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Research on Contribution Degree Algorithm of Equipment System Based on Marginal Utility

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Abstract

The development of the weapon equipment system presents a trend of intelligence, diversification, and integration. Technological innovation and equipment enhancement are the only ways to support the development of the system. Aiming at the problems of complicated and difficult-to-decompose relations between equipment in the system and fuzzy contribution evaluation, this paper proposes a marginal system contribution algorithm. It adopts the OODA cycle theory, establishes a systematic combat network model, and refines key indicators that support the combat capabilities of equipment. Based on typical cases, the combat effectiveness of the system improved from 0.856 to 0.886, and the system contribution of the medium-range missile reached 3.53%. In addition, the marginal system contribution of firepower strike nodes decreases with the increase of system capabilities, and will stabilize in the later period. This shows that scientifically strengthening its system capabilities will help improve the combat effectiveness of the system and also provide a theoretical reference for equipment development.

Keywords

Combat System, OODA, Effectiveness Evaluation, Contribution Rate of Marginal System.

1. Introduction

Scientific and technological innovation promotes changes in the military field, and the development of intelligent and superb weapons will inevitably push war to an integrated system of confrontation. The transformation of China-US relations and international trade sanctions have caused China to face severe challenges. So how to develop and develop weapons systems under the conditions of limited resources, technology and development time is an urgent problem that China needs to solve on the road of system development. Therefore, only by scientifically assessing the effectiveness of the combat system and clarifying the development path of the weapon system can we establish a sound national defense security system better and faster.

Since the contribution of the system provides scientific support for the demonstration of equipment development planning, major military academies at home and abroad and related academies have also actively penetrated into the field of system construction, and their research results are mostly concentrated in military technology and combat capabilities[1-5]. The discussion found that the difficulty of system evaluation lies in the systematic modeling of weapon equipment system and the scientific evaluation of equipment. Therefore, based on the OODA (Observe, Orient, Decide, Act, OODA) cycle theory[6-10], this article analyzes the key indicators that affect equipment capabilities and proposes an accurate marginal system contribution evaluation method.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202010_6(10).0047

2. Evaluation mechanism of contribution of weapon and equipment marginal system

2.1 Weapon system network model

The research of weapon equipment system must make a scientific and accurate description of its structure, taking into account the complexity, dynamics, emergence and evolution of the system[11-12]. To sort out the relationship of material energy and information circulation between weapon systems, this article establishes the weapon equipment system combat network model from the nodes, edges and hierarchical structure of the combat network.

The basic concepts and relationships of combat nodes, edges and combat rings are given.

2.1.1 Node

A node is the most basic element of a combat network, that is, an entity that can independently complete combat activities in a war. According to their functions, they are divided into three categories: reconnaissance and early warning, command and control, and fire strike. In addition, in order to be close to the actual confrontation environment and increase the scientificity and rationality of modeling ideas, target nodes are set according to the characteristics of the enemy's target.

Reconnaissance and early warning node (S): equipment or facilities for collecting information on our battlefield, mainly refers to the entity that reconnaissance, early warning, or surveillance of enemy targets in the battlefield. Mainly focus on the following capability indicators:

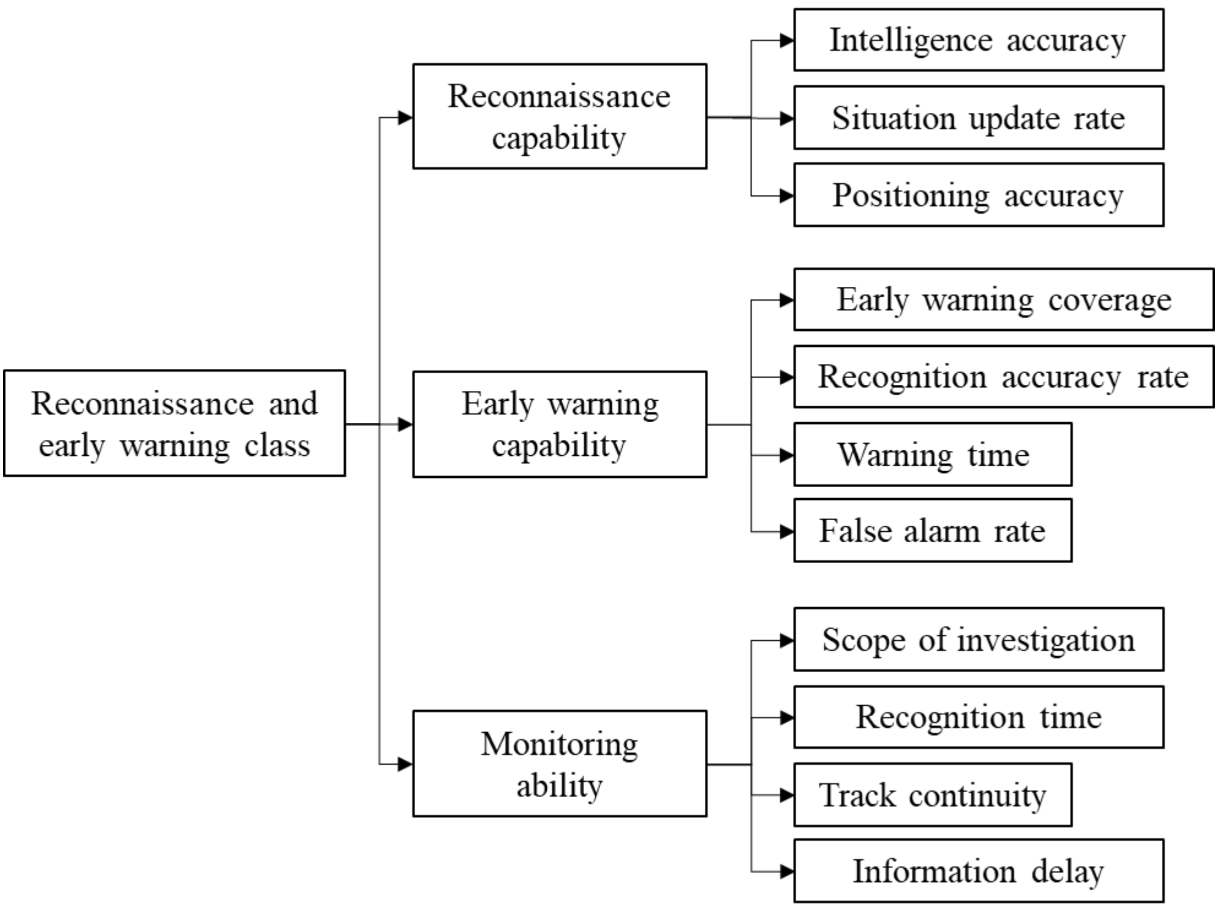

Figure 1: Decomposition of reconnaissance and early warning node capability indicators

Command and control nodes (D): Various facilities with decision-making and corresponding functions in our equipment system, such as command posts at all levels, communication relays, command and control systems, etc. Mainly consider the following capability indicators:

ISSN: 2414-1895 DOI: 10.6919/ICJE.202010_6(10).0047

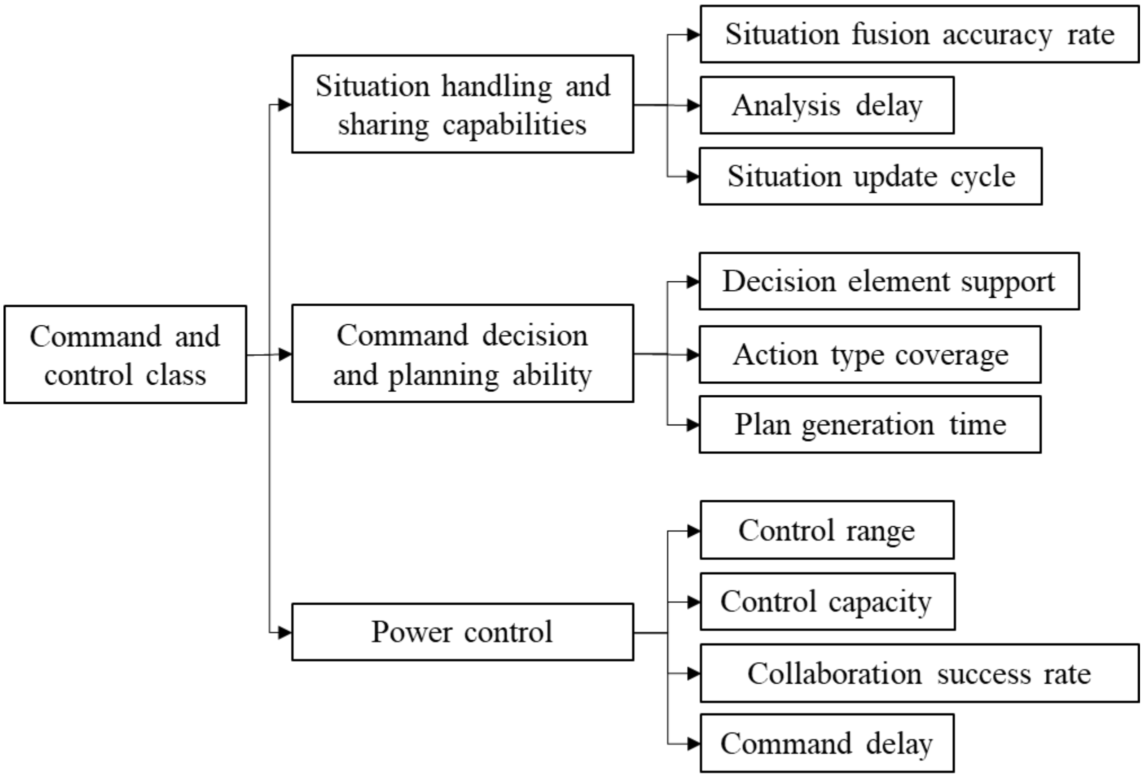

Figure 2: Decomposition of command and control node capability indicators

Firepower Strike Node (I): The entity in our equipment system that can directly affect the target node, which can be a strike or jamming weapon system, or a military shielding facility. Mainly focus on the following capability indicators:

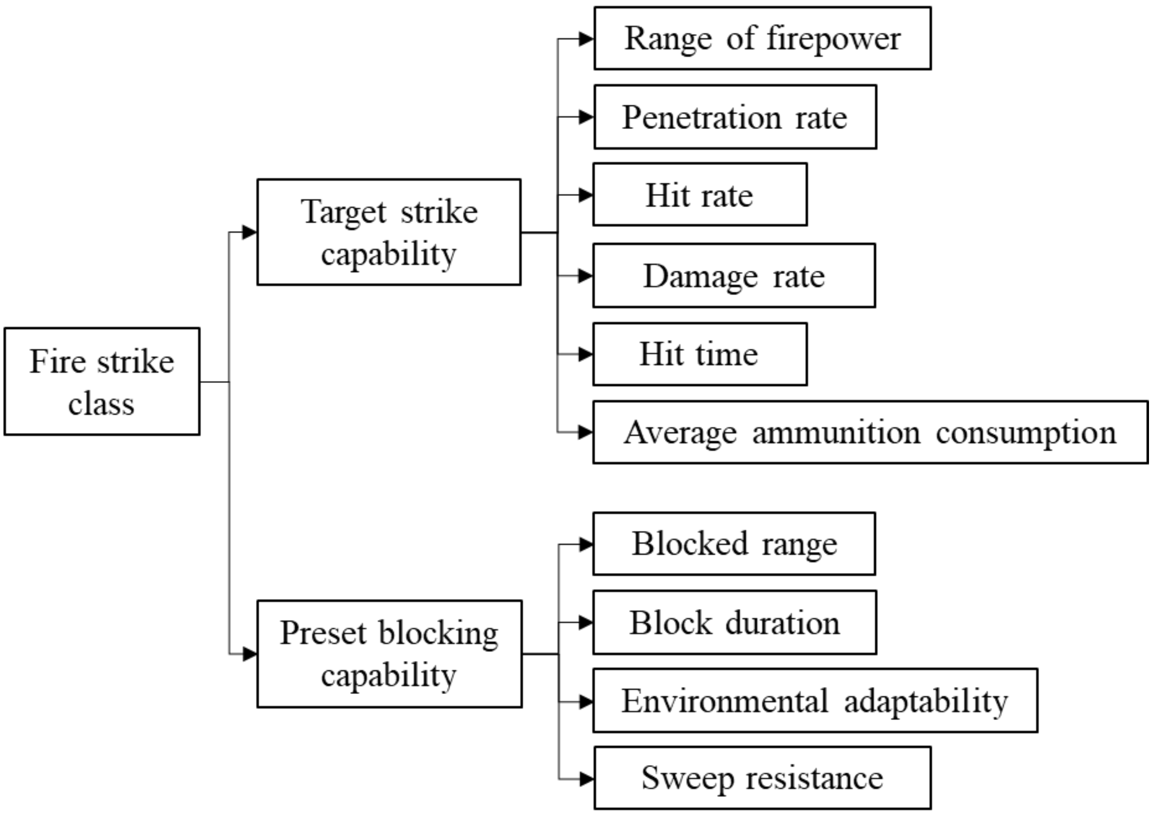

Figure 3: Decomposition of firepower strike node capability indicators

ISSN: 2414-1895
DOI: 10.6919/ICJE.202010_6(10).0047

Target node (T): A target that needs to be attacked, destroyed, interfered with, or intercepted during combat. This article takes enemy ships as the research objective and mainly examines the following capability indicators:

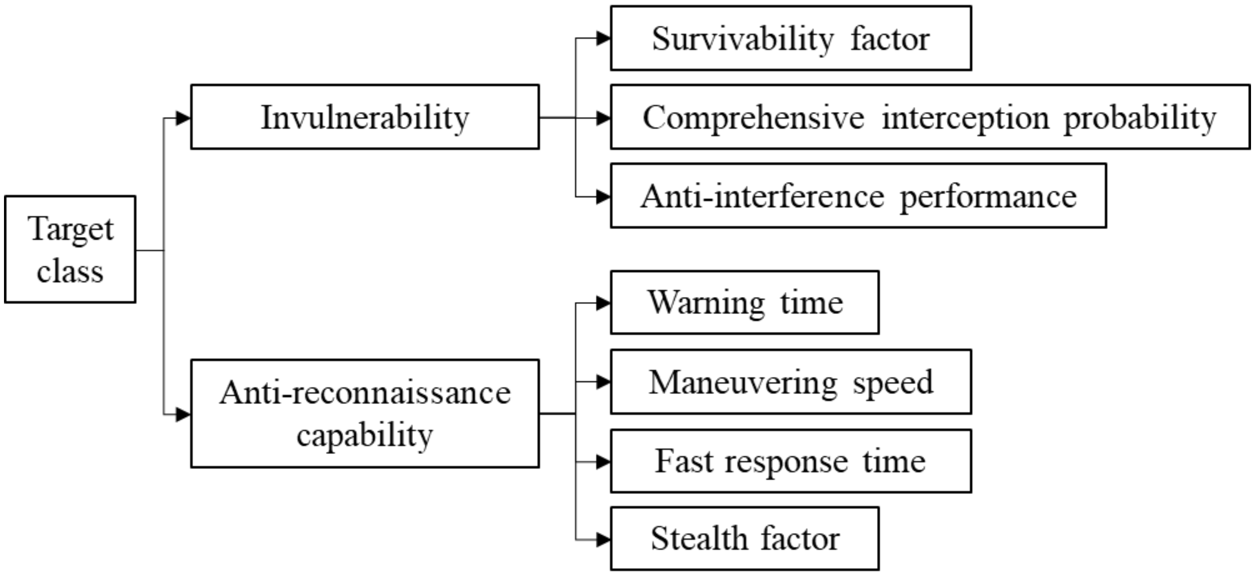

Figure 4: Decomposition of target node capability indicators

2.1.2 Combat side

The combat side is a one-way side that describes the combat activities between entities. According to the capability indicators of the node and the interaction characteristics of the two, the capability of the combat side can be modeled. This article mainly considers six functional relationships between weapon system nodes: T→S, S→S, S→D, D→D, D→I, I→T. Among them, T→S and I→T are used as functional relationship modeling, and the other 4 types are used as information-oriented relationship modeling. It uses improved information entropy to measure the completion of combat activities, that is, the amount of self-information contained in combat activities.

2.1.3 Combat ring

Facing specific combat missions, each combat entity in the weapon equipment system can generate reconnaissance, command, strike and other one-way relationships between them, and they can be combined according to certain rules to form higher-level sub-systems, such as combat rings: $T_2 \rightarrow S_2 \rightarrow S_3 \rightarrow D_2 \rightarrow I_2 \rightarrow T_2$.

Therefore, it is based on the OODA cycle theory to carry out modeling work on the confrontation and communication of equipment in combat. This makes system research no longer theoretically empty, and integrates the actual combat process, making the model more convincing and practical.

2.2 Marginal system contribution algorithm

The system contribution of a weapon system focuses on measuring its improvement in real-time perception, efficient command, precision strike, rapid maneuverability, full-dimensional protection, and comprehensive support. Considering that in different combat contexts, the same equipment makes different contributions, and the system contribution is also different. At the same time, it is a comprehensive measure of the effect of the weapon system on the system in which it is located, and various indicators must be effectively combined. This article defines its concept: Under a given mission, the contribution of the weapon system is the proportion of the completion of the entire mission. It can be considered that the contribution of equipment to the system is reflected by the improvement of combat effectiveness.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202010_6(10).0047

Considering the quality, quantity, and combat allocation of equipment, the calculation method of this article's contribution to the weapon equipment system is as follows:

Calculate the sum of the self-information amount I_i of the uncertainty caused by each side in the i-th combat ring:

$$I_i = \sum_{j=1}^{m} I_{Sj} \tag{1}$$

I_{Sj} represents the self-information amount of the j-th edge， m indicates the number of edges included in the combat mission

I_i can measure the combat effectiveness P_i of the combat ring against the corresponding enemy target. The calculation formula is:

$$P_i = exp(-I_i) = exp(-\sum_{j=1}^{m} I_{Sj}) \tag{2}$$

Assuming that our weapon equipment system can formulate M combat tasks against the enemy's target T_m, the overall uncertainty I of these rings is defined as:

$$I = \frac{1}{\sum_{i=1}^{M} 1/I_i} \tag{3}$$

These military actions against the enemy's target T_m constitute multiple combat loops, and their combat effectiveness P is calculated as follows:

$$P = exp(-\frac{1}{\sum_{i=1}^{M} 1/I_i}) \tag{4}$$

In the course of combat, the main attack target can usually be determined according to the combat mission, that is, the set T=$\{T_1, T_2, \ldots\ldots, T_{|T|}\}$ of enemy targets that need to be attacked by military action. Among them, $|T|$ is the number of enemy targets.

According to the strategic significance of each target, military experts and commanders can prioritize them and give each target a weight value w_k. Through the weighted average of military operations, the combat effectiveness Y of the weapon equipment system for specific missions is obtained.

$$Y = \sum_{k=1}^{|T|} w_k * P_k \tag{5}$$

System contribution degree sts_{Xi} of equipment X_i :

$$sts_{X_i} = \frac{Y_N - Y_O}{Y_O} \tag{6}$$

Among them, Y_O represents the overall combat effectiveness of the original system, and Y_N represents the overall combat effectiveness of the improved system.

On this basis, this paper proposes a calculation method for the contribution of the marginal system, which can more accurately and intuitively analyze the marginal effect of the contribution of the system caused by changes in combat capabilities. The calculation formula of the marginal system contribution $bsts_{Xi}$ of equipment X_i is as follows:

$$bsts_{X_i} = f'(E_{X_i}) = \left(\frac{Y_N - Y_O}{Y_O}\right)\Big|_{E_{X_i}} \tag{7}$$

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3. Case design and analysis

Based on the OODA cycle modeling method, a typical combat scenario is taken as an example to verify the feasibility of the system combat evaluation mechanism.

3.1 Combat system modeling

3.1.1 Operational scenarios

At a certain time in the future, the enemy base T_2 will send ship T_1 to invade our territory and steal resources illegally. In order to safeguard national security interests, we launched firepower strikes against them. Serious damage to the target is regarded as the completion of the combat mission.

3.1.2 Weapon system construction

Weapons and equipment are divided into early warning and reconnaissance categories: electronic reconnaissance satellite S_1, early warning aircraft S_2, photographic reconnaissance satellite S_3 and multi-band radar S_4; command communication category: combat command center D_1; fire strike category: short-range missile I_1, medium-range missile I_2 and long-range missile I_3. Each combat equipment and the enemy constitute a basic system combat network, as shown in Figure 5:

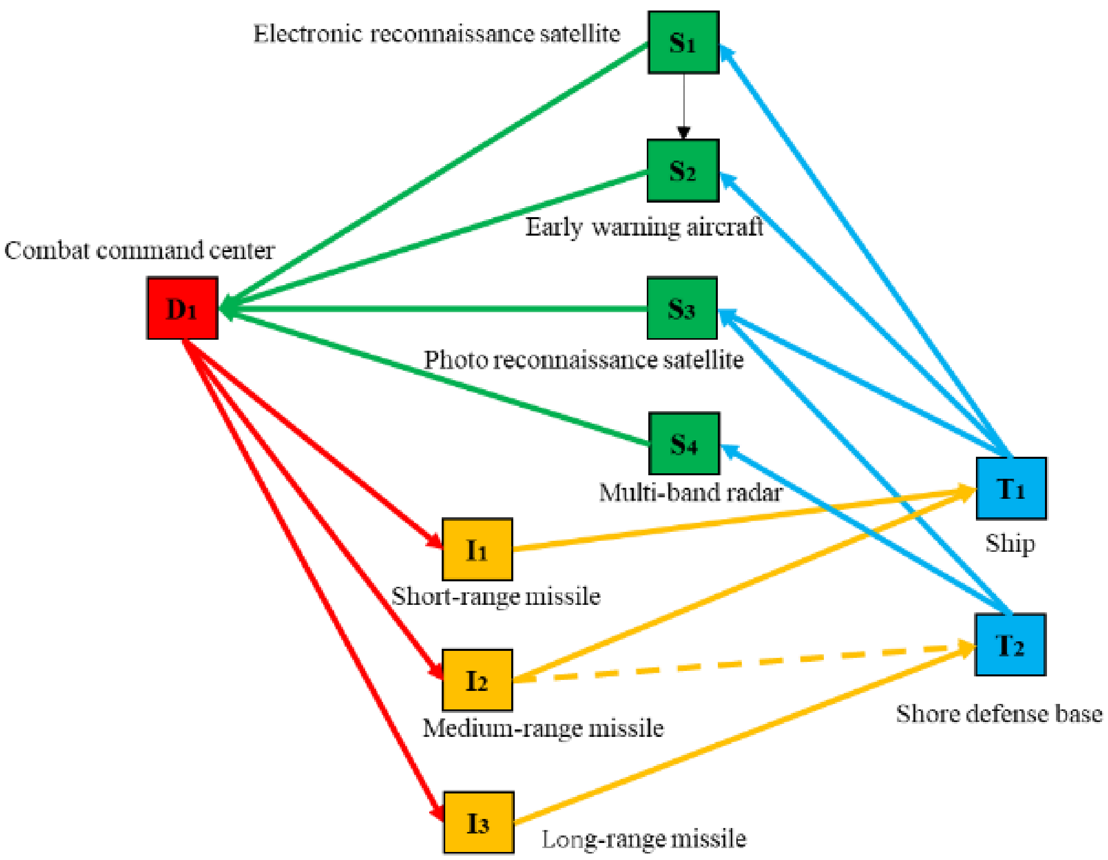

Figure 5: Weapon system combat network

3.2 Operational evaluation and result analysis

3.2.1 Combat effectiveness evaluation

Based on operational assumptions, in order to demonstrate the improvement of system effectiveness by equipment upgrades, this article takes the strengthening of early warning aircraft and medium-range missiles (*the upgraded I_2 has the ability to strike T_2*) as examples to evaluate the changes in their combat capabilities. The results of the combat capability evaluation of each weapon system are shown in Figure 6:

ISSN: 2414-1895 DOI: 10.6919/ICJE.202010_6(10).0047

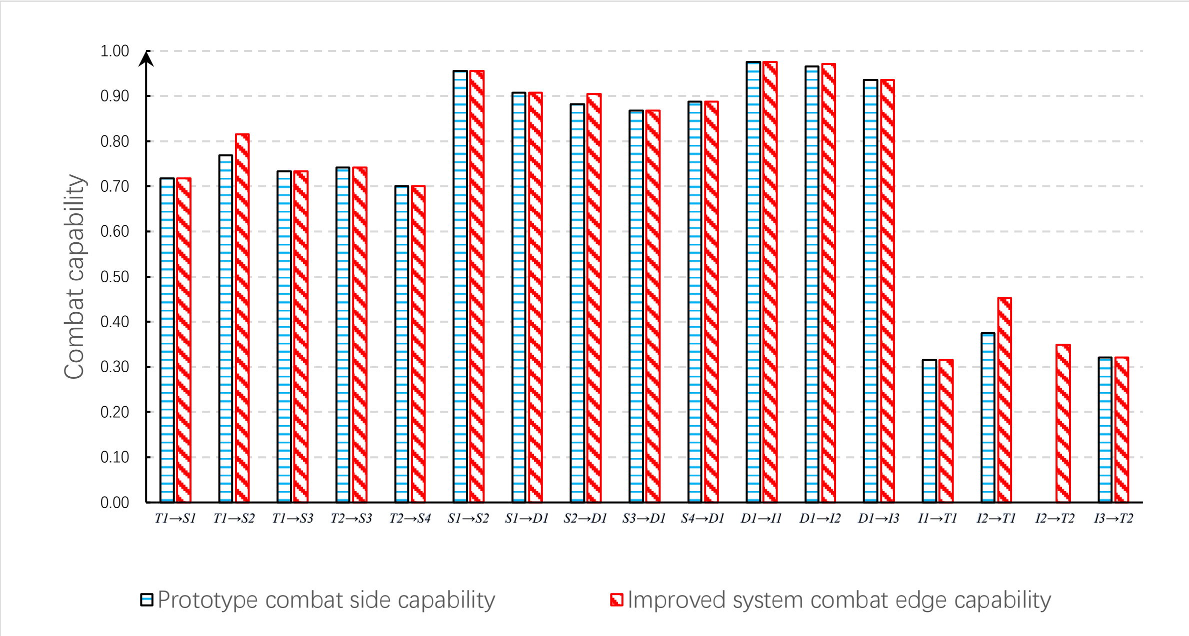

Figure 6: Statistics of operational side capability evaluation value

It can be seen from Figure 6 that the overall information-oriented operational edge capability is higher than the functional operational edge, especially the S→D operational capability is above 0.868, while the T→S operational edge is limited by the performance of the I node. After upgrading I_2, its combat capability has changed greatly.

According to the constructed combat network, the effectiveness of the execution of combat tasks is accurately calculated, and the evaluation results are shown in Figure 7:

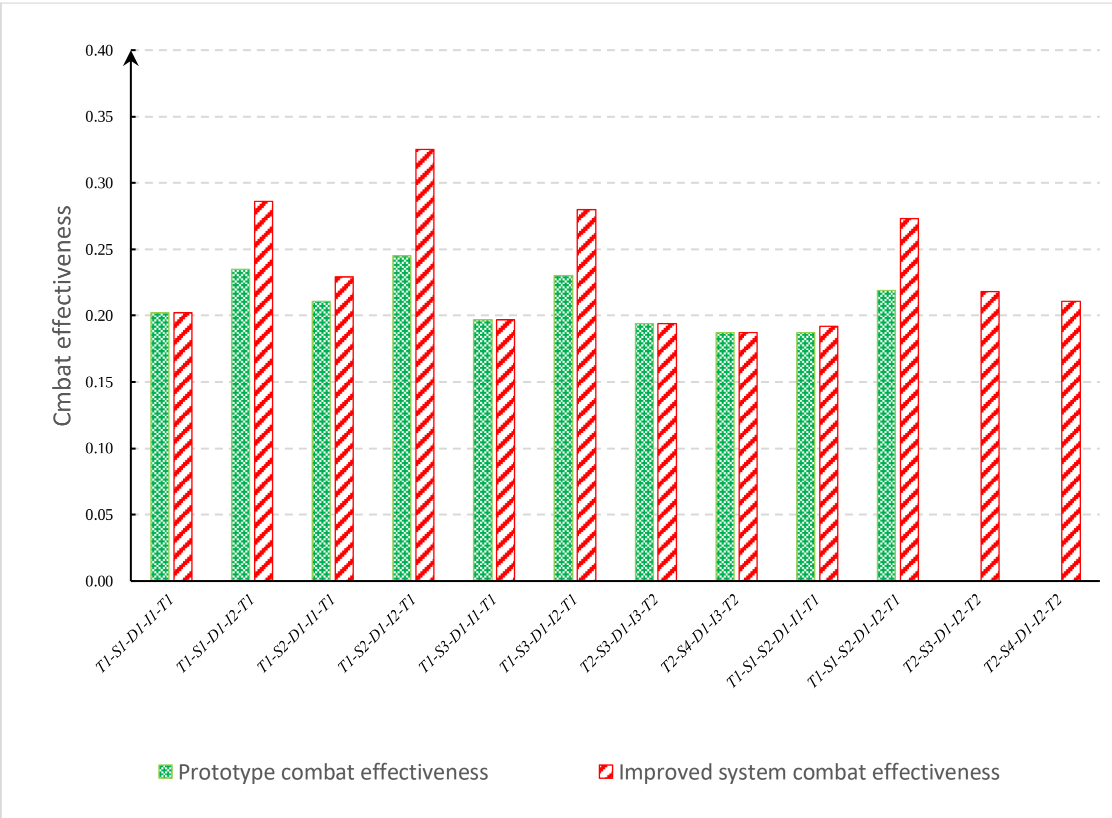

Figure 7: Operational ring effectiveness statistics chart

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The effectiveness of the combat ring indicates the reliability of mission completion. Comparing the performance changes before and after the system is improved, it is as high as 0.325, which is generally higher than the prototype system. This shows that upgraded equipment has significantly improved combat operations, highlighting the contribution of medium-range missiles.

3.2.2 Marginal system contribution evaluation

Assuming that the T_1 and T_2 goals are equally important, the weight is *0.5*, and the system contribution of S_2 and I_2 is calculated:

$$sts_{S_2} = \frac{Y_N - Y_O}{Y_O} = \frac{0.858 - 0.856}{0.856} \times 100\% = 0.23\%$$

$$sts_{I_2} = \frac{Y_N - Y_O}{Y_O} = \frac{0.886 - 0.856}{0.856} \times 100\% = 3.53\%$$

The results show that, compared with the early warning aircraft's contribution of *0.23%*, the medium-range missile is as high as *3.53%*, indicating that it is a high-value quantity in system operations and is conducive to efficiently controlling the battlefield trend.

According to the system contribution degree function of each equipment, the marginal system contribution degree of the fire strike class node is calculated. Their changing trends are shown in Figure 8:

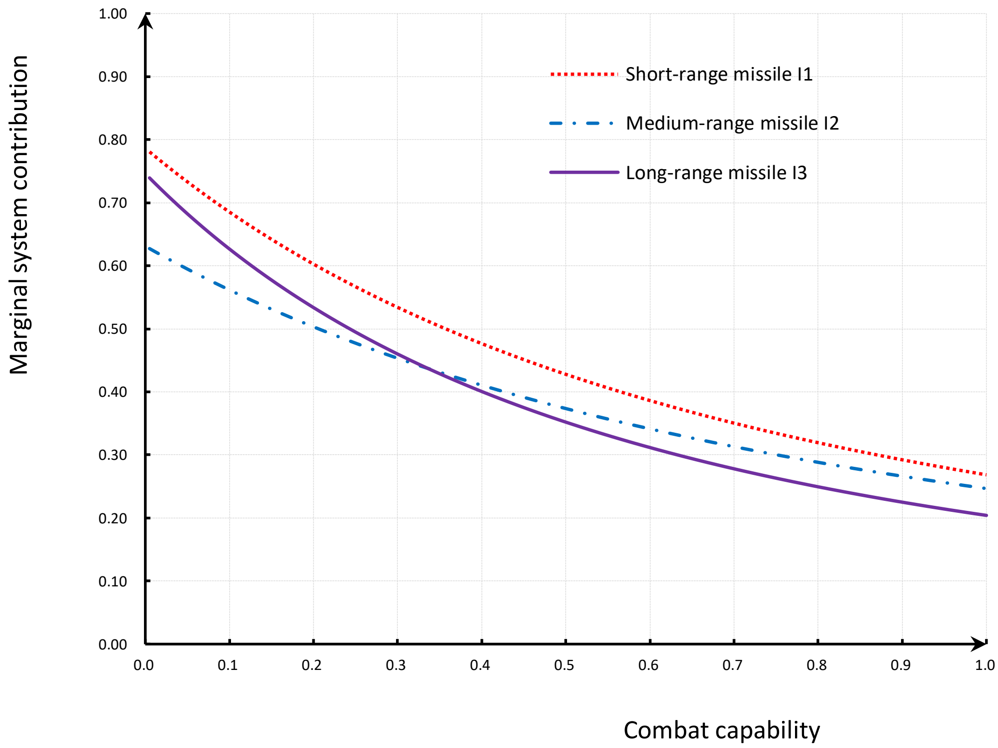

Figure 8: Changes in the contribution of the marginal system of fire strike equipment

It can be seen from Figure 8 that as the combat capability of firepower strike equipment increases, the contribution of the marginal system shows a decreasing trend, tending to *0.20*. After the combat capability reaches *0.60*, focusing on the development of its combat capability will not significantly increase the system contribution of the equipment. From the perspective of the changing trend of the curve, prioritizing the development of short-range missiles and long-range missiles in the early stage and appropriate development of medium-range missiles in the medium-term can save costs and resources. This has a high cost performance and promotes the scientific development of the weapon equipment system.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202010_6(10).0047

4. Conclusion

Based on the existing system research foundation, using the OODA cycle theory, a scientific marginal system contribution degree algorithm is proposed. Combined with operational scenarios, the evaluation results show that the system contribution rate of medium-range missiles is as high as *3.53%*, which can significantly improve the combat effectiveness of the system. In addition, their marginal system contribution is also showing a declining trend, indicating that the cost-effectiveness of equipment upgrades is gradually decreasing. This also provides a certain data reference for the research, development and system development of weapons and equipment.

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