method for the distribution mechanism of projectile and target intersection game. From the value information of both the projectile and the target, the gain cost function of the projectile attacking the ground target and the gain cost function of the ground target defense are established. The distance cost function of projectile and target intersection is introduced, and the payoff matrix of confront game between projectile and target is formed. Based on the gain-loss relationship of the damage calculation model of the projectile intersection confront game, the damage calculation algorithm of the projectile attacking the target based on the game theory is studied. According to the damage probability of the projectile attacking the ground target and the probability data of the ground target defending the projectile, the damage effect of the projectile and the target under different strategies is calculated.

This paper focuses on the modeling and calculation of the damage effect of the target with the attack-defense confront mechanism of projectile-target intersection. The basic model of two-person zero-sum non-cooperative game is introduced. The projectile and the target are taken as the participants in the game confront. and the calculation model for the damage effect of projectile target intersection attack and defense confront is constructed, which is close to the battlefield. The method proposed in this paper reflects the basic mechanism of the damage effect formed by projectile target intersection game confront from two aspects. On the one hand, considering the gain of the fragment group formed by the explosion of the projectile to the target, as the basis of the target damage assessment, it objectively reflects the damage effect of the projectile on the target within a reasonable range of proximity control. On the other hand, from the perspective of the target side, the target should successfully avoid the damage caused by the fragment groups formed by the projectile explosion to their own attack and improve their own survivability. Therefore, considering the specific situation of the projectile-target intersection confront game, this paper establishes a damage calculation method and an evaluation method of damage efficiency that is consistent with the future battlefield projectile fuze attack on the target. It provides new ideas and new methods for the damage assessment of other types of intelligent projectiles confront intelligent targets in the future, and has broad development prospects.

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YUN HAO received the B.S. and Ph.D. degrees in control theory and control engineering from Xi'an Technological University, Xi'an, China, in 1996 and 2021, respectively.

He is currently a Senior Researcher with the Xi'an Microelectronic Technology Institute and Xi'an Technological University, where he is engaged in the research and development of electronic technique, damage test technology, photoelectricity detection technology, optical technology, and measurement and control techniques.

HANSHAN LI received the B.S. degree in electronic measurement and instrumentation from Xi'an Shiyou University, Xi'an, China, in 2001, the M.S. degree in testing and measurement techniques and instruments from Xi'an Technological University, Xi'an, in 2004, and the Ph.D. degree in testing and measurement techniques and instruments from Northwestern Polytechnical University, Xi'an, in 2010.

He is currently a Professor and a Ph.D. supervisor with Xi'an Technological University, where he is engaged in the research and development of photoelectricity detection, measurement and control technology, dynamic object test technology, and image processing technology and target damage assessment. He has also published more than 100 articles in academic journals indexed in well-reputed databases, such as Science Citation Index and holds 35 patents, and won more than 18 science and technology progress awards.