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Research on Application of CAIV in Armament Demonstration

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Abstract

Armament demonstration is a forward-looking and basic work, which plays an important role for supporting scientific rule for the demonstrated project. In this paper, the application of CAIV (cost as an independent variable) is studied in armament demonstration and the model for cost and effectiveness are constructed based on CAIV idea. A balanced space of cost and effectiveness could be gotten from the model with trade-off relationship between cost and effectiveness. This conclusion benefits the affordability and sustainability for armament demonstration.

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Keywords: Armament demonstration; CAIV; Cost; Effectiveness;

1. Literature

1.1. Armament demonstration

Armament demonstration is a process which applies scientific theory and method to analyze the military requirements, missions, and constraint factors for armament demonstration. It is the basis and foundation for the development of new equipment, but also the inevitable requirement for scientific, practical, coordinated and systematic weaponry development [1].

Armament demonstration is essential in the life cycle of armament. Only from the perspective of the costs, according to the Pareto curve of life cycle cost, the cost in the period of demonstration and initial overall technical solution account for 3% of life cycle cost of, but result 70% of life cycle cost[2].

A lot of research is expanded around the armament demonstration, such as equipment demonstration evaluation studies [3], which studied the comprehensive assessment method of ship equipment demonstration. The method concludes the weapon system performance index, the platform system performance index, economy index, risk index, and scheme index to evaluation model; and provides a useful reference for the

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demonstration program assessment and decision-making. Jiang [4] proposed a collaborative decision support system for armament demonstration.

The following research is about information technology of armament demonstration, including simulation studies[5-8]. Some research are around the performance and quality management analysis of armament equipment[9-10].

All these studies show that armament demonstration is a very important part, and the relation between cost and performance issues is a very important problem, because high efficiency usually leads to high costs. How to balance the relationship between cost and performance; how to achieve the balance between higher performance and lower cost is the key to solve the important issues. However, research in this area is relatively rare currently.

1.2. CAIV

Cost as an independent variable (CAIV) is a key tool in the trust to reduce total ownership cost for defense systems[11]. It is a kind of method developed during the process of exploring how to reduce the cost of military acquisition, which is also a kind of new method for controlling cost with the background of armament Acquisition Reform. In 1995, a new group is set up to carry out the definition and application of CAIV. In 1996, it is confirmed that all major program are with CAIV method, and cost should be considered as an independent variable[12].

CAIV could be defined as a methodology to acquire and operate affordable systems by setting aggressive, but achievable total ownership cost (TOC) objectives, and trading off performance and schedule. CAIV takes major responsibility in the area of macroeconomic coordination for government. CAIV reflects two needs. First, CAIV is as an input rather than an output. The past were based on the competition of performance to meet or exceed the requirements, thus cost was as a result of design. But now CAIV stressed that cost is a part of project need and goals itself. Second, CAIV strength the trade-off between cost and performance, and there is equal weight between them.

Above all, CAIV means acquiring affordable effective system. There is a lot of research and application about CAIV[13-14]. Data from RAND shows that some commercial projects can save 15-35% of the R&D costs with CAIV method. And the study also shows that the trade-off between cost and performance is the key of CAIV. According to Kaye, it is critical to control cost under the understanding the actual and potential circumstance fully, such as the alternatives to meet the needs of users. U.S. SCEA draw the conclusion that there is no one kind of tool to complete CAIV process, that is, there is no a standard CAIV process. Thus it is important to study the application of CAIV in armament management.

The application of CAIV (Cost as an Independent Variable) in armament demonstration is studied in this paper, and a trade-off space between efficiency and cost is constructed by CAIV, which limit the cost in a certain range and meet the desired performance.

2. Analysis of CAIV in application

CAIV is a new method based on design on cost to control the EA cost. In order to make sure the application affection of CAIV, the U.S. Department of Defense gave the following steps for CAIV application. And all the project managers should use CAIV by these steps. The steps came from the experience of pilot projects and include performance parameters' selection, trade-off analysis between performance requirement and cost, positive unit procurement cost and support cost goals' setting. The detail of these steps is as follows:

- Key Performance parameters' selection

The first step is key performance parameters' selection for CAIV application, which is the base for trade-off analysis between cost and performance. There are many characters in armament, and the capability could be detailed by a lot of performance indicators, or even more than hundred of indicators for large and complex system. Thus it is important for key performance parameters' selection which should be selected based on the importance level and affection level to project performance. It is better that there is no more than eight key performance parameters selected to represent the performance characteristics of the equipment in the demonstration phase.

- Trade-off analysis between performance and cost

In this step, performance and cost are all as input variables. Trade-off space is the set of all the feasible solution of the input variables. And the boundary of the space consists of the optimal value which meets the performance and cost constraints.

- Positive unit procurement cost and support cost goals' setting

By trade-off analysis between cost and performance, the optimal values of the key performance parameters, the lowest total cost of ownership target and maximum system performance value an be obtained. With the optimal value of the total cost obtaining, the total cost could be divided into the following stages such as R&A, production and O&S by the proportional method, the analogy method or parameter method.

Cost on every phase could be obtained, and the active unit procurement cost and operational and support cost goals could be determined by reducing the cost of every stage by a certain proportion.

3. Application of CAIV in armament demonstration

Trade-off analysis between performance and cost could be carried out in the first stage for equipment demonstration. By trade-off analysis, the optimal value of key performance parameters, the object value of maximum performance and cost for every phase could be determined.
Trade-off model between performance and cost can be divided into three steps:

3.1. The system performance model

Here, with measure of performance (MOP) to describe measure of effectiveness (MOE), the efficacy is expressed as a function of the performance parameters; in the meantime, each constraint of the performance parameters is determined at the same times.

It is difficult to describe the armament system with one single parameter, because the armament system is always large and complex system. Thus, many parameters are selected to describe effectiveness of the system. And the values of system parameters are between threshold value and target value, which is the lowest and highest value to meet operation requirement. Then, the relation between the parameters and the effectiveness of system is as follows.

$$E = G(P_1, P_2, \cdots, P_r) \quad (1)$$

Here E means the system effectiveness, and $P_1, P_2, \cdots, P_r$ means the key performance parameters in the system. G is the relation between E and $P_1, P_2, \cdots, P_r$.

3.2. The system cost model

Decomposed through cost, the total cost of ownership is decomposed into each stage of charges corresponding to the performance parameters obtained by the parameter method a function of the various performance parameters and the total cost of ownership.

The relation between system cost and the performance is as follows.

$$C = \Phi(P_1, P_2, \cdots, P_r) \tag{2}$$

Here, C is the life cycle cost, and $P_1, P_2, \cdots, P_r$ means r key performance parameters in the system. Φ is the relationship between $P_1, P_2, \cdots, P_r$ and C .

For many subsystems in a large and complex system, system cost model could be constructed for every subsystem as follows.

$$\begin{cases} C = \sum C_i \\ C_i = \Phi_i(P_{i1}, P_{i2}, \cdots, P_{ir}) \end{cases} \tag{3}$$

Here, C_i is life cycle cost for subsystem i, P_{i1}, P_{i2},.....P_{ir} is r key performance parameters for the ith subsystem, Φ_i is function between performance parameters and life cycle cost for the ith subsystem.

3.3. The trade-off model between system performance and system cost, consider the parameters of the constraints, the cost-performance trade-offs

Goal of trade-off model between effectiveness and cost is to obtain high effectiveness-cost ratio, which is to say minimum cost and maximum effectiveness are all the goals. That is,

$$\begin{aligned} &Min \quad C = \sum C_i = \sum \Phi_i(P_{i1}, P_{i2}, \cdots, P_{ir}) \\ &Max \quad E = G(P_1, P_2, \cdots, P_r) \\ &\text{s.t.} \quad P_i^L \le P_i \le P_i^U, \quad i = 1, 2, \cdots, r \end{aligned} \tag{4}$$

Here, C is the life cycle cost, and $P_1, P_2, \cdots, P_r$ means r key performance parameters in the system. Φ is the relationship between $P_1, P_2, \cdots, P_r$ and C . C_i is life cycle cost for subsystem i , P_{i1}, P_{i2},......P_{ir} is r key performance parameters for the i th subsystem. Here, P_i^L is the threshold value for the i th performance parameter and P_i^U is the target value for the i th performance parameter.

It is difficult to solve optimal solution for Model(2-4)which is a multi-objective decision problem. Thus, satisfied solution is what the decision makers need here. Trade-off space and satisfied solution could be obtained by the following steps.

Step 1, Solve the minimal cost model (2-5) under the performance parameters constraints, and noted the optimal value with C^*

$$\begin{aligned} &Min \quad C = \sum C_i = \sum \Phi_i(P_{i1}, P_{i2}, \cdots, P_{ir}) \\ &s.t. \quad P_i^L \le P_i \le P_i^U, \quad i = 1, 2, \cdots, r \end{aligned} \tag{5}$$

Step 2, Solve the maximal effectiveness model (2-6) under the performance parameters constraints, and noted the optimal value with E^*

$$\begin{aligned} &Max \quad E = G(P_1, P_2, \cdots, P_r) \\ &s.t. \quad P_i^L \le P_i \le P_i^U, \quad i = 1,2,\cdots,r \end{aligned} \tag{6}$$

Step 3, Combine model (2-5) and (2-6), the following goal programming model is constructed to solve multi -object problems.

$$\begin{aligned} &Min \quad m_1(d_1^+ + d_1^-) + m_2(d_2^+ + d_2^-) \\ &s.t. \quad P_i^L \le P_i \le P_i^U, \quad i = 1,2,\cdots,r \\ &\qquad \sum \Phi_i(P_{i1}, P_{i2}, \cdots, P_{ir}) + d_1^- - d_1^+ = C^* \\ &\qquad G(P_1, P_2, \cdots, P_r) + d_2^- - d_2^+ = E^* \\ &\qquad d_1^+, d_1^-, d_2^+, d_2^- \ge 0 \end{aligned} \tag{7}$$

Here, $d_1^+ \times d_1^- = 0$, $d_2^+ \times d_2^- = 0$.

Based on CAIV, cost is as an independent variable to compliment maximal effectiveness, then (2-4) could be transferred into the following model

$$\begin{aligned} &Max \quad E = G(P_1, P_2, \cdots, P_r) \\ &s.t. \quad P_i^L \le P_i \le P_i^U, \quad i = 1,2,\cdots,r \\ &\qquad C^* \le C = \sum \Phi_i(P_{i1}, P_{i2}, \cdots, P_{ir}) \le C^{**} \end{aligned} \tag{8}$$

Here, c is an independent variable between $\left[C^*, C^{**}\right]$, and C^* is the optimal solution of step 1, and C^{**} is the highest cost that could be afforded. The relationship between effectiveness and cost could be analyzed when the value of C varies, which is the trade-off space between effectiveness and cost.

Then goal programming model by CAIV method based on (2-7) and (2-8) was proposed as follows:

$$\begin{aligned} &Min \quad m_1(d_1^+ + d_1^-) + m_2(d_2^+ + d_2^-) \\ &s.t. \quad P_i^L \le P_i \le P_i^U, \quad i = 1,2,\cdots,r \\ &\qquad \sum \Phi_i(P_{i1}, P_{i2}, \cdots, P_{ir}) + d_1^- - d_1^+ = C^* \\ &\qquad G(P_1, P_2, \cdots, P_r) + d_2^- - d_2^+ = E^* \\ &\qquad 0 \le d_1^+ \le C^{**} - C^* \\ &\qquad d_1^+, d_1^-, d_2^+, d_2^- \ge 0 \end{aligned} \tag{9}$$

Model (2-9) could give the “best” satisfied solution, which compliment the minimal cost and maximal effectiveness.

4. Conclusions

All kinds of key performance parameters have been decided after the trade-off analysis between effectiveness. And object cost in the all phases could be computed by proportion method, analogy method and so on based on the former results, which should be listed in the demonstration documents to be the mandate requirement for new weapon system development. Contractors decompose the cost for every stage to give detail enforcement plan. At the same time, program management office and contractor consult to determine non-key performance parameters to form alternative plan. The final system plan came out based on this.

In this paper, the application of CAIV (cost as an independent variable) is studied in armament demonstration and the model for cost and effectiveness are constructed based on CAIV idea. A balanced space of cost and effectiveness could be gotten from the model with trade-off relationship between cost and effectiveness. This conclusion benefits the affordability and sustainability for armament demonstration.

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