Damage Assessment of Cluster Maneuvering Targets for Mission Oriented

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Abstract. Aiming at the characteristics of complex organization of equipment, uncertain threat degree of target and difficult evaluation of damage effect caused by task diversification, a mission-oriented evaluation method of damage effect of target is proposed based on combat mission requirements. Firstly, the combat characteristics and technical performances of cluster maneuvering targets based on information system are analyzed, and the basic principles, methods and steps of evaluation are determined. Secondly, two evaluation models are established, one is to determine the damage effect by layered weighting method based on investigative information; the other is to predict the target damage by Lanchester equation based on the damage situation of our own equipment, and then to evaluate the damage effect; Finally, the expert experience method is used to endow the two reasonable evaluation model results within heritance factor ρ. The mixed Beta distribution is used to effectively integrate the evaluation results of the two target damage. Task-oriented target damage effect assessment can determine the key nodes affecting the mission, which lays the foundation for formulating operational plan, making operational determination and carrying out efficient equipment support.

1. Introduction

In the course of battle, it is necessary to coordinate the operation of the troops according to the target damage effect, and then realize the mutual coordination of the operation and the effective connection with the strike effect. Whether the military commander can make the correct decision for the next military action depends largely on the accuracy of the target damage effect evaluation. Because of its timeliness, it is necessary to study the fast and accurate method and the key technology of target damage effect evaluation.

The subsystems of cluster maneuvering target system have various functions and types. The information system based on rapid interconnection makes the subsystems closely linked and coordinated, and forms a high-quality and high-quality system combat capability. Moreover, a flexible and changeable formation form can accomplish various combat tasks. Therefore, the
combat mission is taken as traction, which is very important to scientifically and reasonably evaluate the damage effect of cluster targets, focusing on the ability and effect of equipment support.

Professor Li Jing of National Defense University divides the combat effectiveness of weapons and equipment into three forms: battle static, battle strength and battle vitality. Battle vitality refers to the ability of both sides to transform their own mechanical energy, chemical energy, human physical energy and intelligence into the ability to carry out offensive and defensive military operations in the course of warfare. The core idea is that the combat vigor of different target equipment is different. Similarly, the state of equipment before and after damage is different for carrying out different combat tasks. Traditional target damage effect evaluation is to compare the target damage state with its standard state, so the evaluation results are intuitive, accurate and easy to understand. However, the target damage effect is an important basis for operational commanders to make operational decisions and equipment support personnel to formulate equipment support programs, so it is necessary to evaluate the mission completion ability of target damage state for different tasks.

2. Evaluation framework for damage effect of the cluster maneuvering target

Cluster target (system) is composed of multiple sub-unit targets (systems), which refers to the integrated combat system composed of all kinds of weaponry and equipment, such as artillery group, air defense group and armor group, formed according to the operational plan in wartime. Its overall function decreases with the loss of sub-unit target function.

Literature Based on the analysis of information mechanism of information warfare, this paper puts forward the idea of “actuarial and imitation” based on the evaluation of information warfare fire damage effectiveness. The superposition effect of information and fire and the influence degree of fire damage on combat system are modeled pertinently, and the information mechanism and fire damage aircraft are put forward. Combining theory and practice, we can achieve comprehensive evaluation of fire damage effectiveness in information warfare. Literature studied the firing effectiveness of the Naval Formation gun weapon system when attacking the cluster targets on the reef, and gave the analytical algorithm of the number of targets damaged under the conditions of fire-gathering firing and uniformly distributed firing of aiming points, but did not take into account the evacuation characteristics brought by the maneuverability of the cluster targets, which would lead to the destruction of the targets.

The paper mainly includes the following three points: Firstly, all kinds of state information of the target are obtained by means of investigation; the relationship between physical damage state and functional damage state of the target is uncertain and random, which belongs to “grey relation”, and the war means such as deception and camouflage further increase the difficulty of investigation and acquisition of state information of equipment. Based on the dynamic Bayesian network, the target damage effect evaluation of uncertain relationship can be completed on the basis of incomplete information, and then the damage effect evaluation can be carried out according to the structure and nature relationship among the target subsystems.

Secondly, depending on the equipment countermeasure scheme and the equipment combat effectiveness index, the damage effect of each other's target is evaluated in the battle process prediction based on Lanchester equation, given the equipment combat effectiveness index of both sides, combined with our battle damage situation.

Thirdly, a hybrid evaluation method based on expert experience. According to the actual combat situation, experts give the credibility of the two methods, and use inheritance factor to integrate the evaluation results of the two methods with mixed Beta distribution reasonably and effectively.

3. Principles, methods and steps of damage assessment for cluster maneuvering targets

3.1 Basic principles of assessment

(1) Pay attention to information collection, reasonably mapping physical damage-function
damage relationship, scientific weight distribution and clear logical analysis.

The evaluation of damage effect of cluster target is based on the change of combat effectiveness of target, and the change of effectiveness can be predicted by investigating the physical damage of target, and the mapping relationship between physical damage and functional damage, combined with the specific battlefield environment, considering the fire threat and survival of battlefield factors. Then the attenuation of effectiveness is achieved for the specified tasks.

(2) Facing the combat mission, we should grasp the evaluation pulse flexibly and accurately, define the evaluation purpose and dynamically evaluate the damage effect.

Task-oriented damage effect assessment of cluster targets is carried out based on the matching of cluster target functions and specified combat tasks. With the adjustment of combat intentions and tasks, the assessment results are in dynamic change.

3.2 Methods of assessment

According to equipment performance, the relationship between different system targets, the relationship between component damage and function damage, and the relationship between system sub-target damage and cluster target damage effect are determined. There are mainly several relationships:

(1) series system

A system consisting of K components or sub-targets, which are closely related to each other and interdependent, constitutes the function of the system. If any component or sub-target is destroyed, the function of the whole system will be lost. Suppose the function of the system is represented by \( P \), and the effectiveness of each sub part or sub target is expressed as \( p \). The target effectiveness evaluation model that is in line with series nature is as follows:

\[
P = p_1 \times p_2 \times \cdots \times p_k.
\]

(2) parallel system

A system consisting of \( j \) components or sub-targets, which are independent of each other and perform the functions of the system independently. Even if \( j-1 \) components or sub-targets are destroyed, the functions of the whole system can still be maintained. Suppose the function of the system is represented by \( P_1, P_2, \cdots, P_j \), and the effectiveness of each sub part or sub target is expressed as \( p_1, p_2, \cdots, p_j \). The target performance evaluation model with parallel characteristics is as follows:

\[
P = 1 - (1 - p_1)(1 - p_2)\cdots(1 - p_j).
\]

(3) series system and parallel system

Some of the components or sub-targets belong to redundancy settings, while others belong to key components. The target damage effectiveness evaluation model which conforms to the series-parallel nature is as follows:

\[
P = [1 - (1 - p_1)(1 - p_2)\cdots(1 - p_j)] \times p_3 \times p_4.
\]

(4) cold storage system

The battlefield repair capability of the enemy's support force also has a great influence. If the enemy's battlefield repair capability is very strong, even if our target is damaged to a great extent, the enemy can quickly restore the specific function of the target. We have to consider this factor in making operational decisions, so we need to combine the battlefield repair capability of the enemy. The force is modified to the target damage assessment result. Assuming that the repairing degree of the enemy's battlefield repair capability to the target conforms to the linear relationship, the time interval before the decision-making and execution is taken as the repairing time, whether the enemy can repair successfully conforms to a certain probability distribution, and the electronic components conform to the exponential distribution, mechanical and other components conform to the normal distribution. The target damage effect evaluation model conforms to the nature of the cold reserve system.

\[
P = 1 - (1 - p_1)(1 - p_2)\cdots(1 - p_j)s^{-1}.
\]
3.3 Steps of assessment

The maneuvering target of cluster is a complex giant system. The evaluation of its damage effect needs to be from bottom to top, from inside to outside, and carry out systematic analysis from simplicity to complexity. The specific process is shown below.

1. Clear the function of cluster target and sub-target system.
2. Selection of evaluation indicators.
3. Determine the weight of damage caused by different parts and sub-targets.

The determination of weight mainly depends on expert experience. Common methods include AHP, Delphi, Entropy and Fuzzy Cluster Analysis. The above methods can be used flexibly according to the actual situation to achieve complementary advantages. Reference\(^5\) establishes the target damage assessment index system and the classification method of damage grade. Based on this, the weight of each index is determined by AHP method.

| Function        | Components of armored equipment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-----------------|----------------------------------|---|---|---|---|---|---|---|---|---|
| Maneuver        |                                  | 0.9| 0.9| 0.8| 0.7| - | - | - | - | - |
| Fire            |                                  | - | - | - | 0.8| 1 | 1 | 0.5| 0.8| - |
| communication   |                                  | - | - | - | 0.6| 0.8| - | - | - | 1 |

4. The research of key technology

4.1 Lanchester forecast equation

Cluster equipment based on information system can strike pre-planned targets efficiently and accurately according to the established operational plan. When targets are sufficient, there will be
no repetitive attack on targets, which will result in the waste of firepower resources. When targets are scarce, there will be no idle equipment, which will lead to the delaying fighters. At the same time, the probability of ammunition hitting and the probability of ammunition hitting will be taken into account. With the increasing damage probability, it is more and more feasible and effective to use Lanchester equation to predict the war process. Therefore, on the basis of defining the information of the other side’s combat strength and equipment weaving, we can predict the change of the other side’s combat strength and equipment weaving through the change of the other side’s combat strength and equipment weaving.

Assuming that Red Square has three different types of mechanized infantry, armor and self-propelled artillery groups \(X, Y, Z\), the number of which is \(x, y, z\). Blue Square has two different types of equipment \(M, N\), and the number of which is \(m, n\), the damage rate and firepower distribution of Red Square equipment to Blue Square equipment in the following table.

**Table 2.** Damage rate of red equipment to blue equipment.

| Blue equipment | Red equipment |
|----------------|---------------|
| M              | \(\alpha_m\)  |
| N              | \(\alpha_m\)  |

**Table 3.** Fire distribution of red equipment to blue equipment.

| Blue equipment | Red equipment |
|----------------|---------------|
| M              | \(x_1\) \(y_1\) \(z_1\) |
| N              | \(x_2\) \(y_2\) \(z_2\) |

Also, the following is damage rate of blue equipment to red equipment Fire distribution of red equipment to blue equipment.

**Table 4.** Damage rate of blue equipment to red equipment.

| Red equipment | Blue equipment |
|---------------|----------------|
| X             | \(\beta_m\) \(\beta_n\) |
| Y             | \(\beta_m\) \(\beta_n\) |
| Z             | \(\beta_m\) \(\beta_n\) |

**Table 5.** Fire distribution of red equipment to blue equipment.

| Red equipment | Blue equipment |
|---------------|----------------|
| M             | \(m_1\) \(n_1\) |
| N             | \(m_2\) \(n_2\) |
| Z             | \(m_3\) \(n_3\) |

The Lanchester battle damage equations are as follows, at some time in the battle process, according to the damage of our equipment \(X, Y, Z\), the analytic solution of the enemy’s battle damage can be obtained accurately by using the following formula.

\[
\begin{align*}
\frac{dx}{dt} & = -\beta_m \cdot m - \beta_n \cdot n \\
\frac{dy}{dt} & = -\beta_m \cdot m - \beta_n \cdot n \\
\frac{dz}{dt} & = -\beta_m \cdot m - \beta_n \cdot n \\
\frac{dm}{dt} & = \alpha_m \cdot x_1 - \alpha_m \cdot y_1 - \alpha_m \cdot z_1 \\
\frac{dn}{dt} & = \alpha_m \cdot x_2 - \alpha_m \cdot y_2 - \alpha_m \cdot z_2
\end{align*}
\]

(6)

4.2 Integration of two methods of evaluation results

Above two methods are used to evaluate the damage effect of the target. One is based on the investigation information, from the physical damage of components to the functional damage to the final damage effect of the system as a whole; the other is based on the battle damage information of one’s own side and the Lanchester equation to calculate the battle damage situation of the other side, and then according to the nature of each sub-target system and qualitative relationship, the damage effect evaluation of the whole system is calculated. The results obtained by the two methods need to be fused by reasonable methods to effectively inherit the advantages
of both sides and remove the inherent errors. The mixed beta distribution can fuse different information which obeys the same distribution. The inheritance factors can be given by experts according to the actual situation. If the investigation information is more accurate and comprehensive, the inheritance factor of damage effect obtained by investigative information can be set higher. If the enemy’s combat strength is grasped more accurately and the technical performance of weapons and equipment is better understood, the inheritance factor of damage effect obtained by Lanchester equation can be set higher, as follows:

Damage and integrity $1 - \mu(x)$ coincide with binomial distribution. Either evaluation result can be used as empirical value, the other evaluation result can be used as sample value, and then fused. The prior distribution of binomial distribution usually adopts its conjugate beta distribution, assuming that the density function of one of the evaluation results is:

$$f(\theta; \alpha, \beta) = \frac{\theta^{\alpha-1}(1-\theta)^{\beta-1}}{\int_0^1 \theta^{\alpha-1}(1-\theta)^{\beta-1} d\theta},$$

(7)

In the formula, $(0 < \theta < 1, \alpha > 0, \beta > 0)$, $\theta$ is a super parameter of prior distribution. That is, the probability of evaluation results obeys a certain distribution and needs to be adjusted in real time through posteriori information. We can use the following formula to find out. The moment estimation method is used to calculate the super-parameters, in which the variance function is constructed and the adjustment coefficient is used. The smaller the distribution of damage assessment results is, the stronger the robustness is. Order:

$$\begin{align*}
E[X] &= \frac{\alpha}{\alpha + \beta} - \mu(x), \\
D[X] &= \frac{\alpha\beta}{(\alpha + \beta)(\alpha + \beta + 1)} - k^2(1-\mu(x)),
\end{align*}$$

(8)

$x, y$ is super parameter, which also determined by the formula, Assuming another assessment result as a posteriori information, the density function of the posterior distribution Beta($\theta|\alpha + x, \beta + y$) can be obtained as follows.

$$\pi(\theta|x, y) = \frac{\Gamma(\alpha + \beta + x + y)}{\Gamma(\alpha + x)\Gamma(\beta + y)} \theta^{\alpha - 1}(1 - \theta)^{\beta - 1}.$$

(9)

$$\pi_2(\theta) = \frac{\theta^{\alpha - 1}(1 - \theta)^{\beta - 1}}{\Beta(\alpha, \beta)} (1 - \rho),$$

(10)

Combining with expert experience, the reliability of the two methods is given. According to the above mixed beta distribution, then the following distribution function of the final evaluation result is obtained, which expected value is the final damage evaluation result.

$$\pi_{f}(\theta|x, y) = \frac{\rho^\alpha\mu_{f}^{\alpha - 1}(1-\theta)^{\alpha - 1}(1-\theta)^{\beta - 1} + (1-\rho)^\alpha(1-\theta)^\beta}{\Beta(\alpha, \beta)}$$

(11)

5. Conclusions

Aiming at the basic principles, methods and steps of damage assessment for cluster target determination are proposed, and the method has strong pertinence, prominent characteristics and strong operability, which can effectively improve the winning ability and carry out targeted target guarantee. The evaluation model based on mixed Beta distribution makes rational use of investigation information and battle damage information of our own side. The method has strong universality and wide application scope, also it needs to be further strengthened for the reasonable
evaluation of the combat effectiveness of both sides of the enemy and ourselves.

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