Construction of a value-based equipment development decision analysis index system

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Abstract. This article summarizes the feasibility and related achievements of the value-focused thinking in the field of equipment development. On this basis, in response to previous equipment development decisions that mainly considered combat effectiveness, this paper analyzes equipment development decision-making issues from the two dimensions of mission and resource constraints from the perspective of value, constructs a decision value model, and sets a scoring function for it. Using the final value score as the basis for the selection of equipment plans, aiming to provide a method reference for the decision-making of China’s equipment construction plans.

1. Introduction

Equipment development is a typical complex giant system construction, and its decision-making research involves the trade-off of multiple factors such as equipment operational requirements, capability requirements, and economy. Equipment development decision-making is the process of evaluating whether a certain equipment system has the corresponding capabilities and selecting the best plan from multiple equipment construction plans based on the requirements of mission objectives for combat capabilities. The analysis of equipment development decision-making is a hot research topic in the military field, and has great practical significance for the realization of strategic planning and the rational allocation of resources.

Equipment development and construction is based on the top-level planning and overall guidance of the equipment development strategy, with the improvement of new quality combat effectiveness as the focus of the plan, and is achieved through the specific formulation and implementation of the equipment construction development plan. The equipment development strategy argumentation attaches importance to the two-wheel drive role of demand traction and technology promotion. Therefore, to enhance the new quality of combat effectiveness and equipment capabilities requires more attention to the construction needs of equipment, and the combat capability and combat value of the equipment can be brought into play.

2. Overview of Value-Focused Thinking

Value-Focused Thinking (VFT) is a new creative decision analysis method proposed by Ralph L. Keeney of the University of Southern California in the 1990s. It combines qualitative research and quantitative calculation. Its core principle is: "Latent values are the key factors that guide people to make decisions and actions"[1].
The implementation of the value-focused thinking can be summarized into the following steps: ①Clear strategic goals; ②Establish a value model; ③Generate alternative plans; ④Evaluate alternative plans; ⑤Select the best plan.

2.1. The value-focused thinking embodies the decision-making thinking with value as the driving factor
Different from the traditional form of selecting the best solution from the given alternatives, the value-focused thinking first allows decision makers to understand and analyze the problems to be solved according to their own values, and then allows decision makers to play freely. They can create or choose any alternatives that can achieve goals. In the decision-making process, the decision-making goal represents the core value of all decision-makers, and there are no restrictions on the specific strategy used to analyze and solve the problem, mainly relying on the decision-maker’s own value judgment and practical experience. Therefore, it is conducive to stimulating innovative ideas, enhancing decision-makers' ability to understand and solve problems, expanding decision-making space, and increasing the possibility of decision-making analysts to choose the best results, avoiding alternatives in AFT (Alternative-Focused Thinking) methods cannot meet the overall goal or the defect of the decision-maker's value [2].

2.2. Value-focused thinking is suitable for equipment construction decision analysis and research
In the VFT method, value is an element that runs through the entire decision-making process. It determines the goal, expectation and final option of the decision-making, and is the basis for subsequent decision-making analysis. Value not only guides decision makers to choose the best plan, but also helps relevant personnel establish a creative decision analysis environment[3]. The equipment development strategy is related to the long-term construction and development of the future equipment system. The high uncertainty of the future strategic environment and military threat factors determines that the creativity of decision-makers needs to be fully utilized in the process of capability assessment for equipment development strategies[4]. Therefore, The value-centered decision-making thinking method is more suitable for the current equipment construction decision-making analysis and research.

In addition, the value-focused thinking is frequently used by policymakers in the United States, especially in the field of strategic decision analysis of the US Air Force. In 1994, the U.S. Air Force used the Value-focused thinking to carry out the "Space Cast 2020 Operational Analysis" military strategy research for the first time, and determined the various system concepts needed in future space operations and related technologies to support these concepts[5]. On this basis, the U.S. Air Force took another year to conduct research with the strategic goal of "capturing future air and space superiority" and decomposing it into three sub-objectives: perception ability, reach ability, and armed force, and obtained support for these three sub-objectives. Eight functions were analyzed, 29 performance indicators were obtained by analyzing these functions, a complete value model was established, and various related technologies proposed by the U.S. Air Force to obtain superiority in the aerospace field in the next 30 years[6]. The value-focused thinking is also used in the performance evaluation of air force soldiers[7], army equipment procurement decision[8], military aircraft health monitoring and evaluation [9]and other fields.

3. Construction method of value-based equipment development decision analysis index system
3.1. Construction principles
The value of equipment lies in its ability to achieve combat missions. Therefore, the construction of an equipment development decision-making analysis index system must be based on mission objectives, matching the capabilities required to complete combat missions with the capabilities of the equipment itself, and fully embodying them under actual combat conditions. The efficiency value of the equipment saves construction resources and ensures that the decision-making results are as accurate and objective as possible. In general, the construction of a scientific and reasonable equipment development decision-making analysis index system mainly follows the following four principles:
(1) The principle of quantification. True and reliable data is the basis for ensuring scientific and accurate decision-making. In the indicator system, the lowest-level target should be measurable, and its value can be quantified by setting a scoring function.

(2) The principle of comprehensiveness. Proceeding from mission objectives, through the comprehensive analysis of combat missions and combat scenarios, an index system that can fully reflect all factors is constructed. Comprehensiveness emphasizes the integrity of the indicator system.

(3) The principle of simplicity. Simplicity and comprehensiveness do not conflict, but rather complement each other. On the premise that the mission and target requirements can be achieved, try to use as few indicators as possible, highlight the main indicators, and avoid the excessively large indicator system, which leads to excessive time spent on equipment construction decisions and waste of resources. Simplicity emphasizes that the index system should highlight the key points.

(4) The principle of comparability. In equipment construction decision-making, it is mainly through the index system to compare the pros and cons of different equipment schemes. Therefore, the indexes should be comparable[10].

3.2. Build the framework
In the research of equipment development decision-making analysis, after given missions, combat styles, and expected effects, how to evaluate alternative weapons and equipment or combinations should be considered. The performance of modern weapons and equipment is becoming stronger, and the development costs are becoming more expensive. In actual equipment development, resources such as personnel and funds are limited. When determining the development strategy of weapon systems, it is necessary to consider how to effectively allocate these limited resources to achieve the most effective performance[11]. Therefore, this article starts from the two dimensions of mission and resource constraints, and constructs an index system to support the decision-making analysis of equipment development.

3.2.1. Mission task dimensions. The equipment development decision-making analysis framework established from the mission and task dimension, the value model serves the future military strategic goals, and the military goal is transformed into the ability demand that can be quantified research through value decomposition. Military objectives cannot be directly executed by weapons and equipment. They must be broken down into tasks to be completed by weapons and equipment. Combat tasks must also be further refined to obtain combat activities. The various components of weapons and equipment directly perform combat activities. In order to complete specific combat activities, weapons and equipment need to have certain combat capabilities. According to the mapping relationship of "strategic objectives-combat missions-combat activities-equipment capabilities", the capability requirements for accomplishing military objectives can be determined, and the overall benefits of equipment development can be determined.

In addition, the ability list obtained from the decomposition of mission objectives is also the corresponding ability requirements. How to meet these needs depends on equipment or equipment systems. Therefore, it is necessary to realize the "capability-equipment" mapping relationship, and clarify whether the weapon equipment or the combined system of the weapon equipment provides a certain ability or which type of equipment can provide a certain ability. Among the available equipment, the best equipment is selected by comparing the equipment value scores.
The indicator system established from the mission dimension is mainly to ensure that the equipment to be selected has the ability to complete the mission objective, that is, to ensure the combat effectiveness of the equipment. Wang Shaoping comprehensively considered the operational process of hypersonic anti-ship missiles, characteristics of flight trajectory, characteristics of targets and combat environment and other factors, and selected four indicators of missile shooting accuracy, shooting effectiveness, survivability and reliability to form combat effectiveness index system of hypersonic anti-ship missile [12]; Gao Qiang established the unmanned reconnaissance aircraft effectiveness index system, which is divided into three first-level indicators: reliability, survivability and reconnaissance capability [13]; Zhu Ziwei established the artillery equipment effectiveness index system and divides the inherent capabilities of artillery equipment into four types of capabilities: fire strike, battlefield mobility, command communication, and battlefield protection [14].

### 3.2.2. Resource allocation dimensions

Establishing a decision-making analysis framework for equipment development from the resource dimension is mainly reflected in how to make equipment development planning to maximize the economic value of resources under limited resource conditions. The cost, price, effectiveness, and efficiency of equipment are all included in the value concept category that realizes user requirements or needs. This value can be embodied as cost. In the case of limited equipment development funds, the less development costs, the better or the maintenance costs in case of failure, the better; it can be time. When equipment is urgently needed to be put into use, the shorter the development time, the better Good, or the longer the life cycle of the equipment, the better. Therefore, the economic benefits of equipment development can be evaluated through the chain of resource benefit-economic value-cost and time.

For the maintenance support management of equipment contractors, Hu Yuqing established a performance evaluation index system for equipment maintenance contractors from five aspects: repair quality, maintenance costs, user feedback, internal management and core capabilities, to achieve the performance evaluation of equipment maintenance contractors[15]; Xu Shaojie established a radar equipment management performance evaluation index system using the data envelopment analysis (DEA) method, starting from the input indicators and output indicators, and refined the input indicators into manpower, expenditure, spare parts, maintenance equipment, and maintenance. Evaluation of radar equipment in six aspects of facilities and information assurance [16].
3.2.3. Basic framework. According to the above-mentioned index system construction steps, the framework of the equipment development decision analysis index system shown in Figure 2 can be obtained. Among them, combat effectiveness and resource efficiency are mutually restrictive. The more the combat mission is completed, the more comprehensive the equipment performance required, and the higher the equipment development cost. Therefore, it is necessary to find a corresponding balance point between the two, and choose the most economical and effective equipment plan while ensuring the completion of the target.

Figure 2. Comparison of value model frameworks in different dimensions

3.3. Implementation steps
VFT method is a creative decision analysis method. Based on the implementation steps of VFT, this article intends to construct an equipment development decision analysis index system through the following process:

Step 1: clarify typical combat scenarios. This is the basis for building a value model, and the strategic objectives that need to be achieved can be determined through the combat scenario.

Step 2: Build a value model under typical scenarios from the mission goal dimension and resource constraint dimension respectively. According to the strategic objectives, the sub-objectives are decomposed level by level until the sub-objectives are measurable, evaluable, and can fully reflect the goals of the superior.

Step 3: for the underlying sub-objectives decomposed in the previous step, construct corresponding evaluation criteria and determine the scoring function for them. The scoring function of the value model provides a quantitative method for measuring the relative effectiveness of alternatives for each evaluation index. The horizontal axis of the scoring function is the corresponding evaluation index, and the vertical axis is the value score. The scoring function can objectively and truly reflect the physical nature of the evaluation index and its contribution to the upper-level goal.

Step 4: calculate the comprehensive value score of the scheme according to the index weight and scoring function. Through the scoring function, the various abilities of weapons and equipment are converted into different value scores, and they are sorted to determine the optimal solution.

4. Construction of a value-based equipment development decision analysis index system
Based on the above analysis, this article uses the constructed scenario as an example to establish a value-based equipment development decision analysis index system.

4.1. Military mission objectives
The proposed combat scenario is: an island N located in the ocean of T is the territory of country S, which is 1,200 kilometers away from the land of country S. Because its sea area contains a large amount
of mineral resources, oil and gas resources are particularly rich, so other neighboring countries have been fighting against it for a long time. Eyes are eyeing, especially country Y is the most reckless, often provoking and provoking things near the island. At some time in the future, country Y may illegally land on the island and conduct activities, infringing upon the territorial sovereignty of country S. In order to safeguard its own rights and interests, maintain territorial integrity, and contain country Y’s military activities, country S needs to determine an equipment development plan to gain an advantage in war.

According to the assumed conditions, the aforementioned value model framework is used to conduct equipment development decision-making analysis and construct a corresponding index system to screen out the optimal equipment construction plan.

Operational mission objectives: to carry out precision strikes against the Y country's maritime escort.

4.2. Building a value model

On the basis of previous research, based on the mission tasks in the construction scenario, the combat tasks that need to be performed in the war are determined as reconnaissance early warning, command control, fire strike and comprehensive support. Further decomposing combat missions can obtain corresponding combat activities, such as detection, reconnaissance, identification, communication, and positioning required to perform reconnaissance and early warning missions; reception, identification, positioning, control, and decision-making are required to perform command and control missions; fire strike missions require penetration, Hit, damage; comprehensive support tasks need to be repaired and supplied. Therefore, the decision-making value model for combat objectives as shown in the figure below can be established.

![Figure 3. VFT-based equipment development decision analysis efficiency value model](image)

According to the decomposition of the target and the above-mentioned value model, the equipment with the above-mentioned combination of capabilities can be preliminarily selected as the equipment to be developed, that is, alternative plans for equipment development can be determined. From the perspective of resource constraints, construct a resource benefit value model, as shown in the following figure:
Based on the above analysis process, it can be determined that the equipment development decision analysis index system is:

**Mission goal**
- Maximum resource efficiency

**Sub goal**
- Funding
- Time
- Technology

**Evaluation criteria**
- R&D funding
- Logistics support fee
- Research period
- Product Lifecycle
- Technical reliability

**Scoring function**
- Scoring function 16
- Scoring function 17
- Scoring function 18
- Scoring function 19
- Scoring function 20

**Figure 4. Resource value model of equipment development decision analysis based on VFT**

**Figure 5. Value-based equipment development decision analysis index system**

**Determine the scoring function**

1. **Detection distance** $A_1$

The detection distance represents the maximum range that can detect the enemy's activities, and its scoring function is:
Among them, S is the detection distance in kilometers;

(2) Early warning time $A_2$

The early warning time represents the time required to detect enemy activities and transmit the information to the command and control system. The scoring function is:

$$A_2 = \begin{cases} 
1 & T \leq 10 \\
0.75 & 10 < T \leq 18 \\
0.5 & 18 < T \leq 30 \\
0.25 & T > 30 
\end{cases}$$

Among them, T is the warning time, in minutes;

(3) Target recognition accuracy $A_3$

The accuracy of target recognition indicates the accuracy of identifying the position of the enemy's target during the investigation, and its scoring function is:

$$A_3 = e^{-(x-x_0)}$$

Among them, $x_0$ represents the position of the enemy target, $x - x_0$ represents the distance between the detection target and the actual enemy target, that is, the detection deviation, in kilometers. When the deviation is 0, the value score is the highest 1; the greater the deviation, the lower the score.

(4) Communication capacity $B_1$

The communication capacity represents the maximum amount of information that the command and control system can transmit per unit time, which can reflect the communication capabilities of the equipment, and its scoring function is:

$$B_1 = \frac{2}{\pi} \arctan B \times \log_2 \left(1 + \frac{S}{N}\right)$$

Among them, B represents bandwidth, in hertz; S represents average signal power, in watts; N represents noise power, in watts;

(5) Delay degree $B_2$

The degree of delay represents the time required for information to be sent from the command and control system to the combat unit, and its scoring function is:

$$B_2 = \frac{\sum_{i=1}^{N} a_i}{N} \div 100$$

Among them, $a_i$ is the score of the i-th expert, and the score range is 0-100; N is the number of experts;

(6) Decision response time $B_3$

The decision reaction time represents the time interval for the command and control system to make operational deployment decisions after receiving the detection information, and its scoring function is:

$$B_3 = \begin{cases} 
1 & T \leq 1 \\
0.75 & 1 < T \leq 1.5 \\
0.5 & 1.5 < T \leq 2 \\
0.25 & T > 2 
\end{cases}$$

Among them, T represents the decision response time, in hours;

(7) Anti-detection probability $C_1$
Anti-detection probability represents the probability of the enemy target being detected by our army. According to historical experience data, it is scored by experts. The score function is:

\[ C_1 = \frac{\sum_{i=1}^{N} b_i}{N} \times 100 \]

Among them, \( b_i \) is the score of the i-th expert, and the score range is 0-100; N is the number of experts;

(8) Anti-interception probability \( C_2 \)
The anti-interception probability represents the number of times the enemy interception system is breached, and its scoring function is:

\[ C_2 = \frac{N_0}{N} \]

Among them, \( N_0 \) is the number of successful breakthrough interceptions, and N is the number of investigations performed;

(9) Flight speed \( D_1 \)
Flight speed represents the average speed of the missile in flight, and its scoring function is:

\[ D_1 = \begin{cases} 1 & v \geq 1000 \\ 0.75 + \frac{v - 1000}{1000} \times 0.75 & v < 1000 \end{cases} \]

Among them, v represents the flight speed of the missile, in kilometers per hour;

(10) Range \( D_2 \)
Range indicates the distance between the launch point and the impact point of a missile. It is a key factor for a missile to effectively attack its target, and it is also the most important tactical and technical indicator of a missile. For specific combat targets, keeping the firing range within a certain range is the most beneficial. Beyond this range, it will cause redundant capabilities or waste of resources. The scoring function is:

\[ D_2 = \begin{cases} 1 & s < 1000 \\ \frac{1}{1000} & 1000 \leq s < 1300 \\ e^{1300-s} & s \geq 1300 \end{cases} \]

Among them, \( S \) represents the range, in kilometers;

(11) Strike range \( D_3 \)
The strike range represents the effective kill range of the missile, and its scoring function is:

\[ D_3 = \frac{\sum_{i=1}^{N} c_i}{N} \times 100 \]

Among them, \( c_i \) is the score of the i-th expert, and the score range is 0-100; N is the number of experts;

(12) Hit probability \( E_1 \)
The hit probability represents the probability of the missile hitting the target, and its scoring function is:

\[ E_1 = \frac{M_0}{M} \]

Among them, \( M_0 \) represents the number of hits, and M represents the actual total launch;

(13) Explosive equivalent \( E_2 \)
The explosive equivalent represents the energy released when a nuclear warhead explodes. It is an important manifestation of the strength of a missile. Its scoring function is:
$$E_2 = \frac{\sum_{i=1}^{N} d_i}{N} \div 100$$

Among them, $d_i$ is the score of the i-th expert, and the score range is 0-100; N is the number of experts;

(14) Communication maintenance capability $F_1$

Communication maintenance capability means maintaining communication channels and ensuring the smooth transmission of combat information. Its scoring function is:

$$F_1 = \frac{\sum_{i=1}^{N} e_i}{N} \div 100$$

Among them, $e_i$ is the score of the i-th expert, and the score range is 0-100; N is the number of experts;

(15) Material supply capacity $F_2$

Material supply capability means timely provision of materials during combat to avoid shortage of materials, and its scoring function is:

$$F_2 = \frac{\sum_{i=1}^{N} f_i}{N} \div 100$$

Among them, $f_i$ is the score of the i-th expert, and the score range is 0-100; N is the number of experts;

(16) R&D expenditure $G_1$

R&D expenditure represents the cost of equipment from project establishment to production process, and its scoring function is:

$$G_1 = \frac{\sum_{i=1}^{N} g_i}{N} \div 100$$

Among them, $g_i$ is the score of the i-th expert, and the score range is 0-100; N is the number of experts;

(17) Logistics support fee $G_2$

Logistics support means maintenance of equipment and repair of faulty equipment, etc. The scoring function is:

$$G_2 = e^{-(ax + P)}$$

Among them, $a$ represents the repair cost for each failure; $x$ represents the number of failures; $P$ represents the maintenance fee, in yuan;

(18) Development cycle $H_1$

The development cycle represents the time it takes for the equipment to be successfully developed, and its scoring function is:

$$H_1 = \frac{\sum_{i=1}^{N} j_i}{N} \div 100$$

Among them, $j_i$ is the score of the i-th expert, and the score range is 0-100; N is the number of experts;

(19) Product life cycle $H_2$

The product life cycle represents the number of years the equipment can serve, and its scoring function is:

$$H_2 = \frac{\sum_{i=1}^{N} k_i}{N} \div 100$$
Among them, $k_i$ is the score of the i-th expert, and the score range is 0-100; N is the number of experts.

(20) Technical reliability $K_1$

Technical reliability indicates the maturity level of the technology used in equipment development, and its scoring function is:

$$H_2 = \frac{\sum_{i=1}^{N} q_i}{N} \times 100$$

Among them, $q_i$ is the score of the i-th expert, and the score range is 0-100; N is the number of experts.

For the alternatives, combined with the designed scoring function and weight, the value score of each equipment program under each indicator is quantitatively calculated, and integrated into its comprehensive score for completing the combat objective, that is, the score represents ability level under the objective. By comparing the final value scores of different schemes, the equipment unit or equipment system that needs to be developed can be determined.

5. Conclusion

Equipment development decision-making is an important part of current military force development. This article uses the VFT method to study equipment development decision-making analysis indicators, and builds a value model of decision-making indicators, which can more clearly identify key capability indicators that should be paid attention to in equipment development. In the future, further research on weight design and scheme selection is needed to improve the quality and level of equipment decision-making.

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