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COST ANALYSIS AND MEASURE OF EFFECTIVENESS USES IN IMPROVING THE MILITARY CAPABILITIES

MALANCIUC Bogdan-Simion

Ministry of National Defence, Romania

Abstract:
Cost–benefit analysis (CBA) in the military offers a vital tool to help guide governments through both stable and turbulent times. As countries struggle with the dual challenges of an uncertain defense environment and cloudy budgetary prospects, CBA offers a unique opportunity to transform defense forces into more efficient and effective organizations.
Taking difficult decisions is always a struggle in the military. Choosing between cutting cost and raising effectiveness is a hard job for every leader. CBA offers a scientific approach to decision making in the military, especial in the field of resource allocation.

Key words: cost-benefit analysis, effectiveness, cost estimation, decision-making.

1. Introduction

Cost analysis is very important from the perspective of a decision maker or a decision maker's adviser. Cost–benefit analysis (CBA) requires careful consideration of future costs. Cost estimating is the process of collecting and analysing historical data and applying quantitative models, techniques, tools, and databases to predict the future cost of an item, product, program or task.

The term "cost analysis" is broadly used to include not only the process of estimating (measuring) the cost of a project but also the process of discovering, understanding, modelling and evaluating the relevant information necessary to estimate the cost as well as the cost uncertainty and risk. This "cost analysis" is used to help the decision makers to select the best alternatives to achieve the objectives/goals of the organization. [1]

Some examples of military organizations objectives can be: Maximize security, firepower, skills, system capabilities or Minimize deaths, costs. All objectives that cannot be expressed in monetary forms can be grouped under the term Effectiveness. The one remaining – namely Costs, it is to be linked with the notion of Efficiency, ability to avoid wasting materials, energy, efforts, money, and time in doing something or in producing a desired result. In a more general sense, it is the ability to do things well, successfully, and without waste.

It is important to note that cost analysis and estimating, as applied to financial management throughout government and industry, provides for the structured collection, analysis, and presentation of life-cycle cost (LCC) data to assist in decision-making for systems capabilities throughout their useful life. Examples of the components of LCC analysis conducted during each phase are:

- research and development (R&D) - complexity and innovation studies;
- production - performance, scale, and process studies;

- operations and support (O&S) - crew levels, training, fuel consumption support, reliability and maintainability, and logistics studies;
- disposal - feasibility and tradeoff studies.

There are three main applications of cost estimating in the Planning, Programming, Budgeting, and Execution System (PPBES) process:

- preparation and justification of budgets (the cost estimates are performed within all phases of the acquisition process to determine the budget amounts required to fund the program throughout its life-cycle)
- making choices among alternatives (acquisition cost forecasting or analysis of alternatives - AoA),
- source selection (contracting).

The scope of this paper is presenting cost estimating as a most for AoA.

2. Cost estimating and analysis of alternatives

Cost estimates for the AoA requires forecasts of time-phased cash flows that occur over the life of a system. This forms the basis for estimates of the total LCC of a system. The LCC estimates are usually developed using constant currency, and cost comparisons of alternatives are based on the present value of the total LCC.

AoA and selecting the best alternative implies answering to 3 questions:

1. How can we estimate the cost of different alternatives?
2. How can we combine all the objectives into one measure of effectiveness?
3. How do we choose if one alternative is cheapest and another alternative is the most effective?

2.1 Ways to estimate costs

Costs can be defined in several ways. It can be defined or measured as the actual physical resources consumed (iron, oil, timber, number of planes, ships). Costs can be described as what is given up, which is sometimes maned opportunity cost (what you give up to choose / buy your preferred alternative). [2]

The most common way to state cost is in term of money, the currency value of the resources consumed.

According to the International Cost Estimating and Analysis Association (ICEAA), formerly called the Society of Cost Estimating and Analysis (SCEA), estimating is "the art of approximating the probable worth or cost of an activity based on information available at the time." [3] An estimate is a judgment, opinion, forecast or prediction. A cost estimate therefore is a prediction of the likely future cost of a process, product, project, service, program or system.

When you think about the total cost of one alternative you should consider all relevant costs of the system over the lifecycle of the system, based on expected operating conditions.

In the defense acquisition process, a cost estimate is a prediction or forecast of the complete costs of a complex program or weapon system, and it is often a time-phased estimate. The first step in any cost estimate of complex systems is to understand the attributes of the program or weapon system whose cost is to be estimated.

Traditionally, this requires understanding and describing the weapon system in terms of physical and technical parameters, operational and support concepts, mission requirements, and interfaces with other systems. Understanding the program's schedule and acquisition profile is also important in developing a cost estimate. The goal is to understand the relationship between

key weapon systems' attributes and cost. The next step is to develop an explicit framework for the cost estimate. [4]

Having accurate and revealing cost information is critical for decision making. Understanding cost behaviour is the key to useful cost analysis.

We have to keep in mind that lifecycle costs (LCC) has 4 components: Research & Development, Procurement (Investment or Acquisition), Operation & Maintenance, Disposal (Decommissioning or Salvage). All costs should be in the budget the needed period of time.

Cost estimates are designed to inform users about the cost realism, the cost validity, and the cost reasonableness of proposed alternatives, contracts, and budgets.

2.2 Cost estimating techniques

Estimating future costs is always challenging, and is one of the most difficult tasks facing analysts. The three basic methods recognized for use within the professional cost estimating community are:

- analogy - using costs of similar systems to determine the cost of the subject system;
- expert elicitation – ask the experts about what they believe;
- engineering (also called bottom-up or industrial engineering analysis);
- parametric - generalized relationships between system characteristics and costs.

Analogy-based cost estimating, which can also be called "It's like one of these," subjectively compares the new system with one or more existing similar systems for which there is accurate cost and technical data. With this approach, an analyst selects a system that is similar to or related to the system for which costs are being estimated, and adjusts for differences between the two systems (using an index). This approach works well for derivative or evolutionary improvements. Therefore, a relevant starting baseline must exist to apply the method successfully. The analogy estimating approach is faster than the other three approaches, yielding more immediate cost estimates.

Expert elicitation is about what specialists think about future costs. Here can be a problem of overconfidence (costs could be less or experts could not think what can go wrong). We should always ask the experts: What if contract award is disputed? Is the technology unproven? What if we change numbers purchased? Can be some supply shortage?

Industrial engineering is the most detailed method to estimate costs ("Is made up of these"). The bottom-up approach relies on detailed engineering analysis to determine an estimate. To apply this approach to estimate future aircraft engine production costs, an analyst would need the detailed design and configuration information for various engine components and accounting information for all material, equipment, and labor. A conceptual engine design is built from scratch (hence the name "bottom-up"). This approach generates a fairly detailed forecast, but it is very time consuming.

Parametric relationships sometimes known as the statistical method ("This pattern holds"); this technique generates an estimate based on system performance or design characteristics. The parametric relationships used for estimating costs are called cost estimating relationships (CERs). "A parametric cost estimate is one that uses CERs and associated mathematical algorithms (or logic) to establish cost estimates." [5] Parametric methods are usually based on a statistical technique that attempts to explain the correlation between the dependent variable (typically cost) as a function of several explanatory variables such as

technical and performance characteristics, independent variables derived from project parameters, such as:

- intended performance and in-service date (hedonic);
- overall system design characteristics (parametric);
- sub-system design characteristics (synthetic);
- inputs to program work packages (resource-based).

Advantages and disadvantages of the cost estimating methods are presented in the following Table 1:

Model	Description	Advantages	Disadvantages
Analogy	Compare project with past similar projects	Estimates are based on actual experience	Truly similar projects must exist
Expert elicitation	Consult with one or more experts	Little or no historical data is needed; good for new or unique projects	Experts tend to be biased; knowledge level is sometimes questionable
Industrial engineering	Individuals assess each component and then component estimates are summed to calculate the total estimate	Accurate estimates are possible because of detailed basis of estimate; Promotes individual responsibility	Methods are time-consuming; detailed data may not be available, especially early in a program; integration costs are sometimes disregarded
Parametric	Perform overall estimate using design parameters and mathematical algorithms	Models are usually fast and easy to use, and useful early in a program; they are also objective and repeatable	Models can be inaccurate if not properly calibrated and validated; it is possible that historical data used for calibration may not be relevant to new programs

Table 1 [6]

Another thing to keep in mind is that you should have a risk / sensitivity analysis. What can go wrong? What are the associated likelihoods? What are the consequences? Cost estimating process take into consideration all this aspects.

2.3 Time value of money

Using historical data to predict future costs requires that the data not only be relevant to the system under consideration, but that it match the assumptions of the cost estimating model. For example, cost data is recorded in accounting records based on transactions that occur over time. The cost of each transaction reflects the buying power of the currency at the time the transaction was completed. Over time, if a country is experiencing inflation or deflation, the buying power of the same amount of currency changes. As a result, cost information contained in accounting records incorporates inflation or deflation. These effects must be removed before they are used in a cost estimating model; otherwise the cost estimate will be biased.[7]

Another way to say it is that we all prefer money now versus money in the future, we all prefer costs in the future versus costs now. So we must introduce present value analysis as an analytical tool (not a budgetary one!).

This method of present value analysis is used just to compare the costs of alternatives over time.

$$P = F_n / (1+r)^n,$$

where P = present value, F_n = future cost year n, r = discount rate (not inflation, interest, cost of risk, opportunity cost, cost of borrowing money), n = year.

Denominator in above formula is called "discount factor" and it is equal to $(1+r)^n$. For example a discount rate of 0.05 means that $1.050 next year equal $1.000 now. $1.050 two years in the future equal $952.38 now (at 0.05 discount rate).

Usually future currency worth less, but the question is "how much less?". Choosing (calculating!) the right discount factor is very important. In the last period this became even more complicated because of negative interest, possibility that a sum of money from the future worth less than in the present.

There is also the possibility of considering a discount rate equal with zero. Then, undiscounted costs assumes future currency are as valuable as present currency.

2.4 Effectiveness of alternatives

Effectiveness can best be measured in the public sector by developing a framework for solving decision problems with multiple objectives. The framework will provide you with a practical tool for quantitative investigation of all factors that may influence a decision, and you will be able to determine why one alternative is more effective than others. This analytical ability is very important because many real-life decision problems involve more than a single issue of concern. This holds true for personal-life decisions, private sector business decisions, and public sector government resource allocation decisions. [8]

Effectiveness measures the extent to which an alternative helps to pursue objectives, taking into consideration the relative importance of each objective. It does not consider cost.

Government decisions in general, and defense resource allocation decisions in particular, have an added evaluation challenge. Outcomes are difficult, if not impossible, to represent in monetary terms. First, benefit cannot be expressed in terms of profit. Unlike the private sector, the public sector is not profit motivated and this single monetary measure of benefit is not relevant. Second, market mechanisms often do not exist for "pricing out" the many benefits derived from public sector decisions. Thus, it is not possible to convert all the benefits into monetary terms and conduct a cost–benefit analysis (CBA). In national defense, benefits are often characterized in terms such as deterrence, enhanced security, and increased combat capability. No markets exist that generate a price per unit of deterrence or a unit increase in national military security.

So choosing the right objectives, right hierarchy of those, relies on decision maker preferences (you have to be that or have access to him/her for understanding preferences).

There are 3 basic questions to address the decision maker:

1. What is important?

Identifying objectives is the most important step when defining effectiveness.

The decision maker should make an objectives hierarchy from general to specific ones. He / she should made very clear where do you start from and what do you want to achieve. Every objective should be divided until you can measure them clearly. One technique to do that

is to ask "What do you mean by that?" until bottom level of the hierarchy is composed of measurable attributes.

There is a possibility to establish the objectives from some policy documents. This situation should be avoided but could happen when is not possible to speak with the decision maker (because of distance, lack of time…).

2. How much is enough? (value functions)

Each attribute is translated to a value scale between 0 and 1. For example you should put the value 0 when is not enough performance and 1 when performance is at maximum.

3. How important it is? (tradeoff weights)

How important is each objective, relative to each other? This is the step when tradeoffs between attributes are made by the decision maker according to his/her preferences. Each attribute weight is between 0 and 1 and sum of all equal 1.

A decision maker usually can say an order of objectives but cannot say how much more important is. This is the reason that attributes / objectives have to be somehow ranked.

From this "ranked objectives" a measure of effectiveness (MoE) can be derived.

For easier analysis of alternatives the decision maker can put Effectiveness (MoE) and Cost on a graph.

Still remain some questions: Is the required budget reachable? Do you have a required minimum level of effectiveness? How much do you want to spend more to gain something in effectiveness? All this questions are depending on how important the objective is viewed by the decision makers, what are his / her preferences.

Practical application. Choosing a truck for the Army.

Imagine the following decision problem for the fictitious country of Amria, a nation with some security problems and limited funds for addressing these problems:

Amria Army uses a number (around 1.000) of old trucks type DAC 665 produced 20 years ago in a company based in the city of Sengen. There is high need for new trucks to replace the old ones. Main reason to do that is that old DACs have very big maintenance costs, a lot of them not working for different reasons (engine or transmission problems, lack of spare parts). Another reason is that DACs engines are old ones, polluting a lot the environment.

Amria Government decided to make a contract with a firm to improve the Transport Capability of the Army by providing new trucks or modernizing the old ones. A team from the Army Vehicle Command receive the task to analyze this issue and advise the Chief of Land Forces about the best way to resolve this problem. There can be two possibilities: up-grade the existing trucks or sell them and buy new ones.

Special attention is to be paid to the fact that there is a truck factory in Amria, in Sengen city.

After the Army Vehicle Command conducted a research they came with the following offers:

	Upgrade DAC 665	***IVECO HM 6X6***	***Rheinmetall HX***
Price	*30 (engine / transmission*	*100*	*115*

	modernized)		
Warranty	*2 yrs.*	*4 yrs.*	*4 yrs.*
Annual maintenance cost	*8*	*6*	*0 in the first 4 yrs., 8 after*
Protection	*N/A*	*Yes, 25 mm*	*Yes, 40 mm*
Speed	*85 km/h*	*110 km/h*	*125 km/h*
Range	*800 km*	*750 km*	*900 km*
Power	*250 CP*	*400 CP*	*430 CP*
Maximum load	*10 t*	*14 t*	*15 t*
Produced in	*Amria*	*Altland, possibility 50% Amria*	*Altland*
Ground clearence	*390 mm*	*400 mm*	*380 mm*

Expert elicitation told us that there are R&D expenses for modernization of DAC 665 of 2.000 to be made in the first year. Old DAC trucks have a disposal value of 20 / each. Fuel consumption is similar to all alternatives.

Cost analysis (considering LCC of 10 years, all prices above in constant currency, discount rate in the next 10 years - 0.03) for the offers are as follows:

1. Modernizing existing 1.000 DAC 665

We will consider that we will upgrade 1.000 trucks – 100 in year 1, 300 / year in the next 3 years. 2.000 R&D needed in the first year, no disposal cost in the next 10 years.

	YEAR									
DAC	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R&D	2,000	0	0	0	0	0	0	0	0	0
Procurement	3,000	9,000	9,000	9,000	0	0	0	0	0	0
Maintenance	0	800	3,200	5,600	8,000	8,000	8,000	8,000	8,000	8,000
Disposal	0	0	0	0	0	0	0	0	0	0
TOTAL constant	5,000	9,800	12,200	14,600	8,000	8,000	8,000	8,000	8,000	8,000
TOTAL discounted	5,000	9,515	11,500	13,361	7,108	6,901	6,700	6,505	6,315	6,131
										79,035

2. Buying 1.000 new Iveco HM 6X6

We will consider that we will buy 200 trucks/year in 5 years. We will sell next year used DAC trucks (that were replaced by Iveco) resulting a salvage revenue of 20 / piece.

	YEAR									
Iveco	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R&D	0	0	0	0	0	0	0	0	0	0
Procurement	20,000	20,000	20,000	20,000	20,000	0	0	0	0	0
Maintenance	0	1,200	2,400	3,600	4,800	6,000	6,000	6,000	6,000	6,000
Disposal DAC	0	-4,000	-4,000	-4,000	-4,000	-4,000	0	0	0	0
TOTAL constant	20,000	17,200	18,400	19,600	20,800	2,000	6,000	6,000	6,000	6,000

TOTAL discounted	20,000	16,699	17,344	17,937	18,481	1,725	5,025	4,879	4,736	4,599
										111,424

3. Buying 1.000 new Rheinmetall HX

We will consider that we will buy 200 trucks/year in 5 years. We will sell next year used DAC trucks (that were replaced by Rheinmetall) resulting a salvage revenue of 20 / piece.

	YEAR									
Rheinmetall	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R&D	0	0	0	0	0	0	0	0	0	0
Procurement	23,000	23,000	23,000	23,000	23,000	0	0	0	0	0
Maintenance	0	0	0	0	0	1,200	3,200	4,800	6,400	8,000
Disposal DAC	0	-4,000	-4,000	-4,000	-4,000	-4,000	0	0	0	0
TOTAL constant	23,000	19,000	19,000	19,000	19,000	-2,800	3,200	4,800	6,400	8,000
TOTAL discounted	23,000	18,447	17,909	17,388	16,881	-2,415	2,680	3,903	5,052	6,131
										108,976

For **Measure of effectiveness** we will grade the characteristics of the trucks:

	Up-grade DAC 665	***IVECO HM 6X6***	***Rheinmetall HX***
Warranty - MAX	**0**	**1**	**1**
Produced in - MAX	**1**	**0.5**	**0**
Protection - MAX	**0**	**0.625** = (25-0) / (40-0)	**1**
Speed - MAX	**0**	**0.625** = (110-85) / (125-85)	**1**
Range - MAX	**0.33** = (800-750) / (900-750)	**0**	**1**
Power - MAX	**0**	**0.833** = (400-250) / (430-250)	**1**
Maximum load - MAX	**0**	**0.8** = (14-10) / (15-10)	**1**
Ground clearance - MAX	**0.5** = (390-380) / (400-380)	**1**	**0**

and we will consider the relative importance of the trucks' characteristics:

Objectives level 1	**Objectives level 2**	**Relative importance of objective**
Production attributes		0.4
	Warranty in place for the	0.6

	new/modernized truck	
	Country of origin	0.4
Technical characteristics		0.6
	The range with full load	0.15
	Protection for the crew	0.25
	Speed of the truck on the road	0.1
	Power of the engine	0.2
	Ground clearance (for off-road trips)	0.1
	Cargo capacity	0.2

We can calculate now the overall effectiveness for each alternative.

1. Modernization DAC 665

Production: 0.6*0 + 0.4*1 = 0.4
Technical characteristics: 0.15*0+0.25*0+0.1*0.33+0.2*0+0.1*0+0.2*0.5 = 0.133
TOTAL DAC 0.4*0.4 + 0.6*0.133 = **0.2398**

2. Buying Iveco HM

Production: 0.6*1 + 0.4*0.5 = 0.8
Technical characteristics: 0.15*0.625+0.25*0.625+0.1*0+0.2*0.833+0.1*0.8+0.2*1 = 0.6966
TOTAL IVECO 0.4*0.8 + 0.6*0.6966 = **0.73796**

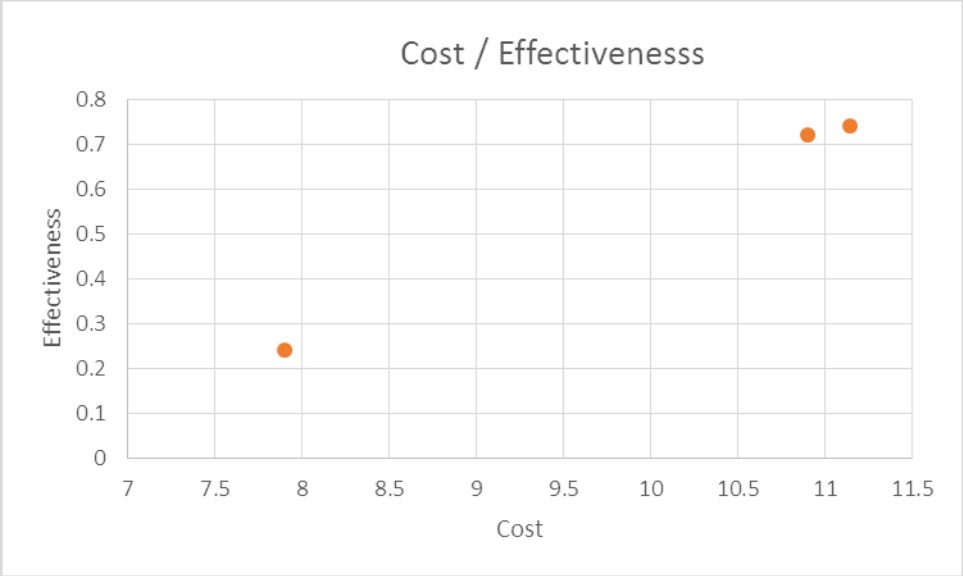
3. Buying Rheinmetall HX

Production: 0.6*1 + 0.4*0 = 0.6
Technical characteristics: 0.15*1+0.25*1+0.1*1+0.2*1+0.1*1+0.2*0 = 0.8
TOTAL RHEINMETALL 0.4*0.6 + 0.6*0.8 = **0.72**

We will have final results:

	Cost	Efectiveness
DAC	79.04	0.24
Iveco	111.42	0.738
Rheinmetall	108.98	0.72

and put the values obtained on a graph.



We can observe that there is a big difference between the modernization of DAC and buying of new trucks Iveco or Rheinmetall.

The final decision have to take into consideration the budget. Is big enough to exclude the cheapest alternative? Also comparing Iveco with Rheinmetall; we can observe that Rheimetall was best at almost every characteristic. One thing raise the effectiveness of Iveco alternative. The fact that can be produced 50% in Amria. Is this really important?

Choosing the best alternative is never a simple thing. The decision maker will have a tough time to explain to Sengen workers why he / she didn't choose DAC modernization over importing trucks from Altland.

3. Conclusion

Cost benefit analysis CBA, seen as a synthesis of economics, management science, statistics, and decision theory, is currently used in a wide range of defense applications in countries around the world to shape national security strategy, to set acquisition policy and to inform critical investments in people, equipment, infrastructure, services, supplies. Faced with severe budget cuts and an uncertain threat environment, defense officials confront urgent decisions on whether to approve specific projects (military housing; training, HQ and maintenance facilities) or programs (fighter planes, UAVs, armored personnel carriers, corvettes, cyber-defense). Military CBA offers a valuable set of analytical tools to increase the transparency, efficiency, and effectiveness of critical defense decisions.

The important thing is that the decision maker to follow a top-down approach. The logical sequence "What do I want to do" (objectives) – "How" (alternatives) – "With what" (prioritization) – "What is the best way" (analysis) is important. Objectives should be specific, measurable, achievable, realistic and time-bound. Measuring effectiveness (of objectives that cannot be translated into monetary form) should have a scientific form, based on statistics and decision theory. Cost have to be estimated in the right way, using the best method that can be applied (analogy, expert judgment, industrial engineering, parametric).

Combining cost with effectiveness the defense officials can choose the right alternative, take the best decision that can be logically explained to the all the stakeholders – state government, leaders in the military, army personnel and the simple resident of the country.

References:

[1] cost.jsc.nasa.gov/PCEHHTML/pceh.htm
[2] faculty.nps.edu/dl/DRMI/AccountingModules
[3] iceeaaonline.com
[4] Constantinescu Maria, Optimizing the use of defence resource in the context of the capabilities based planning implementation in the Romanian Armed Forces, 2010, The 16th international scientific conference Knowledge-Based Organization 2010, Land Forces Academy, Sibiu, Volumul 2, Numărul 1, Pagini 50-58, LAND FORCES ACADEMY Nicolae Balcescu, RomaniaMelese, Richter, Solomon, *Military cost benefit analysis*, Routledge, 2015, page 116
[5] Constantinescu, Maria, "The planning programming budgeting evaluation system as a decision support system in managing defence resources", Strategic Impact Review, nr. 2/2016, ISSN print: 1841-5784, e-ISSN: 1842-9904, ISSN-L 1841-5784, pg 40-47
[6] Melese, Richter, Solomon, *Military cost benefit analysis*, Routledge, 2015, page 126
[7] Melese, Richter, Solomon, *Military cost benefit analysis*, Routledge, 2015, page 132
[8] Melese, Richter, Solomon, *Military cost benefit analysis*, Routledge, 2015, page 198
[9] Melese, Richter, Solomon, *Military cost benefit analysis*, Routledge, 2015, page 113