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Review on Effectiveness Evaluation of Missile Weapon System

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Abstract: *In order to evaluate and compare the advantages and disadvantages of missile weapon systems and assist commanders in making optimal decisions, quantitative scales must be used to measure the effectiveness of missile weapon systems. This paper introduces the concept of missile weapon system effectiveness, expounds the importance and necessity of effectiveness evaluation, summarizes the relevant models, common methods and development process of effectiveness evaluation, analyzes the problems faced by missile weapon system effectiveness evaluation, and looks forward to the development trend of this research field.*

Keywords: *Missile weapon system, System Effectiveness, Effectiveness evaluation, Auxiliary decision.*

1. Introduction

With the continuous development of missile weapons, their mobility, damage means and technical performance have been greatly improved. However, due to the specific conditions such as high scientific and technological content of equipment, high cost and complex combat environment, it is difficult to evaluate their combat effectiveness only by relying on live ammunition exercises or analysis and research of military experts, The combat effectiveness of missile weapon system must be comprehensively evaluated through scientific model and reasonable method, so as to provide reference basis for the commander's optimal decision-making.

This paper aims to summarize the basic concepts, development process, related models and common methods of missile weapon system effectiveness evaluation, analyze the difficult problems faced in this research field, and think and prospect the future research direction.

2. Effectiveness Evaluation of Missile Weapon System

2.1. Basic Concepts of Weapon System Effectiveness

The effectiveness of missile weapon system refers to the extent to which the missile weapon system used to perform specific tasks can achieve the expected objectives in a specific battlefield environment. According to the needs of weapon system operation research, its effectiveness can be divided into three categories [1]:

(1) Single effectiveness: refers to the degree that can be achieved for a single use target when using a missile weapon system, such as command and control effectiveness, launch effectiveness, damage effectiveness, etc. The operation corresponding to single effectiveness is the operation with single target, such as detection, maneuver, shooting and other basic links in fire application.

(2) System effectiveness: refers to the possibility of a weapon system meeting a set of specific task requirements under certain conditions. It is a comprehensive evaluation of the effectiveness of a weapon system.

(3) Combat effectiveness: refers to the degree to which the expected objectives can be achieved by using the combat forces of the weapon system to perform combat tasks under specified conditions. Here, the implementation of combat tasks should cover various main tasks that the weapon system may undertake in actual combat, and involve the whole combat process. Therefore, combat effectiveness is the final effectiveness and fundamental quality characteristic of any weapon system.

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2.2. Development Stage of Weapon System Effectiveness Evaluation

The research of weapon system effectiveness evaluation can be divided into four stages: problem germination, formation and development, rapid development and innovative development.

2.2.1. The Embryonic Stage of The Problem

From the early 20th century to the mid-1950s, under the background of the two world wars, the fields of military operation research and operational application continued to develop. Before and after the First World War, F.W. Lanchester established the Lanchester equation to simulate the loss of troops on both sides of the battle, which has attracted extensive attention. After that, researchers have carried out a series of research on the operational use of radar system, the operational effectiveness of Navy and air force and the improvement of tactical evaluation, which have been applied in actual combat and achieved considerable results.

2.2.2. Formation and Development Stage

From the late 1950s to the early 1980s, effectiveness evaluation was widely used in the field of equipment development, which promoted the development of efficiency and cost analysis theory. At the same time, computer simulation technology also began to sprout and gradually applied to the research of effectiveness evaluation. Dordick [2] introduced performance parameters into effectiveness evaluation, which enriched the evaluation model. Hayward [3] used the action success probability to evaluate the weapon effectiveness. Tillman et al. [4] studied the combat effectiveness of weapon system by using simulation method and WSEIAC (Weapon System Effectiveness Industry Advisory Committee) model. Bouthonnier et al. [5] used the sea (system effectiveness analysis) method to study the effectiveness evaluation of the command, control and communication system of the U.S. national missile defense system, that is, the C-3 system.

2.2.3. Rapid Development Stage

From the late 1980s to the early 21st century, with the continuous progress of military technology, the emergence of sophisticated weapons and equipment and the development of new operational concepts such as electronic warfare and information warfare have greatly promoted the development and research of weapon system effectiveness evaluation. At this stage, the U.S. military established a variety of effectiveness evaluation test platforms for analysis and Research on the combat capability of weapon systems. Experts and scholars also began to use a variety of methods to analyze the combat effectiveness of weapon systems. Gluckman et al. [6] used rough set theory to build an expert evaluation system for efficiency and cost analysis. Gallagher et al. [7] used dynamic programming method to evaluate the comprehensive effectiveness of weapon system. Bowden et al. [8] constructed the effectiveness evaluation model of weapon system based on agent simulation technology. Kohlberg et al. [9] constructed an efficiency cost ratio optimization model based on Lagrange operator for missile defense system. Horn [10] used simulation method to evaluate the comprehensive efficiency of THAAD system. In [11] discusses the operational effectiveness evaluation method of missile weapon system for operational process. In [12], designed an architecture framework for Missile Effectiveness Simulation Evaluation. John [13] constructed the overall framework of weapon equipment effectiveness evaluation based on multi-attribute decision-making method. Lund [14] proposed a network structure including many factors such as efficiency and cost, and studied the combat effectiveness of Pershing missile. Gipson [15] analyzed and evaluated the air defense effectiveness of patriot-3 missile based on the simulation method.

2.2.4. Innovation and Development Stage

Since the beginning of the 21st century, new operational concepts such as joint global warfare, SEG warfare and system warfare have been put forward one after another. Deep learning, artificial intelligence, cloud data processing and 5g technology have developed rapidly, weapons and equipment, operational methods and tactics have been continuously innovated, the form of war has gradually evolved, and the effectiveness evaluation methods of weapon systems have also been rapidly expanded. In [16], discusses the significance of effectiveness evaluation methodology, puts forward the idea and method of soft algorithm for military system effectiveness evaluation, and puts forward several basic technologies of soft measurement for effectiveness evaluation from the perspective of methodology. Ender et al.[17] analyzed and evaluated the operational effectiveness of the defense subsystem in the missile weapon system based on the neural network model. Connors et al.[18] evaluated the effectiveness of the system based on agent simulation method for air-to-air missile, so as to support the commander to make the optimal decision. HocaoğLu[19] aimed at the efficiency optimization of air

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defense missile weapon system, using the method of nonlinear multi-objective programming, the missile target matching planning was carried out, which effectively improved the system efficiency. According to the reality of conventional missile operation in joint operation, in [20], uses the simulation method to evaluate the combat effectiveness of missile weapons. Aiming at the problems existing in the evaluation method of combat capability of conventional missile forces, in [21], evaluates the combat capability of conventional missile forces by combining grey whitening weight clustering and entropy weight method. In [22], focuses on the composition and operational process of submarine launched anti-ship missile weapon system, constructs a more comprehensive weapon system operational effectiveness evaluation index system, improves the analytic hierarchy process by using the group decision-making method, and evaluates the effectiveness of submarine launched anti-ship missile weapon system. Based on PCA-BP Neural Network, in [23], established the operational effectiveness evaluation index system and effectiveness evaluation model of surface to air missile weapon system, and effectively evaluated and predicted the operational effectiveness of surface to air missile weapon system.

2.3. Problems in Weapon System Effectiveness Evaluation

In terms of theoretical research, it shows that the theoretical analysis does not fully keep up with the pace of the development of weapons and equipment. With the progress of science and technology, on the one hand, the speed of upgrading weapons and equipment is accelerating, and gradually becoming intelligent, unmanned and systematic; On the other hand, many new operational concepts such as mosaic warfare and distributed warfare have enriched the operational style and the use mode of weapons and equipment. In this context, the traditional effectiveness evaluation methods are not fully applicable to new weapon systems. The scientificity, effectiveness and applicability of the theoretical methods of weapon system effectiveness evaluation in complex combat environment need to be further improved.

In the aspect of simulation modeling, it presents the characteristics of diversified and refined models, many data variables and difficult simulation. Under the condition of information war, the two sides no longer take the platform as the center, but integrate various units and organically combine specific combat units into an overall system confrontation [24]. In the context of system operations, the operational links are becoming more and more complex and various parameters are numerous, which makes it difficult to build the weapon system effectiveness evaluation index model. There are many input and output variables of the model, and the variables are more and more correlated, increasing the amount of data and simulation time consumption. In addition, The uncertainty of combat operations and the complexity and variability of the actual battlefield environment need to be considered in the simulation modeling. These factors increase the difficulty of efficient and accurate evaluation of the combat effectiveness of the weapon system.

In terms of platform construction, it shows the characteristics of insufficient intelligence and "short supply" of construction level. Weapon system effectiveness evaluation serves the actual needs of weapon equipment development planning and operational decision-making and deployment. It is urgent that the construction of weapon equipment effectiveness evaluation platform can be service-oriented, more intelligent, real-time and efficient [25]. At present, there are many models and methods for weapon system effectiveness evaluation, and there are relatively few research and construction of support platform. With the diversification of combat operations, focusing on various business requirements such as weapon system of systems analysis, weapon equipment life cycle management and combat decision-making [26], it is necessary to strengthen the construction of effectiveness evaluation support platform and build an integrated effectiveness evaluation environment to provide basis support for decision-makers to formulate plans.

3. Common Methods and Models for Effectiveness Evaluation of Missile Weapon System

3.1. Common Methods of Weapon System Effectiveness Evaluation

Up to now, the methods of operational effectiveness evaluation of missile weapon system can be basically divided into three categories: analytical method, statistical test method and system simulation method.

3.1.1. Analytic Method

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Analytical method is one of the most widely used methods in evaluating the effectiveness of weapon equipment system. Its basic principle is to establish an analytical formula between hypothetical conditions and effectiveness indicators to evaluate effectiveness [27]. Some analytical methods can be applied to weapon system effectiveness evaluation, such as exponential method, ADC method and effectiveness index synthesis method combined with many methods.

(1) Index method: index method is a commonly used method in weapon equipment system effectiveness evaluation. Its basic idea is to estimate each weapon equipment according to equipment performance parameters and expert experience, use index value to reflect the effectiveness of different types and models of equipment, and then add the index values of each equipment to obtain the effectiveness value of the whole combat system [28].

(2) Multi index comprehensive evaluation method: for some complex weapon systems, their effectiveness presents a more complex hierarchical structure. There is only mutual influence between the effectiveness indexes of different levels without definite functional relationship. At this time, the effectiveness of weapon systems can be evaluated only through the comprehensive evaluation of the effectiveness indexes of each level. The commonly used comprehensive evaluation methods include linear weighting method, probability synthesis method, fuzzy evaluation method and so on. In [29], comprehensively uses the traditional analytic hierarchy process and grey evaluation theory to evaluate the combat effectiveness of missile weapon system.

(3) ADC method: ADC method is a model for evaluating the effectiveness of weapon systems proposed by the American industrial weapon system effectiveness Advisory Committee (WSEIAC) in 1965. It mainly depends on the effectiveness, reliability and capability of weapons and equipment. In [30], gives a phased ADC system effectiveness evaluation method to evaluate the effectiveness of missile system.

3.1.2. Statistical Test Method

Statistical test method is a method for statistical analysis of systems affected by random factors in a specified field or accurately simulated environment. This method obtains a large number of statistical data through experiments, and carries out statistical analysis to obtain the evaluation efficiency index [31]. Although it is more reliable, it requires a large number of weapons and equipment as the material basis for testing, which can not be implemented before weapon development, and it is costly and time-consuming.

3.1.3. System Simulation Method

Based on the computer simulation of weapon system confrontation and battlefield environment, the system simulation method obtains the relevant data of combat process through simulation test, and then obtains the effectiveness of weapon system. It mainly includes exploratory analysis (EA) method, multi-agent modeling and simulation (ABMS) method and system dynamics (SD) method.

(1) EA method: EA method is a new system analysis method developed by the United States when studying defense planning and equipment system demonstration in the 1990s. At present, this method has also been widely used in the evaluation of network centric warfare and information advantage evaluation.

(2) ABMS method: ABMS is a bottom-up efficiency evaluation method. This simulation method has broad application prospects in solving complex system problems. Based on the ABMS method, in [32], established a composable system simulation model framework and developed a simulation platform for system effectiveness analysis and application, which can be used to evaluate the effectiveness of different systems.

(3) SD method: SD method is suitable for solving the nonlinear relationship between systems. The model has good transparency and can be run repeatedly for many times, but the accuracy of the results obtained by this method is low. In [33], established the system dynamics model of the missile system under the countermeasure condition, and calculated the combat effectiveness of the missile system under the actual countermeasure condition.

3.2. Common Models for Weapon System Effectiveness Evaluation

3.2.1. AN Model

For a complex network, AN model is a system effectiveness model proposed by the U.S. Navy in

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the early 1960s. Its system effectiveness also includes three basic requirements, namely performance, effectiveness and utilization. The mathematical formula is:

$$E_s = P \cdot A \cdot V \tag{1}$$

In the formula, E_s is system effectiveness, P is the performance index, A is the effectiveness index, V is the utilization rate.

3.2.2. WSEIAC Model

WSEIAC model was proposed by the American industrial weapon system effectiveness Advisory Committee in the 1960s. It is the most widely used weapon system effectiveness evaluation model at present. Under the WSEIAC model, system effectiveness can be described by availability vector, credibility matrix and capability matrix, the mathematical formula is:

$$E = A \cdot D \cdot C \tag{2}$$

In the formula, E is system effectiveness, A is the availability vector, D is the credibility matrix, C is the capability matrix.

3.2.3. AMM Model

AMM model is a missile system effectiveness model proposed by the U.S. military on the basis of WSEIAC model. Its mathematical description is as follows:

$$P_{FF} = A_0 \cdot P_{DET} \cdot P_{KSS} \tag{3}$$

In the formula, P_{FF} is the system effectiveness, A_0 is the operational availability, P_{DET} is the probability of system discovering, identifying and transmitting target information, P_{KSS} is the single shot damage probability.

4. Conclusion

This paper mainly introduces the common methods and typical models of missile weapon system effectiveness evaluation, summarizes the four development stages of weapon system effectiveness evaluation, and puts forward the problems faced in the research of weapon system effectiveness evaluation, so as to provide reference for further research in the future.

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