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Cost-Effectiveness Methodology for Maritime Patrol Aircraft

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Abstract

This paper presents a formalized methodology for conducting cost-effectiveness analysis on the ROK Navy's maritime patrol aircraft. The methodology involves a Delphi method application for determining the group of appraisal variables as well as their weight values in the area of aircraft effectiveness analysis. Life-cycle costing was employed to produce cost in terms of present worth values of all costs that occur over the common 20-year life cycle. A wide range of experts was selected so that their opinions could be effectively collected and synthesized to form the framework of the effectiveness model. Such a model development strategy provides easy acceptance of the analysis result and assure fairness of the analysis.

I. Introduction

The ROK Navy Systems Analysis Group was called upon to conduct cost-effectiveness analysis on alternative maritime patrol aircraft candidates. Presently four aircrafts are under consideration for selection. The ROK Navy faces serious north Korean submarine threat. Their submarines could blockade the major ports of the south, interdict the maritime war material flow, and attack the south's naval units in and out of their bases. In order to counter such threat the ROKN needs to acquire a number of maritime patrol/ASW aircraft

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with dual missions capability. As for any major weapon system acquisition process, a formalized cost-effectiveness analysis is required to properly evaluate alternative aircraft before the final selection.

At the outset of the analysis it was decided that the Delphi method be utilized to determine factors for appraisal in the effectiveness analysis area as well as their weight values. Consensus thus achieved would enable easy acceptance of the analysis result. It was, therefore, important that a comprehensive range of expertise be represented through the Delphi process. It was also considered crucial that an efficient and unbiased mediator role be played by the systems analysis group personnel in order to channel the expert knowledge of the participants into a useful result.

A comprehensive identification of all relevant cost factors was deemed necessary to enable a realistic comparison of costs over the common life cycle period. The costs were converted to a common measure, namely, present worth (PW) values at time zero, the time of the initial investment.

Ⅱ. Effectiveness Analysis

There is a common tendency to regard system performance as the major criterion for measuring system effectiveness. In fact, it is a prevelant thinking in military circles, in particular, if a system has good performance indices, then probably other effectiveness indices are just as good. This is a dangerous way of thinking and certainly does not lend itself well to good analysis. Total effectiveness of a system must include other important areas such as maintainability, availability, mission reliability, and supportability in the general sense in addition to the system performance. Therefore, an efficient way had to be found to incorporate these factors comprehensively into analysis and to measure totoal system effectiveness as judiciously as possible.

The Delphi method is commonly used to pool expert knowledge together to form a consensus when subjective judgment and evaluation is needed. Here, the method is used to achieve the following objectives :

1) To achieve consensus in effectiveness model construction.

2) To enable wide acceptance of the analysis result.

The procedure was conducted as follows.

Ⅱ.1 The Delphi Procedure[1]

A group of 17 officers of related areas were selected to form an ad-hoc committee to perform a Delphi process in order to determine appraisal criteria and their weight values for the effectiveness analysis. These officers all had responsibilities within the Navy Headquarters which are related to either selection or operation/maintenance of the maritime aircraft as follows :

Table 1. The Delphi Process

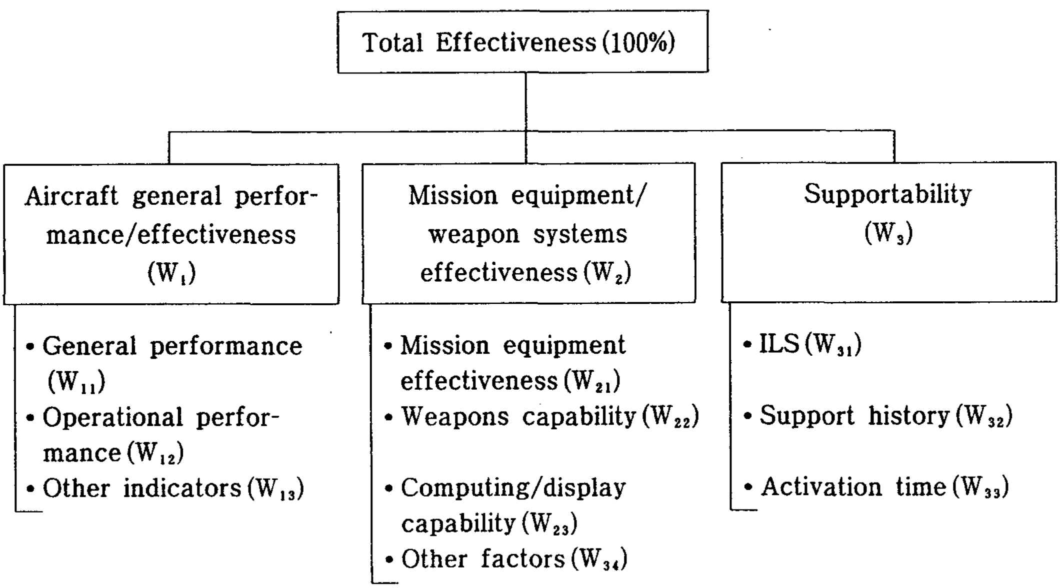
Stage	Presented	Required	Actions/Result
1	· Basic model structure	· Delete/add factors · Initial weight value assignment	· Model modified
2	· #1 weight statistics (min, max & average) · Individual weight of #1 run · Explanation of factors	· #2 weight assignment	· Weight values statistics developed
3	· #2 run statistics · Explanation of factors	· #3 weight assignment	· Convergence of weight values
4	· Subfactor list for each factor · Scoring method	· Validity of subfactors · Add/delete/modify subfactors	· Subfactor list modification · Data acquisition for subfactor scoring

- Policy planning & analysis
- Operations
- Communications/computer systems
- Weapon systems
- Logistics.

Over a period of two weeks in July 1988 four questionnaires were circulated to develop the effectiveness criteria and their weight values. The process may be summarized as in Table 1.

Ⅱ.2 Effectiveness Analysis Model[2)]

Through the first three stages of the Delphi process explained in the previous section, the effectiveness analysis model was constructed as shown in Figure 2.



Note : W_{ij} : weight for effectiveness factor ij.

Fig 2. Structure of Effectiveness Analysis Model

The weights of Fig 2 have simple sum-up relationship as follows :

$$W_1 + W_2 + W_3 = 100$$

$$\sum_{j=1}^{J} W_{ij} = W_i, \text{ for } i = 1, 2, 3$$

In stage #4 of the Delphi process the factors are broken down to subfactors and the weights also need to be broken down accordingly. Thus the following weight sum-up relationship must also hold :

$$\sum_{k=1}^{K} W_{ijk} = W_{ij}, \text{ for } i = 1, 2, 3; \ j = 1, 2, \cdots, J$$

Ⅱ.3 Analysis of Aircraft General Performance & Effectiveness[3)]

The first component of the effectiveness model is a measure of the aircraft general performance and effectiveness. Stage #1 and #2 helped to identify all relevant factors for this component. Stage #4 produced subfactors that contribute to the factors. Thus, we obtain the following detailed structure for the first component of the maritime patrol effectiveness as shown in Table 2.

Table 2. Aircraft General Effectiveness Model

Factor	Subfactor	Elements
General performance (W_{11})	· Flight hours (W_{111}) · Speed (W_{112}) · Loading (W_{113}) · Fuel efficiency per weight (W_{114})	· Flight hours for ASW & · Max speed · Patrol speed · Reserve load room (lbs) · Fuel mileage per unit aircraft weight
Operational performance (W_{12})	· Maritime safety (W_{121})	· Degree of marinization · Self defense capability · Emergency support · Emergency on-sea landing capability

	· Pilotability (W_{122})	· Auto-pilot system · Piloting modes · Instrument flight modes
Other indicators (W_{13})	· Aircraft generation (W_{131}) · Engine reliability (W_{132}) · Practical use (W_{133})	· Initial introduction year · Total engine reliability · Whether in practical use as maritime patrol a/c

Ⅱ. 4 Analysis of Mission Equipment/Weapon Systems Effectiveness

Similarly as before, the structure for analyzing the mission equipment/weapon systems effectiveness was obtained as in Table 3.

Table 3. Analysis Model for Mission Equipment/Weapon Systems Effectiveness

Factor	Subfactor	Elements
Mission equipment effectiveness (W_{21})	Acoustic analysis capability (W_{211})	· Detection frequency range · Simultaneous signal analysis features · Signal analysis mode · Acoustic signal analysis range · Auto tracking · Danger warning feature
	Radar search capability (W_{212})	· Detection range · Detection capability · ECCM capability · Interoperability/expansion capacity · Weather observation function
(cont.)	ESM effectiveness (W_{213})	· Mode of signal analysis · Range of detection frequency · Accuracy · Response time · RWR/danger signal generation · Signal analysis function

	FLIR effectiveness (W_{214})	· Detection range · Analysis capability · Horizontal view width
	MAD effectiveness (W_{215})	· Detection range · Error compensation
	IFF effectiveness (W_{216})	· Querry & response function · Operation mode
	Communication equipment effectiveness (W_{217})	· Tactical communication equipment · TTY · Tactical data interoperability
Weapons capability (W_{22})	Sonobuoy (W_{221})	· No. of rounds
	Torpedo (W_{222})	· No. of rounds
	Missile (W_{223})	· No. of rounds · Effective range
Computing/ display capability (W_{23})	Computer process capability (W_{231})	· Process method · Software configuration · No. of main computers · Main memory capacity · Process speed
	Display & recording capability (W_{232})	· Acoustic signal display/recording · Tactical situation display concept · Recording of Radar/MAD/FLIR data
Other indices (W_{24})	Technology generation (W_{241})	· Acoustic processor · Non-acoustic sensors · Computer system
	Degree of practical use (W_{242})	· Degree of active use

An overlap of coverage may exist between factors W_{231} and W_{241}. The newer a computer system, the better its computing capability would be. Technology, however, was considered so important, particularly in the case of the computer system, that such an overlap was deemed almost necessary. Immense amount of data from both acoustic and nonacoustic sensors needs to be processed efficiently in a manner that would enable rapid and intelligent display and recording of analysis results. A modern technology computer system, therefore, is required for a maritime patrol aircraft to rightly justify the large investment of a range of $30 millions to $100 millions per aircraft.

Ⅱ.5 Analysis of Supportability

In this category of effectiveness analysis it was thought vital to include as many identifiable supportability parameters as possible, although valid data collection was expected to be difficult. The list included such factors as integrated logistic support (ILS) capability, past support history, and the system activation time frame.

The factors, subfactors, and elements for supportability analysis are as listed in Table 4.

Table 4. Supportability Analysis Model

Factors	Subfactors	Elements
ILS Capability (W_{31})	Initial logistic support (W_{311})	· ASWOC quality · Initial spares/equipment support · Maintenance tech support · Tactical support
	Follow-on support (W_{312})	· System production stability · Follow-on technical/maint/spare parts support · In-country support
	Training support (W_{313})	· Training support level & content
	Test & evaluation support (W_{314})	· Basic aircraft test · Test site access · Test requirement level
Past Support History (W_{32})	Military aircraft intergration experience (W_{321})	· Maritime/ASW aircraft · Other military a/c
	Military a/c support current status (W_{322})	· Type & quantity of a/c being supported
Activation Time (W_{33})	Initial delivery time (W_{331})	· #1 a/c delivery time
	Final delivery time (W_{332})	· Final delivery time after T&E

Ⅱ. 6 Scoring Method

Given the inherent difficulty in realistic data acquisition for this type of analysis which requires data related to performance, reliability, quality, etc. of systems which are not in active use or whose operation and maintenance data are not easily available, some reasonable method needs to be devised to evaluate each effectiveness element in an objective way. Depending on the type of data available, the following scoring methods were developed and employed to score alternatives for each effectiveness element.

A. Quantitative Data Scoring

When quantitative data are available for an effectiveness element, scores are assigned between 0 to 1 in the following :[4]

$$S_{ijk} = 0.6 + 0.4 \times \frac{V - R}{M - m}$$

where S_{ijk} : Score for element *ijk*

M : Maximum value

m : Minimum value

R : Required value (set by the navy)

V : Data value for this a/c.

When the required value is not relevent, it is replaced by the minimum value, m.

B. Qualitative Data Scoring

When data are given in terms of quality which can be expressed only as "best," "medium," or "poor," the following score assignment rule was used :

Best = 1.000 ; medium = 0.80 ; poor = 0.60

It is implicit here that the poor quality still meets the navy's requirement albeit poorly.

C. Score Summation

The total effectiveness score of an aircraft system is obtained by summing the weighted score of all elements in the following way :

$$E_x = \sum_i \sum_j \sum_k W_{ijk} \cdot S_{ijk}$$

where E_x : total effectiveness index of system x.

E_x may take a value less than 100.

Ⅲ. Cost Analysis

Ⅲ.1 Methodology[5)]

The life-cycle costing concept was adopted to generate total cost of an aircraft over a common life-cycle of 20 years. Some cost estimating relationships were employed to get estimates of O & M costs. Relative projection of certain cost elements in reference to known cost values of the USN P-3 aircraft was also a useful technique in cost estimation. The time value of money was reflected by using an annual interest rate of 10%. This rate has[6)] commonly been used in ROK defense analysis and is also the recommended interest rate for public economic analysis in the U. S. The cost analysis methodology may be summarized as in Fig. 1.

Ⅲ.2 Manpower Requirement Estimation

The following relationships were used to estimate unit manpower requirement for each aircraft type :

- Unit Crew Size (UCS) = no. of seats × 1.5
- Unit Direct Maintenance Manpower (UDMM)

$$= \frac{\text{Flight hours per month} \times \text{Direct maint man-hrs} \times 1.32}{\text{Monthly maintenance hours (91 hrs)}}$$

- Unit Manpower Requirement (UMR) = UCS + UDMM

Ⅲ.3 O & M Cost Computation

The following relationships show how O & M cost is obtained :

- Annual O & M cost (OMC) = Flight Operations Cost (FOC) + Maintenance cost (MC)
- FOC = Flight Manpower Cost (FMC) + Fuel Cost (FC)
  + Training Consumables Cost (TCC)

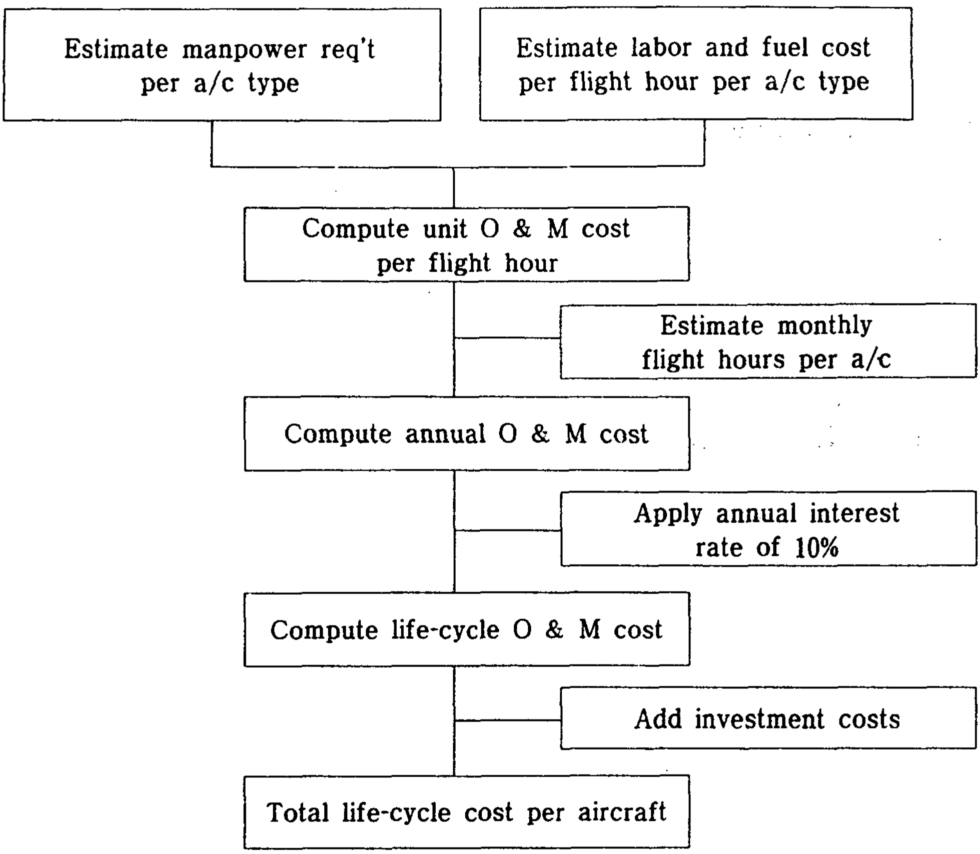


Fig 1. Cost Analysis Procedure

- MC = Maintenance Manpower Cost (MMC) + Maintenance Parts & Material (MPM) + Overhaul Cost (OVC) + Parts Supply Cost (PSC) + Ground Equipment Cost (GEC) + Training Equipment Cost (TEC)

Ⅲ.4 Investment Cost Computation

The investment costs were broken down and identified in the following manner :

- Investment Cost (IC) = Aircraft Cost (AC) + ILS Cost (ILC) + ASWOC Cost (AWC)
- AC = Airframe Cost (AFC) + Equipment Cost (EQC) + Other Cost (OTC) + R & D Cost (RDC)
- ILC = Critical Spare Parts (CSP) + General Supplies & Equipment (GSE) + Training Cost (TRC) + Technical Support Cost (TSC) + Software Support

Cost (SSC) + Manuals Supply Cost (MSC) + Site Survey Cost (SVC) + Transportation Cost (TPC) + Other Support Cost (OSC)

Ⅲ.5 Cost Integration[7)]

The total life-cycle cost was integrated over the 20 year period using a 10% annual interest rate in the following way :

- Total Cost (TC) = OMC × (P/A, 10%, 20Yrs) + IC

  where (P/A, 10%, 20Yrs) : present worth conversion factor for 20 years at 10% rate.

Ⅳ. Cost-Effectiveness Index

The cost-effectiveness index (CE) is computed for an aircraft type x as follows :

$$CE_x = \frac{TC_x}{E_x}$$

where CE_x : CE index for aircraft x.

TC_x : Total cost of a/c x.

E_x : Total effectiveness of a/c x.

The index is computed for the following three cases to assist the decision maker for "what-if" type of questions :

Case 1 : Total effectiveness used.

Case 2 : Effectiveness minus active use history factor.

Case 3 : Effectiveness minus active use history and supportability factors.

A consistent priority pattern in all three cases would present a clear superiority of one alternative over the others. This type of sensitivity analysis enables the decision maker to make the decision after having perused major consequences of his decision in light of future uncertainties.

Ⅴ. Conclusions

For an important defense acquisition project such as the navy's maritime patrol aircraft it is important to reach a consensus over the procedure for evaluating the alternatives. The scientifically devised and organized procedure such as the one presented in this paper experienced a wide acceptance as perhaps the most credible decision support aid.

The validity of data values used in the analysis is another matter. The organization of the Delphi process in particular, contributed to the high acclaim offered to the methodology. This procedure may be used as a reference for other important defense decision analysis.

Efforts to improve on this methodology could be concentrated on adjustment of the vendor supplied data, establishment of common yardstick for each cost element, better ways to establish the supportability measures, and a more careful and wider selection of experts for the Delphi procedure.

NOTES

1) For a brief discussion on the Delphi method, see p. 307 of Engineering Economics (2nd Ed.) by James L. Riggs (McGraw-Hill, 1977).
2) For a general discussion on cost-effectiveness methodology, read Introduction to Systems Cost-Effectiveness by Karl Seiler Ⅲ (Wiley-Interscience, 1969).
3) For an aircraft analysis example, see Case Studies in Military Systems Analysis by William Snyder (Industrial College of the Armed Forces, Washington D. C., 1967).
4) This scoring method assumes that a score of 60 out of 100 is the threshold satisfactory level.
5) For a comprehensive coverage of systems cost analysis, read Cost Considerations in Systems Analysis by G. H. Fisher (RAND Corp., 1971).
6) For an analytic discussion on the topic of the discount rate used for public projects analysis, read p. 437 of Riggs' cited above.
7) For an introduction to the present worth comparison, read Chapter 8 "Present-Worth Comparisons" (pp. 273-249) of Riggs' cited above. For a more in-depth analysis on the method, read Chapter 33 "The Alleged Superiority of the Discounted Present Value Criterion" of Cost-Benefit Analysis (3rd Ed.) by E. J. Mishan (George Allen & Unwin, London, 1982).