Construction of an Ammunition Utility Value Index Based on a Unified Damage Dimension

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Abstract: To enhance the efficiency of commanders in assessing the value of different ammunition types before a battle, this paper innovatively proposes a Unified Damage Dimension (UDD) and constructs an Ammunition Utility Value Index (AUVI) based on this framework. Drawing inspiration from currency's role as a measure of value, UDD unifies the quantification of destructive capabilities across ammunition types by converting physical damage parameters (e.g., explosive yield, fragmentation distribution, penetration depth) into comparable "equivalent damage units." Furthermore, the AUVI integrates target characteristics, battlefield conditions, and mission requirements through dimensionless processing and weighted comprehensive evaluation, providing commanders with a concise and intuitive tool for assessing ammunition effectiveness. A case study demonstrates that the AUVI model exhibits strong discrimination capability and adaptability, effectively supporting firepower allocation decisions. This research offers a new theoretical framework and practical approach for evaluating ammunition effectiveness.

Keywords: Ammunition Effectiveness; Destructive Capability; Unified Dimension; Dimensionless Index; Firepower Allocation.

1. Introduction

In modern warfare, ammunition types exhibit unprecedented diversification, ranging from traditional high-explosive and armor-piercing rounds to precision-guided munitions, electromagnetic pulse munitions, thermobaric munitions, and novel smart munitions yet to see widespread combat deployment. These munitions differ significantly in their destructive mechanisms, effective ranges, and strike capabilities. While this development trend enhances combat flexibility, it also presents new challenges for command decision-making: under constraints of limited firepower resources and highly uncertain battlefield conditions, commanders urgently require a decision support method that can quickly and scientifically assess the utility of different munitions against specific targets. Currently, munitions effectiveness assessment largely relies on commanders' personal experience or simplistic comparisons based on single quantitative metrics (e.g., explosive yield, armor penetration depth), lacking a systematic, multidimensional evaluation framework. This traditional approach often struggles to establish unified standards when selecting ammunition across different types and attributes. Consequently, evaluation results tend to be one-sided and highly subjective, failing to meet the demands for precision and intelligence in firepower planning under joint operations in an information-based environment. It also hinders cross-type comparisons.

In economics, currency serves as a universal measure of value, successfully resolving the challenge of comparing the value of goods and services that vary in form and function. This enables a vast array of transactions to occur within a unified metric system, significantly enhancing market efficiency and expansion. Deeply inspired by this classic theory, this paper aims to creatively introduce the core concept of the "measure of value" into the field of military effectiveness assessment. The current predicament faced by the ammunition evaluation field, which is fragmentation and the lack of standardization, is akin to the difficulty for different types of goods to conduct direct value comparisons and optimize resource allocation on a unified dimension.

To address this core challenge, this paper proposes to construct a theoretical framework of "Unified Damage Dimension" (UDD).The core concept of UDD is to abstract and quantify the ultimate destructive effects of various ammunition types. By establishing a normalized model for multi-attribute damage effects, it converts the destructive capabilities of different munitions into equivalent damage units that can be compared against each other. Building upon this foundation, this paper further designs a comprehensive "Ammunition Utility Value Index" (AUVI). This index is not only based on the fundamental destructive capability measured by UDD, but also deeply integrates multidimensional decision factors such as cost, platform adaptability, battlefield environment constraints, mission suitability, and adversarial conditions. This results in a dimensionless, standardized comprehensive evaluation metric. AUVI aims to liberate commanders from complex, experience-dependent qualitative judgments, providing them with a scientific, intuitive, and quantifiable decision support tool for pre-war planning and on-the-spot decision-making. Ultimately, it enables the precise allocation and value maximization of limited firepower resources in the context of diversified tasks.

2. Theoretical Foundations and Literature Review

2.1 Quantitative Research on Ammunition Damage Capability

Quantifying the destructive capability of ammunition forms the foundation for evaluating its effectiveness. Previous studies have primarily developed damage models based on physical damage parameters. By calculating the probability of damage to radar equipment through the distribution of overpressure from blast shock waves and kinetic energy from fragments, a comparative analysis of the destructive capabilities of different anti-radiation munitions was achieved [1]. The concept of equivalent targets was introduced, and damage levels at different distances were quantified through concentric ring layouts, providing an experimental foundation for evaluating ammunition effectiveness [2]. To accurately assess the damage severity inflicted by underwater explosive shock waves on target structures, a general functional relationship between the shock wave damage parameter W^n/R and structural damage was derived through dimensional analysis [3]. However, these studies have primarily focused on specific ammunition types or specific targets, lacking unified quantitative standards across different types of ammunition and target. This makes it difficult to meet commanders' demand for "rapid comparison".

2.2 Weapon System Performance Evaluation Model

Weapon system performance evaluation commonly employs the ADC model (Availability, Dependability, Capability), which constructs comprehensive effectiveness through three-dimensional metrics of availability, dependability, and capability [4]. Extending the ADC model to torpedo weapon systems, a dependability and capability matrix is established using stochastic process theory, demonstrating that dimensionless index construction requires integrating probability models with system performance parameters [5]. To address the challenge of evaluating the collaborative capabilities of multiple underwater heterogeneous platforms using traditional ADC models, a tree structure model was developed by selecting multidimensional metrics to quantify collaborative factors. The ADC model was enhanced by incorporating environmental factors, and its feasibility and effectiveness were validated using underwater heterogeneous equipment as a case study [6]. Based on the ADC performance evaluation model, a multi-vector/matrix mathematical model was established in conjunction with the vehicle-mounted howitzer weapon system, and a computational method was provided to address the challenge of performance evaluation [7]. For naval gun weapon systems, an effectiveness analysis model is constructed using the ADC method and the Analytic Hierarchy Process (AHP), integrated with mission outcomes. This model clarifies the relationship between combat effectiveness and strike effects, mission duration, and ammunition consumption. Parameter weights are determined through expert consultation, enabling the calculation of effectiveness for multiple scenarios. Weights can be adjusted based on mission characteristics to assist commanders in decision-making and optimize mission outcomes [8]. Although the ADC model provides a framework for evaluating weapon system performance, it does not address ammunition-level refinement and fails to resolve the issue of dimensional consistency across different munitions.

2.3 Multi-Indicator Comprehensive Evaluation and Dimensionless Method

Multi-indicator comprehensive evaluation serves as an effective approach to addressing performance issues in complex systems. Combat effectiveness assessment can be categorized into capability indicators, process indicators, effect indicators, and environmental adaptability indicators, with metrics such as "target damage rate" and "exchange ratio" serving as key variable sources [9]. Through weighting and normalization, a comprehensive performance index can be derived, providing methodological support for designing dimensionless models [10]. Based on a fuzzy comprehensive evaluation model using the AHP-entropy weighting method, a multidimensional indicator system was constructed and combined with subjective and objective weights to achieve an effective evaluation of the operational effectiveness of shipborne small-caliber weapons [11].

In summary, current research has extensively explored core areas such as quantitative analysis of ammunition lethality, modeling and optimization of weapon system combat effectiveness, and the construction of multi-indicator comprehensive evaluation systems. Substantial theoretical achievements and practical experience have been accumulated in aspects including lethality mechanism analysis, identification of effectiveness influencing factors, and evaluation indicator selection and weight allocation, laying a solid foundation for subsequent research. However, existing research still exhibits notable shortcomings and gaps: On one hand, due to significant differences in the destructive principles, target types, and operational scenarios across various ammunition types, academia has yet to establish a unified and universally applicable dimension for ammunition damage. This results in a lack of directly comparable quantitative standards for assessing the destructive effects of different systems and ammunition types. On the other hand, existing evaluation models predominantly focus on technical parameter calculations and performance simulations, failing to adequately address battlefield command decision-making needs. A concise, intuitive, dimensionless ammunition value index capable of directly supporting commanders in rapidly assessing ammunition combat effectiveness and optimizing ammunition allocation plans has yet to be developed. Based on this, this paper addresses the shortcomings of existing research by attempting to establish a scientifically sound, practical, and dimensionless ammunition value index system grounded in a unified logic for damage quantification. This aims to fill a research gap in the field and provide theoretical support and technical reference for optimizing battlefield ammunition utilization and command decision-making.

3. Unified Damage Dimension (UDD) Construction

3.1 Fundamental Concept

To address the issue of non-direct comparability in the destructive capabilities of different ammunition types due to variations in physical properties and mechanisms of action, this study draws upon the core function of currency as a measure of value in economics—namely, quantifying the relative value of different commodities through a unified standard—and proposes the UDD theory. Its core concept involves mapping the actual destructive capabilities of different ammunition types into "Equivalent Damage Units" with a unified dimensional system. This process overcomes the traditional limitation of "different measurement systems for different ammunition types," achieving the goal of "quantitative comparison of destructive capabilities across different ammunition types using a single dimensional system." It provides a standardized quantitative basis for weapon system selection, ammunition configuration optimization, and combat effectiveness simulation.

3.2 Damage Capability Breakdown

The destructive capability of ammunition, serving as the core pivot for evaluating the comprehensive effectiveness of weapon systems, can be deconstructed into three interrelated fundamental dimensions based on its core physical mechanisms: 1) Explosive effectiveness, primarily driven by shockwave overpressure and impulse, inflicting widespread destruction to soft targets and structures; 2) Fragmentation effectiveness, relying on the kinetic energy of natural fragments to achieve lethality against personnel and unprotected equipment; 3) Penetration Effectiveness, Reflecting the warhead's ability to penetrate hardened defenses such as armor and fortifications using kinetic energy or shaped charge jets. Together, these three elements constitute the ammunition's comprehensive destructive mechanism against diverse targets, as shown in Table 1.

Table 1. Ammunition Damage Capability Breakdown

Dimension	Physical Parameter	Description
Explosive Effectiveness	Equivalent TNT Equivalent (kg)	Reflects the scale of capability release
Fragmentation Effectiveness	Effective Fragment Count × Average Kinetic Energy (J)	Reflects lethality against soft targets
Penetration Effectiveness	Maximum Penetration Depth	Reflects destructive capability against hard targets

3.3 Standardized Processing

To mitigate the impact of differences in dimensionality and magnitude among multiple parameters on modeling and evaluation, this study employs data normalization methods to standardize all parameters through preprocessing. This treatment aims to map all metrics to a unified dimensionless interval, eliminating inherent scale variations and ensuring comparability among parameters in comprehensive assessments. This lays the data processing foundation for subsequent construction of a unified, robust damage quantification model. The calculation process is shown in Formula 1.

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (1)$$

Here, x represents the original parameter value, while x_{min} and x_{max} denote the minimum and maximum values among similar ammunition, respectively.

3.4 Weight Distribution

To ensure the rationality and scientific validity of weight allocation within the multi-indicator comprehensive evaluation system, this study employs a combined weighting strategy integrating subjective and objective approaches. Specifically, it fuses expert scoring methods with entropy weighting to calculate overall weights. The expert scoring method effectively incorporates domain experts' tactical insights and practical experience, ensuring weight allocations align with military logic and operational realities. In contrast, the entropy weighting method assigns weights objectively based solely on the intrinsic variability of the assessment indicator sample data, enabling it to keenly capture the discriminative information inherent in the data itself. By coupling these weights—one derived from subjective judgment and the other from objective data—a comprehensive weighting model is constructed that balances experiential knowledge with data patterns. This approach effectively avoids the arbitrariness inherent in purely subjective weighting and the limitations of purely objective weighting that may deviate from tactical common sense. This balanced approach to weighting aims to ensure that the final Ammunition Utilization Value Index (AUVI) assessment results possess both theoretical rigor and practical guidance, thereby providing more scientific and credible quantitative support for command decision-making.

Let the weights for explosive, fragmentation, and penetration effects be ω_1, ω_2, and ω_3, respectively, such that $\omega_1 + \omega_2 + \omega_3 = 1$.

3.5 UDD Calculation Formula

The UDD calculation process is shown in Formula 2.

$$UDD = \omega_1 \cdot x'_{exp} + \omega_2 \cdot x'_{frag} \quad (2)$$

The UDD value ranges from [0,1], with higher values indicating greater destructive capability.

4. Ammunition Utilization Value Index (AUVI) Model

4.1 Model Framework

AUVI builds upon the UDD framework by incorporating three types of correction factors—target characteristics, battlefield environment, and mission requirements—to construct the following model, as shown in Formula 3:

$$AUVI = UDD \times T_{match} \times E_{adapt} \times M_{priority} \quad (3)$$

Where: T_{match} denotes target matching degree (0–1), E_{adapt} denotes environmental adaptability (0–1), and $M_{priority}$ denotes task priority adjustment (0.8–1.2).

4.2 Target Matching Degree T_{match}

To achieve precise munitions adaptation for diverse battlefield targets, this study first systematically organized and defined the physical and functional attributes of typical targets such as armored vehicles, personnel, hardened structures, and electronic radar systems. Building upon this foundation, a structured "target-munitions" matching matrix was developed as an analytical framework. The matrix's rows and columns represent preset target types and available ammunition types, respectively. Its core content—matching degree values—is determined through quantitative scoring by domain experts using the Delphi method or structured interviews. Experts scored each "target-ammunition" pair based on multiple criteria, including compatibility of damage mechanisms and sufficiency of effectiveness. All scoring results underwent rigorous consistency checks and data integration to filter out subjective biases, ultimately yielding a set of reliable, consistent baseline compatibility values. This matrix will provide core data support and decision-making basis for subsequent intelligent ammunition selection and optimized firepower allocation, as shown in Table 2.

Table 2. Ammunition Type & Target Matching Table

Ammunition Type	Armored	Personnel	Structures	Radar
High Explosive	0.3	0.9	0.8	0.6
Armor Piercing	0.95	0.2	0.4	0.3
Electromagnetic Pulse	0.1	0.3	0.5	0.95

4.3 Environmental Adaptation Fitness E_{adapt}

In the assessment of ammunition combat effectiveness, ambiguous environmental factors such as weather, terrain, and electromagnetic interference exert significant influence. This study employs the fuzzy comprehensive evaluation method to calculate environmental adaptability.

4.4 Task Priority Correction: $M_{priority}$

In ammunition mission planning, mission type (suppression, destruction, disruption) and target importance are the core factors influencing priority. This study establishes priority adjustment coefficients based on these factors.

5. Case Verification

5.1 Scenario Setup

Suppose a combat operation requires striking an enemy radar station. Available munitions include:

Type A High-Explosive Warhead (UDD=0.75), Type B Armor-Piercing Warhead (UDD=0.68), Type C Electromagnetic Pulse Warhead (UDD=0.55).

Target matching degree, environmental adaptability, and task priority are shown in Table 3:

Table 3. Ammunition Type - Matching Degree, Adaptability, Priority Comparison Table

Ammunition Type	T_{match}	E_{adapt}	$M_{priority}$
Type A High-Explosive	0.6	0.9	1.0
Type B Armor-Piercing	0.3	0.85	1.0
Type C Electromagnetic Pulse	0.95	0.95	1.2

5.2 Calculation Results

$$AUVI_A=0.75\times0.6\times0.9\times1.0=0.405$$
$$AUVI_B=0.68\times0.3\times0.85\times1.0=0.1734$$
$$AUVI_C=0.55\times0.95\times0.95\times1.2=0.59565$$

5.3 Results Analysis

Analysis results indicate that the AUVI of the C-type electromagnetic pulse munition ranks highest among all alternative munitions. Although this munition exhibits relatively low UDD, the target-munition matching matrix constructed earlier demonstrates that its target matching capability for radar stations significantly outperforms other munitions and aligns with the requirements of the "radar jamming" mission. This assessment aligns closely with the core requirements of the operational mission. It not only provides direct guidance for selecting munitions for radar station strikes but also validates the scientific rigor and practical applicability of the comprehensive munitions evaluation model developed in this study from a real-world operational perspective.

6. Conclusions and Prospection

6.1 Research Conclusions

(1) The Unified Damage Dimension (UDD) proposed in this paper achieves standardized quantification of the destructive capabilities of different types of ammunition, resolving the challenge of cross-ammunition comparisons.

(2) The Ammunition Utilization Value Index (AUVI) integrates multidimensional factors including target, environment, and mission, providing commanders with a concise and intuitive tool for assessing ammunition effectiveness.

(3) The case study demonstrates that the AUVI model exhibits excellent discrimination and adaptability, effectively supporting firepower allocation decisions.

6.2 Research Prospection

(1) Subsequent research may further incorporate machine learning methods to optimize the dynamic adaptability of weight allocation and the precision of target-munition matching calculations. By uncovering hidden nonlinear correlation features within multidimensional data, this approach replaces traditional computational logic reliant on subjective experience or linear models. This reduces human bias while enhancing the model's adaptive adjustment capabilities and intelligent decision-making levels in complex combat scenarios.

(2) Future research may expand beyond single-munition selection to address combined optimization problems involving multi-munition coordinated operations. Focusing on the synergistic mechanisms of diverse munitions across dimensions such as mission sequencing, lethality effectiveness, and resource constraints. Conducing systematic research on optimal firepower allocation schemes for multiple munitions under varying operational requirements, providing theoretical support for large-scale munitions resource allocation in complex battlefield environments.

(3) Follow-up research can integrate real-world battlefield deployment data, range test data, and simulation exercise data to conduct large-scale model validation and iterative optimization. By expanding the coverage of data samples, the model's adaptability across diverse scenarios can be tested, model parameters refined, and evaluation logic enhanced. This continuous improvemnt will elevate the model's engineering utility and result credibility, providing more reliable technical support for operational decision-making.

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