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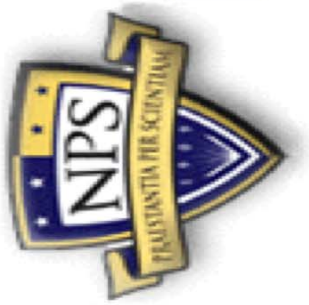

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The Economic Evaluation of Alternatives

Dr. Francois Melese

Abstract: This paper offers a comprehensive set of approaches for procurement officials to structure public investment decisions to improve acquisition outcomes. Called the "Economic Evaluation of Alternatives" (EEoA), these approaches address a significant weakness in most contemporary military "Analyses of Alternatives" (AoAs). While AoAs correctly focus on lifecycle costs and operational effectiveness of alternatives, "affordability" is an after-thought, at best only implicitly addressed in final stages of the analysis. In sharp contrast, EEoA encourages analysts and decision-makers to include affordability explicitly, and up-front in structuring an AoA. This requires working with vendors to build alternatives based on different funding (budget/affordability) scenarios. A key difference between traditional AoAs and the EEoA approach is that instead of modeling competing vendors as points in cost-effectiveness space, EEoA solicits vendor offers as functions of optimistic, pessimistic, and most likely funding (budget) scenarios. The Decision Map offered in the concluding section provides a comprehensive guide for practitioners. This paper also illustrates how, by embedding affordability directly into an AoA, EEoA provides a unique opportunity to achieve a significant defense acquisition reform—to coordinate the Requirements Generation System, Defense Acquisition System, and Planning, Programming, and Budgeting System (PPBS), to lower costs, and improve performance and schedules.

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The Economic Evaluation of Alternatives*

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ABSTRACT

This paper offers a comprehensive set of approaches for procurement officials to structure public investment decisions to improve acquisition outcomes. Called the "Economic Evaluation of Alternatives" (EEoA), these approaches address a significant weakness in most contemporary military "Analyses of Alternatives" (AoAs). While AoAs correctly focus on lifecycle costs and operational effectiveness of alternatives, "affordability" is an after-thought, at best only implicitly addressed in final stages of the analysis. In sharp contrast, EEoA encourages analysts and decision-makers to include affordability explicitly, and up-front in structuring an AoA. This requires working with vendors to build alternatives based on different funding (budget/affordability) scenarios. A key difference between traditional AoAs and the EEoA approach is that instead of modeling competing vendors as points in cost-effectiveness space, EEoA solicits vendor offers as functions of optimistic, pessimistic, and most likely funding (budget) scenarios. The Decision Map offered in the concluding section provides a comprehensive guide for practitioners. This paper also illustrates how, by embedding affordability directly into an AoA, EEoA provides a unique opportunity to achieve a significant defense acquisition reform—to coordinate the Requirements Generation System, Defense Acquisition System, and Planning, Programming, and Budgeting System (PPBS), to lower costs, and improve performance and schedules.

Biography

Dr. 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 for the Joint Staff and the Office of the Secretary of Defense. In 2008, he helped edit 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." His experience in implementing the model for the Joint Staff was recently published in the *Armed Forces Comptroller*. At the request of NATO HQ, Dr. 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."

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The Economic Evaluation of Alternatives (EEoA):

"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**)**

1) Introduction: Making the Case for "Affordability"

America's security, billions of taxpayer dollars, and the survival of U.S. soldiers can all hinge on an Analysis of Alternatives (AoA).[1] Routinely conducted to support major military investment decisions, the AoA is a core component of the defense acquisition process. AoAs shape future forces, influence defense spending, and occasionally redefine the defense industry.

This paper reveals a significant weakness in the Multiple-Criteria Decision-Making (MCDM) approach that underpins many contemporary AoAs.[2] The weakness is that while MCDM techniques, and therefore most AoAs, correctly focus on lifecycle costs and the operational effectiveness of alternatives, "affordability" is an after-thought, often only implicitly addressed through a weight assigned to costs. As the former chairman of Lockheed Martin Corp. (and current BENS task force chair on defense acquisition reform) explains: "…affordability is rarely considered." (Norm Augustine quoted in E. Newell "Business group urges reform of Pentagon contract requirements process," Government Executive, www.govexec.com July 27, 2009)

This paper offers a comprehensive set of approaches for procurement officials to structure public investment decisions to improve acquisition outcomes. Called the "Economic Evaluation of Alternatives" (EEoA), these approaches address a significant

[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 whenever the term AoAs references major defense acquisition programs (MDAPs), or the acquisition of major automated information systems (MAISs).

[2] For examples of the MCDM approach see Clemen (1996), French (1986), Keeney (1982, 1992, 1997), Keeney & Raiffa (1976), or Kirkwood (1997).

weakness in most contemporary military Analyses of Alternatives (AoAs)—affordability. An important goal of EEoA is to encourage and guide analysts and decision-makers to integrate affordability early in the acquisition process.

In sharp contrast to traditional AoAs, the "Economic Evaluation of Alternatives" (EEoA) explicitly addresses affordability up-front. This requires working with vendors to build proposals based on funding (resource/budget) scenarios. 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 generates vendor proposals as *functions* of optimistic, pessimistic, and most likely funding (resource/budget) scenarios.

Given the current economic crisis and future public spending challenges, affordability is a growing concern. As a consequence, it is imperative that the Department of Defense (DoD) obtain the best value for every dollar it invests in its major defense acquisition programs (MDAPs), and major automated information systems (MAISs). 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 embedding affordability into AoAs. The U.S. Government Accountability Office (GAO) confirms that a major challenge facing DoD is to "achieve a balanced mix of weapon systems that are *affordable*" (GAO, 2009, p. 5).[3]

Unlike the traditional MCDM approach to AoAs that focuses on costs and operational effectiveness (schedule and performance), the EEoA approach adds another dimension—affordability. EEoA makes a clear distinction between the "life-cycle

[3] 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).

costs" or "price" of an alternative, its operational effectiveness (schedule and performance), and the resources (funding or budget) likely to be available for the overall program. By embedding affordability directly into an AoA, EEoA provides a unique opportunity to achieve a significant defense acquisition reform—to coordinate the Requirements Generation System, Defense Acquisition System, and Planning, Programming, and Budgeting System (PPBS), to lower costs, and improve performance and schedules.[4]

2) Integrating Requirements Generation, Defense Acquisition, and PPBS

In stressing affordability, the Economic Evaluation of Alternatives (EEoA) offers an analytical approach that addresses a major concern expressed by the U.S. Government Accountability Office (GAO):

> DoD's processes for identifying war-fighter needs [Requirements Generation System], allocating resources [Planning, Programming, and Budgeting System (PPBS)], and developing and procuring weapon systems [Defense Acquisition System] are fragmented [so that] DoD commits to more programs than resources [budgets/funding] can support... DoD allows programs to begin development without a full understanding [of] the resources [budgets/funding] needed.[5]
>
> GAO 2009, March 18, Highlights

This observation is echoed in a recent study by BENS (Business Executives for National Security)):

[4] DoD's Planning, Programming, Budgeting and Execution (PPBE) process is the principal decision support system used 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 to identify military investment opportunities, and the Defense Acquisition System (DAS) to develop and procure new weapon systems.

[5] "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.

> "[R]equirements are largely determined…*without adequate input as to what is* ***affordable*** *from a planning, programming, and budgeting perspective*."
>
> "Getting to Best: Reforming the Defense Acquisition Enterprise" BENS Executive Summary, May 2009, p.10

Embedding affordability directly into an AoA provides a unique opportunity to achieve a significant defense acquisition reform—to coordinate the Requirements Generation System, Defense Acquisition System, and Planning, Programming, and Budgeting System (PPBS). A brief overview of DoD's budget development and acquisition systems highlights the valuable role affordability can play in structuring an EEoA.

The primary purpose of PPBS is to make hard choices among alternative military capabilities and investments necessary for national security within fiscal constraints. The requirements generation process naturally fits into the Planning phase of PPBS. The first step in any investment analysis is to identify the derived demand for a key capability, program, or project. The focus of EEoA is on materiel investments identified to fill critical capability gaps. [6] This is accomplished through DoD's requirements generation system.

Operator demands ("requirements") are identified and refined in the Planning phase of the PPBE process. Whenever a "materiel" solution is recommended,

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[6] 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). (JCIDS 2007 p.A-1; DoD 5000.2 2008 p.14) 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.

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). MDAP and MAIS proposals that emerge from the Planning process enter the DAS and are incorporated in the Programming phase of PPBE.

Ideally, the Planning phase of PPBE establishes fiscally constrained guidance and priorities for the military services, including readiness, sustainability and modernization. This guidance provides direction for DoD Components (military departments and defense agencies) to develop their individual program and investment proposals, or Program Objectives Memorandum (POM). In this Programming phase of PPBE, the POMs detail resource-allocation decisions (funding, personnel, etc.) proposed by each Component for its programs, projected six years into the future. A challenge is that the DAS data needed to evaluate major defense acquisition investments in an EEoA requires lifecycle cost estimates that project well beyond the six years of the POM.

Senior leadership in OSD and the Joint Staff subsequently review each Component POM to ensure it satisfies the Strategic Planning guidance, and that it can be integrated into an effective and affordable overall national defense program. 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 DoD's biennial defense budget projects funding only two years into the future, it includes more financial detail than the POMs.[7] The Under Secretary of Defense

[7] Translating the budget implications of these decisions into the usual Congressional appropriation categories

Comptroller and the Office of Management and Budget (OMB) jointly review budget submissions to ensure programs are affordable, i.e., satisfy current fiscal constraints. [8]

The primary focus of Multi-criteria Decision-making (MCDM) as traditionally applied in AoAs, is to estimate 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 paper emphasizes another key aspect—"Affordability."

In helping generate investment alternatives, and illuminating the benefits and costs of those alternatives, AoAs have the potential to contribute to requirements generation in the Planning phase of PPBE, and through DAS decision milestones, could also influence the Programming phase of PPBE. However, according to the GAO:

> "[T]he vast majority of capability proposals that enter the JCIDS [Requirements Generation] process are…approved *without accounting for resources* [funding/budgets] that will be needed to acquire the desired capabilities"[9] (GAO, 2009, p. 6).

The concern for the availability of resources or future affordability is a primary focus of this paper.

(Military Personnel, Procurement, Operations & Maintenance (O&M), Military Construction, etc.) generates the defense budget and Future Year Defense Program (FYDP).

[8] 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).

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

The EEoA approach represents an important step in the long-running effort to integrate DoD's Requirements Generation and Defense Acquisition Systems with PPBE. In considering alternative budget scenarios that rely on FYDP forecasts, EEoA injects an explicit constrained optimization approach into defense acquisition investment decisions that parallels one already embedded in PPBE—choosing an optimal mix of forces, equipment and support that maximizes national security subject to fiscal constraints.

3) Integrating Affordability Assessments into AoAs

The primary concern expressed by GAO and others is that military requirements are often approved without fully accounting for resources available i.e. ignoring future funding or budget realities. This reflects a fundamental weakness in the way AoAs have traditionally been structured. While AoAs attempt to estimate costs and effectiveness of competing alternatives, affordability is often addressed as a separate exercise, and then only ex-post.[10] This is reflected in GAO's concern that "at the program level, the key cause of poor outcomes is the approval of programs with business cases [AoAs] that contain inadequate knowledge about…resources [funding] needed to execute them" (2009, p. 7). Ironically, this directly contradicts the department's own policy outlined in *DoD Directive 5000.01* which explicitly states: "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

[10] "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.

affordability in establishing capability needs" (DoD 5000.01 2007 Enclosure 1 p.5).

Current DoD directives require that an AoA be performed at key milestone decision points (i.e., A, B, C) for all major defense acquisition programs (MDAP) and Major Acquisition Information Systems (MAIS). Affordability assessments (a separate exercise) are only required at Milestones B and C. (USD(AT&L), 2008, December 2, Enclosure 4, p. 40). The Economic Evaluation of Alternatives (EEoA) offers a mechanism to embed affordability assessments into AoAs as early as Milestone A.

According to the Defense Acquisition Guidebook, the purpose of an affordability assessment is to demonstrate that a program's projected funding requirements are realistic and achievable.[11] "In general, the assessment should address program funding over the six-year programming [FYDP] period, and several years beyond. The assessment should also show how the projected funding fits within the overall DoD Component plan"[12] (2006, July 7, Section 3.2.2). In preparing affordability assessments, one possible source of data is the Future Years Defense Program (FYDP).[13] EEoA provides a mechanism for analysts and decision-makers to embed affordability assessments directly into AoAs.

[11] 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).

[12] 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.

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

4) An Intuitive Guide to the 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 investments that maximize value (performance or effectiveness) for a given budget. Structuring the military investment problem as a constrained optimization—i.e., maximizing effectiveness subject to a budget constraint (or alternatively minimizing costs of obtaining a given level of effectiveness),[14] could boost the value of an AoA since it would directly rely upon higher level resource allocation decisions in the Planning and Programming phases of PPBE.

Unfortunately, MCDM techniques typically applied to structure AoAs do not lend themselves to this interpretation. As a consequence, rather than being constrained by budgets, budgets are typically the output of an AoA, generating so-called "funding requirements."[15] Our third approach to structuring an EEoA turns this on its head. Instead of *generating* a budget through the AoA process, 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.[16] This offers an alternate approach to defense investment decisions based on

[14] These dual constrained optimization approaches represent the first two of six ways proposed in this study to structure an Economic Evaluation of Alternatives (EEoA).

[15] A recent Senate Report states that "Awards are made on the basis of the solicitation of factors and sub-factors by a Source Selection Official who, using his or her discretion and independent judgement [e.g., guided by an AoA], makes a comparative assessment of […] competing proposals, trading off relative benefits and costs" (Chapter 1, Commercial Practices p. 65). The Senate Committee's recommendation is that "Regulatory guidance […] be provided in FAR to [include] a minimum weight to be given to cost/price" (p. 102). Missing in this discussion is an explicit and realistic acknowledgement of "affordability"—the resources, funding, or budgets available for the procurement—something only indirectly and implicitly addressed in assigning a "weight" to cost (see Section 2 of this study).

[16] This is in the spirit of the Department of the Army's Acquisition Procedures, which explicitly states that "Cost as an Independent Variable (CAIV) applies to all defense acquisition programs [….and] treats cost as an input to,

explicit funding (resource/budget/affordability) scenarios that supports the "… long-standing DoD policy to seek full funding of acquisition programs..." (Defense Acquisition Guidebook, Chapter 3.23 Full Funding, Defense Acquisition University https://akss.dau.mil/dag/DoD5000.asp?view=functional, downloaded 4/18/09)

According to the Defense Acquisition Guidebook, affordability assessments should also provide details as to how excess funding demands will be accommodated by reductions in other mission areas, or in other accounts.[17] This "Opportunity Cost Approach" is an illustration of the last of six ways identified in this paper to structure an EEoA.

Whereas funding decisions for major programs take place through the PPBE process, the GAO finds that: the 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.[18] (2009, March 18, p. 6)

EEoA directly responds these challenges. It also responds to other concerns highlighted by GAO that continue to confront DoD's Defense Acquisition System, including: "(1) [to make] better decisions about which programs should be pursued or

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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).

[17] 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.

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

not pursued given *existing and expected funding*; [and] (2) [to develop] an analytical approach to better prioritize capability needs" (2009, March 18, Highlights).

In generating alternatives under optimistic, pessimistic and most likely budget scenarios, EEoA requires explicit interaction with the PPBE process. In sharp contrast with the MCDM approach that underlies most AoAs, EEoA approaches explicitly identify and emphasize budget and funding constraints, or affordability. Widespread adoption of 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 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 6 illustrates the six recommended approaches to structure an Economic Evaluation of Alternatives (EEoA).[19] The final section concludes with a Decision Map to guide analysts and decision-makers in selecting which of the six approaches is best suited to their circumstances.

[19] An Appendix is available upon request that reveals the static, deterministic, multi-stage, constrained-optimization, micro-economic production (procurement auction) model that underpins the central EEoA approach.

5) 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 U.S. 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, privatization, or 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.[20] (OMB, 1992, October 29) 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 and Raiffa (1976); Clemen (1996); Kirkwood (1997); Parnell (2006); Ramesh & Zionts (1997); etc.).

This paper describes some limitations with the current decision criteria used in most AoAs and proposes an alternate methodology derived explicitly from the constrained-optimization approach recommended for an EEoA. The latter approach is 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.—most often attributed to Lancaster (1969a; 1969b; 1971; 1979). A key difference

[20] 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.

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

The EEoA approach directly responds to GAO's observation that affordability needs to be an integral part of any business case (AoA): "[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, 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, p. 5).

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 (e.g. through AoAs) to guide public investment decisions. The development of "Measures of Effectiveness" (MOE's)[21]

[21] 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" (2006, July 7).

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 and Hogan (1995); Melese and Bonsper (1996, December); Melese, Stroup, and 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. 120). They stress that "[t]he choice of an appropriate economic criterion is…the central problem in designing a [cost-effectiveness] analysis" (p. 158).

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 (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. Next, 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 to be largely meaningless unless alternatives are constructed for a specific budget (funding/affordability) scenario, or to achieve a specific level of effectiveness. Meanwhile, the second decision criterion also turns out to be

misleading in the absence of a specific budget (funding/affordability) scenario, and a good understanding of "opportunity costs." [22]

A) "Bang-for-the-Buck" (Benefit/Cost or Effectiveness/Cost) ratios

It is well known that the application of a Benefit/Cost ratio (or "bang-for-the-buck") decision criterion to rank alternatives is largely meaningless unless alternatives are constructed for a specific budget (funding) scenario, or to achieve a specific level of effectiveness. Yet, the next three examples illustrate this nevertheless remains a popular decision criterion in the absence of budget or effectiveness constraints.

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, p. 6-3 & 6-10).

2. In presenting what they claim is a "novel cost-benefit analysis" for the "comprehensive evaluation of competing military systems," authors of an article in the Acquisition Review Quarterly define a "merit function" as "a single number…[that] reflects the ratio of benefits derived to dollars spent" (i.e. a benefit/cost ratio). They assert: "with this…approach, the cost effectiveness of competing systems can be compared and "provides for objective and reliable decision making," where "a large system merit [benefit/cost ratio] is preferable to a small one." (E. Byrns, E. Corban & S. Ingalls 1995 "A Novel Cost-Benefit Analysis for Evaluation of Complex Military Systems," Acquisition Review Quarterly, Winter)

[22] Ironically, if a budget scenario is specified, there is no need to take the MCDM approach that underpins most AoAs since it is possible to adopt the EEoA approach. The EEoA approach constructs alternatives to fit within a budget envelope, converting the problem into a straightforward MOE maximization. (See Section 6)

3. Similarly, in a section entitled *Comparing Costs and Benefits*, the Department of the Army's *Economic Analysis Manual* 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).[23]

Each of these examples recommends using a Benefit/Cost ratio as the decision criterion. Each also neglects including either an affordability constraint (keeping the level of cost fixed), or a performance constraint (keeping the level of effectiveness fixed). Unfortunately, a noted RAND analyst, the legendary Gene Fisher (1971), clearly points out in his classic text *Cost Considerations in Systems Analysis*:

> The use of [benefit/cost] 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)

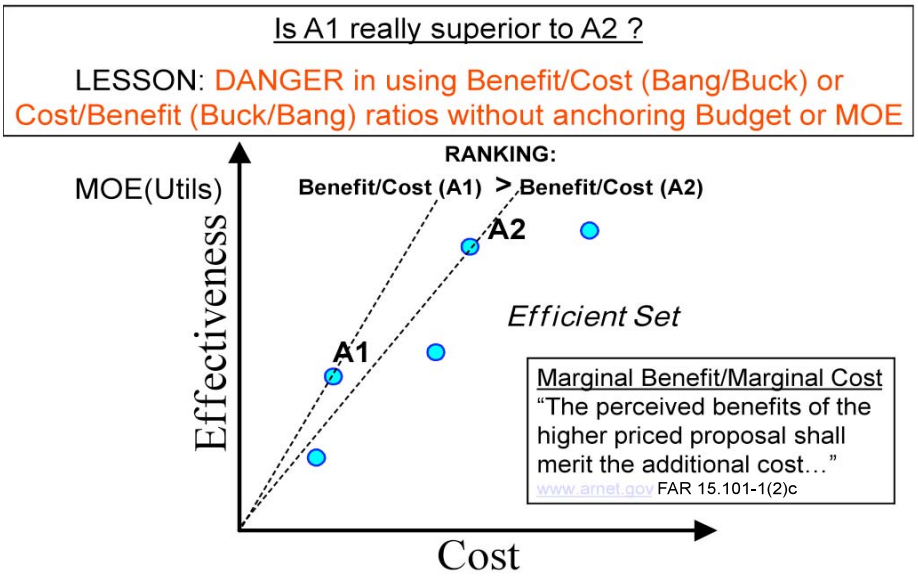

Figure 1: Inappropriate Application of Benefit-Cost Ratios

[23] A fourth example involves 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 an alternative in "[t]he last column is the ratio of effectiveness over cost" (p. 45-6).

A simple, extreme example helps illustrate the danger in using Benefit/Cost ratios without anchoring either 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.[24] Applying a 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.

However, 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 that A2 offered a higher Benefit/Cost ratio than A1. Anyone that chooses A2 strictly on the basis of "bang-for-the-buck" ignoring affordability 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 through the requirements generation system, Defense Acquisition System, and PPBS), it is imperative that analysts and decision-makers explore budget and opportunity cost implications of going with the high-cost alternative (for example, the extra $990 million to obtain 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 ratio is the [decision] criterion. [While] it may be a plausible criterion at first glance…it allows the absolute magnitude of [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

[24] 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 for a given budget (or a specified effectiveness at minimum cost), and might better have been put that way at the outset…[25] (p. 165-7)

The Economic Evaluation of Alternatives (EEoA) approach follows this advice, and another of Hitch and McKean's (1967) recommendations:

> "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." (p.167)

> "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 conclusion is that the use of Benefit/Cost ratios as a decision criterion in AoAs does not pose a problem as long as the analysis is structured paying close attention to affordability (i.e. for a fixed budget (funding/affordability level)), or performance (i.e. for a fixed level of effectiveness (MOE)).[26] Since, AoAs typically consider alternatives that differ in both their costs (price) and benefits (MOEs), using Benefit/Cost (or Effectiveness/Cost) ratios to rank alternatives is at best "misleading,"[27] Partly as a consequence, decision scientists developed another decision criterion, Multi-Criteria Decision Making (MCDM) to rank investment options, one routinely applied in AoAs. This second popular decision criterion is examined below.

B) 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

[25] 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).
[26] An additional (necessary and sufficient) condition is a linear, separable, additive objective function.
[27] "Usually, ratios are regarded as potentially misleading because they mask important information" (DoD, 2006, July 7, Section 3.3.1).

interchangeably" (French, 1986, p. 105)[28] 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 their "utility" function, to generate a Measure of Effectiveness (MOE) for each alternative.[29]

To uncover a DM's utility function, beginning with Saaty (1977), decision scientists bridged an important implementation gap. Multiple objective (analytic) hierarchy approaches were developed to 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, roughly analogous to a weighted average of its attributes, provided certain assumptions are satisfied such as "additive independence," etc. (see French (1986); Keeney and Raiffa (1976); and

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[28]

[29] "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).)

Keeney (1994)). There is a vast literature concerned with eliciting preference weights and the normalization of characteristics data that involves several important issues reserved for future research.[30]

Temporarily overlooking these issues, it is interesting to note in passing that maximizing a linear multi-attribute utility function subject to a budget (affordability) 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 rank 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, MCDM techniques that underpin most AoAs do not rely on an explicit discussion of budgets, affordability, or funding (resource constraints) to structure the decision problem. As a consequence, the problem is typically not structured as described above.

Instead of structuring an AoA as a constrained optimization, a popular decision-analysis approach is (towards the end of an AoA) to simply attach a weight to cost and introduce it directly into the utility function.[31] As opposed to a benefit/cost (or

[30] For example, one issue is that normalization is not necessary, and worse, can be misleading. The author is aware of several applications where relative weights were assigned to different attributes based on soliciting acceptable trade-offs among *measurable characteristics* from decision-makers, but then later applying those same weights to the *normalized values* of the characteristics to obtain MOEs. (Personal correspondence with DoD officials)

[31] "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 EC 2004a and EC 2004b).

effectiveness/cost) ratio, this popular MCDM approach generates an overall "value" function that is essentially a weighted average of cost and effectiveness.

Alternatives are ranked and selections made through an unconstrained optimization where the best alternative is the one 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). The linear, additive separable version of this value function is frequently 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.

The typical decision sciences' (MCDM) approach to an AoA[32] involves:

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

This requires two important modeling efforts: 1) *Building an Effectiveness (MOE) model* (non-cost factors; performance=quality, schedule, etc.); and 2) *Building a Cost* model (costs/prices; estimate total system lifecycle costs, total ownership costs). Once these independent modeling efforts are completed, the overwhelming challenge is to integrate the two either using benefit/cost ratios (discussed earlier), or by assigning a relative weight to cost (a value for w2 in the example above).

[32] "An AoA is an analytical Comparison of the operational Effectiveness, suitability, and Life-Cycle Cost of Alternatives that satisfy established Capability needs." (Defense Acquisition Guidebook, Chapter 3.3 Analysis of Alternatives, Defense Acquisition University https://akss.dau.mil/dag/DoD5000.asp?view=functional, downloaded 4/18/09)

The typical recommendation in the applied literature to integrate cost and effectiveness is to ask the DM: "How important is cost relative to effectiveness?" Promoting this approach are both the Federal Acquisition Regulations (FAR) and the Office of Management and Budget (OMB):[33]

- "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, DoD, NASA, 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 Circular A-76 p.B-8)

A key proponent of this (MCDM) decision methodology offers an example of administrators evaluating alternative pollution control devices being asked to answer 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*, one cannot expect the DM to provide a sensible answer. Ironically, the author (a proponent of this methodology) 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" [34] (Keeney, 1994, p. 797).

Figures 2 and 3 offer an illustration. Figure 2 reflects a situation where the

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[33] 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).

[34] 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.

decision-maker believes costs to be important enough (and thus assigns a sufficiently large relative weight, w2/w1, to cost) that the preferred alternative is A1 (the low-cost option). The opposite case is illustrated in Figure 3.[35]

How does a decision-maker (DM) decide on an appropriate weight to assign to costs? Consider an extreme case. Suppose affordability is not an issue, so funding is not an issue. In that case the budget is not binding, making costs irrelevant. Clearly this means a zero weight should be assigned to costs and the alternatives can be ranked exclusively on the basis of their MOEs (e.g. A2 wins). As a consequence, any weight (w2) applied to costs must reflect an implicit concern about affordability (budgets/funding levels).

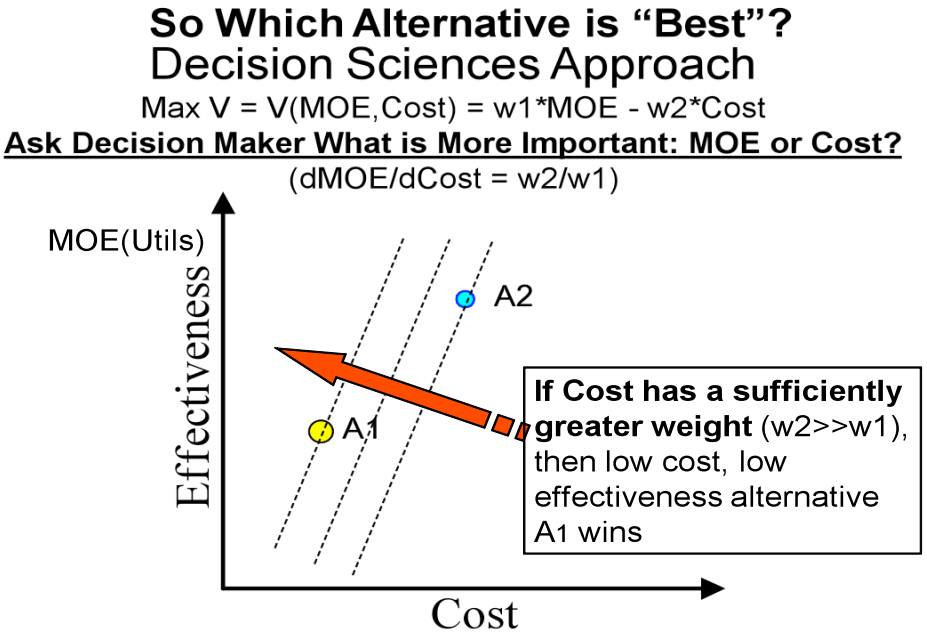

Figure 2: When Cost is relatively more important than Effectiveness.

[35] 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.

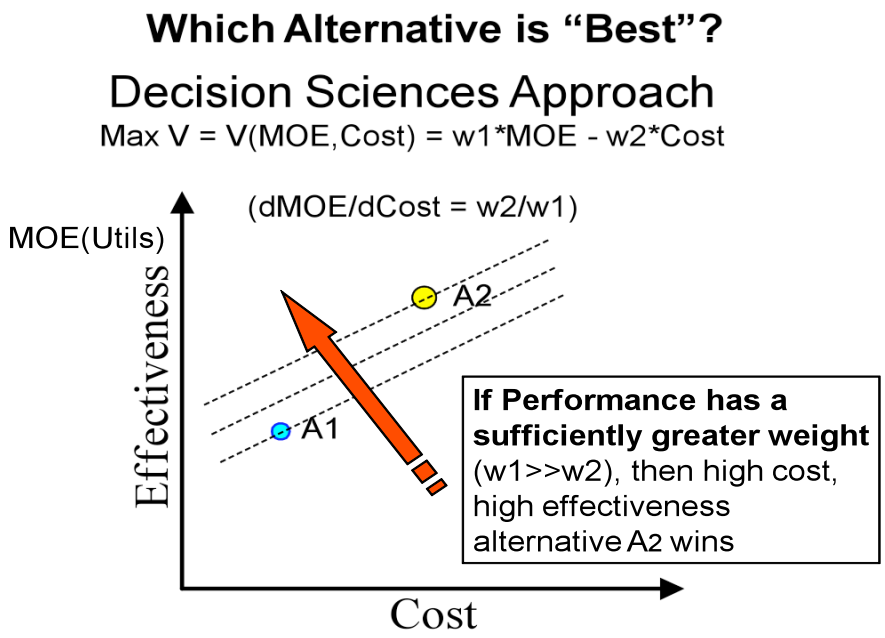

Figure 3: When Effectiveness is relatively more important than Cost.

A key hypothesis in the Economic Evaluation of Alternatives (EEoA) is that if a DM pays any attention to costs (i.e., places a weight on cost) it is because he/she acknowledges an implicit affordability or budget constraint, or recognizes there may be some opportunity cost for funds committed to the program. This is directly related to the higher-level affordability discussions in Section 1 that included requirements generation, Defense Acquisition, and PPBE.[36]

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

[36] 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).

constrained optimization (mathematical programming) EEoA approach is 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 relative cost (price) of alternatives (as illustrated in Figures 2 and 3), the rankings that resulted would only coincidentally correspond to rankings obtained under the full information constrained optimization EEoA (where MOE is maximized subject to the budget constraint).[37]

This is a damning result that clearly undermines the way MCDM is typically applied to support AoAs. If there is no guarantee the MCDM approach will yield consistent results under full information (including affordability), then using this criterion with less than perfect information (i.e. in the absence of 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 p.9) A very real risk in applying the 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).

In conclusion, the popular MCDM Decision Sciences approaches that underpin most AoAs either ignore affordability and apply a benefit/cost (effectiveness/cost) ratio criterion,[38] or implicitly attempt to capture affordability through a relative weight assigned

[37] 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).

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

to cost in a value function such as, Maximize V = V(MOE,Cost) = w1*MOE - w2*Cost. [39] 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 [affordability]…is specified has the virtue of being aboveboard." (pp.165-7)

Rather than attempt to get a DM to reveal their affordability concerns through a weight assigned to costs (or prices) of alternatives, EEoA recommends a transparent and accountable approach—to treat "cost as an independent variable" (CAIV).

The relevant CAIV concept discussed here follows a definition posted on the Office of the Under Secretary of Defense (Acquisition & Technology) website in early 1999. It states that CAIV is the "DoD's acquisition methodology of making…performance a function of ***available budgeted resources***" (see Lorell & Gaser 2001 p.33). The Office of Management and Budget (*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." According to the Defense Acquisition Guidebook "all participants…are expected to recognize the reality of fiscal constraints" (2006, July 7, Section 3.2.4). It is clear from these examples that CAIV is directly concerned with affordability. The next section illustrates how affordability is directly incorporated into an Economic Evaluation of Alternatives (EEoA).

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specified. (Hitch & McKean pp. 165-7)

[39] 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.

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

There are six ways that analysts and decision-makers can structure a deterministic Economic Evaluation of Alternatives (EEoA). The first, third, and fourth approaches are in the spirit of "cost as an independent variable" (CAIV). It is also useful to distinguish between: i) intra-program analysis approaches (#1-5), and the ii) inter-program analysis approach (#6). 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." The six EEoA approaches appear in Table 1.

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**

There are two possibilities highlighted within the Intra-program analysis approach outlined in Table 1. The first possibility is that DMs (analysts) are able to construct/define/build alternatives ("endogenous alternatives"). The second possibility is that alternatives are already constructed/defined/built (pre-specified) and must simply

be evaluated ("exogenous alternatives"). This section describes each of the six EEoA approaches in some detail.[40]

An earlier quote from Hitch and McKean (1967) highlights the first two EEoA approaches: "[A] criterion in which the budget or level of effectiveness is specified has the virtue of being aboveboard" (p. 167). Starting with the Fixed Budget Approach #1, it is useful to recall another 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).

1. Fixed Budget Approach

In his groundbreaking book *Cost Considerations in Systems Analysis*, Fisher (1971) describes the first approach to EEoA:

> "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). "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/funding] the consumer is assumed to behave in such a way that he maximizes his utility" (p. 10).

Drawing on these observations, the Fixed Budget Approach to EEoA leverages Lancaster's "characteristics approach to demand theory" (1969a; 1969b; 1971; 1979). Leveraging studies by Gorman (1980), Stigler (1945), Theil (1952), and others (that also provided the early foundations of the MCDM literature), Lancaster offers economists (and defense analysts) a familiar way to analyze the consumer (defense decision-maker's) choice problem (i.e. to choose among alternative defense investments).

[40] A separate paper available upon request 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.

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 multiple criteria, attributes, or characteristics, subject to a budget [funding/affordability] constraint.[41] In this approach, the cost-effective alternative is the one that, for a given budget (funding/expenditure/affordability level), generates the best mix of characteristics evaluated using the decision-maker's utility function.

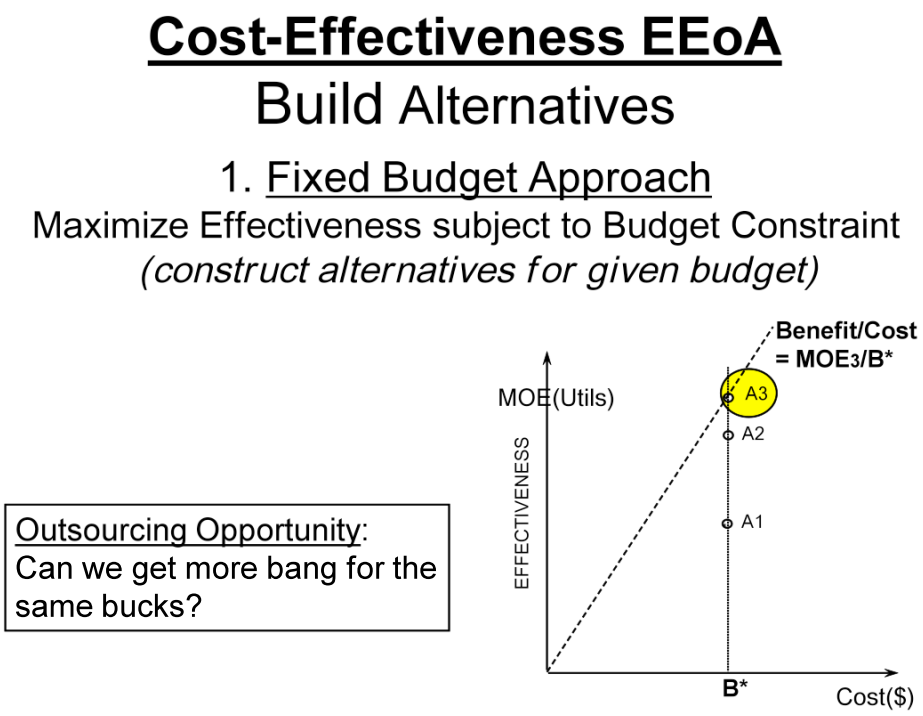

Figure 4: Fixed Budget Approach.

This Fixed Budget Approach illustrated in Figure 4 is the first of six ways proposed to structure an EEoA. In Figure 4, the Budget (funding/affordability level)

[41] 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.

estimate for the program is set at B*. The three vendor alternatives constructed given this budget are A1, A2, and A3. Given its superior performance in terms of its MOE, vendor A3 wins the competition, which, in this case, is also determined by the highest Benefit/Cost ratio. [42]

2. Fixed Effectiveness Approach

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: "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).

Figure 5 offers an illustration where the least cost option for a fixed MOE is A1 that also offers the highest Benefit/Cost ratio.

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.

[42] 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."

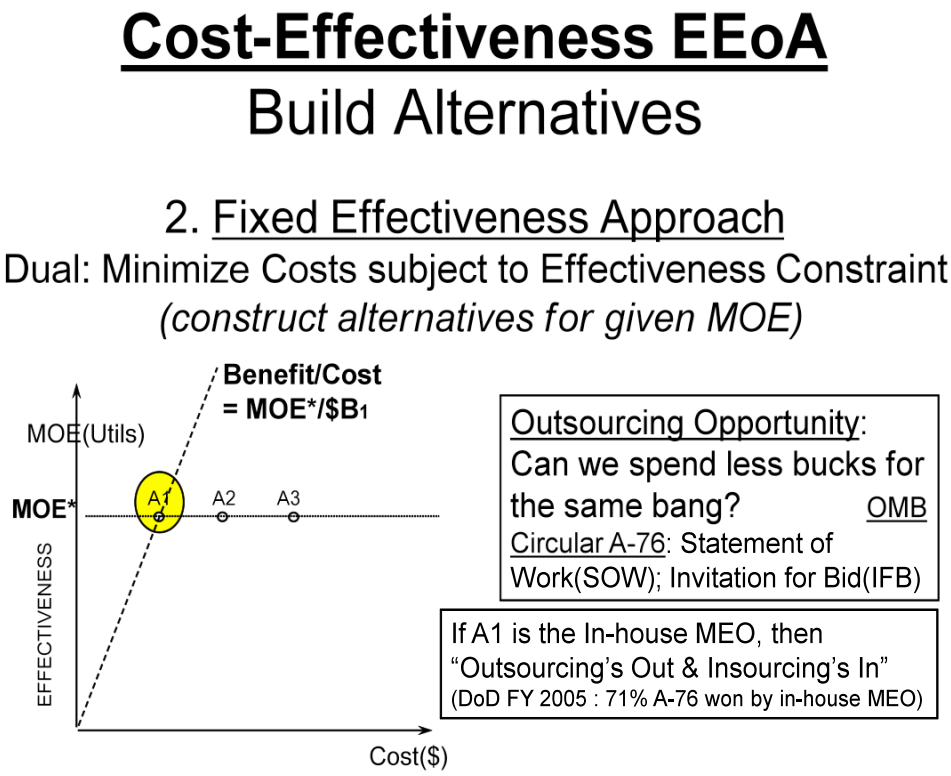

Figure 5: Fixed Effectiveness Approach.

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, Chap. 146, Sec. 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" (January 3, 2007).

This law concerning public-private competitions offers another illustration of the Fixed Effectiveness Approach, minimizing the cost of achieving a given MOE.

3. Expansion Path (Response Function) Approach

In an earlier quote, Hitch and McKean (1967) strongly hint at the third approach to structure an EEoA:

> The test of ***maximum effectiveness for a given budget*** seems much less likely to mislead the unwary"(p.167) "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) [bold italics added]

This third way to structure an EEoA provides a foundation for all the others. It is described here and modeled mathematically in a companion paper available upon request. The model involves a three-step process that includes multiple players.

For ease of exposition, we assume three players: the military buyer and two competing 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 an affordability assessment—e.g. optimistic (B1), pessimistic (B2) and most likely estimates of the budget (funding) for the program.

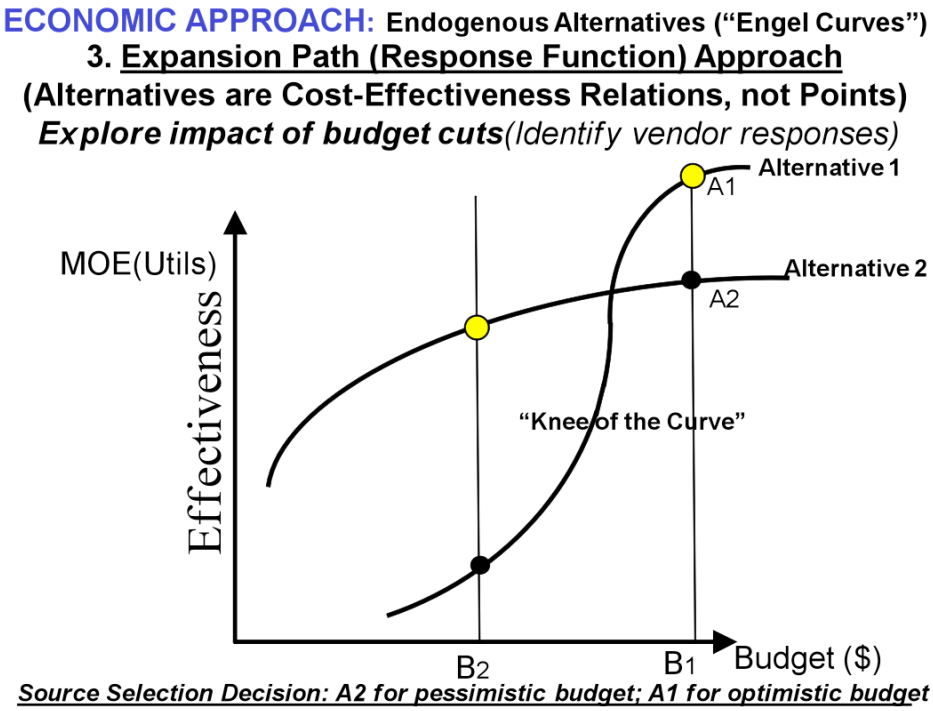

Figure 6: Expansion Path Optimization Approach.

Assuming the award will be made without discussions (pursuant to *FAR* 52.212-1 and 52.215-1), the military buyer employs a secret scoring rule[43] 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.[44]

Each vendor is assumed to have different production and cost functions to generate the desired attributes. The vendors constrained optimizations define distinct expansion paths, one for each vendor. From the Envelope Theorem, the Lagrangian

[43] The buyer reveals desired attributes/characteristics of the investment to the sellers, but not the weights, and requests a single offer from each seller based on a pre-specified budget (affordability) constraint, and then chooses 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).

[44] 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.

multiplier in each vendor's constrained optimization problem reveals the marginal product (the extra output or attribute mix they are capable of producing) if the military buyer (DoD) relaxes its funding constraint (i.e., corresponding to a more optimistic budget). The model is briefly described below.

Economic Evaluation of Alternatives Approach #3:

Military Buyer Goal: Select an alternative that Maximizes
MOE = utility function = U(non-cost factors/attributes),
Subject to BUDGET constraint

Vendor Goal: Select a mix of non-cost factors that
Maximizes Q = Production Function = Q(non-cost factors/attributes)
Subject to Sum of Costs of Attributes = c1 x a1 + c2 x a2 +… <= Budget

Military Buyer Requirements
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)
AFFORDABILITY: Estimate budget (forecast funding available for the program)

Private Vendor Requirements
Production Function: Possible attribute mixes given vendor-specific technology
Total Costs: Vendor-specific costs of producing each attribute
Vendor Proposal constructed as a function of Buyer's Budget constraint

This third, fundamental EEoA approach follows Hitch and McKean's (1967) recommendation:

> "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).

This is illustrated in Figure 6 with two notional Budget levels, B1 (pessimistic), and B2 (optimistic). The three-stage procurement auction process is summarized in Table 2.

Table 2: Three Stage Multiattribute Procurement Auction (Expansion Path Optimization Approach).

1) First Stage: (CAIV)

- **The DoD provides notional budget guidance** (B) to alternative vendors for the program. DoD searches for the optimum product (Procurement) and/or service (R&D; O&M) package that it can obtain at that price, B. ***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, 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 their particular budget constraint*** (which includes 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 their production function (technical production possibilities) and their vendor-specific costs of generating those characteristics.

3) Third Stage: (Selection)

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

Expansion paths exist for each vendor that reveal the combination of attributes each vendor can offer at different budget levels (e.g., pessimistic, optimistic, and most likely). In Figure 6 each vendor's expansion paths are transformed (through the government's utility function) into cost-utility or cost-effectiveness response functions (A1 and A2). These response functions reveal each vendor's proposals under different budget scenarios, and represent the most general definition of "alternatives" in the Economic Evaluation of Alternatives (EEoA). Given a range of likely budgets for the

program, the most effective vendor over that range of budgets can be selected by the buyer.[45] This approach explicitly addresses a key concern voiced by GAO:

> "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).

Whereas the first three ways to structure an EEoA assume alternatives can be constructed/built (endogenous alternatives), the last three approaches assume alternatives are exogenously determined so that decision-makers analyze pre-specified alternatives. Interesting examples in the latter case are where an alternative costs more but offers greater utility (MOE), while others cost less and offer less utility (MOE).

4. Modified Budget Approach

Suppose alternatives are provided that have been developed 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). If the overall budget or desired level of effectiveness (MOE) for a program is not available (and analysts and DMs have not structured the problem in terms of affordability), then it is likely these pre-specified alternatives solicited from different vendors have different costs and yield different measures of effectiveness (MOE).

The first step in evaluating these alternatives might be to create a scatter plot of effectiveness versus cost (see Figure 7). In the absence of any other information, given two alternatives A1 and A2 that differ in both costs and effectiveness, leveling the

[45] For example, if the PPBE process ultimately results in narrowing the budget/expenditure constraint for the program around B2, then Alternative 2 is selected. Note that if the planning process allows the optimistic budget assumption, B1, to persist, then A1 would have been selected, but when reality struck and budget B2 was all that was available, choosing A1 would have turned out to be highly inferior decision. (see Figure 6) This EEoA approach relies upon and reinforces the importance of iterative interactions between the requirements generation system, defense acquisition system and PPBE process.

playing field requires that the DM determine the highest cost alternative they are willing to consider (say A2), which can be used as a notional budget for the program. The fourth way to structure an EEoA recognizes that the highest-cost (highest-utility) alternative under consideration (A2 in Figure 7) reveals a possible budget constraint.

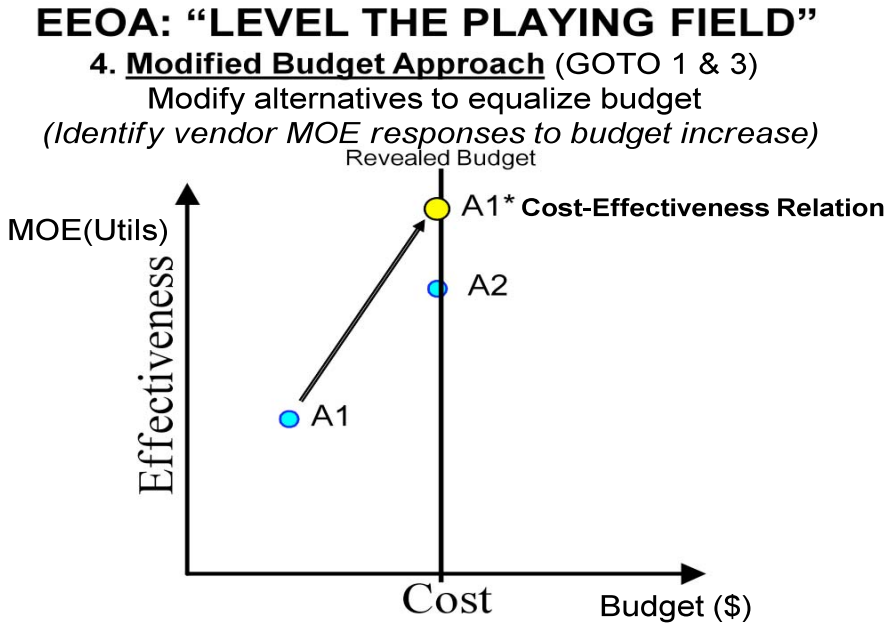

Figure 7: Modified Budget Approach.

Then, in order to "level the playing field," a decision-maker can ask the lower cost, lower utility vendor (A1) how they might use the extra money to increase the utility of their proposal (say from A1 to A1*).[46] Note that this effectively returns the problem to the first (and third) way of structuring an EEoA: "maximize effectiveness (MOE) for a given budget."

[46] 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.

5. Modified Effectiveness Approach

Similarly, the fifth way to structure an EEoA levels the playing field for a threshold choice of utility (MOE). This returns the problem to the second (and third) way of structuring an EEoA: minimizing the cost of achieving a given level of MOE.

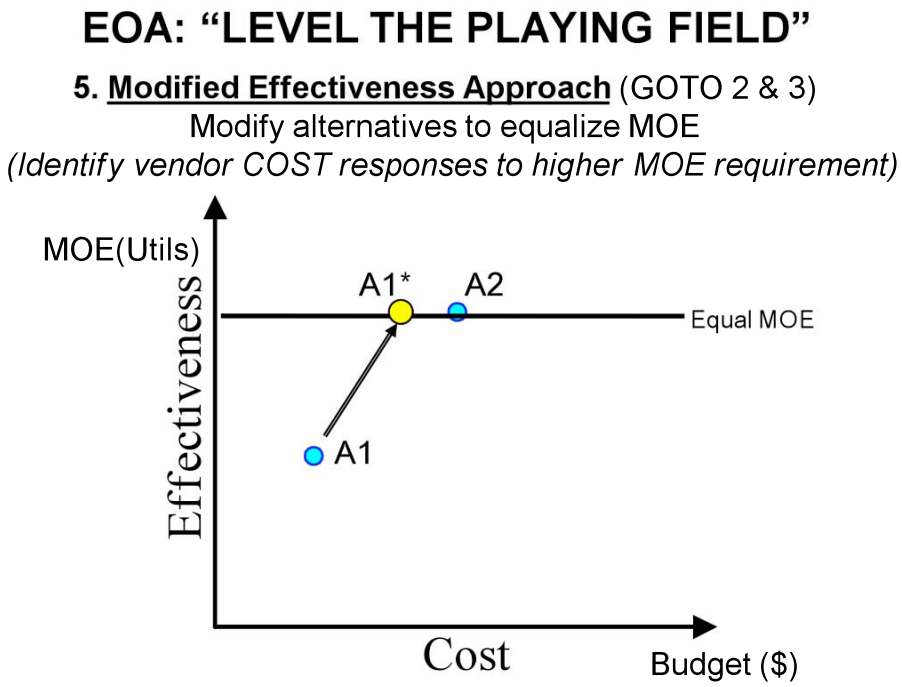

Figure 8: Modified Effectiveness Approach.

For example, in Figure 8, anchoring the desired MOE at a target level such as that offered by vendor 2, the government could ask vendor 1 how much it would cost to achieve the same target level of MOE? In Figure 8, vendor 1 is preferred since the response (A1*) minimizes the budget required.[47]

6. Opportunity Cost (or Effectiveness) Approach

Finally, suppose analysts and/or DMs find themselves in a situation where i) alternatives cannot be modified to obtain response functions, and ii) future funding is

[47] Note that the response function for vendor A includes points A1 and A1*.

unknown and the specific desired level of MOE cannot be determined. In this case it is likely some alternatives (bundles) will cost more but offer more effectiveness, while others cost less and offer less effectiveness. For example, see Program A in Figure 9.

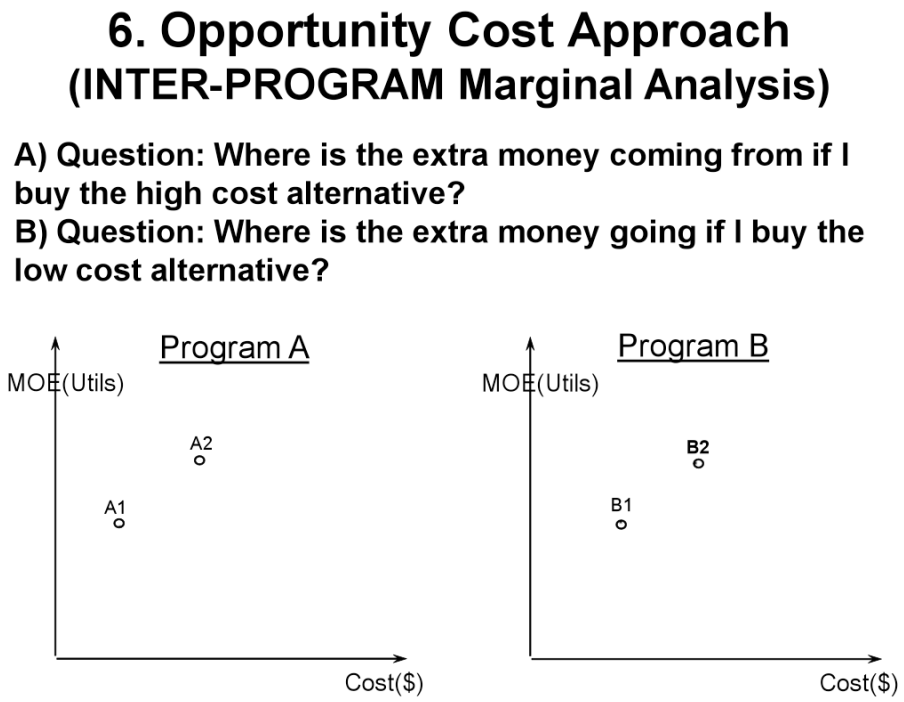

Figure 9: Opportunity Cost Approach

The sixth and final approach to structure an EEoA involves an inter-program comparison called the “Opportunity Cost Approach.” Rather than modify the alternatives to level the playing field as in EEoA approaches #4 and #5, the Opportunity Cost Approach requires a more challenging inter-program analysis to choose between lower-cost, lower-effectiveness alternatives (say A1 in Figure 9), and higher-cost, higher-effectiveness alternatives (A2). 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. If 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 (i.e. program B in Figure 9).

This involves a higher-level inter-program analysis similar to that illustrated in Figure 9. The DM must consider the loss in utility (MOE) in other programs that might be sacrificed (e.g. a budget cut in program B shifting the decision from B2=>B1), for funds to be released to purchase greater utility (MOE) in the program under review (e.g. boosting the budget of program A to shift the decision from A1=>A2). "[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).

Alternatively, the DM can explore how much more utility the extra money might generate somewhere else if they went with the low-cost alternative (A1 in program A). These are tough but useful questions that break through the sub-optimization of most traditional AoAs. As a consequence, EEoA encourages critical communication to take place between different layers of the organization, and a seamless interface between the requirements generation system, the acquisition system, and PPBS.[48]

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

[48] 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, mor 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)

Economic Evaluation of Alternatives (EEoA) using one of the six approaches summarized in Figure 10 can help achieve the primary goal of defense acquisition reform—to coordinate Requirements Generation, Defense Acquisition, and PPBS to lower costs, and improve performance and schedules.

7) Conclusion: A Decision Map for Decision-makers

This study identifies several major challenges that face current military cost-effectiveness, analyses of alternatives (AoA). It also critically examines key assumptions and decision criteria used by the military to structure acquisition decisions. An alternative micro-economic set of approaches to structure acquisition decisions is proposed, called the Economic Evaluation of Alternatives (EEoA).

The study reveals a significant weakness in the multi-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 an after-thought, only implicitly addressed through a weight assigned to costs.

In contrast, EEoA encourages analysts and decision-makers to embed affordability assessments directly into AoAs. 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, this EEoA approach 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. In demonstrating how to embed affordability directly into an AoA, EEoA represents an important step in the long-running effort to achieve a significant defense acquisition reform—to integrate DoD's Requirements Generation System and Defense Acquisition System with PPBS, to lower costs, and improve performance and schedules.

The primary goal of this study was to help improve public investment decisions. An important secondary goal was to develop a Decision Map to help structure Economic Evaluations of Alternatives (EEoAs) to improve defense acquisition outcomes. This paper provides a set of six approaches practitioners and acquisition officials can employ to structure an EEoA. The Decision Map illustrated in Figure 10 can be used as a guide by analysts and decision-makers to select which of the six EEoA approaches is best suited to their circumstances.

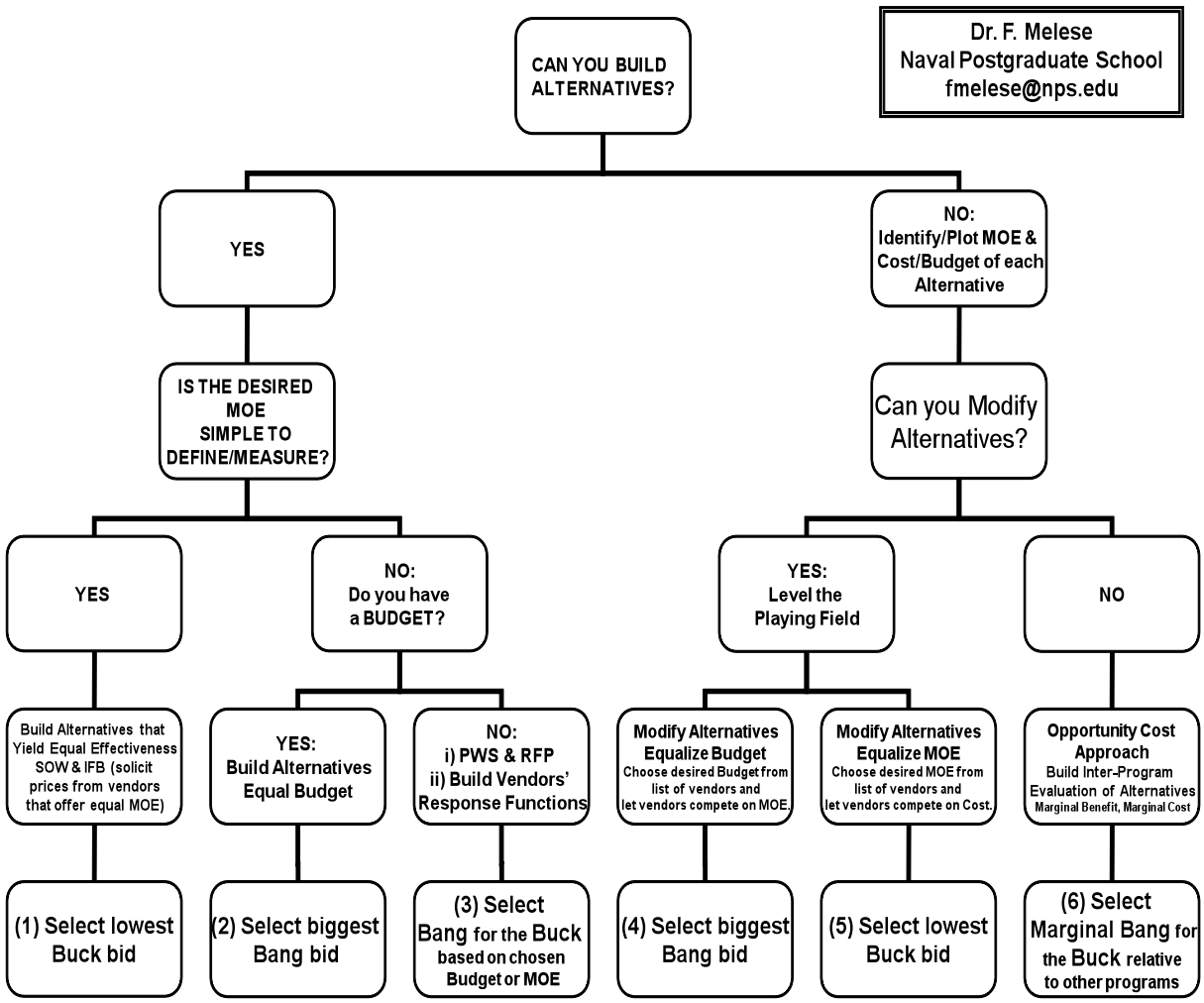

Figure 10: Decision Map to Structure an EEoA.

References:

Beil, D., & Wein, L. (2003). An Inverse-Optimization-Based Auction Mechanism to Support a Multiattribute RFQ Process. *Management Science*. 49(11).

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

DoD (November 20, 2007) Department of Defense **DIRECTIVE NUMBER** 5000.01, USD(AT&L), SUBJECT: The Defense Acquisition System

DoD (December 8, 2008) Department of Defense **INSTRUCTION NUMBER** 5000.02, USD(AT&L), SUBJECT: Operation of the Defense Acquisition System

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-464). 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.

EC 2004a, Article 55 of the European Commission DIRECTIVE 2004/17/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 31 March 2004: Coordinating the procurement procedures of entities operating in the water, energy, transport and postal services sectors

EC 2004b, Article 53 and 54 of the European Commission DIRECTIVE 2004/18/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 31 March 2004: On the coordination of procedures for the award of public works contracts, public supply contracts and public service contracts

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)

Defense Federal Acquisition Regulation Supplement (DFARS) DFARS http://www.acq.osd.mil/dpap/dars/dfars/html/current/tochtml.htm

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). *Moving Toward Market-Based Government*. IBM Endowment for The Business of Government: New Ways to Manage Series. June.

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*.

Station, November 1956.
Henry, M., & Hogan, W. (1995). Cost and effectiveness integration. *PHALANX*

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.

104th Congress of the United States of America, 2nd Session

Abstract:	Act supporting the efficient procurement of information technologies within the federal government.
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Contributors:	
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Clinger-Cohen Act “Information Technology Management Reform Act of 1996” (Public Law 104-106)

JOINT CAPABILITIES INTEGRATION AND DEVELOPMENT SYSTEM (JCIDS), CHAIRMAN OF THE JOINT CHIEFS OF STAFF INSTRUCTION J-8 CJCSI 3170.01F May 2007

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, RAND Project Ari Force, Santa Monica.

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.

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) *On Measures of Effectiveness* Phalanx, Dec

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* (pp. #-#). 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 (pp. #-#). 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 Title 10—Armed Forces, Subtitle A, Part IV, Chapter 146, Section 2462, January 3, 2007.

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 (pp. #-#). New York: Springer-Verlag.

MATHEMATICAL APPENDIX

(Available Upon Request)