



A Review of Economic Research on Aerospace Equipment Products

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Abstract. Since the development of domestic aerospace equipment products, the previous design philosophies have often emphasized advanced functionality, performance, and reliability. In recent years, as cost requirements for equipment have become increasingly important, cost-effectiveness has emerged as one of the key capability indicators for such products. Against this backdrop, related technologies and management methods have gradually become a research focus in the field of equipment products. To further promote the application of cost-effectiveness-related technical methods, this paper systematically reviews and evaluates existing research on enhancing the cost-effectiveness of aerospace equipment products. First, the main models and methods for cost-effectiveness management of products are summarized. Next, design analysis and optimization methods oriented toward cost-effectiveness are outlined. Finally, a summary of cost analysis and modeling is provided, with the aim of offering references for subsequent research and practice.

Keywords: Economy; Trade-off Design; Aerospace; Cost Modeling; Cost Management

1 Introduction

In recent years, the intensifying competition in the aerospace equipment sector and the rapid advancement of technology have driven continuous innovation in equipment products. This has led to a significant increase in product complexity, accompanied by a substantial rise in costs. Under the new competitive paradigm, the traditional equipment development philosophy that solely pursued performance superiority can no longer meet the demands of the current landscape.

Driven by this new competitive environment, the global aerospace equipment sector has been undergoing reforms to adapt to the evolving requirements. For instance, at the governmental level, cost research and reviews are continuously being conducted [1, 2]. Concurrently, the U.S. military is exploring low-cost equipment solutions [2, 3], and private aerospace companies, represented by SpaceX, are persistently advancing low-

cost technologies [4-5]. Meanwhile, China has also been actively promoting the affordability of equipment products in recent years [6]. Within the aerospace sector, various research institutes are vigorously enhancing the economic efficiency of their products [7].

In contemporary equipment development, affordability is no longer an isolated "cost reduction" target. Instead, it has become a core design parameter that must be integrally balanced with mission effectiveness, reliability, and development schedules. The ultimate goal is to achieve product "affordability." To enhance product affordability, this paper reviews research related to the affordability of aerospace equipment products from 2015 to 2025, with a primary focus on programs and practices in the Chinese aerospace sector (e.g., CASC, CASIC, AVIC, etc.). To provide reference and draw insights, internationally representative best practices (e.g., from NASA, ESA) are also selectively incorporated for comparative analysis. The literature retrieval process is illustrated in Fig. 1. According to the key dimensions of affordability work for equipment products, this paper presents the research status in affordability management and design, summarizes cost modeling methods, and provides an outlook on related technological developments.

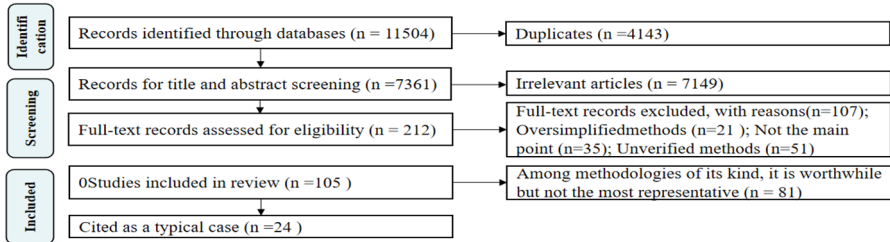


Fig. 1. The process of literature retrieval

2 Economic Management Models and Methods

Research on economic management methods for products in the aerospace field can currently be categorized into three main types: Life Cycle Costing, Target Costing, and Value Engineering. Although these methods have different conceptual focuses, they respectively face challenges in practical application, such as difficulties in adapting methodologies to specific engineering practices and weak organizational culture adaptability. Attention must be paid to their applicability boundaries during implementation.

2.1 Life Cycle Cost Management

Life Cycle Costing emphasizes coordinating the costs and benefits across all stages of a product from a systemic perspective to avoid long-term economic losses caused by local optimization. Domestic research primarily focuses on three areas: model construction, methodological innovation, and data-driven approaches. For instance, Hu Ping proposed cost control strategies encompassing the development, production, operation, and retirement phases, highlighting the necessity of systematic integration [8]. Xiao Jun

et al., considering the characteristics of civil aircraft, integrated traditional estimation methods with target costing to construct an LCC framework [9]. Zhang Nan et al. promoted digitalization of whole-chain cost control by building multi-type cost databases [10]. Fig. 2 illustrates common definitions of the full life cycle for equipment products.

However, current LCC research often shows weakness in the early conceptual stage, primarily due to high parameter uncertainty and lack of historical data at this stage, making predictive models difficult to construct. Furthermore, functional silos within organizations hinder cross-phase cost coordination, leading to "data silos." Future research should focus on developing dynamic cost prediction models suitable for high uncertainty and promoting the establishment of cross-departmental data governance and coordination mechanisms.

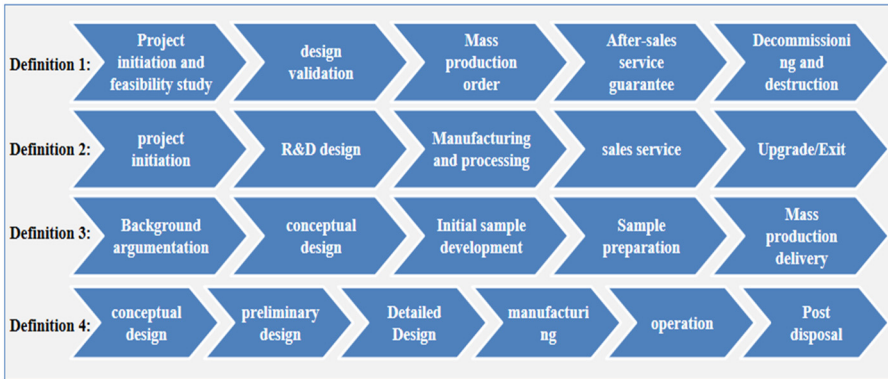


Fig. 2. Example of Product Life Cycle Definition

2.2 Target Costing

Target Costing, starting from the market-acceptable price, sets cost targets in the early product design phase and decomposes them layer by layer. It is an important tool for responding to market competition. In terms of methodological innovation, Liu Yigong et al. integrated Earned Value Management with target costing, proposing a dynamic control model suitable for complex aviation projects [11]. Regarding risks, Du Juan pointed out that target setting needs to balance stability with industrial chain coordination [12]. Shi Nannan et al. proposed a differentiated target costing strategy based on task importance [13].

Although target costing is widely applied in the design phase, systematic research on its application in the manufacturing phase remains weak, and the standardization of cost data construction lags. Its failure often stems from overly rigid early target setting, which fails to adapt to engineering changes and technical risks. Simultaneously, the "performance-first" mindset within organizational culture hinders the effective implementation of cost targets. Subsequent efforts should explore dynamic cost modeling in smart manufacturing environments and promote the construction of cross-enterprise cost collaboration platforms.

2.3 Value Engineering

Value Engineering aims to minimize life cycle cost by optimizing the function-to-cost ratio. Fig. 3 illustrates the value engineering methodology. A typical case is the US F-6 project, which demonstrated that VE involves not only technical optimization but also a systematic shift in project management philosophy [14]. Domestic research mostly concentrates on theoretical framework construction. For example, You Mingyi proposed a unified value-cost-risk assessment system [14], while Li Yushun advocated for lean cost management guided by customer value [15].

Value Engineering offers limited benefits in scenarios with highly specific requirement indicators, and its effectiveness highly depends on the organization reaching a consensus on functional value. A prevalent culture in domestic aerospace equipment development that "emphasizes functional performance and reliability design over cost design" makes it difficult for VE to be effectively implemented. Systematically advancing VE practice in the future requires changes in design culture, top-level cost control, and functional analysis during the requirements phase.

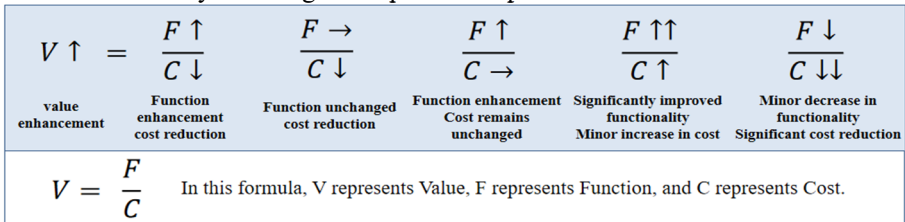


Fig. 3. Diagram of the Value Engineering Method

3 Design for Affordability

Design for affordability refers to specific technical approaches aimed at enhancing product affordability, primarily comprising two methods: the application of Commercial Off-The-Shelf (COTS) products and trade-off design. The effectiveness of its implementation depends not only on the methods themselves but also significantly on the organization's capability to balance "design freedom" and "cost constraints."

3.1 Application of Commercial-off-the-shelf Products

COTS products significantly reduce costs by replacing customized, high-cost components while meeting reliability requirements. NASA studies indicate that using commercial components from leading industry manufacturers is a viable path [16]. Domestic research, such as that by Li Zhi et al., compares automotive-grade and military-grade components, pointing out the advantages of automotive-grade parts in terms of cost-reliability balance [17]. Li Zhengrui et al. demonstrated the application of low-cost components in high-reliability scenarios through system design approaches aided by thermal simulation technology [18].

However, there is currently a lack of standardized COTS assessment systems, and the risks associated with domestic COTS applications have not been systematically identified and managed. The prevalent "military-specification first" mindset within organizations often leads to a conservative attitude towards commercial components, hindering their adoption in critical systems. It is recommended to establish full-lifecycle COTS quality and risk assurance specifications and promote the development of relevant standards.

3.2 Mission-Effectiveness-Oriented Multi-Objective Trade-off Design

The core of modern design for affordability is maximizing mission effectiveness under cost constraints, or minimizing total cost while meeting specific effectiveness thresholds. This necessitates integrating affordability as a design input from the early stages, conducting systematic trade-off analyses with other key objectives such as performance, reliability, and schedule. Its essence is a multi-objective optimization problem aimed at finding a set of non-dominated solutions (Pareto front), rather than a local optimum for a single objective. However, this process often becomes superficial due to the lack of multi-source data, such as cost data, in the early design stages. The following sections review existing trade-off methods from the perspectives of cost versus performance and cost versus reliability.

Cost-Performance Trade-off.

In cases of cost-performance trade-off design, Shi Nannan et al. proposed that the key to affordable design for complex aerospace systems lies in defining constraints and key parameters during the requirements and conceptual design phases, and identifying optimal combinations through multi-objective trade-off analysis [13]. Fig. 4 shows an example of the cost-effectiveness trade-off for a missile weapon system. A typical international case involves Honeywell, which, through trade-off analysis of the performance, size, and cost of radars operating at different frequencies, determined the suitable radar frequency and antenna size for the small aircraft transport domain [19]. The underlying principle in these cost-performance trade-off cases is treating cost as one of the objective parameters during the product design process and achieving balance through multi-objective optimization modeling. Given current research progress, it is difficult to model most products using precise quantitative mathematical models; however, qualitative engineering practice is still achievable through classification and categorization methods.

The research frontier is currently shifting from qualitative, classification-based methods towards quantitative trade-off models based on probabilities and multi-objective optimization algorithms. These modern models can handle dozens or even hundreds of design variables and constraints simultaneously, directly outputting the cost-performance Pareto front. This provides decision-makers with a clear 'cost-effectiveness' map, thereby supporting the selection of system architectures that optimize mission effectiveness.

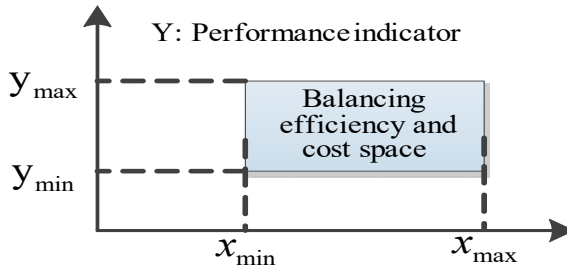


Fig. 4. Example of Cost-Performance Trade-off for a Missile Weapon System

Cost-Reliability Trade-off.

In the design trade-offs between cost and reliability, a typical approach is the application of commercial off-the-shelf products as mentioned above. Beyond this, related research primarily employs modeling methods. For instance, Hu Haifeng et al. demonstrated through a reliability-cost model that appropriately reducing reliability requirements within an acceptable range can significantly reduce costs [20]. Fig. 5 shows an example of the cost-reliability tradeoff. Similarly, Shi Feng et al. utilized a relationship model between reliability and cost to control product costs [21]. As indicated above, for highly complex products, reliability prediction itself involves considerable errors. The introduction of cost variables further exacerbates modeling uncertainties, thereby limiting the practical applicability of such models. Nevertheless, balancing these factors has a significant impact on improving the economic efficiency of equipment. Therefore, continued exploration of comprehensive modeling methods based on probabilistic design and systems engineering is of great importance.

Future research on reliability-cost trade-offs needs to move beyond traditional deterministic models towards probability-based risk design. By quantifying reliability uncertainties as probability distributions and coupling them with cost models, a more realistic reflection of the risks in trade-off decisions can be achieved, leading to a more scientific balance between product reliability and life-cycle cost.

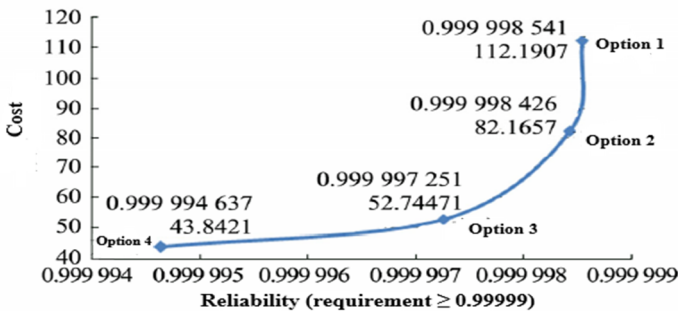


Fig. 5. Relationship Model between Cost and Reliability for an Aerospace Product

4 Product Cost Modeling

Cost models serve as the foundation for identifying cost drivers and supporting economic decision-making. However, existing models often fail during the early R&D phase due to insufficient data granularity and overly idealistic assumptions, particularly when organizations lack a culture of cost data accumulation and sharing mechanisms.

Among related modeling approaches, Wu Shihui et al. proposed a fuzzy prediction model for project cost and schedule based on possibility, which is suitable for high-risk projects [22]. Additionally, Jiangsu Jiarui Co., Ltd. developed a comprehensive cost analysis model to address issues of dispersed data [23]. Meanwhile, Ahmed Raza et al. formulated a maintenance cost equation for avionics equipment, along with a mathematical model for the cost impact of intermittent faults [24]. Fig. 6 shows an example of structural cost estimation using a cost model.

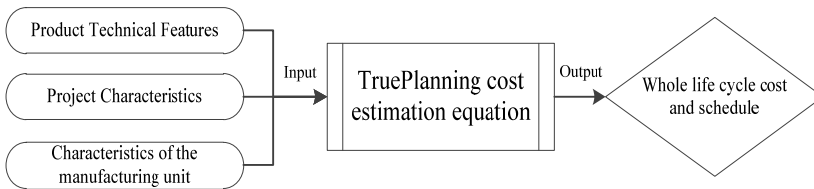


Fig. 6. A structural component using the TruePlanning estimation model

5 Frontier Trends and Future Outlook

As the digital-intelligent transformation of the aerospace industry continues to deepen, cutting-edge technologies like artificial intelligence are providing new ideas to break through the limitations of traditional affordability management and design. The core lies in achieving deeper-level system trade-offs by enhancing cost insight and decision-making intelligence.

In terms of affordability management, digital engineering can lay the foundation for high-precision dynamic cost management by building digital twins that span the entire product lifecycle. Model-Based Systems Engineering (MBSE) incorporates cost as an inherent parameter of the system model, enabling the evaluation of different technical pathways' impact on Total Ownership Cost as early as the conceptual design phase [25].

Regarding affordability design, generative design allows designers to set constraints such as cost and performance, enabling algorithms to automatically generate numerous optimal design solutions. This facilitates the discovery of superior balance points between cost, performance, and reliability that are difficult to identify using traditional methods [26].

In the area of cost modeling and estimation, AI technologies can automatically mine complex cost drivers from vast amounts of historical data to establish more accurate estimation models. Particularly in the early stages where data is scarce, generative AI can assist in predicting cost ranges. Furthermore, blockchain technology can effectively

enhance cost transparency within complex supply chains, strengthen cost traceability, and provide a trusted data foundation for target cost management and supply chain collaboration [27-28].

6 Conclusion

Deeply integrating affordability into the development process has become crucial for enhancing the competitiveness of aerospace equipment. Related research is shifting from isolated cost control towards multi-objective system trade-offs within a "cost-mission effectiveness" framework. In this context, advanced technologies like artificial intelligence are providing new methodologies and tools to support this shift. Looking ahead, improving the affordability of equipment products requires focus on the following three areas: First, technological integration, deeply embedding advanced cost modeling and affordability design methods. Second, data-driven approaches, establishing a full lifecycle cost data foundation to support intelligent decision-making. Third, systemic empowerment, fostering a "value-oriented" design culture and institutionalizing affordability requirements within development standards and processes.

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