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THE ECONOMIC EVALUATION OF ALTERNATIVES (EEOA): RETHINKING THE APPLICATION OF COST-EFFECTIVENESS ANALYSIS, MULTI-CRITERIA DECISION-MAKING (MCDM) AND THE ANALYSIS OF ALTERNATIVES (AOA) IN DEFENSE PROCUREMENT

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The Economic Evaluation of Alternatives (EEoA): Rethinking the Application of Cost-effectiveness Analysis, Multi-criteria Decision-making (MCDM) and the Analysis of Alternatives (AoA) in Defense Procurement

Presenter: Presenter: Dr. Francois Melese joined the Naval Postgraduate School in 1987 and today is Professor of Economics at the Defense Resources Management Institute (DRMI). He has consulted extensively, most recently with the Joint Staff and the OSD. In 2008, he helped edit the DoD's first *Strategic Management Plan*. He has published extensively on a variety of topics, including a co-authored paper entitled "A New Management Model for Government." Results in implementing that model for the Joint Staff were recently published in the *Armed Forces Comptroller*. At the request of NATO HQ, Melese has represented the US as an expert in defense management and public budgeting throughout Europe. He recently organized a major NATO meeting in Monterey on "Building Integrity and Defense Institution Building."

Abstract

Our primary goal is to improve public investment decisions by providing defense analysts and acquisition officials a comprehensive set of approaches to structure an "Economic Evaluation of Alternatives" (EEoA). This study identifies a significant weakness in the Multi-criteria Decision-making (MCDM) approach that currently underpins many contemporary AoAs. While MCDM techniques, and therefore most AoAs, correctly focus on lifecycle costs and operational effectiveness of alternatives, "Affordability" is often only implicitly addressed in the final stages of the analysis. In contrast, the adoption of EEoA encourages decision-makers to include affordability explicitly and up-front in the AoA. This requires working with vendors to build alternatives based on different funding (budget/affordability) scenarios. The key difference between the traditional MCDM approach to AoAs and the EEoA approach is that instead of modeling alternatives from competing vendors as points in cost-effectiveness space, EEoA models alternatives as functions of *optimistic*, *pessimistic*, and *most likely* funding (budget) scenarios. The Decision Map offered to practitioners to structure EEoAs provides a unique opportunity to achieve a significant defense acquisition reform—to coordinate the requirements generation system (JCIDS), Defense Acquisition System (DAS), and PPBE process, to lower the costs of defense investments, and improve performance and schedules.

Introduction to the Problem: Making the Case for "Affordability"

Our nation's security, billions of taxpayer dollars, and the survival of our soldiers can all hinge on an Analysis of Alternatives (AoA).[1] Routinely conducted by the US Department of Defense (DoD), the AoA is a key component of the defense acquisition process. Investment

[1] This study often uses the term "Analysis of Alternatives" (AoA) in its broad, generic sense. Although focused on defense acquisition, the results of the study apply to any public-sector procurement. It should be clear in context when the term AoAs references major defense acquisition programs (MDAPs) as opposed to the acquisition of major automated information systems (MAISs).

decisions supported by AoAs help shape future forces, influence defense spending, and occasionally transform the defense industry.

This study points to a significant weakness in the Multiple-criteria Decision-making (MCDM) approach that underpins many contemporary AoAs. The weakness is that while MCDM techniques, and therefore most AoAs, correctly focus on lifecycle costs and the operational effectiveness of individual alternatives, "Affordability" is an after-thought, often only implicitly addressed through a weight assigned to costs.

In contrast, the approach recommended in this study encourages analysts and decision-makers to include affordability explicitly in the AoA. This requires working with vendors to build alternatives based on different funding (budget/affordability) scenarios. Supported by a static, deterministic, multi-stage, constrained, optimization micro-economic production (procurement auction) model described in Section 3 (with the math relegated to the Mathematical Appendix available upon request), this "Economic Evaluation of Alternatives" (EEoA) explicitly addresses affordability up-front. The key difference between the MCDM approach to AoAs and the EEoA approach is that, instead of modeling decision alternatives from competing vendors as points in cost-effectiveness space, EEoA models alternatives as functions of *optimistic*, *pessimistic*, and *most likely* funding (resource/budget) scenarios. Given the current financial crisis and future public-spending challenges, affordability is a growing concern. As a consequence, it is imperative that the DoD gets the best value for every dollar it invests in major defense acquisition programs (MDAPs) or major automated information systems (MAISs).

A brief review of the DoD's high-level, fiscally constrained budget development and acquisition systems highlights the key role that affordability needs to play up-front in any AoA. The Planning, Programming, Budgeting and Execution (PPBE) process is the principal decision support system used by the DoD to provide the best possible mix of forces, equipment, and support within fiscal constraints. Two other major decision support systems complement the PPBE process: a requirements generation system called the Joint Capabilities Integration and Development System (JCIDS) and the Defense Acquisition System (DAS).

Based on strategic-level guidance (the *National Security Strategy*, *National Military Strategy, Quadrennial Defense Review, Strategic Planning Guidance*, etc.), the requirements generation system reviews existing and proposed capabilities and identifies critical capability gaps. To fill those capability gaps, senior leadership examines the full range of "doctrine, organization, training, materiel, leadership and education, personnel and facilities" (DOTMLPF) (CJCS, 2007, p. A-1; USD (AT&L), 2008, p. 14).

Whenever a "materiel" solution is recommended, prospective military investments are identified that serve as the basis for AoAs that underpin the development of new acquisition programs in the Defense Acquisition System (DAS). The DAS provides principles and policies that govern major defense acquisition decisions and milestones. To ensure transparency and accountability, and to promote efficiency and effectiveness, various instructions (e.g., *FAR*, *DFARS, DoD Directive 5000.01, DoD Instruction 5000.02*, etc.) specify statutory and regulatory reports (e.g., AoAs) and other information requirements for each milestone and decision point.

The primary purpose of PPBE is to make hard choices among alternative military investments necessary for national security within fiscal constraints. As we identify alternative materiel investments that can fill current capability gaps, the requirements generation process (JCIDS) naturally fits into the Planning phase of PPBE.

The first step in any investment analysis is to identify the derived demand for a key capability, program, or project. This is accomplished through the DoD's requirements generation system (JCIDS). Ideally, user demands are expressed and refined in the Planning phase of the PPBE process. MDAP and MAIS proposals that emerge from JCIDS and the Planning process enter the Defense Acquisition System (DAS) and are incorporated in the Programming phase of PPBE.

The Planning phase of PPBE establishes fiscally constrained guidance and priorities for military forces, including readiness, sustainability and modernization. This guidance provides direction for DoD Components (military departments and defense agencies) to develop their individual program proposals or their Program Objective Memorandum (POM) in the Programming phase. The POM details resource-allocation decisions (funding, personnel, etc.) proposed by each Component for its programs, projected six years into the future. DAS data for major defense acquisitions generally includes lifecycle cost estimates that project well beyond the six years of the POM.

Senior leadership in the OSD and the Joint Staff subsequently review each Component POM to ensure it satisfies the Planning guidance, and that it can be integrated into effective and affordable overall defense programs. The Budgeting phase of PPBE occurs concurrently with the Programming phase.

The Budgeting phase converts the Programming phase's (output-oriented) view into the (input-oriented) format required by Congressional appropriation structures. While the DoD's biennial defense budget projects funding only two years into the future, it includes more financial detail than the POMs. The Under Secretary of Defense Comptroller and the Office of Management and Budget (OMB) are responsible for reviewing budget submissions to ensure programs are affordable, i.e., satisfy current fiscal constraints. The GAO recognizes the major challenges faced by the DoD to "achieve a balanced mix of weapon systems that are affordable" (GAO, 2009, p. 5).[2]

The primary focus of Multi-criteria Decision-making (MCDM), as traditionally applied in AoAs, is to evaluate the lifecycle costs and operational effectiveness of alternative defense investments. "An AoA is an analytical comparison of the operational effectiveness, suitability, and Life-Cycle Cost of alternatives that satisfy established Capability needs" (DoD, 2006, July 7, Section 3.3). This study emphasizes another key aspect—"Affordability."

In helping generate investment alternatives, and illuminating advantages and disadvantages of those alternatives, AoAs have the potential to contribute to requirements generation in the Planning phase of PPBE, and through DAS decision milestones, also in the Programming phase of PPBE. However, according to the GAO: "while JCIDS provides a framework for reviewing and validating needs […] the vast majority of capability proposals that enter the JCIDS process are validated or approved without accounting for resources [funding, budgets] […] that will be needed to acquire the desired capabilities" (GAO, 2009, p. 6).[3]

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[2] According to the Government Accountability Office (GAO), over the next 5 years, the DoD plans to spend more than $357 billion on development and procurement of major defense acquisition programs (GAO, 2009, p. 4).

[3] "A 2008 DoD directive established nine joint capability-area portfolios, each managed by civilian and military co-leads […]. However, without […] control over resources [funding/budgets], the department is at

We believe the GAO's results reflect a weakness in the way AoAs have traditionally been structured. While AoAs provide a sharp focus on cost and effectiveness estimates of competing alternatives, the affordability (funding/budget realities) of the overall program is at best implicit, and usually conducted ex-post.[4] This is reflected in the GAO's concern that "at the program level, the key cause of poor outcomes is the approval of programs with business cases [e.g., AoAs] that contain inadequate knowledge about […] resources [funding] […] needed to execute them" (2009, p. 7).

Yet *DoD Directive 5000.01* explicitly states that, "All participants in the acquisition system shall recognize the reality of fiscal constraints […]. DoD components shall plan […] based on realistic projections of the dollars […] likely to be available […and] the user shall address affordability in establishing capability needs" (USD (AT&L), 2007, Enclosure 1, p. 5).

For all major (ACAT 1) defense acquisition programs, an AoA is required at key milestone decision points (i.e., A, B, C). Affordability assessments are required at Milestones B and C for major defense acquisition programs and automated information systems (USD (AT&L), 2008, Enclosure 4, p. 40).

According to the *Defense Acquisition Guidebook*, the purpose of an affordability assessment is to demonstrate that the program's projected funding requirements are realistic and achievable.[5] "In general, the assessment should address program funding over the six-year programming period, and several years beyond. The assessment should also show how the projected funding fits within the overall DoD Component plan" (DoD, 2006, July 7, Section 3.2.2.).[6]

The Economic Evaluation of Alternatives (EEoA) essentially embeds an explicit affordability assessment into an AoA. In preparing affordability assessments, one possible source of data is the Future Years Defense Program (FYDP).[7] According to the *Defense Acquisition Guidebook*, affordability assessments should provide details as to how excess

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risk […] of not knowing if its systems are being developed within available resources [funding/budgets]" (GAO, 2009, p. 11).

[4] "Typically, the last analytical section of the AoA plan deals with the planned approach for the cost-effectiveness comparisons of the study alternatives" (DoD, 2006, July 7, Section 3.3). Note that there is no mention of "affordability," but instead only an ex-post cost-effectiveness trade-off that implies a concern for affordability. Moreover, this trade-off occurs at the end of a process in which alternatives under consideration have been developed independently of any cost/budget/funding/affordability constraint. The US Marine Corps (PA&E) has a similar approach to structuring an AoA.

[5] Since this assessment requires a DoD Component corporate perspective, the affordability assessment should not be prepared by the program manager nor should it rely too heavily on the user. It requires a higher-level perspective capable of balancing budget trade-offs (affordability) across a set of users (2006, July 7, Section 3.2.2).

[6] A first step in the program's affordability assessment is to portray the projected annual modernization funding (RDT&E plus procurement, measured as TOA) in constant dollars for the six-year programming period and for twelve years beyond. Similar funding streams for other acquisition programs in the same mission area also would be included. What remains to be determined is whether this projected funding growth is realistically affordable relative to the DoD Component's most likely overall funding. The model in this study proposes structuring the Economic Evaluation of Alternatives not only for a *most likely* budget but also for an *optimistic* and *pessimistic* budget.

[7] An output of the DoD's PPBE process, the FYDP is an OSD database that contains future budget projections.

funding demands will be accommodated by reductions in other mission areas, or in other accounts.[8] This Opportunity Cost Approach is the last of six ways proposed in this study to structure an Economic Evaluation of Alternatives (EEoA).

Nesting the Requirements Generation and Defense Acquisition Systems within PPBE suggests formulating the military's acquisition problem in terms of identifying and funding specific defense investments that maximize value (performance or effectiveness) for a given budget. If AoAs were framed as a constrained optimization—i.e., maximizing performance subject to a budget constraint (or alternatively minimizing costs subject to a given level of performance)—they could be used to support resource-allocation decisions in the Programming phase of PPBE.[9] These dual constrained-optimization approaches represent the first two of six ways proposed in this study to structure an Economic Evaluation of Alternatives (EEoA).

Unfortunately, MCDM techniques typically applied to structure an AoA do not easily lend themselves to this interpretation. As a consequence, instead of being constrained by budgets, budgets are more often the output of an AoA, generating and/or supporting so-called "funding requirements." Our third approach to structuring an Economic Evaluation of Alternatives (EEoA) turns this on its head.

Instead of generating a budget through the AoA process, we propose that decision-makers or analysts forecast an *optimistic*, *pessimistic*, and *most likely* budget as part of the PPBE process, and then approach vendors to generate alternatives that fit within that budget envelope.[10] This offers an alternate approach to defense investment decisions based on explicit funding (resource/budget/affordability) scenarios. This also supports the "long-standing DoD policy to seek full funding of acquisition programs, based on the most likely cost" (DoD, 2006, July 7, Chapter 3.23).

The primary goal of this study is to improve defense decisions by bringing the taxpayer up-front alongside the warfighter in the defense acquisition process. This is accomplished by explicitly introducing an affordability assessment in EEoA through *optimistic*, *pessimistic*, and *most likely* funding scenarios. Unlike traditional MCDM approaches to AoAs that focus on cost and operational effectiveness, an EEoA adds a third dimension. It makes a clear distinction

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[8] Note that in the "off-year" of the biennial PPBE process, DoD Components are restricted to the second year of the biennial budget and are required to submit Program Change Proposals (PCPs) and/or Budget Change Proposals (BCPs) to account for any program-cost increases, schedule delays, etc. PCPs address issues over a multi-year period, whereas BCPs address issues focused on the upcoming budget year. Moreover, to stay within fiscal constraints, BCPs and PCPs must identify resource reductions in other programs to offset any cost growth. This is similar in spirit to the "opportunity cost" approach that we propose as one of six ways to structure an EEoA.

[9] Translating the budget implications of these decisions into the usual Congressional appropriation categories (Military Personnel, Procurement, Operations & Maintenance (O&M), Military Construction, etc.) generates the defense budget and Future Year Defense Program (FYDP).

[10] This is in the spirit of the Department of the Army's Acquisition Procedures, which explicitly state that "Cost as an Independent Variable (CAIV) applies to all defense acquisition programs [….and] treats cost as an input to, rather than an output of, the materiel requirements and acquisition processes." The Army guidance emphasizes "CAIV is focused on […] meeting operational requirements with a solution that is affordable […and that does] not exceed cost constraints [and to] establish CAIV-based cost objectives (development, procurement, and sustainment costs) early in the acquisition process." Moreover, the "RFP must […] solicit from potential suppliers an approach […] for meeting CAIV objectives" (DoA, 1999, July 15, p. 63).

between the "lifecycle cost" or "price" of an alternative, its operational effectiveness, and "funding" (budget or resources) available.

The EEoA approach responds to two fundamental challenges highlighted by the GAO that continue to face the DoD's Defense Acquisition System: "(1) [to make] better decisions about which programs should be pursued or not pursued given existing and expected funding; [and] (2) [to develop] an analytical approach to better prioritize capability needs" (GAO, 2009, March 18, Highlights).

In stressing affordability, EEoA offers an analytical approach that begins to resolve a major concern expressed by the GAO:

> DoD's processes for identifying war-fighter needs [JCIDS], allocating resources [PPBE], and developing and procuring weapon systems [DAS…] are fragmented […so that] DoD commits to more programs than resources [budgets] can support […]. DoD allows programs to begin development without a full understanding [of] the resources [budget/funding] needed.[11] (2009, March 18, Highlights)

Whereas funding decisions for major programs take place through the PPBE process, the GAO finds that:

> [T]he process does not produce an accurate picture of the department's resource needs [funding/budget requirements] for weapon system programs [...]. Ultimately, the process produces more demand for new weapon system programs than available resources can support.[12] (2009, March 18, p. 6)

The EEoA approach proposed in this study represents an important step in integrating the DoD's requirements generation and Defense Acquisition Systems with PPBE. For instance, in considering alternative budget scenarios that rely on the FYDP, it injects an explicit constrained-optimization approach into the Defense Acquisition System (DAS) that parallels the one already embedded in the PPBE process.[13]

In generating alternatives under *optimistic*, *pessimistic* and *most likely* budget scenarios, the EEoA requires explicit interaction with the PPBE process. In sharp contrast with the MCDM approach that underlies most AoAs, the EEoA approaches explicitly identify and emphasize budgets, funding, and affordability. Ultimately, widespread adoption of the EEoA would contribute to the goal of:

> greater consultation between requirements, budget, and acquisition processes [that] could help improve the department's […] portfolio of weapon programs […]. This means that decision makers responsible for weapon system requirements, funding, and

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[11] "The lack of early systems engineering, acceptance of unreliable cost estimates based on overly optimistic assumptions, failure to commit full funding, and the addition of new requirements well into the acquisition cycle all contribute to poor outcomes" (GAO, 2009, March 18). Whereas this study focuses on funding risks, Melese, Franck, Angelis and Dillard (2007, January) introduce an economic approach called "Transaction Cost Analysis" that addresses the other GAO concerns.

[12] The cost of many programs reviewed by the GAO exceeded planned funding/budget levels (GAO, 2008, July 2).

[13] Office of Management and Budget (OMB) Circular A-11 titled Preparation and Submission of Budget Estimates is the official guidance on the preparation and submission of budget estimates to Congress. The Army's Acquisition guidance emphasizes "the requirement for presenting the full funding for an acquisition program—that is the total cost [for] a given system as reflected in the most recent FYDP […] pertains to all acquisition programs" (DoA, 1999, July 15, p. 41).

> acquisition execution must establish an investment strategy in concert […], assuring requirements for specific weapon systems are clearly defined and achievable given available resources [funding/budgets]. (GAO, 2008, July 2, p.10, 14)

The next section offers a brief description and critical evaluation of the status quo. We review two common decision criteria used in cost-effectiveness analyses. The first is the popular "bang-for-the-buck" or Benefit/Cost ratio. The second criterion is essentially a weighted average of cost and effectiveness, a decision rule generated by the standard static, deterministic MCDM approach to cost-effectiveness analysis that underpins most contemporary AoAs.

Section 3 offers a set of alternate approaches to resolve the decision-criterion problem. Six intuitive approaches are described to structure an Economic Evaluation of Alternatives (EEoA).[14] Section 4 concludes with a Decision Map to guide analysts and decision-makers in selecting which of the six approaches is best suited for them to structure an Economic Evaluation of Alternatives (EEoA).

A Critical Evaluation of the Status Quo: Two Popular Decision Criteria

Today, most modern military investment (and disinvestment) decisions are supported by some form of cost-benefit analysis (CBA). The US Department of Defense (DoD) applies CBA to anything from milestone decisions for Major Defense Acquisition Programs (MDAPs and MAISs), to outsourcing (OMB Circular A-76; Eger & Wilsker, 2007), to public-private partnerships, to privatization, to Base Realignment and Closure (BRAC) actions (see OMB Circular A-94; FAR; DFARS; DoD 5000 series, etc.).

When benefits cannot be expressed in monetary terms, analysts develop so-called "measures of effectiveness" (MOEs), in which case CBA is generally referred to as "cost-effectiveness" analysis (OMB, 1992, October 29).[15] The most common methodology and approach for building MOEs and structuring cost-effectiveness analyses is alternately referred to as Multiple-criteria Decision-making (MCDM), Multi-attribute Utility Theory (MAUT), or Multiple-objective Decision-making (MODM) (see French, 1986; Keeney & Raiffa, 1976; Clemen, 1996; Kirkwood, 1997; Parnell, 2006; Ramesh & Zionts, 1997; etc.).

This study describes some limitations of the current decision criteria methodology and proposes an alternate methodology derived explicitly from a constrained-optimization approach, closer in spirit to the economic origins of cost-effectiveness analysis in Gorman (1980); Hitch and McKean (1967); Michael and Becker (1973); Stigler (1945); Theil (1952); etc.—although often attributed to Lancaster (1969a; 1969b; 1971; 1979). The six approaches we offer to structure an Economic Evaluation of Alternatives (EEoA) resolves the decision-criterion

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[14] Appendix 3 (in the Mathematical Appendix—available upon request) reveals the static, deterministic, multi-stage, constrained-optimization, micro-economic production (procurement auction) model that underpins the central EEoA approach.

[15] Fisher (1965) argues that "numerous terms […] convey the same general meaning […] 'cost-benefit analysis,' 'cost-effectiveness analysis,' 'systems analysis,' 'operations analysis,' etc. Because of such terminological confusion, […] all of these terms are rejected and 'cost-utility analysis' is employed instead" (p. 185). Although this study uses the terms "cost-benefit" and "cost-effectiveness" interchangeably, the assumption throughout is that neither "benefits" nor "effectiveness" can be measured in monetary terms.

problem. A key difference between the MCDM approach to an AoA and the Economic Evaluation of Alternatives (EEoA) is that instead of modeling decision alternatives from competing vendors as points in cost-effectiveness space, the EEoA models the alternatives as functions of *optimistic*, *pessimistic*, and *most likely* funding (resource/budget) scenarios.

The EEoA approach directly responds to the GAO's observation that affordability needs to be an integral part of any business case analysis of alternatives: "[o]ur work in [uncovering] best practices has found that an executable business case [requires] demonstrated evidence that […] the chosen concept can be developed and produced within existing resources [funding/budgets]" (GAO, 2008, p. 6). Benchmarking against the private sector, the GAO emphasizes that "successful commercial enterprises […] follow a disciplined integrated process during which the pros and cons of competing proposals are assessed based on strategic objectives […] and available resources [budgets/funding]" (GAO, 2009, March 18, p. 5, emphasis added).

A distinctive feature of defense investment decisions is that multiple criteria such as cost and effectiveness cannot easily be combined into a single, overall objective such as "government profitability." The problem of ranking public investments when benefits cannot be expressed in dollars has spawned an extensive literature in management science, operations research and the decision sciences.

This literature models investment alternatives as bundles of measurable characteristics (attributes or criteria). Techniques that mostly fall under the umbrella of MCDM are routinely used by analysts and decision-makers (for example, through AoAs) to guide public investment decisions. The development of "Measures of Effectiveness" (MOE's)[16] and lifecycle cost calculations are used to help rank alternatives. An ongoing concern is how to integrate costs and effectiveness in the final selection process (see Henry & Hogan, 1993; Melese & Bonsper, 1996, December; Melese, Stroup, & Lowe, 1997; etc.).

In their pioneering work applying economic analysis to defense, Hitch and McKean (1967) define a "criterion" as the "test by which we choose one alternative […] rather than another" (p. 160). They stress that "[t]he choice of an appropriate economic criterion is […] the central problem in designing a [cost-effectiveness] analysis" (p. 160).

The two most popular decision criteria used to integrate cost and effectiveness in AoAs are: 1) to construct Benefit/Cost (or MOE/Cost) ratios, and 2) to assign a weight on cost relative to effectiveness and construct a weighted average of cost and effectiveness (often using a linear, separable, additive "value" function). The latter decision criterion is a common prescription for AoAs that emerges from MCDM. Both approaches, however, are problematic.

We first focus on what is arguably the most commonly applied criterion—Benefit/Cost ratios. Then, we move to the most common MCDM decision criterion—to assign a relative weight to the cost (price) of alternatives in an overall value function. At first glance, the Benefit/Cost (MOE/Cost) ratio or "bang-for-the-buck" criterion is appealing. However, it turns out

[16] The Defense Acquisition Guidebook, Section 3.3.1: AoA Plan, states that "measures of effectiveness […] provide the details that allow the proficiency of each alternative in performing the mission tasks to be quantified […]. A measure of performance typically is a quantitative measure of a system characteristic (e.g., range, […] logistics footprint, etc.) chosen to enable calculation of one or more measures of effectiveness" (DoD, 2006, July 7).

to be largely meaningless unless alternatives are constructed for a specific budget scenario or to achieve a specific level of effectiveness. Meanwhile, the second decision criterion can also be misleading in the absence of a specific budget scenario (and a good understanding of "opportunity costs").[17]

"Bang-for-the-Buck" (Benefit/Cost or MOE/Cost) Ratios

It is relatively well known that a Benefit/Cost ratio (or "bang-for-the-buck") decision criterion is largely meaningless unless alternatives are constructed for a specific budget scenario or to achieve a specific level of effectiveness. Yet, the next four examples illustrate that this remains a popular decision criterion, even when alternatives differ in both costs and effectiveness.

1. In a military text entitled *Executive Decision Making*, the author offers that "[w]hen we cannot fix cost or effectiveness, we might combine them to help us choose between alternatives […]. If neither can be fixed […] we can establish a cost/effectiveness ratio" (Murray, 2002, pp. 6-3, 6-10).
2. The Department of the Army's *Economic Analysis Manual*, in a section entitled *Comparing Costs and Benefits*, states: "When the results yield unequal cost and unequal benefits […] in this situation all alternatives […] may be ranked in decreasing order of their benefit/cost ratios" (DoA, 2001, February, p. 32).
3. Finally, in a recent landmark RAND study on Capabilities-based Planning, the author falls into the same trap. In a section entitled *Choosing Among Options in a Portfolio*, Paul Davis (2002) develops "A Notional Scorecard for Assessing Alternatives in a Portfolio Framework," where alternatives differ in both their costs and effectiveness. Nevertheless, the decision criterion recommended by the author to select among alternative options in "[t]he last column is the ratio of effectiveness over cost" (pp. 45-46).

Each of these diverse examples recommends using a Benefit/Cost ratio as the decision criterion. However, another RAND analyst, Gene Fisher (1971), clearly points out in his classic text *Cost Considerations in Systems Analysis*:

> The use of ratios usually poses no problem as long as the analysis is conducted in [a] framework […] with the level of effectiveness or cost fixed. However, it is common to encounter studies where this has not been done, with the result that the comparisons [are] essentially meaningless. (p. 11)

[17] Ironically, given a budget scenario, there is no need to take the MCDM approach that underpins most AoAs since it is possible to adopt the EEoA approach—which constructs alternatives to fit within a budget envelope, converting the problem into a straightforward MOE maximization.

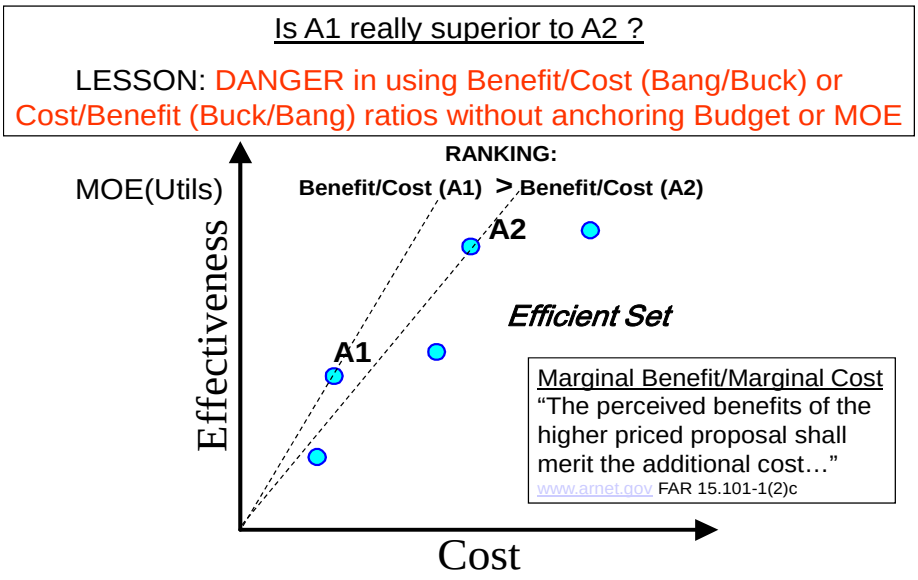

Figure 1. Inappropriate Application of Benefit/Cost Ratios

A simple, extreme example helps illustrate the danger in using Benefit/Cost ratios without anchoring the Budget, or a specified Measure of Effectiveness (MOE). Suppose Alternative A1 in Figure 1 costs $10 million and yields an MOE of 10 utils, while Alternative A2 costs $1 billion and yields an MOE of 900 utils.[18] Applying the Benefit/Cost ratio criterion indicates that A1 has a bigger "bang-for-the-buck" since it returns 1 util per million dollars, while A2 only offers 0.9 utils per million dollars. Strictly using Benefit/Cost ratios to rank alternatives is dangerous in this case since it ignores the absolute magnitude of the costs involved. Suppose the situation was reversed and A2 offered a higher Benefit/Cost ratio than A1. Anyone that chooses A2 strictly on the basis of "bang-for-the-buck" would be in for an unpleasant surprise (a 1-billion vs. 10-million-dollar decision).

Since affordability and opportunity costs are always a concern in public investment decisions (especially those made through the PPBE process, requirements generation system, and Defense Acquisition System), it is imperative that analysts and decision-makers explore the budget and opportunity cost implications of going with the high-cost alternative (for example, the extra expenditure of $990 million for an additional 890 utils of MOE) or, equivalently, of the savings in going with the low-cost alternative.

In applying economic analysis to defense, Hitch and McKean (1967) warn:

One common "compromise criteria" is to pick that [alternative] which has the highest ratio of effectiveness to cost. [M]aximizing this ration is the [decision] criterion. [While] it may be a plausible criterion at first glance […] it allows the absolute magnitude of

[18] In Figure 1, the slope of any ray from the origin represents a constant Benefit/Cost ratio anywhere along that ray. The steeper the slope, the greater the Benefit/Cost ratio.

> [effectiveness] or cost to roam at will. In fact, the only way to know what such a ratio really means is to tighten the constraint until either a single budget (or particular degree of effectiveness) is specified. And at that juncture, the ratio reduces itself to the test of maximum effectiveness for a given budget (or a specified effectiveness at minimum cost), and might better have been put that way at the outset […]. The test of maximum effectiveness for a given budget (or alternatively, minimum cost of achieving a specified level of effectiveness) […] seems much less likely to mislead the unwary.[19] (pp. 165-167)

Our Economic Evaluation of Alternatives (EEoA) approach follows this and another of Hitch and McKean's (1967) recommendations. "As a starter […] several budget sizes can be assumed. If the same [alternative] is preferred for all […] budgets, that system is dominant […]. If the same [alternative] is not dominant the use of several […] budgets is nevertheless an essential step, because it provides vital information to the decision maker" (p. 176).

We conclude that the use of Benefit/Cost ratios as a decision criterion poses no problem as long as the analysis is structured with the level of either utility (MOE) or budget/funding fixed.[20] Since Benefit/Cost ratios are "misleading"[21] in any context in which alternatives differ in both costs (price) and benefits (MOE), decision scientists have developed another decision criterion to rank investment options in AoAs. This second popular decision criterion is examined below.

Weighted Averages of Cost and Effectiveness: Assigning a Weight to Cost

MCDM is often used as an umbrella term, and we will do so here. "In the literature the terms multi-attribute decision making (MADM), multi-criteria decision making (MCDM), and multi-objective decision making (MODM) are used almost interchangeably" (French, 1986, p. 105). In a typical MCDM evaluation, a decision-maker (DM) is asked to identify desired attributes (criteria/characteristics) of a project, program or system to fill some critical capability gap, given a specific threat scenario. Next, the DM is asked to reveal agreeable trade-offs among those attributes. An exercise of this sort helps analysts uncover the DM's underlying trade-offs or "utility" function, used to generate a Measure of Effectiveness (MOE) for each alternative.[22]

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[19] The authors continue: "Of course, if the ratios did not alter with changes in the scale of achievement (or cost, the higher ratio would indicate the preferred system, no matter what the scale […]. But to assume that such ratios are constant is inadmissible some of the time and hazardous the rest" (Hitch & McKean, 1967, p. 167).

[20] An additional (necessary and sufficient) condition is a linear, separable, additive objective function.

[21] "Usually, ratios are regarded as potentially misleading because they mask important information" (DoD, 2006, July 7, Section 3.3.1).

[22] "Measures of Effectiveness […] provide the details that allow the proficiency of each alternative in performing the mission tasks to be quantified […]. A measure of performance typically is a quantitative measure of a system characteristic (e.g., range, etc.) chosen to enable calculation of one or more measures of effectiveness […]. The cost analysis normally is performed in parallel with the operational effectiveness analysis. It is equal in importance in the overall AoA process […]. [I]ts results are later combined with the operational effectiveness analysis to portray cost-effectiveness comparisons" (DoD, 2006, July 7, Section 3.3.1).

In attempting to understand a DM's utility function, decision scientists beginning with Saaty (1977) bridged an important implementation gap. Objectives (analytic) hierarchy approaches were developed that help reveal underlying utility functions. For example, an objectives hierarchy can help a DM work down from a high-level objective (provide national security) to a relevant set of sub-objectives (an effective airlift capability), to specific attributes (mobility, transportability, etc.), and, finally, to measurable characteristics (mobility=speed (S), range (R); transportability=payload (P), weight (W), etc.).

The outcome in this example is a utility function for airlift capability: U=U(M(S,R); T(P,W)), where the characteristics might be measured respectively in mph, miles, cubic feet, and pounds. The standard assumption in the literature is to define a linear, separable additive utility function that generates an MOE for each alternative that is roughly analogous to a weighted average of its attributes (provided certain assumptions are satisfied such as "additive independence," etc. (see French, 1986; Keeney & Raiffa, 1976; Keeney, 1994). There is a vast literature concerned with eliciting preference weights and the normalization of characteristics data that involves several important issues discussed in the Mathematical Appendix (available upon request).

Temporarily overlooking these issues, it is interesting to note in passing that maximizing a linear multi-attribute utility function subject to a budget constraint yields a decision rule analogous to the Benefit/Cost ratio criterion discussed above. Under the assumption of a fixed budget and linear additive separable utility function, the Benefit/Cost decision rule can be used to evaluate alternatives. In this case, the winning alternative is the one that generates the highest MOE per dollar or the biggest "bang-for-the-buck." With a more general (non-linear) utility function, the equivalent optimization generates a more complex Marginal Benefit/Marginal Cost decision rule.

In reality, the MCDM techniques that underpin most AoAs often do not rely on an explicit discussion of the budget (affordability/funding/resources) to structure the decision problem. As a consequence, the problem is generally not structured as a constrained optimization, as described above.

Instead, a popular decision-analysis approach is to simply attach a weight to cost and introduce it directly into the utility function.[23] This common practice generates an overall "value" function that is essentially a weighted average of cost and effectiveness. The solution is found through an unconstrained optimization by selecting the alternative that maximizes the "overall effectiveness" or "value" function V=V(MOE; COST). "Deterministic decision analysis is concerned with finding the most preferred alternative in decision space by constructing a value function representing a decision maker's preference structure, and then using the value function to identify the most preferred solution" (Ramesh & Zionts, 1997, p. 421).

[23] "In the European Union, a legislative package intended to simplify and modernize existing public procurement laws was recently adopted. As before, the new law allows for two different award criteria: lowest cost and best economic value. The new provisions require that the procurement authority publishes ex-ante the relative weighting of each criteria used when best economic value is the basis for the award" (see European Commission, 2004a; 2004b).

The linear, additive separable version of this value function is often used to calculate a positively weighted MOE and negatively weighted cost for each alternative. For example, see Beil & Wein (2003), Che (1993), Clemen (1996), Kirkwood (1997), French (1986), Keeney & Raiffa (1976), Keeney (1994), Hwang and Yoon (1981), Liberatore (1987), Pinker, Samuel, and Batcher (1995), Varzsonyi (1995), etc. According to the *Defense Acquisition Guidebook*: "An AoA is an analytical comparison of the operational effectiveness, suitability, and life-cycle cost of alternatives that satisfy established capability needs." (DoD, 2006, July 7, Chapter 3.3)

The typical decision sciences' approach to an AoA can be described as:

> Given several Alternatives, select the preferred alternative that provides the Best Value, or Maximizes: V(MOE,COST) = w1***MOE** - w2***COST**

This requires two important modeling efforts: 1) MOE—*Building an Effectiveness model* (non-cost factors; performance=quality, schedule, etc.); and 2) COST—*Building a Cost* model (costs/prices; estimate total system lifecycle costs, total ownership costs). Once the independent modeling efforts are completed, the overwhelming challenge is to assign a relative weight to cost (w2 in the example above). A typical response in the applied literature is to ask the DM: "How important is cost relative to effectiveness?"

A key proponent of this decision methodology offers an example of administrators and regulators asking questions such as: "Which is more important, costs or pollutant concentrations?" (Keeney, 1994, p. 797). As the author is quick to point out, the problem with this approach is that without some estimate of the *total budget available* or any knowledge of *opportunity costs of funds*, one cannot expect the DM to provide a sensible answer. In fact, the author warns: "I personally do not want some administrator to give two minutes of thought to the matter and state that pollutant concentrations are three times as important as cost" [24] (Keeney, 1994, p. 797). The *Federal Acquisition Regulations* (*FAR*) and the Office of Management and Budget (OMB) both promote similar approaches:[25]

- "The solicitation shall state whether all evaluation factors other than cost/price, when combined [i.e., MOE], are significantly more important than, approximately equal to, or significantly less important than cost/price" (General Services Administration, 2005, March, Section 15.101-1(2)).
- "The specific weight given to cost or price shall be at least equal to all other evaluation factors combined unless quantifiable performance measures can be used to assess value and can be independently evaluated" (OMB, 2003, p. B-8).

Consider an extreme case. If we suppose that affordability is not an issue, then funding is not an issue and the budget is not binding, making costs irrelevant. In this case, a zero weight

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[24] Surprisingly, the author has continued to write prolifically in this field and continued to promote this decision criterion, apparently never taking the time to reflect back on these key observations.

[25] According to the FAR, "source selection" is the decision process used in competitive, negotiated contracting to select the proposal that offers the "Best Value" to the government. "In different types of acquisition, the relative importance of cost or price may vary" (General Services Administration, 2005, Section 15.101). In describing some lessons learned, Gansler (2003) recommend: Use performance-based contracting; Do not list tasks [mix of inputs], instead state results sought or problems to be solved [desired attributes/characteristics of outputs/outcomes]; Choose contractors according to "Best Value"; in the source selection, trade-off performance and price instead of simply awarding to the lowest bidder (p. 15).

should be assigned to costs and the analysis of alternatives can be made exclusively on the basis of MOEs.

Thus, any weight applied to costs must reflect an implicit concern about affordability (budgets/funding levels). Figures 2 and 3 offer an illustration. Figure 2 reflects a situation in which the decision-maker believes costs to be important enough (and thus assigns a sufficiently large relative weight, w2, to cost) that the preferred alternative is A1 (the low-cost option). The opposite case is illustrated in Figure 3.[26] How does a decision-maker (DM) decide on appropriate weights to assign to MOE and costs? A key hypothesis in the EEoA is that if a DM pays any attention to costs (i.e., places any weight on cost) it is because there is a (implicit) budget constraint or opportunity cost of funds for the program. This is directly related to our higher-level affordability discussions in Section 1 that involved requirements generation (JCIDS), the Defense Acquisition System (DAS), and PPBE.[27]

The irony, as Keeney (1994) rightly observed, is that to assign any weight to costs requires the DM to have some understanding of the budget (funding/resources) available and an appreciation of relevant opportunity costs. But if this information is known, then the DM has no reason to take the MCDM approach and assign a weight on costs since the more robust, constrained-optimization (mathematical programming) EEoA approach becomes available.

In fact, it is relatively straightforward to demonstrate that even if the DM had perfect information about the budget (funding/affordability) and attempted to interpret that information through a weight assigned to the cost (price) of alternatives (as illustrated in Figures 2 and 3), the rankings that result would only coincidentally correspond to rankings obtained under the full information, constrained-optimization EEoA (in which an MOE utility function is maximized subject to the budget constraint).[28]

This is a damning result that clearly undermines the way MCDM is typically applied to support AoAs. If there is no guarantee this MCDM approach will yield consistent results under full information, then using this criterion with less than perfect information (i.e., without explicit assumptions about affordability/budgets/funding), is clearly problematic. In fact GAO emphasizes "[w]ith high levels of uncertainty […] funding needs are often understated" (GAO, 2008, September 25, p. 9).

[26] Note that the slope of the straight-line indifference curves that reflect the DM's relative preference (or trade-offs) between MOE and Cost are given by –w2/w1.

[27] In fact, the Army's Economic Analysis (EA) Manual states that "[a] good EA should go beyond the decision-making process and become an integral part of developing requirements in the PPBE process" (DoA, 2001, February, p. 12).

[28] The weight on cost in the unconstrained-optimization (MCDM) approach roughly corresponds to the Lagrangian multiplier (shadow price) of the budget constraint in the constrained-optimization (the EEoA approach).

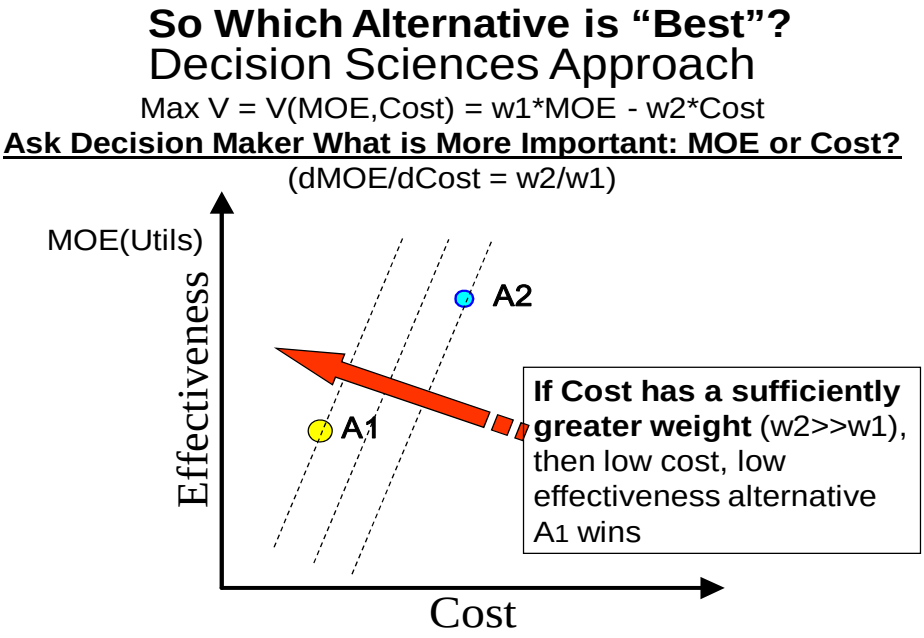


Figure 2. When Cost is Relatively More Important than Effectiveness

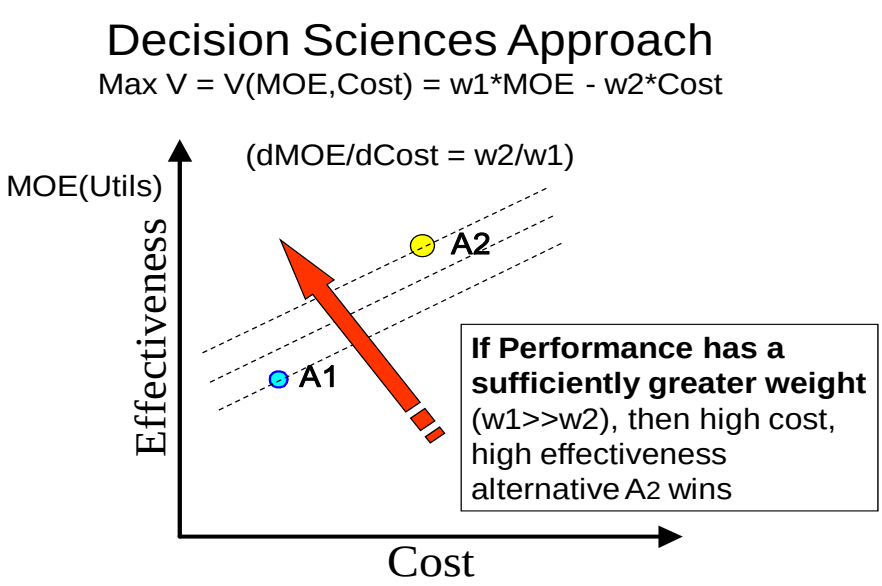


Figure 3. When Effectiveness is Relatively More Important than Cost

In conclusion, the popular MCDM, Decision Sciences approach that underpins many AoAs implicitly attempts to capture affordability through a relative weight assigned to cost in a

value function such as, Maximize V = V(MOE,Cost) = w1*MOE - w2*Cost.[29] Again, to quote Hitch and McKean (1967):

> One ubiquitous source of confusion is the attempt to maximize gain [w1*MOE] while minimizing cost [w2*Cost] […] If a person approaches a problem with the intention of using such a [decision] criterion, he is confused to begin with […] [A] criterion in which the budget […] is specified has the virtue of being aboveboard. (pp.165-167)

A very real risk in this MCDM approach is that if AoAs "fail to balance needs with resources [funding/budgets], […] un-executable programs [are allowed] to move forward, [and] program managers […] are handed […] a low probability of success" (GAO, 2009, p. 10). Rather than attempt to get a DM to reveal their affordability concerns through a weight assigned to costs (or prices) of alternatives, the EEoA recommends a more transparent and accountable approach—to treat "cost as an independent variable" (CAIV).

The CAIV concept adopted here follows a definition posted on the OUSD (A&T) website in early 1999 that CAIV is the "DoD's acquisition methodology of making technical and schedule performance a function of available budgeted resources" (see Lorell & Graser, 2001, p. 33). OMB Circular A-109 for Major Systems Acquisition mentions the goal of "design-to-cost": "Under the CAIV philosophy, performance and schedule are considered dependent on the funds available for a specific program" (OMB, 1976). According to the *Defense Acquisition Guidebook*, "all participants […] are expected to recognize the reality of fiscal constraints" (DoD, 2006, July 7, Section 3.2.4).

Six Ways to Structure an "Economic Evaluation of Alternatives" (EEoA)

We have identified (what we believe are the only) six ways that analysts and decision-makers can structure a deterministic Economic Evaluation of Alternatives (EEoA) that avoid the issues (decision-criteria problems) discussed in the last section. These involve two main categories of approaches: 1) Intra-program analysis and 2) Inter-program analysis. The first, third, and fourth approaches are very much in the spirit of "cost as an independent variable" (CAIV). By recalling the earlier quote from Hitch and McKean (1967), we are reminded of the first two EEoA approaches: "[A] criterion in which the budget or level of effectiveness specified has the virtue of being aboveboard" (p. 167). The six EEoA approaches appear in Table 1.

[29] In a section describing "Building a Model," Fisher (1965) comments: "Since by definition a model is an abstraction from reality, the model must be built on a set of assumptions. These assumptions must be made explicit. If they are not, this is to be regarded as a defect of the model design" (p. 190). It is easy to conceal the importance of affordability (budget/funding) issues in the MCDM, Decision Sciences approach that underpins many AoAs. In sharp contrast, the Economic Evaluation of Alternatives approach encourages explicit affordability (budget/funding) assumptions.

Table 1. Six Approaches to Structure an EEoA

I) INTRA-PROGRAM ANALYSIS
- *A) Build Alternatives*
  1. Fixed Budget Approach
  2. Fixed Effectiveness Approach
  3. Expansion Path Approach (Construct alternatives as Cost-output/Effectiveness Relations or "Response Functions": Multi-stage Micro-economic Production Model)
- *B) Modify Existing Alternatives: "Level the Playing Field"*
  4. Modified Budget Approach: GOTO 1.
  5. Modified Effectiveness Approach: GOTO 2.

II) INTER-PROGRAM ANALYSIS
  6. Opportunity Cost/Benefit Approach

In the case of Intra-program analysis, the decision-maker (DM) associated with the program is assumed to have sufficient information to be able to select an alternative without reference to competing programs. That is not the case in Inter-program analysis, which requires an explicit "opportunity cost approach."

There are two possibilities highlighted within the Intra-program analysis approach. The first possibility is when DMs (analysts) are able to construct/define/build alternatives ("endogenous alternatives"). The second possibility is when the alternatives are already constructed/defined/built and must simply be evaluated ("exogenous alternatives").

This section describes each of the six Economic Evaluation of Alternatives (EEoA) approaches in some detail. The Mathematical Appendix describes the static, deterministic, multi-stage, constrained-optimization, micro-economic production (procurement auction) model that underpins the third, and most general, approach to the EEoA, the Expansion Path Approach. We begin with the Fixed Budget Approach, based on the earlier quote from Hitch and McKean (1967): "The test of *maximum effectiveness for a given budget* seems much less likely to mislead the unwary" (p. 167, emphasis added).

1. Fixed Budget Approach

In his groundbreaking book *Cost Considerations in Systems Analysis*, Fisher (1971) states: "In the fixed budget case, the alternatives being considered are compared on the basis of effectiveness likely to be attainable for the specified budget level" (p. 12). In other words, Fisher also explains that, "The analysis attempts to determine that alternative (or feasible combination […]) which is likely to produce the highest effectiveness" (p. 10).

In a footnote, Fisher (1971) adds: "the fixed budget situation is somewhat analogous to the economic theory of consumer [optimization…]. For a given level of income [budget] the consumer is assumed to behave in such a way that he maximizes his utility" (p. 10). Drawing on this comparison, the Fixed Budget Approach to the EEoA leverages Lancaster's "characteristics approach to demand theory" (Lancaster, 1969a; 1969b; 1971; 1979). Originating in the works of Gorman (1980), Stigler (1945), Theil (1952), and others (that also provided an early foundation for some of the MCDM literature), Lancaster offers economists (and defense analysts) a familiar way to analyze the consumer (or defense DM's) choice problem (such as choosing among defense investment alternatives).

In Lancaster's model, different vendors generate different bundles of characteristics evaluated by decision-makers ("consumers"). Lancaster's model proposes that to choose among alternative bundles of commodities (say computers), defense decision-makers maximize their utility function, defined over a desired set of criteria, attributes, or characteristics—hence the term adopted by decision scientists, Multiple-criteria Decision-making (MCDM)—subject to a budget [funding/affordability] constraint, which is mostly not adopted by decision scientists.[30] In this approach, the cost-effective alternative is the one that, for a given budget or expenditure, generates the best mix of characteristics, evaluated using the decision-maker's utility function.

Cost-Effectiveness EEoA

Build Alternatives

1. Fixed Budget Approach

Maximize Effectiveness subject to Budget Constraint

(construct alternatives for given budget)

Outsourcing Opportunity:
Can we get more bang for the same bucks?

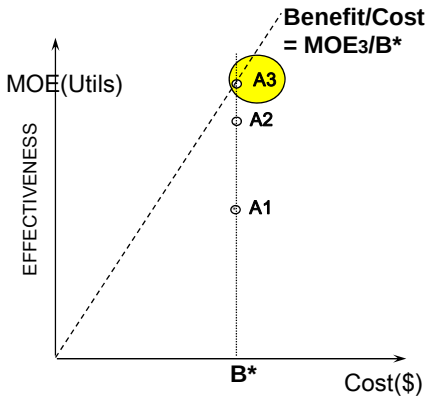


Figure 4. Fixed Budget Approach

This Fixed Budget Approach is the first of six ways proposed to structure an Economic Evaluation of Alternatives (EEoA) and is illustrated in Figure 4.[31] The Budget estimate for the program in Figure 4 is set at level B*. The three alternatives constructed given this budget are A1, A2, and A3. Given its superior performance in terms of its MOE, A3 wins the competition, which, in this case, can also be determined from its Benefit/Cost ratio.

2. Fixed Effectiveness Approach

[30] Note that we refer to the usual deterministic "utility function" that is conventional in the economics literature. This is in contrast to the way a utility function is typically defined in the decision sciences and operations management literature as a stochastic function. The "value function" described in the latter literature is similar to our "utility function," except that costs can enter into a value function and are excluded from our utility function since they appear as part of the budget constraint.

[31] Note that in the first and second EEoA approaches, since either the budget (funding level) or MOE (level of effectiveness) is anchored in the constrained optimization, the Benefit/Cost ratio decision criterion can be used as a decision rule in the selection process. The steeper the slope from the origin through an alternative (A1, A2, A3), the bigger the "bang-for-the-buck."

The second way to structure an EEoA is the dual of the first: minimize the cost of achieving a given MOE. RAND Corporation's AoA for the KC-135 Recapitalization adopts this approach, stating: "in this AoA, *the most 'cost-effective' alternative* [fleet] means precisely *the alternative whose effectiveness meets the aerial refueling requirement at the lowest cost*" (Kennedy et al., 2006, p. 7, emphasis added). Figure 5 offers an illustration.

Another example is the section on cost-effectiveness analysis in *OMB Circular A-94* that states: "A program is cost-effective if, on the basis of life cycle cost analysis of competing alternatives, it is determined to have the lowest costs […] for a given amount of benefits […]. Cost-effectiveness analysis can also be used to compare programs with identical costs [budgets/funding] but differing benefits" (OMB, 1992, October 29, p. 4). The latter part of the quote refers to the first approach to structuring an EEoA, and the former refers to the second approach.

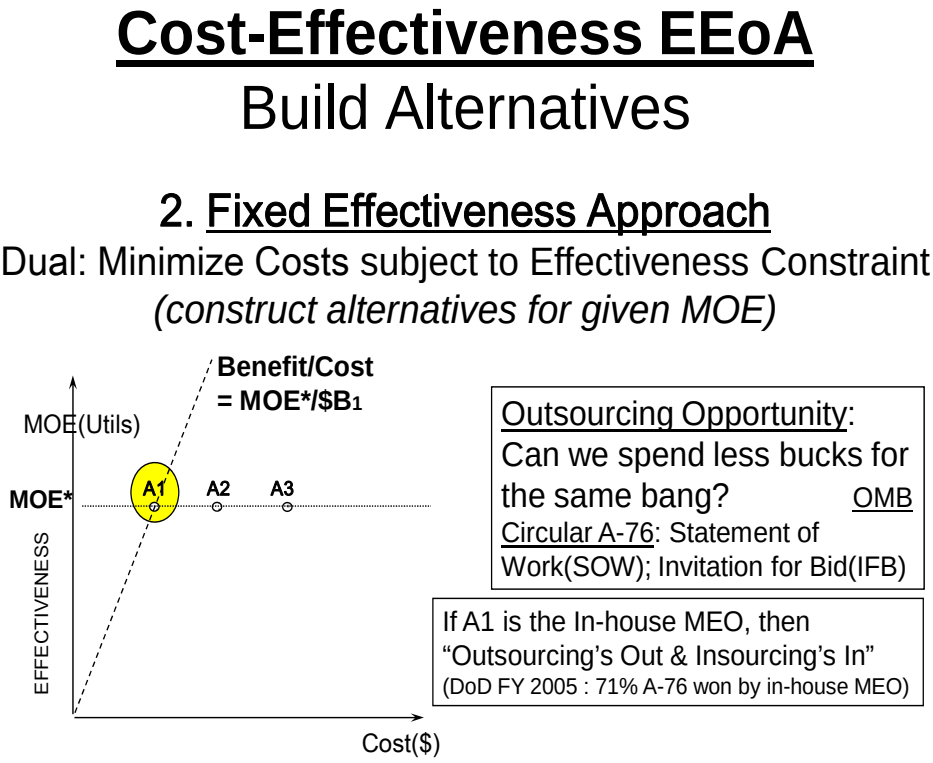


Figure 5. Fixed Effectiveness Approach

Another example of the Fixed Effectiveness Approach to structuring an EEoA is given by public-private (competitive sourcing) competitions conducted under *OMB Circular A-76*, which "requires […] a structured process for [evaluating] the most efficient and cost-effective method of performance for commercial activities" (2003, May 29). This involves four steps: 1) develop a Statement of Work (SOW) or Performance Work Statement (PWS) to define desired performance/effectiveness, 2) construct the Most Efficient Organization (MEO) for the in-house competitor, 3) issue an Invitation for Bid (IFB) for well-defined, routine commercial activities (SOW or PWS), and 4) compare bids or proposals (source selection) and select the "least cost" for IFB.

Finally, Title 10, Subtitle A, Part IV, Chapter 146, Section 2462 of the US Code reads: "A function of the Department of Defense […] may not be converted […] to performance by a contractor unless the conversion is based on the results of a public-private competition that […] examines the cost of performance of the function by Department of Defense civilian employees and the cost of performance of the function by one or more contractors to demonstrate whether converting to performance by a contractor will result in savings to the Government over the life of the contract" (2007, January 3). This offers another example of the Fixed Effectiveness Approach to structuring an EEoA.

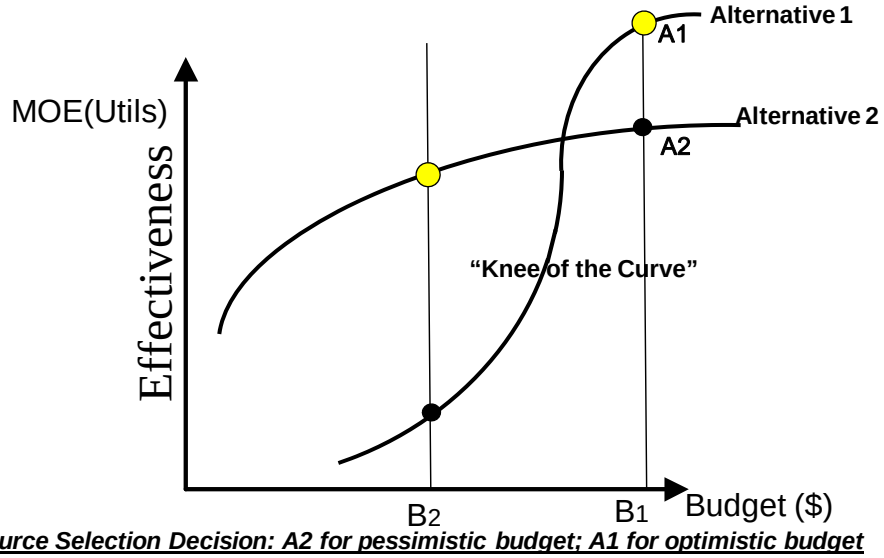
3. Expansion Path (Response Function) Approach

Hitch and McKean (1967) strongly hint at the third way to structure an EEoA: "The test of *maximum effectiveness for a given budget* seems much less likely to mislead the unwary" (p. 167). They explain, "As a starter, […] *several budget sizes can be assumed*. If the same [alternative] is preferred for all […] budgets, that system is dominant. If the same [alternative] is not dominant, the use of several […] budgets is nevertheless an essential step, because it provides vital information to the decision maker" (p.176, emphasis added).

This third way to structure an EEoA is the foundation for all the others and is described mathematically in the Mathematical Appendix (available upon request). It is modeled as a three-step process that involves multiple players.

For ease of exposition, we assume three players: the military buyer and two private vendors. The first step is for the military buyer to publish a synopsis of the solicitation. This synopsis (solicitation) states all significant non-price factors (criteria/attributes/characteristics) that the agency expects to consider in evaluating proposals, along with *optimistic*, *pessimistic* and *most likely* estimates of the budget.

ECONOMIC APPROACH: Endogenous Alternatives ("Engel Curves")
3. Expansion Path (Response Function) Approach
(Alternatives are Cost-Effectiveness Relations, not Points)
Explore impact of budget cuts *(Identify vendor responses)*



Source Selection Decision: A2 for pessimistic budget; A1 for optimistic budget

Figure 6. Expansion Path Optimization Approach

Assuming the award will be made without discussions (pursuant to *FAR* 52.212-1 and 52.215-1 (General Services Administration, 2005)), the military buyer has a secret scoring rule[32] used to rank vendors that is only revealed after the award of the contract. Once a solicitation is issued in the form of an RFP or IFB, interested vendors submit their offers and the selection process begins.[33]

Each vendor is assumed to have different production and cost functions (to generate the attributes). The vendors constrained optimizations define distinct expansion paths, one for each vendor. From the Envelope Theorem, the Lagrangian multiplier in each vendor's optimization reveals the marginal product (the extra output or attribute mix possible for them to produce) from relaxing the funding constraint, i.e., using a more optimistic budget.

Economic Evaluation of Alternatives Approach:
Military Buyer Goal: Select an alternative that Maximizes
MOE = utility function = U(non-cost factors/attributes),
Subject to BUDGET constraint = TC
Vendor Goal: Select a mix of non-cost factors that
Maximizes Q = Production Function = Q(non-cost factors/attributes)
Subject to TC = Sum of Costs of Attributes = c1 x a1 + c2 x a2 +… <= Budget
Military Buyer:
(MOE) build-effectiveness model (non-cost factors: Performance = quality, schedule, etc.)
(COST) build-cost model (costs/prices: Estimate total system lifecycle costs, total ownership costs)
(BUDGET) Estimate budget (funding level for the program)
Private Vendor:
(Q) Understand Production Function Generates Attributes
(TC) Identify cost of producing each attribute
Construct Alternatives as a function of the Military Buyer's Budget constraint

This EEoA approach illustrated in Figure 6 follows Hitch and McKean's (1967) recommendations: "As a starter […] several budget sizes can be assumed. If the same [alternative] is preferred for all […] budgets, that system is dominant […]. If the same [alternative] is not dominant the use of several […] budgets is nevertheless an essential step, because it provides vital information to the decision maker" (p. 176).

The expansion path for each vendor (see Mathematical Appendix) reveals what that vendor can offer at different budget levels (e.g., *pessimistic*, *most likely* and *optimistic*). The set of each vendor's proposals under the different budget scenarios is an "alternative." When the set of expansion path proposals of each vendor are transformed (through the government's

[32] The buyer can request a single offer from each supplier and choose the one he prefers among the submitted offers. "We call this procedure a 'single-bid auction with secret scoring rule'" (Asker & Cantillon, 2004, p. 1).

[33] The budget announcements are analogous to an agency exploring in order to uncover its true "reservation price" for the acquisition (given the competing demands for scarce budgets). The adoption of this approach of evaluating vendor proposals under different reservation prices could eventually lead to greater use of fixed-price contracts.

utility function) into a cost-utility or cost-effectiveness (MOE) function for that particular vendor, then, given a range of likely budgets for the program, the most effective vendor over that range of budgets can be selected (see Figure 6).

This approach explicitly addresses a key concern of the GAO that "A cost estimate is […] usually presented to decision makers as a […] point estimate that is expected to represent the most likely cost of the program but provides no information about the range of risk and uncertainty or level of confidence associated with the estimate" (GAO, 2009, p. 9). The three-stage procurement auction process is summarized in Table 2 below.

Table 2. Three Stage Multi-attribute Procurement Auction (Expansion Path Optimization Approach)

1) First Stage: (CAIV)

- **The DoD provides notional budget guidance** (B) to alternative vendors for the program. The DoD searches for the optimum product (Procurement) and/or service (R&D; O&M) package that it can obtain at that price, B. The **DoD also reveals optimistic and pessimistic budget guidance.**
- **The DoD defines the set of characteristics/attributes that it values,** and this is known to vendors. However, the DoD's precise utility function over those characteristics is unknown to vendors (secret scoring rule).

2) Second Stage: (Target Costing)

- **Vendors have different costs and production functions** for generating products or services (defined as bundles of characteristics).
- **Each vendor maximizes its output offer** (an optimal mix of the desired characteristics) **subject to its particular budget constraint** (which includes the DoD's budget guidance and the vendor's individual costs to produce a unit of each characteristic).
- **This is the product and/or service package (output) a particular vendor is able to propose for each possible budget** (B), given its production function (technical production possibilities) and its costs of generating those characteristics.

3) Third Stage: (Selection)

With the latest budget forecast, the **DoD selects** among the optimized characteristic bundles proposed by each **vendor** the **bundle/alternative** (total product/service package) **that maximizes the DoD's utility function.**

Whereas the first three ways to structure an EEoA assume that alternatives can be generated by the decision-maker, the last three assume that alternatives are exogenously determined and that the decision-maker must choose among pre-specified alternatives. The interesting cases are those in which an alternative costs more but offers greater utility, while others cost less and offer less utility.

4. Modified Budget Approach

Suppose that the overall budget or desired level of effectiveness for a program is not available and that the alternatives are derived exogenously—for example, on the basis of a manpower or squadron constraint (e.g., one computer per person or a certain number of aircraft per squadron). Then, it is likely that the pre-specified alternatives solicited from different vendors have different costs and yield different measures of effectiveness (MOE). The first step might be

to create a scatter plot of effectiveness versus cost (see Figure 7). In the absence of any other information, the highest cost alternative a DM is willing to consider can be used as a notional budget estimate for the program.

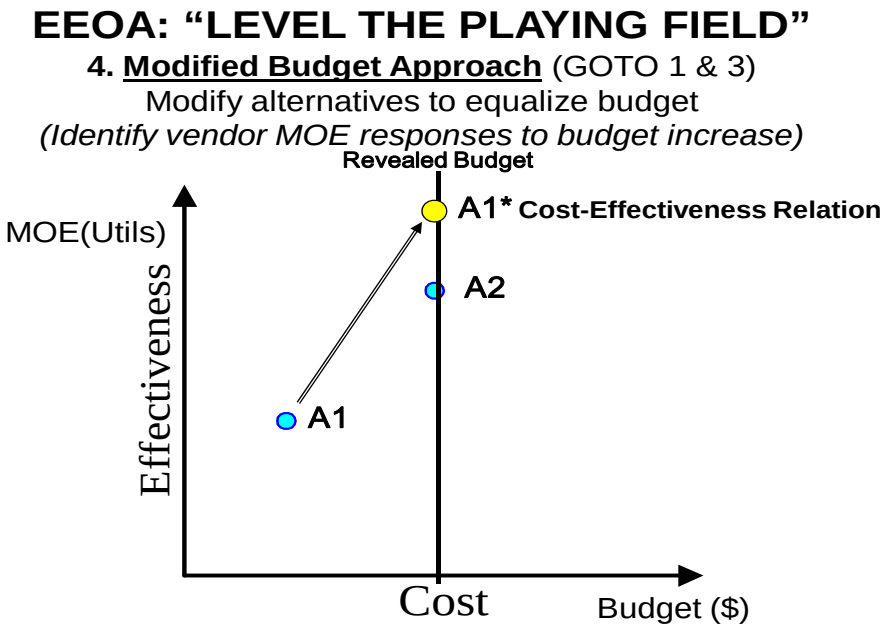


Figure 7. Modified Budget Approach

The fourth way to structure an EEoA recognizes that the highest-cost (highest-utility) alternative under consideration (for example, A2 in Figure 7) reveals a possible budget constraint. By "leveling the playing field," the decision-maker asks how the extra money might be used by the lower-cost (lower-utility) vendor (A1) to increase the utility of that alternative (from A1 to A1*).[34] Note that this effectively returns the problem to the first (and third) way of structuring an EEoA.

5. Modified Effectiveness Approach

Similarly, the fifth way to structure an EEoA levels the playing field for a threshold choice of utility (or effectiveness), returning the problem to the second (and third) way of structuring an EEoA. For example, in Figure 8, anchoring the desired MOE at a target level such as that offered by vendor 2, the government would return to vendor 1 and ask, how much would it cost to achieve the same target level of MOE? In Figure 8, vendor 1 is preferred since the response (A1=>A1*) minimizes the budget required.

[34] Alternatively, different valuable uses for the money saved by choosing the lower-cost alternative could be brought into the effectiveness calculation. Some will recognize this search for the "next best alternative use of funds" as the standard economic definition of opportunity costs. This sets the stage for the sixth way to structure an EEoA.

EOA: "LEVEL THE PLAYING FIELD"

5. <u>Modified Effectiveness Approach</u> (GOTO 2 & 3)
Modify alternatives to equalize MOE
(Identify vendor COST responses to higher MOE requirement)

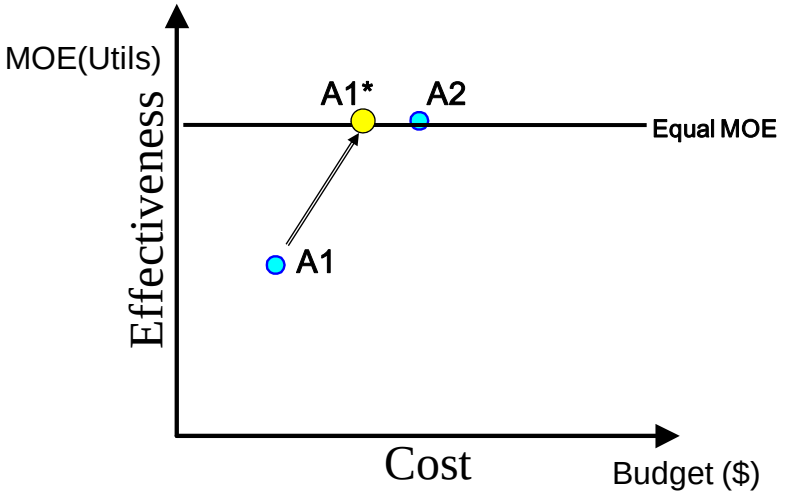


Figure 8. Modified Effectiveness Approach

6. Opportunity Cost (or Effectiveness) Approach

Finally, what if 1) we cannot modify alternatives to obtain response functions, and 2) we don't know, or cannot assume, a given budget or desired level of MOE? In this case, some alternatives (bundles) cost more but offer more effectiveness, while others cost less and offer less effectiveness ("efficient set"). The sixth and final way to structure an EEoA involves an inter-program comparison we call the Opportunity Cost Approach.

Rather than modify the alternatives to level the playing field, the Opportunity Cost Approach accepts both lower-cost, lower-effectiveness alternatives (A1 in Figure 9) and higher-cost, higher-effectiveness alternatives (A2) but requires a more challenging inter-program analysis.

The main challenge in selecting an alternative in this context is that the DM must reach beyond the immediate program, A, into higher-level inter-program considerations (perhaps entering the requirements generation system or the PPBE process).

If the alternatives are exogenously determined, and it is not possible to level the playing field, then to find the most cost-effective solution requires information about other competing programs (e.g., program B in Figure 9). "[T]he assessment should provide details as to how excess funding […] demands will be accommodated by reductions in other mission areas, or in other […] accounts" (DoD, 2006, July 7, Section 3.2.2).

This involves an inter-program analysis similar to that illustrated in Figure 9. What is the loss in utility in other programs that might be sacrificed (B2=>B1) for the funds to be made available to purchase greater utility in the program under review (A1=>A2)? Alternatively, how much more utility might the extra money generate somewhere else if we went with the low-cost alternative (A1)? These are tough but useful questions that break through the sub-optimization

of most traditional AoAs. In this way, the EEoA approach encourages critical communication to take place between different layers of the organization.[35]

6. Opportunity Cost Approach
(INTER-PROGRAM Marginal Analysis)

A) Question: Where is the extra money coming from if I buy the high cost alternative?
B) Question: Where is the extra money going if I buy the low cost alternative?

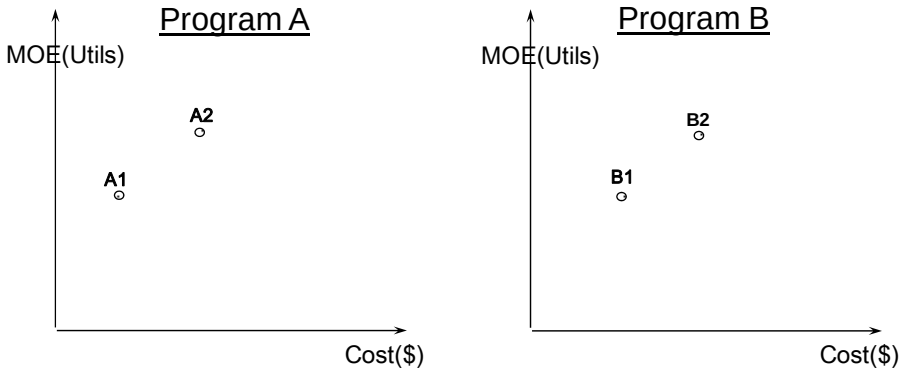


Figure 9. Opportunity Cost Approach

The bottom line is that it is often more transparent, efficient, and effective to develop MOEs that are independent of costs and to treat costs as an independent variable (CAIV). Equally important are the roles of budget (funding) forecasts and opportunity costs in helping structure defense investment decisions. Structuring an Economic Evaluation of Alternatives (EEoA) using one of the six approaches summarized in Table 1 could help achieve the primary goal of defense acquisition reform—to help coordinate the requirements generation system (JCIDS), Defense Acquisition System (DAS), and PPBE to lower the costs of defense investments and improve performance and schedules.

Conclusion: A Decision Map for Decision-makers

This study identified several major challenges that face current military cost-effectiveness analyses. It also critically examined key assumptions of the decision sciences'

[35] Fisher (1965) quotes Secretary of Defense Robert McNamara: "Suppose we have two tactical aircraft which are identical in every important measure of performance [MOE] except one—aircraft A can fly ten miles per hour faster than Aircraft B. Thus, if we need about 1,000 aircraft, the total additional cost would be $10million. If we approach this problem from the viewpoint of a given amount of resources, the additional combat effectiveness […] of Aircraft A would have to be weighed against the additional combat effectiveness which the same $10million could produce if applied to other defense purposes—more Aircraft B, more or better aircraft munitions, or more ships, or even more military family housing […] This kind of determination is the heart of the planning-programming-budgeting […] problem with the Defense Department." (p.182)

literature, which are frequently used by the military to structure acquisition decisions. An alternative micro-economic set of approaches to structure acquisition decisions was proposed, called the Economic Evaluation of Alternatives (EEoA).

This study points to a significant weakness in the multiple-criteria, decision-making (MCDM) approach that underpins many contemporary AoAs. The weakness is that while MCDM techniques, and therefore most AoAs, correctly focus on lifecycle costs and the operational effectiveness of individual alternatives, affordability is often only implicitly addressed through a weight assigned to costs.

In contrast, the EEoA approach recommended in this study encourages analysts and decision-makers to include affordability explicitly in the AoA. This requires working with vendors to build alternatives based on different funding (budget/affordability) scenarios. Supported by a static, deterministic, multi-stage, constrained-optimization, micro-economic production (procurement auction) model described in Section 3, this EEoA approach explicitly addresses affordability up-front. The key difference between the MCDM approach to AoA, and the EEoA approach, is that instead of modeling decision alternatives from competing vendors as points in cost-effectiveness space, the EEoA models alternatives as functions of *optimistic*, *pessimistic* and *most likely* funding (resource/budget) scenarios.

The primary goal of this study was to help improve public investment decisions by providing a set of six approaches practitioners (acquisition officials and others) can employ to structure an Economic Evaluation of Alternatives (EEoA). An important secondary goal of the study was to develop a Decision Map to guide practitioners and acquisition officials in structuring cost-effectiveness analyses to improve defense acquisition outcomes. The Decision Map to structure an EEoA appears below.

Decision Map to Structure an Economic Evaluation of Alternatives (EEoA)

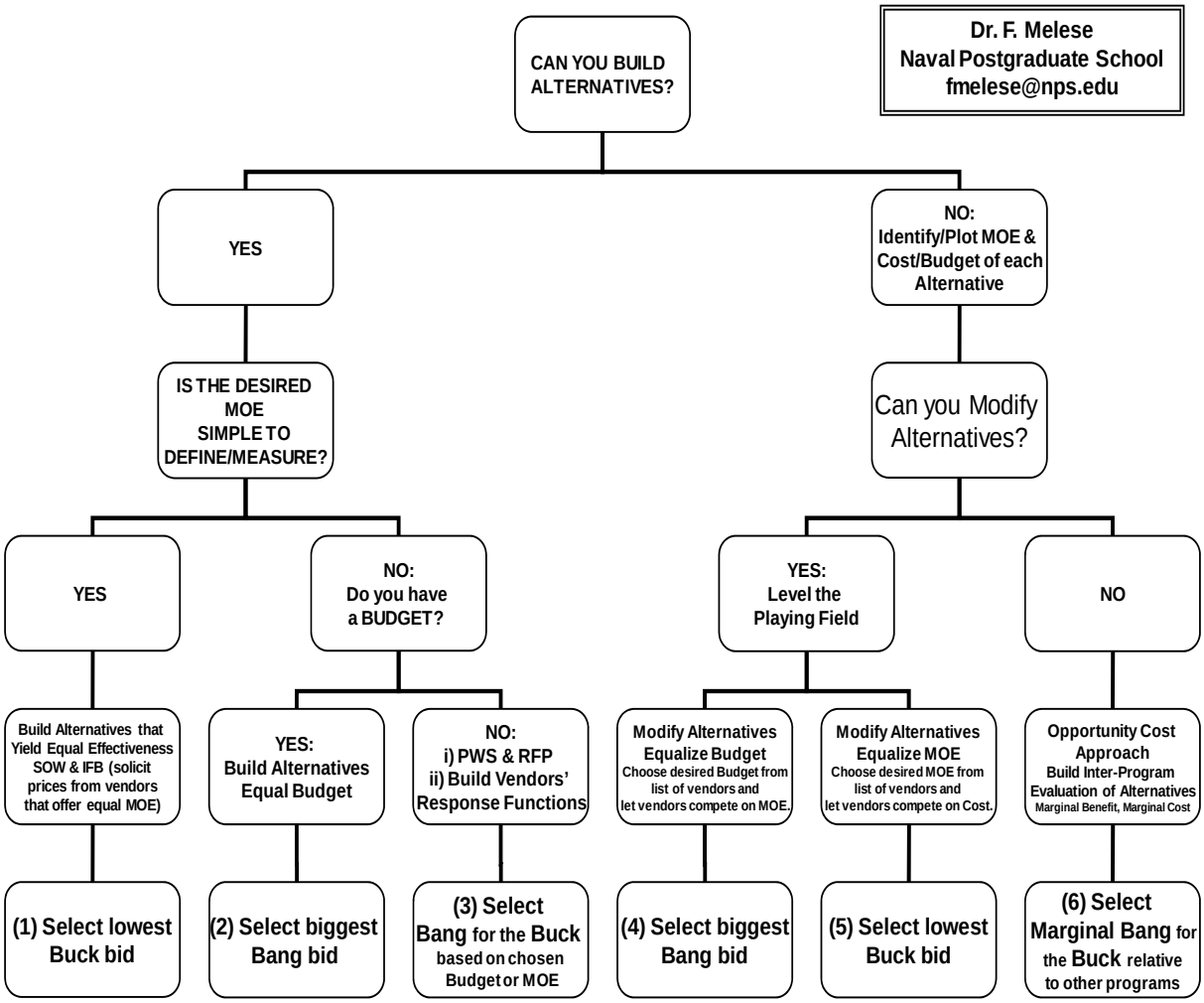


Figure 10. Decision Map to Structure EEoAs

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List of References

Asker, J., & Cantillon, E. (2004). *Properties of scoring auctions*. Unpublished Working Paper.

Beil, D., & Wein, L. (2003). An inverse-optimization-based auction mechanism to support a multiattribute rfq process. *Management Science, 49*(11).

CJCS. (2007, May). *Joint Capabilities Integration and Development System (JCIDS)* (CJCSI 3170.01F). Washington, DC: Author.

Che, Y. (1993). Design competition through multidimensional auctions. *RAND Journal of Economics, 24*.

Clemen, R. (1996). *Making hard decisions: An introduction to decision analysis* (2nd ed.). Belmont, CA: Duxbury Press.

Corner, J., & Kirkwood, C. (1991). Decision analysis applications in the operations research literature. *Operations Research, 39*(2).

Davis, P. (2002). *Analytic architecture for capabilities-based planning, mission-system analysis, and transformation*. Santa Monica, CA: National Defense Research Institute, RAND.

DoA. (1999, July 15). *Pamphlet 70-3*. Washington, DC: US Army Headquarters.

DoA. (2001, February). *Economic analysis manual.* Arlington, VA: US Army Cost and Economic Analysis Center.

DoD. (1984, May 22). *The Planning, Programming, and Budgeting System (PPBS)* (DoD Directive 7045.14). Washington, DC: Author.

DoD. (1987, April 9). *Implementation of The Planning, Programming, and Budgeting System (PPBS)* (DoD Directive 7045.07). Washington, DC: Author.

DoD. (1995, November 7). *Economic analysis for decisionmmaking* (DoD Directive 7041.3). Washington, DC: Author.

DoD. (1998). *DoD Guide to cost as an independent variable* (DA PAM 70-3). Washington, DC: Author.

DoD. (2006, July 7). *Department of Defense (DoD) defense acquisition guidebook.* Chapter 1.1 (Integration of the DoD Decision Support System); Chapter 1.2 (Planning, Programming, Budgeting and Execution Process; Office of Management and Budget (OMB) and the PPBE Process). Retrieved March 16, 2009, from https://acc.dau.mil

Dyer, S., & Sarin, R. (1979). Measurable multiattribute value functions. *Operations Research, 27.*

Dyer, S., Fishburn, P., Steuer, R., Wallenius, J., & Zionts, S. (1992). Multiple criteria decision making, multi-attribute utility theory. *Management Science*, *38*(5).

Edwards, W., von Winterfeldt, D., & Moody, D. (1988). Simplicity in decision analysis. In D. Bell, H. Raiffa, & A. Tversky (Eds.), *Decision making: Descriptive, normative, and prescriptive interactions* (pp. 443l-4464). Cambridge, England: Cambridge University Press.

Eger, R., & Wilsker, A. (2007). Cost effectiveness analysis and transportation: Practices, problems and proposals. *Public Budgeting and Finance, 27*(1).

European Commission. (2004a, March 31). *Coordinating the procurement procedures of entities operating in the water, energy, transport and postal services sectors* (Directive 2004/17/EC of The European Parliament and of The Council), EC 2004a, Article 55.

European Commission. (2004b, March 31). *On the coordination of procedures for the award of public works contracts, public supply contracts and public service contract* (Directive 2004/18/EC of The European Parliament and of The Council), EC 2004b, Articles 53, 54.

Ewing, P., Tarantino, W., & Parnell, G. (2006). Use of decision analysis in the Army base realignment and closure (BRAC) 2005 military value analysis. *Decision Analysis*, *3*(1).

Federal Acquisition Streamlining Act of 1994. (Public Law 103-355)

Federal Acquisition Reform Act of 1995. (Public Law 104-106)

Federal Activities Inventory Reform Act of 1998. (Public Law 105-270)

Fisher, G. (1965). The role of cost-utility analysis in program budgeting. In D. Novick (Ed.), *Program budgeting*. Cambridge, MA: Harvard University Press.

Fisher, G. (1971). *Cost considerations in systems analysis.* New York: American Elsevier Publishing.

Fowler, B., & Cason, P. (1998). The cost exchange ratio: A new aggregate measure of cost and operational effectiveness. *JMORS*, *3*(4).

French, S. (1986). *Decision theory: An introduction to the mathematics of rationality*. Cambridge: Ellis Horwood.

Gansler, J. (2003, June). *Moving toward market-based government*. New Ways to Manage Series. IBM Endowment for the Business of Government.

GAO. (2008, July 2). *Defense acquisitions: A knowledge-based funding approach could improve major weapon system program outcomes* (GAO-08-619). Washington, DC: Author.

GAO. (2008, September 25). *Defense acquisitions: Fundamental changes are needed to improve weapon program outcomes* (GAO-08-1159T). Testimony of M. Sullivan, Director of Acquisition and Sourcing Management before the Subcommittee on Federal Financial Management, US Senate. Washington, DC: Author.

GAO. (2008, December). *Defense logistics: Improved analysis and cost data needed to evaluate the cost-effectiveness of performance-based logistics* (GAO-09-41). Washington, DC: Author.

GAO. (2009, March 18). *Defense acquisitions: DoD must prioritize its weapon system acquisition and balance them with available resources* (GAO-09-501T). Testimony of M. Sullivan, Director of Acquisition and Sourcing Management before the Committee on the Budget, House of Representatives. Washington, DC: Author.

General Services Administration, Department of Defense, National Aeronautics and Space Administration. (2005, March). *Federal acquisition regulation (FAR)*. Washington, DC: Author.

Golabi, K., Kirkwood, C., & Sicherman, A. (1988). Selecting a portfolio of solar energy projects using multiattribute preference theory. *Management Science, 34*.

Gorman, W. (1980). The demand for related goods: A possible procedure for analysing quality differentials in the egg market. *Review of Economic Studies, 47*.

Henry, M., & Hogan, W. (1993, September). Cost and effectiveness integration. Retrieved April 20, 2009, from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA275710&Location =U2&doc=GetTRDoc.pdf

Hitch, C., & McKean, R. (1967). *The economics of defense in the nuclear age*. Cambridge, MA: Harvard University Press.

Howard, R. (1988). Decision analysis: Practice and promise. *Management Science, 34.*

Hwang, C., & Yoon, K. (1981). *Multiple-attribute decision making: Methods and applications.* New York: Springer-Verlag. Keeney, R. (1982). Decision analysis: An overview. *Operations Research, 30*(5).

Keeney, R. (1992). *Value-focused thinking.* Cambridge, MA: Harvard University Press.

Keeney, R. (1994). Using values in operations research. *Operations Research, 42*(5).

Keeney, R., & Raiffa, H. (1976). *Decisions with multiple objectives: Preferences and value tradeoffs*. New York: John Wiley & Sons.

Kennedy, M., et al. (2006). *Analysis of alternatives (AoA) for KC-135 recapitalization.* Santa Monica, CA: Project Air Force, RAND.

Kirkwood, C. (1997). *Strategic decision making.* New York: Duxbury Press.

Lancaster, K. (1966a). A new approach to consumer theory. *Journal of Political Economy, 74*.

Lancaster, K. (1966b). Change and innovation in the technology of consumption. *American Economic Review, 61*.

Lancaster, K. (1971). *Consumer demand: A new approach*. New York: Columbia University Press.

Lancaster, K. (1979). *Variety, equity, and efficiency*. New York: Columbia University Press.

Larsen, R., & Buede, D. (2002). Theoretical framework for the continuous early validation method. *Systems Engineering, 5*(3).

Liberatore, M. (1987). An extension of the analytic hierarchy process for industrial R&D project selection and resource allocation. *IEEE Transaction on Engineering Management, 34*(1).

Lorell, M., & Graser, J. (2001). *An overview of acquisition reform cost saving estimates*. Santa Monica, CA: RAND Project Air Force.

Melese, F. (2007, May 17). Outsourcing for optimal results: Six ways to structure an analysis of alternatives. In *Proceedings of the 4th Annual Acquisition Research Symposium: Creating synergy for informed change*. Monterey, CA: Naval Postgraduate School.

Melese, F., & Bonsper, D. (1996, December). Cost integration and normalization issues. PHALANX, *29*(4).

Melese, F., Franck, R., Angelis, D., & Dillard, J. (2007, January). Applying insights from transaction cost economics to improve cost estimates for public sector purchases: The case of U.S. military acquisition. *International Public Management Journal,10*(4).

Melese, F., Stroup, M., & Lowe, J. (1997). Integrating cost and effectiveness: An economic perspective. *PHALANX, 30*(3).

Michael, R., & Becker, G. (1973). On the new theory of consumer behavior. *Swedish Journal of Economics*, *75*(4).

Murray, C. (2002). *Executive decision making* (6th ed.). Newport, RI: National Security Decision Making Department, US Naval War College.

OSD. (2009, January 15). *Defense federal acquisition regulation supplement* (DFARS). Washington, DC: Author. Retrieved April 20, 2009, from http://www.acq.osd.mil/dpap/ dars/dfars/html/current/tochtml.htm

OMB. (1976, April 5). *Major systems acquisitions* (OMB Circular A-109). Washington, DC: Author.

OMB. (1992, October 29). *Guidelines and discount rates for benefit-cost analysis of federal programs* (OMB Circular A-94). Washington, DC: Author.

OMB. (2003, May 29). *Performance of commercial activities (Public-private competitions)* (OMB Circular A-76 (Revised)). Washington, DC: Author.

Parkes, D., & Kalagnanam, J. (2005). Models for iterative multiattribute procurement auctions. *Management Science, 51*(3).

Parnell, G. (2006). Value-focused thinking using multiple objective decision analysis. In *Methods for conducting military operational analysis* (Chap. 19). Alexandria, VA: Military Operations Research Society.

Pinker, A., Samuel, A.H., & Batcher, R. (1995, December) On measures of effectiveness. *PHALANX*.

Quade, E. (1989). *Analysis for public decisions* (3rd ed.). Englewood Cliffs, NJ: Prentice Hall.

Ramesh, R., & Zionts, S. (1997). Multiple criteria decision making. In S. Gass & C. Harris (Eds.), *Encyclopedia of Operations Research and Management Science*. Boston, MA: Kluwer.

Retchless, T., Golden, B., & Wasil, E. (2007). Ranking US Army Generals of the 20th century: A group decision-making application of the analytic hierarchy process. *Interfaces, 37*(2).

Ruefli, T. (1974). Analytic models of resource allocation in hierachical multi-level systems. *Socio-Economics Planning Science, 8*.

Ruefli, T. (1971). PPBS—An analytical approach. In R. Byrne et al. (Eds.), Studies in budgeting. Amsterdam: North Holland.

Saaty. T. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology, 15*.

Saaty, T. (1980). *The analytic hierarchy process.* New York: McGraw-Hill.

Smith, J., & von Winterfeldt, D. (2004). Decision analysis in management science. *Management Science, 50*(5).

Stigler, G. (1945). The cost of subsistence. *Journal of Farm Economics, 27*.

Theil, H. (1952). Qualities, prices and budget enquiries. *Review of Economic Studies, 19*.

Thomas, C., & Sheldon, R. (1999). The knee of the curve. *Military Operations Research*, *4*(2).

US Code. (2007, January 3). Title 10—Armed Forces, Subtitle A, Part IV, Chapter 146, Section 2462.

US Congress. (1997). *Clinger-Cohen Act—Information Technology Management Reform Act of 1996* (Public Law 104-106). 104th Congress, 2nd Session. Washington, DC: Chief Information Officers Council.

USD (AT&L). (2007, November 20). *The defense acquisition system* (DoD Directive 5000.01). Washington, DC: Author.

USD (AT&L). (2008, December 8). *Operation of the defense acquisition system* (DoD Instruction 5000.02). Washington, DC: Author.

Vazsonyi, A. (1995, December/January). Multicriteria decision making. *Decision Line*, *26*(1).

Willard, D. (1998). Cost-effectiveness, CAIV, and the knee of the curve. *Phalanx, 31*(3).

Winterfeldt, D., & Edwards, W. (1986). *Decision analysis and behavioral research*. Cambridge, England: Cambridge University Press.

Zahedi, F. (1986). The analytic hierarchy process—A survey of the method and its applications. *Interfaces, 16*.

Zionts, S. (1980). Methods for solving management problems involving multiple objectives. In G. Fandal & T. Gaul (eds.), MCDM: Theory and applications. New York: Springer-Verlag.

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