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Commonality, an increasingly popular strategy in developing complex defense projects, leverages sharing or reuse across projects to significantly reduce life-cycle costs. Despite its potential within DoD as a best practice, programs focused on commonality have met with mixed success. This article argues that commonality strategies must be matched with complementary acquisition strategies to improve outcomes. Full, open competition is not the best acquisition strategy if commonality can unlock life-cycle affordability. Metrics and payment structures must consider the commonality goals to be achieved; otherwise, contractor motivations and government goals will be misaligned. The recommendations in this article draw on commonality research conducted on behalf of the National Aeronautics and Space Administration (NASA), which examined 19 DoD, commercial, and NASA case studies.

With the fast-paced nature of technology, rapidly fielding systems has never been more important. Success depends on well-defined requirements and the ability to rapidly respond to change during and after deployment. The inability to rapidly respond may cause the system to become obsolete before initial fielding. Creating a structure where processes allow for changes during system development requires restructuring system development values and principles at all levels. This article addresses progress toward agility and defines agile values and principles being used by agile organizations in the Business, System, and Software Aspects. It also defines operationally effective agile practices being utilized to implement those values and principles that provide a starting point for inserting agility into the system development process.

As the volume of government contracting increases, so does the importance of monitoring government contractors to guard against Organizational Conflict of Interest (OCI). For contracting officers to identify OCIs, they must be able to identify the relevant business interests of a contractor's affiliates. This information may be private or not easily obtained. Using newly released data to develop preliminary visualizations of contractor organizational structures shows the organizational structure of many contractors to be complex and multinational. The complexity and the lack of easily available public information make it very unlikely that contracting officers could identify OCIs without substantial improvements in government data collection.

Half-Life Learning Curves in the Defense Acquisition Life Cycle

p. 283

Adedeji B. Badiru

Learning curves are useful for assessing performance improvement due to the positive impact of learning. In recent years, the deleterious effects of *forgetting* have also been recognized. Workers experience forgetting or decline in performance over time. Consequently, contemporary learning curves have attempted to incorporate forgetting components into learning curves. An area of increasing interest is the study of how fast and how far the forgetting impact can influence overall performance. This article introduces the concept of half-life analysis of learning curves using the concept of growth and decay, with particular emphasis on applications in the defense acquisition process. The computational analysis of the proposed technique lends itself to applications for designing training and retraining programs for the Defense Acquisition Workforce.

Decision Cost Model for Contractor Selection

Victor J. Apodaca and Peter C. Anselmo

As U.S. Government facilities age and new facilities are constructed, the need to hire contractors for an increasing number of government construction projects is imperative. The current government technical evaluation for contractor selection is less than optimal. This article introduces an alternative technical evaluation methodology to the current government contractor selection process: a Decision Cost Model (DCM) that can be applied to ensure cost-efficient contractors are selected in awarding construction contracts. Applying the DCM ensures contractors with the lowest expected total cost are recommended for project awards. Also presented are ways DCM can be applied to increase efficiency in the selection process for future government construction projects, while simultaneously meeting taxpayers' expectations of receiving maximum value for their tax dollars.

http://www.dau.mil/pubscats/Pages/ARJ.aspx

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From the Chairman and Executive Editor

This issue's theme, "The Visible Hand of Defense Systems Management," reflects the fact that the development and fielding of military systems and services has never been directed solely by the "invisible hand" of market mechanisms, but rather has always relied on strong guidance by the "visible hand" of deliberate, well-considered management of the acquisition process. The origins of this process are engagingly described in Alfred Chandler's *The Visible Hand: The Managerial Revolution in American Business,* this issue's selection for the Defense Acquisition Professional Reading List and reviewed by Dr. Nayantara Hensel, a member of the *Defense ARJ*'s Research Advisory Board.

The first article, "Relieving Joint Pain" by Anthony Wicht and Edward Crawley, describes how strategic planning for commonality among acquisition programs can translate directly into life-cycle savings. The next article, "Inserting Agility in System Development" by Matthew Kennedy and Dan Ward, argues that a hands-on approach to change management during the system development cycle can avoid system obsolescence before initial fielding. Melissa Thomas' article, "Identifying Organizational Conflict of Interest," suggests the need for a robust means of collecting information and monitoring government contractors to guard against organizational conflict of interest during the acquisition process. Adedeji Badiru, in "Half-Life Learning Curves in the Defense Acquisition Life Cycle," introduces the concept of half-life analysis of learning curves (i.e., reflecting the decay of some learning even as other learning increases) as a potential tool for planning career and training strategies in the defense acquisition process. Finally, Victor Apodaca, in the online-only article "Decision Cost Model for Contractor Selection," introduces an alternative technical evaluation methodology to the current government contractor selection process using a statistical model to identify the contractor with the lowest expected total cost.

Dr. Larrie D. Ferreiro
Executive Editor
Defense ARJ

DAU Center for Defense Acquisition Research

Research Agenda 2012–2013

The Defense Acquisition Research Agenda is intended to make researchers aware of the topics that are, or should be, of particular concern to the broader defense acquisition community throughout the government, academic, and industrial sectors. The purpose of conducting research in these areas is to provide solid, empirically based findings to create a broad body of knowledge that can inform the development of policies, procedures, and processes in defense acquisition, and to help shape the thought leadership for the acquisition community.

Each issue of the *Defense ARJ* will include a different selection of research topics from the overall agenda, which is at: *http://www.dau.mil/research/Pages/researchareas.aspx*

Measuring the effects of competition

- What means are there (or can be developed) to measure the effect on defense acquisition costs of maintaining an industrial base in various sectors?
- What means exist (or can be developed) of measuring the effect of utilizing defense industrial infrastructure for commercial manufacture in growth industries? In other words, can we measure the effect of using defense manufacturing to expand the buyer base?
- What means exist (or can be developed) to determine the degree of openness that exists in competitive awards?
- What are the different effects of the two best value source selection processes (tradeoff vs. lowest price technically acceptable) on program cost, schedule, and performance?

Strategic competition

- Is there evidence that competition between system portfolios is an effective means of controlling price and costs?

- Does lack of competition automatically mean higher prices? For example, is there evidence that sole source can result in lower overall administrative costs at both the government and industry levels, to the effect of lowering total costs?

- What are the long-term historical trends for competition guidance and practice in defense acquisition policies and practices?

- To what extent are contracts being awarded non-competitively by congressional mandate, for policy interest reasons? What is the effect on contract price and performance?

- What means are there (or can be developed) to determine the degree to which competitive program costs are negatively affected by laws and regulations such as the Berry Amendment, Buy-America Acts, etc.?

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Relieving Joint Pain: *Planning Government Acquisition of Complex Common Systems*

Anthony C. Wicht and Edward F. Crawley

Commonality, an increasingly popular strategy in developing complex defense projects, leverages sharing or reuse across projects to significantly reduce life-cycle costs. Despite its potential within DoD as a best practice, programs focused on commonality have met with mixed success. This article argues that commonality strategies must be matched with complementary acquisition strategies to improve outcomes. Full, open competition is not the best acquisition strategy if commonality can unlock life-cycle affordability. Metrics and payment structures must consider the commonality goals to be achieved; otherwise, contractor motivations and government goals will be misaligned. The recommendations in this article draw on commonality research conducted on behalf of the National Aeronautics and Space Administration (NASA), which examined 19 DoD, commercial, and NASA case studies.

image designed by Diane Fleischer »


Commonality

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Commonality, the sharing of parts or processes across different products, has long been popular in commercial industries such as automotives and electronics because it reduces life-cycle costs and improves reliability. Today, commonality is enjoying increasing interest from the defense industry as the emphasis on life-cycle affordability strengthens (Brown & Flowe, 2005). Joint Services programs such as the Joint Strike Fighter (JSF) and Joint Tactical Radio System (JTRS) develop partially common systems that meet the needs of different Services. Other programs such as the National Polar-orbiting Operational Environmental Satellite System (NPOESS) attempt to exploit commonality between the needs of DoD and other agencies. Even within a single Service, commonality is a useful strategy, for example in the adaptation of the M577 command post vehicle from the M113 armored personnel carrier, which simplifies development and decreases logistics costs (Terry, Jackson, Ryley, Jones, & Wormell, 1991). The major benefit from commonality is affordability, which has increased attention on the strategy in recent years as defense budgets have tightened. Commonality will continue to be an important tool for acquisition professionals while cost pressure on defense budgets remains high.

Despite commonality's promise of increased affordability, the performance of defense acquisition based on commonality has lagged behind comparable commercial projects. NPOESS was canceled, JTRS was fundamentally restructured in 2005, and the threat of Nunn-McCurdy breaches is still a factor in the program stability of the JSF. We hypothesized that the different acquisition environments between commercial and defense commonality projects were partly responsible. Therefore, the objective of the research was to examine current government acquisition practices in commonality, and synthesize a best-practice acquisition strategy for future commonality projects.

Extensive literature on commonality already exists; however, it focuses on the application of commonality platforms to business strategy (Meyer & Lehnerd, 1997; Robertson & Ulrich, 1998) or stops at the identification of technically feasible commonality. (For examples from the DoD context, see the RAND report by Held, Newsome, & Lewis, 2008.) Boas and Rhodes developed management approaches to commonality (Boas & Crawley, 2006; Rhodes, 2010), which built on the more general advice in the platforming literature, but no work on commonality was found that specifically examined acquisition. In the acquisition literature, Scherer's unsurpassed economic analysis of the effect of acquisition strategy on weapon effectiveness in the DoD informed much of the analysis in the second half of this study (Scherer, 1964). Additionally, handbooks for the acquisition professional emphasize that the acquisition approach must take into account particulars of the acquisition at hand (Defense Acquisition University, 2011; Rendon & Snider, 2008). However, no piece of the acquisition literature delivered specific advice for acquiring common systems.

Objective and Outline

To fill this gap, this article aims to answer four questions:

- Which principles from the extensive literature on commercial commonality form necessary background knowledge for the defense acquisition professional?
- Which acquisition approaches represent best practice when formulating an acquisition strategy for a new Joint Services program, or an intra-Service program involving commonality?
- Which additional contract terms such as payment provisions or intellectual property considerations improve acquisition outcomes in the commonality environment?
- Are the acquisition regulations flexible enough to permit best-practice commonality acquisition?

At the outset, it is important to note that commonality is not the only approach for improving acquisition outcomes. Other product development philosophies such as flexibility, robustness, interoperability, adaptability, and open architectures are widely discussed in the literature and can improve the performance of acquisitions. Contrasting these alternative approaches is beyond the scope of this article; however, similar analysis to that presented in this article could be used to craft acquisition strategies that complement these development philosophies.

This article will first summarize the research method and sketch the case studies, followed by a presentation of the background concepts on commonality, which distinguish commonality-focused acquisitions from

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single-product acquisitions. Finally, the article will turn specifically to acquisition approaches, analyzing the alternative ways in which an acquisition could be approached and recommending specific strategies.

Research Method

The research in this article builds on 19 commonality case studies conducted by the MIT Space Systems Architecture Group (Boas, 2008; Hofstetter, 2009; Rhodes, 2010; Cameron, 2011; Wicht, 2011). Of these, 16 cases informed the general commonality principles presented in the first half of this article, and were instrumental in developing the concepts and process maps that identify commonality as a best practice. A further three case studies conducted by the authors were specifically targeted at acquisition and were complemented by 17 short interviews with DoD and NASA personnel involved in the acquisition process. The following paragraphs briefly describe the acquisition case studies; however, full reports on the cases are available in Wicht (2011). The three cases examined in detail were JTRS and two nongovernment launch vehicle manufacturers who requested anonymity.

JTRS was a Joint Services project to produce software-defined radios that were interoperable among the Services. Commonality of software between the radios was intended to deliver development and maintenance savings as well as performance benefits from improved interoperability. The initial architecture for the radios was designed by a working group including government and industry representatives. The detailed design and manufacture of the radio hardware and software were distributed across multiple contractors. Interviews with a range of former DoD personnel and consultants involved with JTRS were undertaken to capture how the acquisition approach affected the realized commonality.

The two commercial launch vehicle manufacturers both produce families of launch vehicles for DoD, NASA, and commercial applications. Both have worked as contractors to DoD or NASA previously. The launch vehicle manufacturers were examined because each had development tasks comparable in complexity to those undertaken by government agencies like DoD and NASA.

Two avenues of investigation were pursued. First, in their position as system integrator, how did the commercial companies structure their acquisitions to develop and maintain the right level of commonality? Second, in their position as a contractor to DoD or NASA, what potential pitfalls did they see in the commonality acquisition strategies proposed?

After conducting the case studies, acquisition approaches uncovered during the short interviews and case studies were qualitatively evaluated against the commonality process map. Acquisition structures were then graded as Good, Moderate, or Poor according to how well the structure itself facilitated the processes that underpin commonality. A second pass through the Good and Moderate approaches was then undertaken to refine contractor payments, incentives, intellectual property, and other provisions to develop acquisition strategies that best implement commonality.

Definitions

To understand the interaction between commonality and acquisition strategy, key commonality definitions and background are presented here. Although no widely agreed-upon definitions for commonality are prevalent throughout the defense acquisition community, an excellent RAND paper contains a DoD lexicon for commonality (Newsome, Lewis, & Held, 2007). The following simple definitions will be used in this article:

Common having identical elements

Unique the antithesis of common

Similar some identical and some unique elements

Family a set of similar end-items that perform different functions

Variant any one member of a family

Commonality Concepts

Using these definitions, it is possible to summarize the concepts distilled from the 19 case studies and the product literature, which shape the application of commonality to real-world projects that an acquisition strategy must address.

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Concept 1: Commonality is not an end in itself. The first concept is that commonality is not an end in itself. Commonality carries both advantages and disadvantages, and therefore the best project is not necessarily the one with more commonality. The optimum amount of commonality is that amount which best meets the customer's needs in terms of life-cycle affordability and performance.

Seeing commonality as an enabler rather than an end goal carries two implications for acquisition. First, contractors should not be incentivized to target maximum commonality or fixed percentages of commonality because this misaligns contractor incentives and customer needs. Second, the benefits of commonality should be balanced against the costs of achieving it. The acquisition strategies recommended for commonality are likely to cost more to implement than full and open competition.

Concept 2: Realized commonality is always less than initially planned commonality ("divergence"). Boas demonstrated that the level of realized commonality is always less than the level initially planned. This decrease is called divergence. From Concept 1, it follows that divergence may be positive or negative for the project. Divergence is positive if it occurs to accommodate the emergence of new technologies, learning from the development of earlier variants or changes in the field conditions for the product. Divergence is negative if it stems from mismanagement or attempts to improve the performance of individual variants at the expense of the family.

The implication for acquisition is that the acquisition structures must have controls to limit detrimental divergence, but not penalize beneficial divergence. More generally, foreknowledge of the inevitability of divergence can help manage expectations, prepare more accurate project budgets and schedules, and avoid overreaction to a normal corollary of commonality development.

Concept 3: Commonality projects are offset in time. Boas also showed that complex development projects experience time offsets between the development of variants to lower the peaks in labor and capital demand. Offsets often mean that the first-in-time variant team develops the common systems, with a resultant bias toward the better defined needs of the first-in-time variant.

The implication of offsets for acquisition are twofold. One, the first-in-time project must be incentivized to consider the needs of all later-in-time projects during the first development phase. Two, the requirements for subsequent variants must be well defined when the first variant is undergoing concept studies. This requires earlier funding for the subsequent variants.

Concept 4: Commonality requires up-front cost and delivers benefits later in the product life cycle. Offsets lead to a consistent cost structure for commonality projects. The first-in-time variant bears the burden of developing all common systems before it is operational. This means the first-in-time variant incurs a cost penalty relative to the development cost of the other variants. In a sensible commonality program, the additional cost of commonality is recovered over the life cycle at the family level through lower development costs for subsequent variants and more effective sharing of recurring costs across the family.

The implication for acquisition is that development decisions must be taken based on life-cycle costs, not development costs, and based on family-level cost-benefit analysis, not variant-level cost-benefit analysis. If the first variant is to implement commonality, it must receive extra funding and high-level management support to permit spending on the up-front costs. Without these measures, first-in-time variants have no incentive to implement commonality.

Concept 5: Three commonality strategies exist—Reactive Reuse, Building Block, and Widespread Forward. Three general commonality strategies are observed (Boas, 2008). The simplest, Reactive Reuse, examines previous products for elements that could be used again in the next variant. The original products never planned for reuse, thus avoiding the up-front commonality costs pointed out in Concept 4. However, the Reactive Reuse benefits the project under development because it reduces development cost and risk, making it an attractive strategy. With such ad hoc reuse, substantial affordability improvements are difficult to achieve. When planning occurs during development of the first variant, commonality projects can share more effectively than one-way reuse.

Such thinking leads to Building Block commonality, which occurs when commonality of selected high-value systems is planned. The first variant in time develops a common building block that takes into account the needs of future variants and will be used in those future variants. Building Block commonality is a more sophisticated strategy than Reactive Reuse because it requires a trade between the cost of developing the building block and the life-cycle savings from commonality.

Widespread Forward commonality occurs when commonality becomes embedded into an organization's engineering culture, and each design decision is examined for its commonality implications. In the 19 case studies examined, Widespread Forward commonality only occurred when one corporation tightly controlled the development process. Widespread Forward commonality is unlikely to be the right strategy for multicontractor government acquisition.

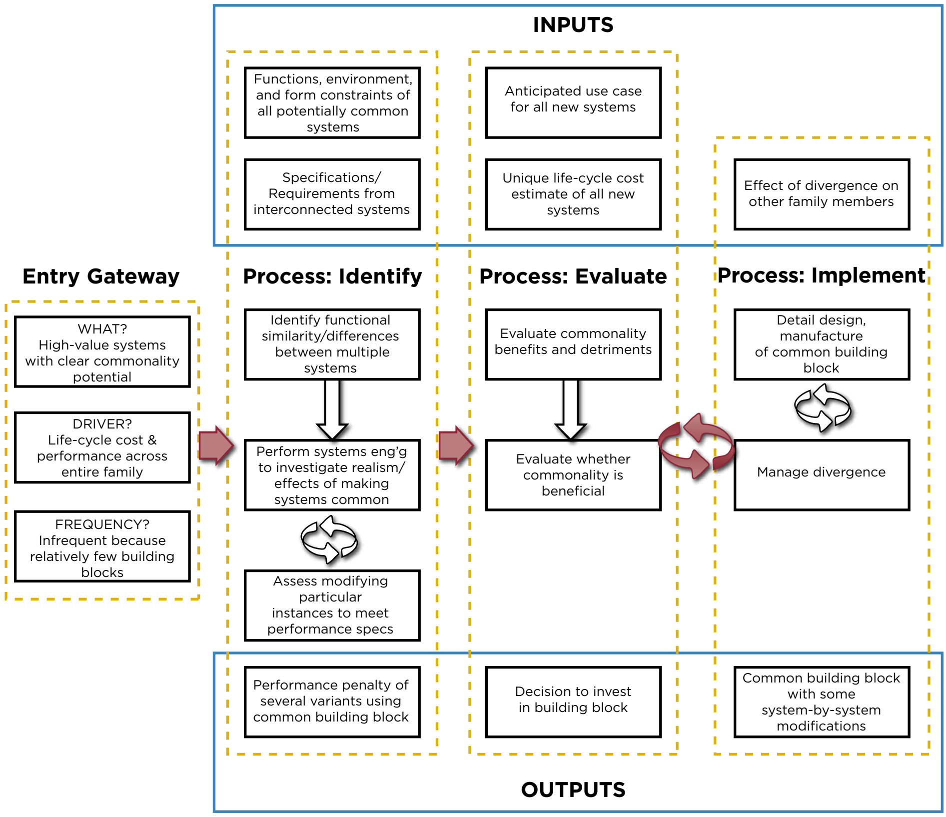
The implication of these three strategies for acquisition is that commonality can operate in three significantly different modes, and an acquisition strategy appropriate for one may not be appropriate for the others.

Synthesizing a Commonality Process Map

After reviewing these principles, commonality is clearly problematic for existing acquisition approaches. For example, how should a contractor be incentivized to develop a common system where directly measuring commonality is not a good reflection of the needs of the customer? How can programs funded year-to-year "invest" in commonality for future cost savings? Does the emphasis on competition in acquisition allow the sort of cooperation between contractors needed to develop common systems?

The first step in designing an effective acquisition strategy is to be clear about the steps required for a commonality acquisition. Figure 1 lists steps that represent a process map for Building Block commonality. The process map was developed by examining the 19 case studies and synthesizing lessons learned in the commonality projects studied into a set of best-practice steps. The process maps are consistent with the analysis of the case studies undertaken by Boas, Hofstetter, Rhodes, and Cameron.

FIGURE 1. PROCESS MAP FOR BUILDING BLOCK COMMONALITY



Additional explanation of how the process maps fit the observed performance of commonality projects is presented in Wicht (2011). Slightly different process maps for the Reactive Reuse and Widespread Forward strategies were also developed. Space precludes their inclusion here; however, full details are presented in Wicht (2011), along with a full explanation of the elements of the process map and the tools that can be used to undertake the processes.

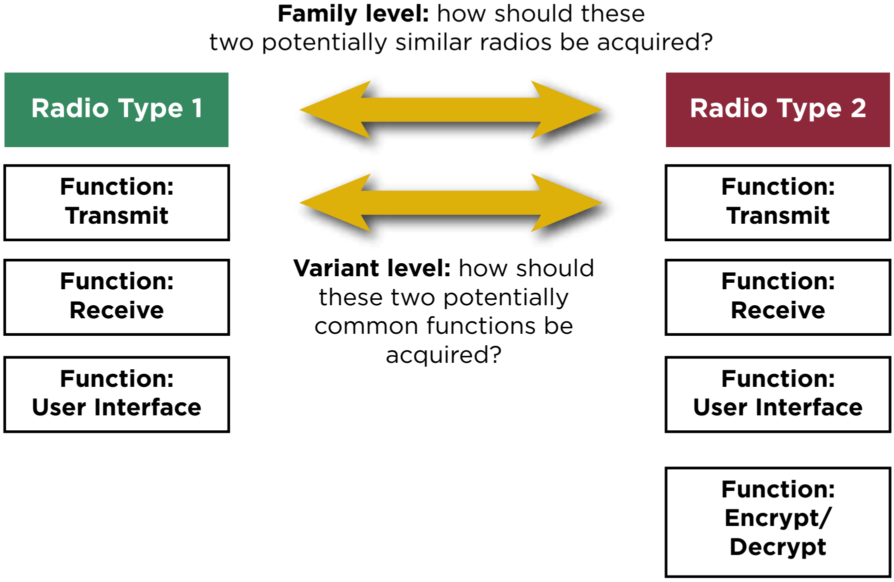
Figure 1 shows a process that consists of an entry gateway followed by three interactive processes: Identify, Evaluate, and Implement. The entry gateway screens commonality opportunities to allow only those opportunities suitable for Building Block commonality into the process steps. The Identify process takes the engineering environment of the potentially common systems and evaluates the technical feasibility and performance penalty of using common systems in place of unique. The second process, Evaluate, measures the benefits and drawbacks to the common solution under the assumed use case, compares those with the unique solution, and results in a decision to invest in the common building block or to pursue the unique solution instead. The third process is Implement, which manages divergence and requires reexamination of the cost-benefit analysis undertaken in the Evaluate process as the estimated costs and benefits become better known. The management of divergence through the Implement process is ongoing throughout the product life cycle.

Designing Acquisition Strategies for Commonality

Two levels of acquisition strategy are important in designing most commonality acquisitions. The family-level acquisition strategy considers the acquisition strategy applied to the family of products as a whole. It examines which organizations (if any) have responsibility for management, systems engineering, and design trade-offs across the whole family. The variant-level acquisition strategy considers the acquisition strategy at the level of the systems that integrate to produce a variant. It asks, for example, whether a single contractor is responsible for a single system across all variants, or whether each system is separately competed on each variant.

To illustrate these differences, a simplified example from the JTRS case study is presented in Figure 2. The top level (the family-level acquisition strategy) concerns the relationship between the organization or organizations responsible for producing Radio Type 1 and Radio Type 2. Different commonality outcomes could be expected if the same company was responsible for both radios compared to multiple competitors responsible for one type of radio each. The lower level (called variant level) in this example asks questions such as: Should the transmitter be separately competed for each radio? Should it be separately competed by the government and supplied as Government Furnished Equipment (GFE)? Or should both transmitters be awarded to a single company? Again, different commonality outcomes could be expected under these different acquisition structures.

FIGURE 2. DEFENSE RADIO PROGRAM



The variants are decomposed into their function because Hofstetter (2009) showed that the first gateway for technically feasible commonality is delivery of a common function. This is common sense: A single company developing the transmitters for two radios is more likely to deliver commonality than a single company developing the transmitter for one and the user interface for another.

The following questions will introduce and explore the best approaches for structuring the acquisition, first at the family level and then at the variant level.

1

Which Family-level Acquisition Structure Should Be Used?

Figure 3 displays three options for family-level acquisition structures, which were identified through the research, case studies, and interviews described in this section.

- **Single Total System Performance Responsibility (TSPR) Contractor.** This approach awards a single contractor the responsibility for development of the whole family, often referred to as TSPR, or a Lead System Integrator (see Flood & Richard [2005] or Loudin [2010]).

- **Multiple Contractors plus Systems Engineering and Technical Assistance (SETA).** The government's systems engineering and integration capabilities are enhanced by awarding a contract for SETA to a separate contractor.

- **Multiple Prime Contractors.** This approach is the traditional avenue of acquisition through competition. A contract is separately competed and awarded for each variant.

FIGURE 3. GOVERNMENT INVOLVEMENT IN SYSTEMS ENGINEERING AND INTEGRATION

Each strategy was analyzed for its effect on commonality by separately considering how well each process step shown in Figure 1 could be undertaken under the particular acquisition strategy. The three case studies and 17 additional interviews yielded extensive information about how each of the acquisition strategies performed in helping to achieve the key commonality processes identified in the process maps. A table was used to score each acquisition strategy at the family and variant levels against the processes required by best-practice commonality for each strategy, as shown in the process maps discussed earlier. Four scores were possible: (a) under this acquisition strategy, the process step was more likely to be achieved; (b) under this acquisition strategy, the process step was less likely to be achieved; (c) under this acquisition strategy, there would be no effect on achieving the process step; or (d) under this acquisition strategy, the likelihood of achieving the process step could increase or decrease, depending on other factors.

Figure 4 presents an example of an analysis for the specific case of an acquisition strategy using a directed subcontractor (basically, selecting a contractor that has built the system in a previous variant without a competitive process). Each of the three commonality strategies (Reactive Reuse, Building Block, and Widespread Forward) head a pair of columns. The left-hand column describes the commonality process steps necessary for best-practice commonality, and the right-hand column contains an assessment of how well that process would be performed with a directed subcontractor acquisition strategy, color coded by the four possible scores. The complete set of tables covering every acquisition strategy is detailed in Wicht (2011). The analysis is coarse, but this level of detail was justified because it revealed enough to draw new conclusions about how acquisition structures for commonality should be conducted.

The analysis concluded that effective family-level acquisition structures have three roles in commonality:

- They provide strong systems engineering to arbitrate performance-affordability trades made by the variants.

- They provide strong management to resist variant-level improvements in cost or performance if they adversely affects the family.

- They share information and intellectual property between the variants.

However, the extent to which the acquisition structures achieve this depends on the strength of systems engineering within the government program office and the force of intellectual property provisions within the contract.

FIGURE 4. EVALUATION OF DIRECTED CONTRACTOR (VARIANT-LEVEL STRATEGY)

Commonality Strategy ->		**REACTIVE REUSE**		**COMMON BUILDING BLOCK**		**WIDESPREAD FORWARD COMMONALITY**	
		Required Process (From Commonality Process Diagrams)	**Process Performance Under Acquisition Strategy (Analysis based on case studies, interviews, and literature)**	**Required Process (From Commonality Process Diagrams)**	**Process Performance Under Acquisition Strategy (Analysis based on case studies, interviews, and literature)**	**Required Process (From Commonality Process Diagrams)**	**Process Performance Under Acquisition Strategy (Analysis based on case studies, interviews, and literature)**
ENTRY GATEWAY		Single systems or components	(I) A subcontractor is likely to see benefit in reusing its own designs; it has visibility and reliability, at least, as an incentive (cost also under fixed- price contract)	High-cost systems, clear commonality potential	(U) Directed subcontractor can look back in time at previous projects but cannot look forward because it is only engaged to work on a single system at a time	Many systems/ components	(U) Can only operate on the systems/ components that are in its system; no incentive to look forward; low barriers to retrospective planning; however
		Up-front cost/ reliability improvements		Cost/performance across whole family and life cycle		Cost/performance across whole family and life cycle	
		Isolated incidents or culture		Infrequently entered		Frequent, often culture	
IDENTIFY	**INPUTS**	Requirements of proposed system	(I) The directed subcontractor has good visibility into its own designs and the new requirements	Functions and constraints of potential common systems	(W) Directed subcontractor cannot look forward to potential common systems	Functions and constraints of potential common systems	(W) Directed subcontractor cannot look forward to potential common systems
		Form/function of existing systems		N/A		N/A	
		Requirements from interconnected systems	The structure doesn't assist with performance-cost trades across subcontractor-prime boundaries	Requirements from interconnected systems	The structure doesn't assist with performance-cost trades across subcontractor-prime boundaries	Requirements from interconnected systems	The structure doesn't assist with performance-cost trades across subcontractor-prime boundaries
	PROCESS	Assess performance difference	(I) Subcontractor should be well placed to assess its previous design	Identify functional similarity/difference	(W) Subcontractor is chosen to do a new design based on its existing design, preventing it from identifying the best building block for future systems	Identify functional similarity/ difference	(U) Subcontractor cannot look forward, but can do system engineering within its own systems
		Perform systems engineering	Subcontractor can't go outside its own system to do system engineering trade	Perform systems engineering		Perform systems engineering	
		Assess modifying existing item	(I) Subcontractor should be well placed to assess modification cost	Assess modifying particular instances		Assess modifying particular instances	
EVALUATE	**INPUTS**	Anticipated use case for new system	Requires good systems engineering	Anticipated use case for all new systems	(W) Subcontractor unlikely to develop a system that looks forward to new future systems	Anticipated use case for all new systems	(W) Subcontractor unlikely to develop a system that looks forward to new future systems
		Life-cycle cost estimate of unique new system	(I) Subcontractor should be well placed to assess unique cost	Unique life-cycle cost of all new systems		Unique life-cycle cost of all new systems	
	PROCESS	Evaluate commonality benefits and detriments	Subcontractor has most of the information to do this, but is not incentivized to consider beyond its own involvement in the life cycle	Evaluate commonality benefits and detriments	(W) Directed subcontractor is likely to concentrate on the particular instance, rather than weighting across the whole family including future variants	Evaluate commonality benefits and detriments	(W) Directed subcontractor is likely to concentrate on the particular instance, rather than weighting across the whole family including future variants
		Evaluate if commonality is beneficial		Evaluate if commonality is beneficial		Evaluate if commonality is beneficial	
IMPLEMENT	**INPUTS**	N/A		N/A		Continuous Identify	(U) No incentive to continually identify/ evaluate, but no barriers to it within the system
		N/A		N/A		Continuous Evaluate	
		N/A		Effect of divergence on other family members	May be able to assess impact of divergence on existing system, but not future systems	Effect of divergence on other family members	Cannot assess effect of divergence on future systems
	PROCESS	Manufacture/ modify existing system	(I) Subcontractor already has all the intellectual property and liability for the system	Manufacture/modify existing system	(U) Subcontractor already has all the IP and liability for the system. However, without incentives a common subcontractor is unlikely to produce common systems	Manufacture mostly common systems	(W) Systems likely to change for future systems due to bias toward current variant. No incentive to manage divergence
		Manage divergence	(U) Subcontractor not incentivized to manage divergence if cost plus	Manage divergence	(W) Constantly biased toward current variant	Manage divergence and convergence	

KEY	
	(I) More likely to be achieved
	(U) May be more or less likely to be achieved depending on additional factors
	(W) Less likely to be achieved
	No effect

Figure 5 shows the results of the family-level analysis in more detail. The first conclusion is that if the government systems engineering capabilities are strong, then any of the strategies are likely to be successful. Factors other than commonality can be allowed to govern the choice of family-level acquisition strategy, and attention should be focused instead on the variant-level acquisition strategy. In this context, "strong" government systems engineering includes the ability to assess commonality benefits and drawbacks across the whole family life cycle; the ability to communicate requirements from interfacing systems across the whole family to the team developing the common system; and the capability to resist unjustified variant-level divergence that is detrimental to family life-cycle cost and performance.

FIGURE 5. THREE ROLES OF COMMONALITY IN EFFECTIVE FAMILY-LEVEL ACQUISITION STRUCTURES

STRATEGY	SYSTEMS ENGINEERING	MANAGEMENT	INFORMATION SHARING
Multiple Contractors	Systems engineering is performed by the government, which is in the best position to decide its own needs. Requires a strong government systems engineering capability.	Government will enforce compromises between the two systems. May be difficult on fixed-price contracts.	Information sharing limited to bare minimum required by contract as contractors are likely to be competitors.
SETA	As for multiple contractors, except that the SETA organization can augment government capabilities.	SETA could enforce compromises to make up for lack of government capacity.	SETA may improve information sharing if government is under-resourced, but won't affect intellectual property.
TSPR	Systems engineering likely to be influenced to promote metrics on which the TSPR is judged. Difficult to craft metrics for commonality without good independent understanding of life-cycle costs, yet a lack of systems engineering experience in the government sometimes drives TSPR choice.	TSPR contractor likely to be closer to its teams than government. However divergence may be managed to minimize up-front cost, not life-cycle cost.	Information sharing within TSPR teams likely to be good. However intellectual property may be closely held by major subcontractors.

The conclusions to be drawn from the family-level analysis shown in Figure 5 are fourfold. First, if government systems engineering is weak, then independent systems engineering from a SETA organization is probably preferable to adopting a TSPR approach. Second, if existing (or generated) intellectual property is likely to be involved in the common elements, then the rights to use that intellectual property throughout the family should be included. Third, the applicability of a family-level structure is not affected by the type of commonality that will be implemented. Reactive Reuse, Building Block, and Widespread Forward commonality all require good systems engineering, strong management, and effective information sharing. However, if any are weak, then the more sophisticated commonality approaches should be ruled out. The program should implement Reactive Reuse or discard commonality as the architecting strategy.

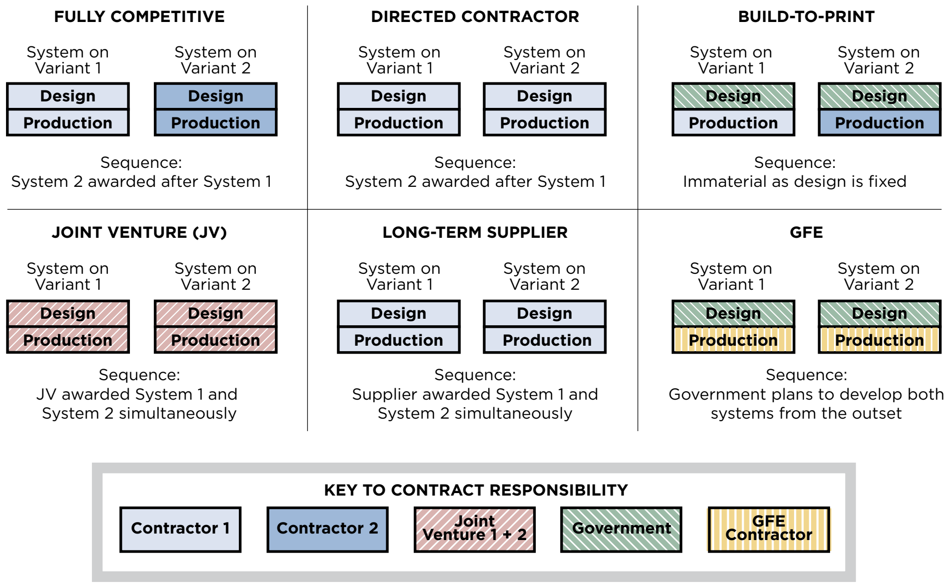
The fourth and final conclusion revealed by the analysis was that the family-level acquisition strategies are not strongly coupled with the performance of the variant-level acquisition strategies, which allows the family-level structures and the variant-level structures to be evaluated separately. The variant-level acquisition strategies are examined in the following section.

Which Variant-level Structure Should be Used?

For the variant-level structures, six possibilities were considered (Figure 6).

- **Fully competitive.** The system is acquired by allowing all qualified bidders to submit proposals for each system and choosing the best system independently for each variant.
- **Joint venture.** A joint venture between two organizations is formed to build two systems, when, in the absence of the joint venture, the organizations would have built one each.
- **Directed contractor.** A contractor that has built the system in a previous variant is selected without a competitive process.
- **Long-term supplier.** A contractor is chosen competitively as the sole supplier of a particular system across all variants.
- **Build-to-print.** Detailed system specifications are provided by the government for contractors to build to on each variant.
- **GFE.** A completed system is supplied directly to a contractor by the government.

FIGURE 6. CHOOSING A VARIANT-LEVEL POSSIBILITY (SIX POSSIBLE SCENARIOS)



Not all of the system acquisition strategy variant-level structures are equally favored within the acquisition community. For example, directed contractors are not preferred when full and open competition is available, but if sufficient justification exists, then a sole-source acquisition could be used:

> Agencies acquiring major systems shall… (b) sustain effective competition between alternate systems and sources for **as long as is beneficial.** (Federal Acquisition Regulation [FAR] Subpart 34.002)

Figure 7 shows the relative support for each system acquisition strategy variant-level structure within the acquisition community, divided into Good, Moderate, and Poor support. The six variant-level structures are then examined for effect on the commonality processes. At this stage, the contract is assumed to simply reflect the natural incentives of its structure, without specific contract terms, which will be investigated in the next section. Figure 8 summarizes the analysis of the variant-level strategies.

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FIGURE 7. SUPPORT WITHIN ACQUISITION COMMUNITY FOR EACH SYSTEM ACQUISITION STRATEGY VARIANT—LEVEL STRUCTURE

SYSTEM ACQUISITION STRATEGY	SUPPORT FOR IMPLEMENTING THIS STRATEGY (excluding commonality effect)
Fully Competitive	Good: Default position under the FAR
Joint Venture	Medium: Joint ventures lessen competition and must not be forced on the market
Directed Contractor	Medium: A sole source justification may be used if there are good reasons to do so
Long-Term Supplier	Poor: Long-term supply arrangements are difficult to justify under the FAR on decade-long time scales
Build-to-Print	Good: A common strategy; however, the downside is that the solution may be prematurely constrained
GFE	Medium: Although used, scoping interviews suggested GFE raised implementation difficulties

The first point evidenced from Figure 8 is that the variant-level strategy needs to be matched with the commonality strategy. For example, a directed contractor works well for Reactive Reuse, but poorly for Building Block and Widespread Forward commonality. This in part explains why defense projects struggle to achieve effective commonality: the acquisition strategy most often used for commonality acquisition projects in the defense industry is Fully Competitive, which performs moderately well for Reactive Reuse, and poorly for Building Block and Widespread Forward commonality.

The strategies that work well for Reactive Reuse are the strategies that place the reused system and the system to be developed under one contractor. In an approximate order of preference, and taking into account Figures 7 and 8:

- A directed contractor is a good strategy because the contractor has the intellectual property and practical know-how to reuse its previous system. There is clear justification for sole-sourcing in this instance, so acquisition regulations are unlikely to be problematic.

- A joint venture between the contractors who are to develop the two systems works well for reuse; however, this will only be appropriate in circumstances where the joint venture

FIGURE 8. EFFECT OF CONTRACT STRUCTURE ALONE ON COMMONALITY

System Acquisition Strategy	Acquisition Support (from Figure 6)	Effect of Acquisition Structure on Commonality Process		
		Reactive Reuse	Building Block	Widespread Forward Commonality
Fully Competitive	Good	Medium: No-guarantee winner of competition will have developed previous variants and have access to existing designs for reuse.	Poor: If each variant is recompeted, there is no incentive for first contractor to meet the needs of the second contractor. Therefore, no incentive to develop building block.	Poor: Lack of incentive to consider other systems or future development because the future development may be won by a competitor.
Joint Venture	Medium	Good: Assumes JV includes companies with previous expertise; JV can investigate and evaluate reuse opportunities.	Poor: No major advantage in having a JV develop the building block over a single corporation developing the building block.	Poor: No major advantage in having a JV develop widespread commonality over a single corporation.
Directed Contractor	Medium	Good: Directed contractor will be selected based on experience developing previous systems; gives expertise to reuse.	Poor: Difficulty incentivizing contractor to develop for future, because at the time of the first variant the directed contractor had no expectation it would be chosen in future and so behaved as if fully competitive.	Poor: Difficulty incentivizing contractor to develop for future, because the directed contractor has no expectation it will be chosen in future.
Long-term Supplier	Poor	Good: Long-term supplier will be selected based on experience building previous systems; gives expertise to reuse.	Good: Same contractor works on all variants of the building block. Therefore, possible to incentivize up-front investment for future payoff.	Medium: The contractor is able to invest up-front in future benefits. Commonality across the supplier's boundaries with other suppliers is still not possible.
Build-to-Print	Good	Medium: Places onus of investigating and evaluating commonality on government. Government (as customer) may not have insight into details of previous engineering decisions.	Good: Government could develop ongoing building block as long as the design is well known at the outset and divergence is minor and well managed. Government is responsible for additional up-front cost and is well placed to trade up-front cost against life-cycle affordability.	Poor: Structure is not responsive to divergence because the design and manufacturing organizations are separate. Also difficult to set up and manage each time a new commonality opportunity appears.
GFE	Medium	Poor: Places onus of investigating and evaluating commonality on GFE contractor that does not have previous expertise (if it does, effectively it is a directed contractor).	Good: GFE supplier could develop good building block so long as design is well known at time GFE contract is let. Can tolerate more divergence than Build-to-Print because GFE contractor remains responsible for design and can evaluate economic case for divergence.	Poor: Structure is not adaptable because there is a firm boundary between GFE and non-GFE. Commonality opportunities across this boundary will not be implemented.

would be natural in the market. Incentivizing the joint venture may create economic responsibilities for the government that outweigh commonality savings.

- Creating a long-term supplier for a particular system works well to encourage reuse. The disadvantage is that it is difficult to justify under acquisition regulations because the long-term supplier must obtain a contract for the duration of the family development, which for many acquisitions may be a decade or more.

The strategies that work well for developing Building Block commonality are:

- A Build-to-Print strategy, where the government creates the design for the common building block, which is then competitively manufactured for each variant. This works well when the design is well known at the outset, and when divergence is likely to be low—for example, in low-clockspeed industries.

- A GFE strategy, where the building block is developed and manufactured by the government (or a separate contractor to the government) and supplied to each variant. This approach is more tolerant of divergence than Build-to-Print because the government can manage divergence that occurs as a result of learning during manufacturing, and could be used on higher technology projects. However, both government and contractors expressed aversion to GFE projects due to programmatic and liability risks.

- Creating a long-term supplier responsible for the building blocks on an ongoing basis. This relieves the government of responsibility for developing the building block, but raises the same sole-sourcing concerns mentioned in Reactive Reuse.

The poor performance of strategies on Widespread Forward commonality reinforces the observation made in Concept 5 that it is an inappropriate strategy for multicontractor acquisitions. If Widespread Forward were to be used, establishing a long-term contractor for the system across all variants is likely to be the most successful strategy.

Of course, an acquisition strategy is about more than contract structure. Several examples were found in the acquisition case studies of the same subcontractor producing unique designs for different customers with similar needs. The provisions of the contract dealing with issues such as payment structure and intellectual property affect the acquisition result, and were investigated in detail in the case studies and scoping interviews. Figure 9 summarizes the recommended contract additions for those strategies that were graded Medium or Good in Figure 8.

In Reactive Reuse, contracts were improved through the use of fixed-price contracts for development and manufacture. The fixed-price contract incentivizes reductions in the up-front development cost, thereby encouraging reuse. An award fee based on thorough investigation and evaluation of commonality may also help.

Incentive fees may also be considered in Reactive Reuse, especially if there will be benefits to the government through the life cycle from commonality, not just a reduction in up-front cost. Incentive fees should not be tied to fixed levels of commonality, for example, paying a fee based on the percentage of commonality achieved because this discourages an analysis of whether a particular reuse opportunity is net-beneficial. It also raises very practical difficulties in assessing whether any incentive should be paid for two similar parts. Instead, base incentive fees on a transparent life-cycle cost model if one is available. Basing incentive fees on a life-cycle cost model developed and maintained by the contractor should be avoided. The case study that did this had difficulty establishing wide confidence in the model.

An additional consideration for reuse is that the requirements of the contract should be expressed only in terms of minimum acceptable performance (though incentive fees could be offered for improvements) so that trades can be made between performance and affordability. Every instance of reuse examined in our case studies involved this trade. Overconstraining the performance specification will hamper efforts to implement commonality.

Finally, consideration should be given to intellectual property provisions. The contractor should be given relevant access to government-owned intellectual property to increase the range and qual-

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FIGURE 9. CONTRACTING ADDITIONS THAT IMPROVE VIABLE STRUCTURES

System Acquisition Strategy	Effect of Acquisition Structure on Commonality Process		
	Reactive Reuse	Building Block	Widespread Forward Commonality
Fully Competitive	Fixed-price contract to encourage reuse. Add incentive fees if life-cycle cost savings from commonality are expected. Improve contractor knowledge of reuse opportunities through a domain-wide knowledge base and strong government intellectual property on previous projects.		
Joint Venture	Fixed-price contract to encourage reuse. Add incentive fees if life-cycle cost savings from commonality are expected.		
Directed Contractor	Fixed-price contract to encourage reuse. Add incentive fees if life-cycle cost savings from commonality are expected.		
Long-term Supplier	Fixed-price contract to encourage reuse. Add incentive fees if life-cycle cost savings from commonality are expected.	Cost-plus contracts to encourage identification of commonality opportunities. Firm requirements across existing and future systems. IP provisions that allow supplier switch if necessary to avoid monopoly. Good government understanding and encouragement that up-front costs will be higher. Add incentive fees if life-cycle cost savings from commonality are expected.	Lead/Follower contracts to keep costs low. Strong system engineering and cost modeling to support life-cycle-based incentives.
Build-to-Print	Good government insight into previous designs. Strong government negotiation of IP on previous projects so government has technology to reuse. Good government core engineering skills.	Very firm requirements across existing and future systems. Good government core engineering skills in the initial design phase.	
GFE		Cost-plus contracts to encourage identification of commonality opportunities. Add incentive fees if life-cycle cost savings from commonality are expected. Firm requirements across existing and future systems. Need to deal with liability and programmatic responsibility for GFE.	

ity of elements that the contractor may reuse. Consider also obtaining rights to the *new* intellectual property developed in the design to allow unplanned reuse by subsequent designs.

Building Block commonality benefits from many of the same contract provisions. The required performance should not be overconstrained, and the contractor should be encouraged to trade affordability and performance.

However, the payment basis to the contractor should be different for Reactive Reuse. A cost-plus contract is preferable because it enables the contractor to investigate a wider range of commonality opportunities and develop the best building block, even if it costs more initially. Incentive payments based on the estimated life-cycle cost of the building block can be used to ensure the building block does not become overdesigned. An award fee and close supervision by a government systems engineering team will further reduce the risk of abuse of the cost-plus structure.

The intellectual property in the building block *must* be obtained by the government, with the right to license it to other parties; otherwise, the government risks price increases by the building block contractor because of the government's high cost to switch contractors.

Analysis of Acquisition Regulations

During the course of this analysis, the FAR and DoD 5000.2 were closely examined. No major changes were considered necessary to improve commonality projects. The sections that permit sole-sourcing adequately cover the rationale for commonality sole-sourcing, for example FAR 6.302(1)(a)(ii).

However, several trends in defense acquisition impact commonality acquisition. The emphasis on open architectures (Rendon & Snider, 2008, p. 59) is in tension with commonality because it encourages a proliferation of innovative designs rather than the consistent use of a single design. For many programs, open architectures may be the preferred solution, but it is important to recognize that commonality and openness are mutually exclusive strategies. The trend toward greater use of commercial off-the-shelf products is synergistic with commonality because it encourages the same performance-affordability trades (and can be seen as a particularly widespread form of Reactive Reuse).

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Finally, the trend toward fully funding acquisitions and allowing the Services to retain amounts saved on acquisitions (Carter, 2010, p. 3) is likely to improve commonality outcomes because it encourages projects to "invest" in common building blocks over time.

Recommendations

Five recommendations are set forth as a result of this research:

1. Defense acquisitions that seek to use commonality to improve affordability must integrate the commonality strategy and the acquisition strategy.

2. The family-level contract and management structure must be built around a strong systems engineering team, which has the vision and authority to force variants into performance-affordability compromises that achieve value at the family level.

3. At the variant level, traditional competitive procurement approaches do not work well for commonality, and sole-sourcing, GFE, and Build-to-Print approaches should be considered instead.

4. The payment structure, incentive and award fees, performance specifications, and intellectual property provisions of the contract must all be considered from a commonality viewpoint for a successful project.

5. No changes to the FAR are required to implement effective commonality.

Conclusions

Simply transplanting the principle of commonality from commercial product development, without regard to the different approaches used in government acquisition, invites disaster. In particular, the government acquisitions with the most to gain from commonality are those with a mix of contractors are working independently on projects that overlap significantly. Commonality is not implemented over such distributed development frameworks in commercial development, and government acquisition must break new ground. Understanding how to use an acquisition strategy to incentivize sensible commonality between companies is a critical step in allowing commonality to realize its affordability promise.

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Keywords: *Agile, Systems Engineering, Information Technology (IT), DoD Agile IT Acquisition, IT Box, Scrum*

Inserting Agility in System Development

Matthew R. Kennedy and Lt Col Dan Ward, USAF

With the fast-paced nature of technology, rapidly fielding systems has never been more important. Success depends on well-defined requirements and the ability to rapidly respond to change during and after deployment. The inability to rapidly respond may cause the system to become obsolete before initial fielding. Creating a structure where processes allow for changes during system development requires restructuring system development values and principles at all levels. This article addresses progress toward agility and defines agile values and principles being used by agile organizations in the Business, System, and Software Aspects. It also defines operationally effective agile practices being utilized to implement those values and principles that provide a starting point for inserting agility into the system development process.

image designed by Diane Fleischer »


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With the fast-paced nature of technology, the need to rapidly field systems has never been more important. Success does not just depend on well-defined requirements, but also on one's ability to respond to change during development, deployment, and post-deployment. The inability to rapidly respond to change may cause the system to become obsolete before initial fielding. Creating a structure where processes allow for changes to occur during system development requires a restructuring of system development values and principles at all levels.

Three Aspects of a Software Intensive System Development

Software Intensive System (SIS) development can be understood as having three aspects: Business, System, and Software. Although the three aspects sometimes overlap one another, general responsibilities can be attributed to each. The Business Aspect is responsible for the overall acquisition of the system, including contracting, funding, operational requirements, and overall system delivery structure. Next, the System Aspect is responsible for the technical and technical management aspects of the system, and serves as the interface between management and engineers. The Software Aspect is responsible for the software items contained in the SIS. Viewing SIS development through the lens of these aspects helps highlight components of the work that are often neglected.

Agility is "the speed of operations within an organization and speed in responding to customers (reduced cycle times)" (Massachusetts Institute of Technology, n.d.). It must be incorporated into each aspect. The degree of agility when developing an Information Technology (IT) system determines the organization's ability to respond to change.

Currently, each aspect is at a different maturity in terms of the agile frameworks and methodologies available. However, the speed at which changes can be made during development is held captive by the aspect that is most resistant to change. This article addresses each aspect and its progress toward agility, and defines the agile values and principles being used by agile organizations in both the Business and Software Aspects. It defines agile practices being utilized to implement these values and principles to provide a starting point for inserting agility into the system development process.

Business Aspect

The Business Aspect is where operational requirements are realized and the strategy for overall system development is identified. Currently, the Department of Defense (DoD) uses DoD Instruction (DoDI) 5000.02 to manage how it will perform the acquisition of weapon systems, services, and Automated Information Systems (AIS) (DoD, 2008).

Recognizing that the current DoDI 5000.02 was not responsive to the changing needs of technology, Congress signed the Fiscal Year 2010 National Defense Authorization Act (NDAA), which directed the Secretary of Defense to "develop and implement a new acquisition process for information technology systems" (NDAA, 2009). This new Defense Acquisition System process must include:

- early and continual involvement of the user;
- multiple, rapidly executed increments or releases of capability;
- early, successive prototyping to support an evolutionary approach; and
- a modular, open-systems approach (NDAA, 2009).

Moreover, this process should be based on the March 2009 *Report of the Defense Science Board (DSB) Task Force on Department of Defense Policies and Procedures for the Acquisition of Information Technology* (NDAA, 2009). The DSB report concluded that "the conventional DoD acquisition process is too long and too cumbersome to fit the needs of the many IT systems that require continuous changes and upgrades" (DSB, 2009). The report also noted that an agile acquisition approach would increase IT capability and program predictability, reduce cost, and decrease cycle time.

The DSB has developed an Agile Business Aspect framework, which is divided into four phases: Business Case Analysis and Development, Architectural Development and Risk Reduction, Development and Demonstration, and Operations and Support (DSB, 2009).

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Figure 1 depicts the four phases of an Agile Business Aspect Framework (DSB, 2009). A brief description of each phase follows:

- **Business Case Analysis and Development:** "Establish the need for the proposed capability and develop the concept for the proposed solution and perform a cost-benefit analysis to quantify the benefits of the solution."

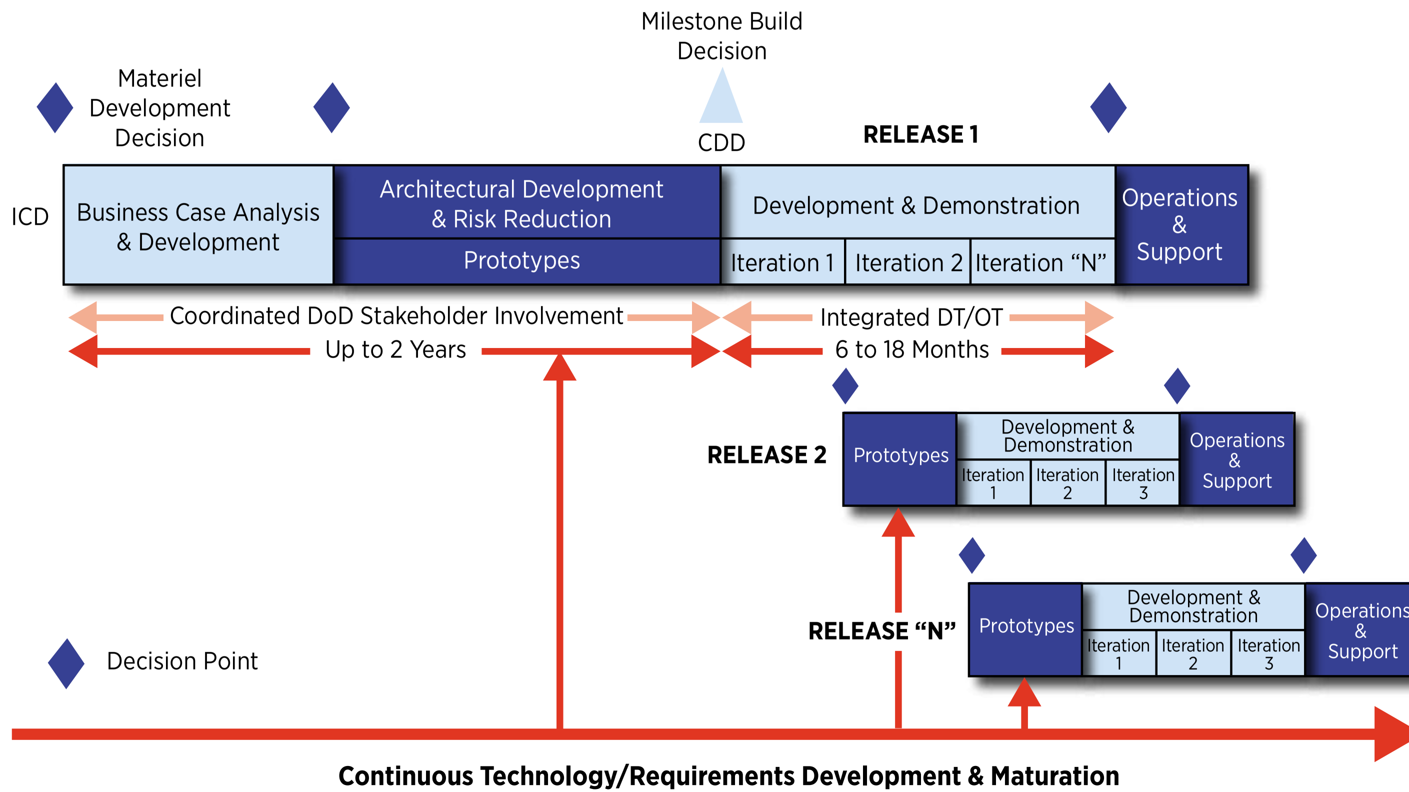
- **Architectural Development and Risk Reduction:** "The core architecture is built and architecturally significant features demonstrated. Prototyping begins during this phase and continues throughout the acquisition life cycle to assess the viability of technologies and minimize high-risk features."

- **Development and Demonstration:** "The period when operational capability is built and delivered for a discrete number of releases. Capabilities are prioritized and parsed into groupings to establish release baselines for the sub-programs. Includes development of training programs and testing in realistic environments to ensure successful fielding of new capabilities."

- **Operations and Support:** "Provides materiel readiness, user training, and operational support over the total program life cycle."

In addition to the emerging IT Acquisition framework, the DoD developed an agile requirements process for IT systems called the "IT Box" (Wells, 2009). The Joint Requirements Oversight Council Memorandum 008-08 stated, "IT programs are dynamic in nature and have, on average, produced improvements in performance every 12–18 months" (Joint Requirements Oversight Council, 2009). Recognizing the need for performance improvements, the "IT Box" allows IT programs the flexibility to incorporate evolving technologies. This allows for greater agility in the current DoD requirements process.

FIGURE 1. AGILE BUSINESS ASPECT MODEL



Note. CDD = Capabilities Development Document; DT = Direct Test; ICD = Initial Capability Document; OT = Operational Test

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To be used in conjunction with the framework is a guiding value set called FIST (Fast, Inexpensive, Simple, Tiny), which may be utilized throughout the process (Ward, 2010). The FIST approach identifies a set of priorities and preferences that should be employed by project leaders during the development process to streamline, accelerate, and simplify (Ward, 2010). These values are declared in the FIST manifesto as:

> Talent *trumps* process.
>
> Teamwork *trumps* paperwork.
>
> Leadership *trumps* management.
>
> Trust *trumps* oversight. (Ward, 2010)

The FIST Manifesto also contains a series of principles and implementation guidelines, which can be applied to all three aspects of development (System, Software, and Business). These principles follow:

- Fixed funding and floating requirements are better than fixed requirements and floating funding.
- Complexity is cost.
- Simplicity scales. Complexity does not.

The implementation guidelines include:

- Minimize team size and maximize team talent.
- Incentivize and reward underruns.
- Requirements must be achievable within short time horizons. (Ward, 2010)

The FIST approach describes a particular pattern of decision making that has been successfully used on various DoD programs. Recent examples include the Marine Corps "Harvest Hawk," which incorporated a gunship modification onto a C-130 airframe. This modification was fielded just 18 months after the program was announced (Axe, 2010). Similarly, the U.S. Air Force's new intelligence, surveillance, and reconnaissance aircraft—the MC-12W—flew its first combat mission just 6 months after the contract was signed. This is a divergence from the typical decade-long weapons system program and shows the DoD can deliver inexpensive systems on short timelines.

In addition to rapidly delivering inexpensive systems, capabilities produced by using the FIST approach tend to outperform more expensive, complex systems when actually fielded. Examples include the Air Force's Condor Cluster supercomputer, which was developed for one-tenth the cost of a traditional supercomputer and uses one-tenth the electricity of comparable systems. It operates at 500 TFLOPS (**T**era **FL**oating point **OP**erations per **S**econd), making it the fastest supercomputer in the entire DoD.

The Agile Business Aspect framework and the FIST approach are examples of how the Business Aspect is making advancements toward becoming more agile and adaptive to changing requirements, which is required to keep pace with today's rapidly changing environment.

System Aspect

The System Aspect addresses the technical and technical management pieces of the system and serves as the interface between management and engineers. Utilizing various systems engineering standards and guides, operational requirements are decomposed into technical requirements. The System Aspect holds the overall responsibility for the development of the system given the contractual, schedule, and fiscal constraints of the Business Aspect.

Though the systems engineering process is generally portrayed in a waterfall-like fashion, the systems engineering community has moved toward an incremental delivery approach. The (DAG) identifies incremental development as a capability that *Defense Acquisition Guidebook* that "is developed and fielded in increments with each successive increment building upon earlier increments to achieve an overall capability". This incremental approach relies heavily on prototyping and allows for technology maturation in subsequent releases (DAU, 2010). The move toward an incremental delivery allows the systems engineering process to better adapt to change than the waterfall-like implementation. However, with the rapid rate of change, the incorporation of an incremental model alone may not be enough. Currently, no agile systems engineering frameworks, principles, or values are in place to guide the System Aspect.

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Software Aspect

The Software Aspect addresses the software items contained in the SIS. Provided a set of requirements from the System Aspect, the Software Aspect creates the software items required for the system.

Software development has been on a continuous process improvement track for decades. Initially, the waterfall software development methodology was used, where software was developed in one long release cycle (Royce, 1970, pp. 1–9), although this approach was described as "risky and invites failure." The waterfall software development methodology provides the fundamental steps required to develop software. However, it has one major flaw in that it assumes that once the requirements process is complete, the requirements will remain unchanged throughout the development life cycle. This assumption rarely holds true in practice as change is inevitable in all large software projects (Sommerville, 2004).

Long waterfall-like development cycles do not allow for requirements changes, a flaw identified by Royce in his original paper. Breaking software development cycles into a series of increments allows one to better adapt to changing requirements. In the incremental model, an increment is a potentially shippable piece of functionality. Incremental delivery allows the user to gain value from a portion of the system prior to the entire system being released.

Agile Software Development

Though seen as an improvement over the waterfall software development methodology, the incremental approach has several disadvantages; namely, the majority of requirements must still be known up-front (U.S. Air Force, 2003). Agile processes have emerged to match the pace in which change is encountered during software development.

Agile software development is a broad term used to describe development methodologies that adhere to a set of values and principles defined by the Agile Manifesto (Beedle et al., 2001). The Agile Manifesto was formed when a group of 12 people calling themselves the Agile Alliance gathered to find an alternative to the current documentation-driven, heavyweight software development process (Beedle et al., 2001). Through this effort, they framed the following set of values to improve the way software is developed (Beedle et al., 2001):

- Individuals and interactions over processes and tools;
- Working software over comprehensive documentation;
- Customer collaboration over contract negotiation; and
- Responding to change over following a plan.

The Agile Manifesto also defines the following principles, which are used to separate agile practices from their heavyweight counterparts (Martin & Martin, 2006):

- Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.
- Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage.
- Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.
- Working software is the primary measure of progress.
- Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.
- Simplicity—the art of maximizing the amount of work not done—is essential.

The application of these principles varies in practice as no predetermined number of principles must be utilized for a development methodology to be deemed "agile." Several development methodologies are in use today; however, a survey conducted by VersionOne, which included almost 1,700 individuals and 71 countries, found Scrum and eXtreme Programming to be the most widely followed methodologies (VersionOne, 2007). Other common methodologies include Crystal, Dynamic Systems Development Methodology, and Lean Software Development.

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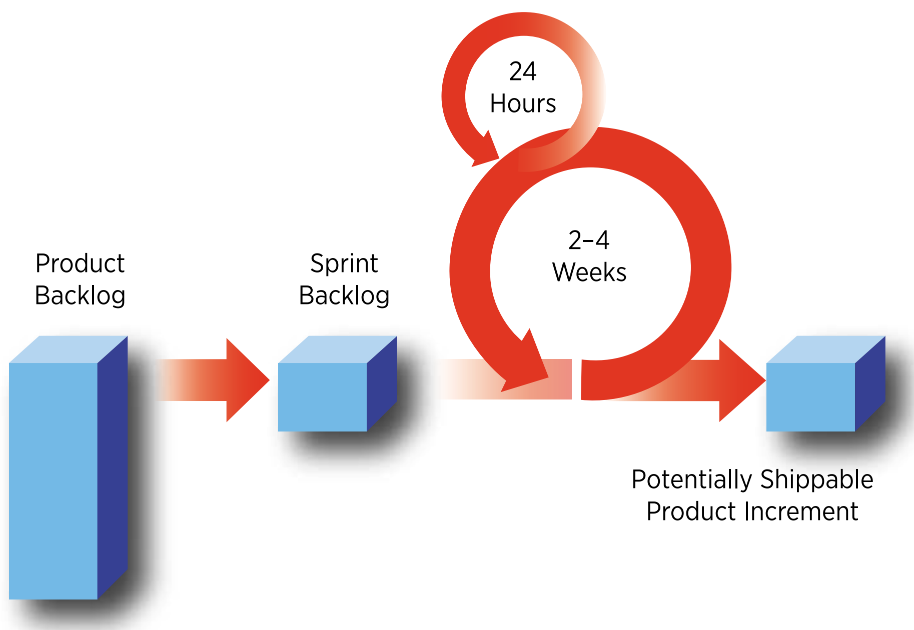
Scrum

Scrum is a framework used for project management, which is designed for projects where it is difficult to look ahead (Brede Moe, Dingsøyr, & Dybå, 2008, pp. 76–85). It provides a framework with which these activities will be executed (Figure 2). Scrum comprises self-organizing and self-managing teams that release a potentially shippable product in sprints (increments) of 2–4 weeks.

FIGURE 2. SCRUM FRAMEWORK



Note. Adapted from *The SCRUM process/SCRUM framework* [Web page], by Expert Program Management (n.d.) at http://www.expertprogrammanagement.com/2010/08/the-scrum-process/.

The process starts with a product backlog (requirements) that is prioritized by the user prior to the start of each sprint. The team then selects what can be accomplished within the designated sprint duration; however, the team must select the requirements in the order specified by the user. These selected requirements then become the sprint backlog. The items on the sprint backlog are what will be delivered to the customer at the end of the sprint.

eXtreme Programming

Whereas Scrum is a process to manage a product, eXtreme Programming (XP) is an agile development methodology focused on software development as a whole. XP is one of the most well-documented agile methodologies, and it consists of the following 12 rules (Cohen, Lindvall, & Costa, 2003):

1. The Planning Game	2. Small Releases	3. System Metaphor	4. Simple Design
5. Continuous Testing	6. Refactoring	7. Pair Programming	8. Collective Code Ownership
9. Continuous Integration	10. 40-Hour Work Week	11. On-site Customer	12. Coding Standards

No set number of rules need be practiced by a team to claim they are doing XP (Wolak, 2001). However, the strength of XP is in the combination of the rules and not implementing a single rule alone (Cohen, Lindvall, & Costa, 2003).

The Software Aspect has a greater selection of agile methodologies to utilize during development, allowing for valuable resources when inserting agility within the Software Aspect.

Maintaining Agility Between Aspects

With the growing complexity of today's systems, the systems engineering effort becomes increasingly important to success. Currently, both the Business and Software Aspects have an agile framework and a proven set of agile values to help guide development. However, traversing from the Business Aspect to the Software Aspect requires passing through the System Aspect, which could hinder the agile advances made in the other aspects. The System Aspect's ability to respond to the agile processes developed within the Business Aspect, as well as fostering the agile processes in the Software Aspect, could play a pivotal role in overall system success.

Agile Principles

When combining the FIST implementation guidelines and principles and comparing them against similar principles, much constancy is evident.

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Though no one-to-one relationship exists between the FIST principles/guidelines and the Agile Manifesto principles, they all remain important complementary principles while developing a complete agile organization.

Agile Practices

Agile projects use various practices to implement the Agile Values and Principles identified. When considering both the Software and Business Aspects, a common set of practices emerges. These practices are:

Incremental Development	Small Teams
Iterative Development	Time Boxing
Short Time-lines	Lean Initiatives
Retrospectives (Lessons Learned)	Prototyping
Empowered/Self-organizing/ Managing Teams	Continuous User Involvement
Prioritized Product Backlog (Requirements)	Co-located Teams

Implementation of these practices varies greatly from project to project. Using co-located teams as an example, a large program retrofitting military aircraft may be structured in a way to have the teams located on the same installation so that the contracting, development, and testing activities are located on the same installation. This contrasts with software development teams, which implement the practice of co-located teams by having the development team work in the same room.

These practices are well-documented and demonstrated and offer great promise for helping deliver affordable systems that are available when needed and effective when used. By implementing these proven practices, we can increase agility with the Systems Aspect.

What to Expect from Implementing Agile Practices

Studies have been conducted over the last decade documenting the results when utilizing agile practices. Rally Software Development Corporation found an average 37 percent decrease in time-to-market and a 16 percent increase in productivity (Software Engineering Institute, n.d.). Findings from seven individual studies found a benefit-to-cost, productivity, and quality ranging from 14 percent to 93 percent (Rico, 2008). The averages from the study can be found below:

67 percent, average increase in productivity,

65 percent average increase in quality, and

49 percent improvement in cost (Rico, 2008).

Conclusions

More than ever, military technology programs need to rapidly field systems within tight budget constraints and still maintain an ability to respond to change. The Agile approach provides a useful starting point to achieve these objectives of speed, thrift, and agility.

Inserting agility within an organization is a journey, not a destination. Agile practices that work for one organization may not be as effective when implemented at another organization. Conversely, agile practices found effective within an organization last year may no longer be as effective as their initial implementation due to external, internal, or personnel changes. These changes may require periodic modification or even removal of practices to remain competitive in today's fast-paced world of IT. It is not a single practice that makes an organization agile, but a combination of practices.

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Keywords: *Organizational Conflict of Interest (OCI), Organizational Structure, Central Contractor Registration, Transparency Act*

Identifying Organizational Conflict of Interest: *The Information Gap*

M. A. Thomas

As the volume of government contracting increases, so does the importance of monitoring government contractors to guard against Organizational Conflict of Interest (OCI). For contracting officers to identify OCIs, they must be able to identify the relevant business interests of a contractor's affiliates. This information may be private or not easily obtained. Using newly released data to develop preliminary visualizations of contractor organizational structures shows the organizational structure of many contractors to be complex and multinational. The complexity and the lack of easily available public information make it very unlikely that contracting officers could identify OCIs without substantial improvements in government data collection.

image designed by Diane Fleischer »

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As government has come to rely more heavily on contractors for goods, services, and advice, it needs to ensure that procurement remains competitive and that contractor performance is not compromised by outside interests. Organizational Conflict of Interest (OCI) refers to conflicts that arise because of conflicting incentives of contractors due to their own activities or the activities of related entities. Government contracting officers are required to identify and respond to possible OCIs during the contracting process. The current policy debate focuses on issues such as the definition of an OCI, the objectives of government in avoiding or mitigating OCIs, the relevant contractor relationships and activities that should be considered when identifying an OCI, and the appropriate responses of contracting officers to OCIs once identified (Guttman, 1977; Taylor, 1983; Taylor & Dickson, 1984; Gordon, 2005; Szeliga, 2005; Yukins, 2011).

Little attention has been paid to the question of how contracting officers are to obtain the information necessary to identify an OCI in the first place. Identification of an OCI would require identification of those entities considered to be sufficiently closely related to the contractor to be important as well as knowledge of the relevant activities of these related entities.

An important current debate involves the extent to which the business interests of a contractor's affiliates should be imputed to the contractor so as to give rise to a conflict. The Federal Acquisition Regulation (FAR) Section 2.101 (General Services Administration, 2005) defines "affiliates" as "associated business concerns or individuals if, directly or indirectly—(1) Either one controls or can control the other; or (2) A third party controls or can control both." While control could be contractual, the discussion has centered primarily on ownership relationships that link companies in a single organizational structure.

In practice, however, contracting officers have few means of learning the organizational structure of contractors.[1] Even the problem of providing a definitive identification of contractors is one that the government has not yet solved. It has even less information about the contractual relationships of the contractor and its affiliates, such as teaming arrangements or subcontracting relationships, which can have multiple tiers. Even if the relevant business entities were identified, the government has no way of identifying their relevant activities or financial interests.

This article explains the information gap that prevents effective implementation of OCI policy and focuses in particular on the opacity of contractor organizational structures. An analysis of newly available data from Usaspending.gov suggests the complexity of the organizational structure of contractors and the failure of government policymaking to adapt.

Organizational Conflict of Interest

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The government is continuing to develop and articulate its policy on OCIs, including the definition of an OCI, the government's objectives in identifying and responding to OCIs, the ways in which contracting officers should identify OCIs, and the appropriate response for contracting officers after having identified an OCI. In 2010, the Defense Council advanced a proposed rule to update the Defense Federal Acquisition Regulation Supplement (proposed DFARS rule) that would have effectively codified existing U.S. Government Accountability Office (GAO) case law on OCIs (Papson, Doyle, & Ginsberg, 2011; Defense Federal Acquisition Regulation Supplement [DFARS], 2010, April). Under criticism, it retreated from certain key provisions of the proposed rule in its final rulemaking, awaiting a broader revision of the rules on OCI by the Federal Acquisition Regulation Council (DFARS, 2010, December). In 2011, the FAR Council published a proposed rule ("proposed FAR rule") that offered an alternative model (FAR, 2011).

A key policy question is the extent to which the business interests of other related entities, and in particular affiliates related by ownership interests, should be imputed to the contractor. A series of prior decisions by the GAO had affirmed that "all business interests within the larger corporate enterprise are imputed to every entity and person within the enterprise" (Papson et al., 2011, p. 2; Comptroller General, 1995). Accordingly, in 2010 the Defense Acquisition Regulations Council issued a proposed rule that defined a contractor as "a party to a government contract other than the government and includes the total contractor organization, including not only the business unit or segment that signs the contract. It also includes all subsidiaries and affiliates" (DFARS, 2010, April, p. 20958). The proposed FAR rule does not have this definition of a contractor, but defines an OCI with respect to the relationship between contractors and their affiliates (FAR, 2011, p. 23242).

The Role of Information

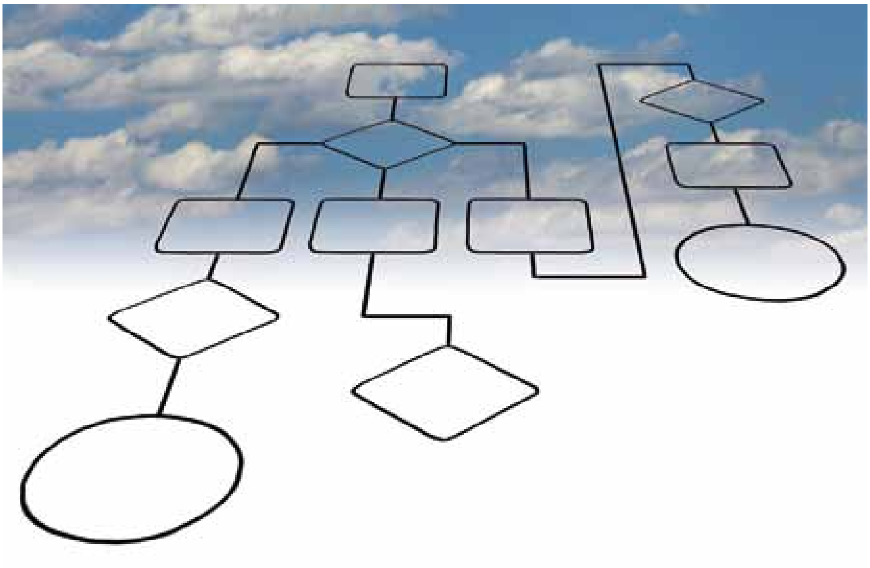
To identify an OCI, contracting officers would have to identify the affiliates of a contractor and their relevant financial and business interests. At present, the FAR Section 9.506 enjoins contracting officers to do the following:

> … seek the information from within the Government or from other readily available sources. Government sources include the files and the knowledge of personnel within the contracting office, other contracting offices, the cognizant contract administration and audit activities and offices concerned with contract financing. Non-Government sources include publications and commercial services, such as credit rating services, trade and financial journals, and business directories and registers. (FAR, 2005, p. 9.5-3)

The provision in the proposed FAR rule is similar, providing that the "contracting officer should seek readily available information about the financial interests of the offerors, affiliates of the offerors, and prospective subcontractors from within the government or from other sources and compare this information against information provided by the offeror" (FAR, 2011, p. 23247). The proposed FAR rule also provides explicit language for the contracting officer to include in the solicitation to require contractors to disclose information regarding potential OCIs if the contracting officer has determined that the nature of the contract is such that an OCI might arise from contract performance (FAR, 2011, p. 23239).

Contracting officers are not likely to be able to assess the financial interests and activities of affiliates or prospective subcontractors using readily available sources, and while competitors may have an incentive to bring information about a contractor's OCI to the attention of a contracting officer, it remains questionable whether competitors are in fact much better positioned to do so. The offerors themselves may lack this information. The DFARS proposed rule had provided that, where the contracting officer has determined that the nature of the contract is such that an OCI might arise from contract performance, the contractor must describe any other work performed by itself or its affiliates within the past 5 years that is associated with the offer it plans to submit (DFARS, 2010, April, p. 20957). The Coalition for Government Procurement, an association of 300 contractors, argued that this requirement would "have the unintended consequence of driving contractors that lack sophisticated tracking systems [to track sales of commercial items and services] out of the marketplace" (M. Vakerics, personal communication, July 21, 2010).[2]

Indeed, contracting officers may be hard pressed to identify affiliates in the first place. Information on the organizational structure of contractors is not always in the public domain.



The Available Information on Contractors' Identities and Complexities of Contractor Organizational Structures

Contractors' Identities

To identify OCIs, contracting officers must first know who the companies are that contract with the government. Because company names may not be unique, because a single business can operate under a variety of names, and because locations can change, this requires that contractors be given unique identifiers. Since 1998, the government has used a number issued by the private firm Dun & Bradstreet ("D&B") to identify government contractors.[3] A business that wishes to contract with the government gives D&B its legal business name and physical address, and receives a nine-digit Data Universal Numbering System number ("D-U-N-S" or "DUNS" number). The DUNS number is "a unique global identifier attached to operating entities; the D-U-N-S Number is never reassigned to another company, in any place, at any time" (Dun and Bradstreet, n.d.[a]). A different DUNS number is required for every business location or co-located subdivision. Under FAR section 4.11, the contractor then uses its DUNS number to register in the Central Contractor Registration (CCR) database maintained by the Department of Defense. The CCR relies upon D&B to notify the CCR of any changes to the contractor's business name or address.

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Millions of business locations have DUNS numbers because the D&B identification system is widely used. Dun & Bradstreet has assigned DUNS numbers to more than 100 million companies (Dun and Bradstreet, n.d.[b]). However, not every business has a DUNS number. The Excluded Parties List System, the government's tool for identifying debarred companies, warns that not all debarred firms have DUNS identifiers.

In addition to identifying the company, contracting officers must identify the affiliates of the contractor. Company organizational structures can be opaque even for companies incorporated in the United States. While the Securities and Exchange Commission requires publicly traded companies to disclose some types of information, such as ownership and purchase and sale of stocks (Securities and Exchange Commission, 2009), there is little legal requirement for disclosure for businesses that are not publicly traded. In 2006, the GAO testified before the Senate that in the process of incorporation, minimal ownership information is collected (GAO, 2006). The GAO reported that "[m]ost states do not require ownership information at the time a company is formed or on the annual and biennial reports most corporations and limited liability companies (LLC) must file" (GAO, 2006). Even when states do collect such information, they do not verify it. As a consequence, there may be no publicly available information on the organizational structure of a private business. The difficulty of identifying organizational structures is such that when a company is debarred from federal contracting because of misbehavior, the debarment does not extend to wholly owned subsidiaries, in large part because the government has no way to identify them (Governmentwide Debarment and Suspension, 2003, p. 66538).

Nor is this data routinely collected when a contractor registers prior to bidding on a government contract. When contractors enter the D&B website to register for a DUNS number as required under the FAR, they may optionally enter information about their parent company. No

DUNS number is assigned to the parent company in this process, and so the parent company may not have a unique identifier. Further, there is no provision for entering multiple parents, where a contractor is a joint venture. When the contractor logs into the CCR with its DUNS number, the CCR collects substantial information that includes the number of its employees and annual receipts, including affiliates, to determine if the contractor is a small business. It does not, however, collect any information about the contractor's organizational structure (Central Contractor Registration, 2011).

Both the data identifying the contractor—the DUNS number—and whatever data links the contractor to its parent company are claimed by D&B as private property even though, in the case of government contractors, D&B acquired the data as a consequence of a monopoly established by federal regulation. D&B bundles and sells corporate information and analysis through a la carte reports or through institutional subscriptions—including to the U.S. government. Among Dun & Bradstreet's analytic products is the *Corporate Family Tree Plus*, which allows the user to get information about the affiliates of a company (D&B Marketing Solutions, n.d.). Some contracting officers may have access to the *Corporate Family Tree* product to investigate the organizational structure of contractors, but it is not universally available and subscriptions are costly.

Recently, some data linking contractors to parents have become publicly available through a government transparency initiative. The government has been engaged in a decades-long process to collect, centralize, standardize, improve the quality of, and make available procurement data (Acquisition Advisory Panel, 2007). The Federal Funding Accountability and Transparency Act of 2006 (Transparency Act) mandated that by 2008 the Office of Management and Budget (OMB) would establish a single searchable and freely available website that included basic information on awards of federal contracts. This information includes the name and location of the entity receiving the award and "a unique identifier of the entity receiving the award and of the parent entity of the recipient, should the entity be owned by another entity" (Federal Funding Accountability and Transparency Act of 2006, p. 120). Shortly thereafter, the government established the website Usaspending.gov, offering a user-friendly interface that allows the public to search a database of government contracts, to view summary statistics, or to download raw data directly.

The data quality problems that have plagued earlier incarnations of this database have not been resolved. Both the comprehensiveness and the quality of the data it offers have been criticized (see, e.g., Lee, 2011). Moreover, the OMB has not yet complied with the legislative requirement that the parents of contractors be listed and identified by unique identifiers. It cannot, given that the government neither collects information on parents nor assigns them identifiers.

In 2009, Dun & Bradstreet decided to allow Usaspending.gov to release data linking contractors to their parent companies, which it had "protected in [the Dun & Bradstreet] licensing relationship since its inception" (B. William, personal communication, October 20, 2009).[4] However, there are still consequences for the government's reliance on third party data. The government has no control over the data quality. D&B does not have the data that the government must supply by law because it does not require contractors to supply information on their parents or assign parents a DUNS number. The property rights asserted by D&B also limit the use of the data that it does have. The Usaspending.gov website contains a disclaimer titled "Limited Liability," which states that some of the data provided "is the intellectual property of the third party information suppliers," is supplied without any kind of warranty, is for internal use only, cannot be used for commercial or marketing purposes, and prohibits "systematic access" or extraction of content from the website.

Complexities of Contractor Organizational Structures

While the quality of data provided on Usaspending.gov linking contractors to parent companies is poor, analysis of that data suggests that a significant number of contractors may have complex organizational structures. Using the Contractor Network Extraction Software (CNES) written by the author to analyze the Usaspending.gov data, it was possible to reconstruct part of the organizational structures of contractors by matching parents and subsidiaries using either the DUNS number or, where this is lacking, the company name. This in turn allows analysis at the organizational level as well as visualization of these organizations using freely available social network analysis software.

CNES is a do file that runs under STATA, a data analysis and statistical software package. The program treats each Usaspending.gov record containing the contractor DUNS number ("dunsnumber") and parent DUNS number ("parentdunsnumber") as an edge in a directed graph whose nodes are DUNS entities (businesses or co-located subdivisions). The program then breaks the data into separate components by traversing each graph and assigning a common identifier ("componentnum") to each edge in the same graph. The user can then use STATA or CNES utilities to select components of interest (for example, components containing a particular business name or components of a particular size), and export them to Netdraw or Pajek for visualization. Under optional name-based matching, the program will match edges based on the contractor name ("recipientorcontractorname") and parent name ("parentrecipientorcontractorname") if DUNS numbers are not available. Whether an edge has been matched based on DUNS number or name is preserved in the variable "pnamematch," and exported as a tie strength variable for Netdraw, which allows the user to see the basis for the match in the visualization of the component. This is important because name-based matching is more error-prone than matching based on DUNS numbers. Readers who wish more information are invited to consult the program source code and the program documentation, which are freely available under a GNU General Public License at http://www.usgcontractors.info.

The Figure shows a Netdraw visualization of the organizational structure of three large government contractors based on 2010 Usaspending.gov data. Each node represents a DUNS entity (a location or co-located subdivision of a business) or is a placeholder for a parent that is named in the dataset, but whose DUNS number is not given.

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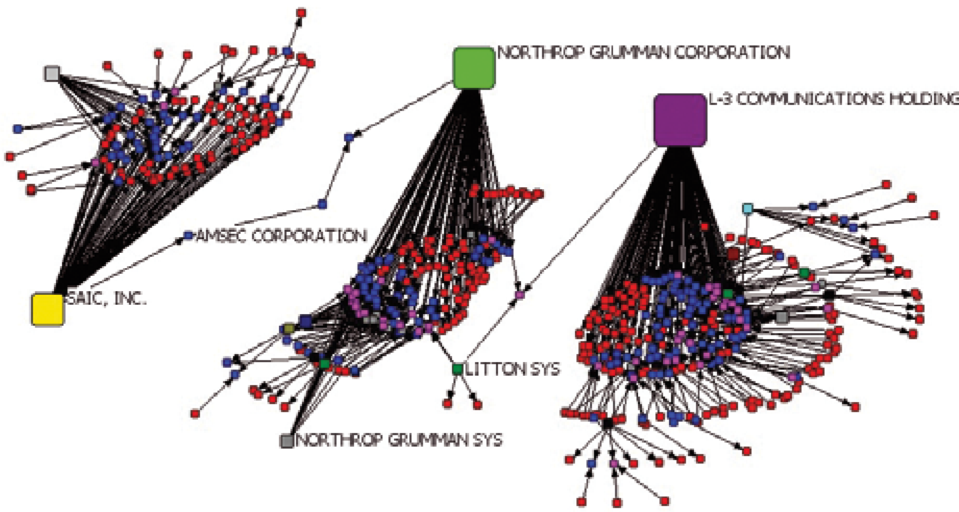
FIGURE. VISUALIZATION OF THREE LARGE GOVERNMENT CONTRACTORS USING CONTRACT NETWORK EXTRACTION SOFTWARE (CNES)



Note. Visualization of three large government contractors—SAIC, Inc., Northrup Grumman Corporation, and L-3 Communications Holdings—joined in a single network perhaps through joint ventures or transfer of business units. Adapted from 2010 Usaspending.gov data using the author's Contract Network Extraction Software; visualized using Netdraw (Borgatti, 2006). Each node is a possible location, subdivision, or subsidiary. The color and size of nodes indicate "degree," or the number of other nodes to which it is connected.

The contractor networks produced by this method must be treated as hypotheses that remain to be confirmed by other means because the data quality is poor. The quality and timeliness of the parent linkage data are unknown—such relationships are very fluid, and it is not clear if there is any auditing to ensure the correctness of data entered in these fields. Joint ventures are reported inconsistently, and all parents may not be listed.Some entities may have multiple DUNS numbers and use them inconsistently. Name-based matching risks erroneous matches if companies have the same name, as well as the risk of mistakenly treating the same company as two different companies because of variations in the entry of the company name (although the program does control for the most common variations). Finally, because Usaspending.gov only contains data on contractors and their parents, the data do not include parts of the organizational structure that are neither contractors nor the parents of contractors. Accordingly, the networks produced are necessarily fragmented and partial.

Notwithstanding, the analysis suggests the complex organizational structure of an important percentage of government contractors. Analyzing the 2010 data from Usaspending.gov, roughly 10 percent of the 166,000 contractor organizational structures, or about 17,000 organizations, have seven or more related locations or subsidiaries, while about 6 percent have 20 or more. Locations and subsidiaries can be nested several levels deep, and some organizations are multinational. Because these structures are partial, more complete data would likely show a greater level of complexity.

Many individual companies contract across a range of government agencies, which suggests that any process for gathering information on contractor organizational structures must be located at a governmental, rather than an agency level. For example, in 2010 Oshkosh Corporation contracted with agencies including the Department of Defense, the Department of Interior, the Department of Justice, the Department of Homeland Security, the General Services Administration, and the National Aeronautics and Space Administration. But even companies that contract with only a single agency may belong to organizations that contract more widely. For example, as foreign aid has been militarized over the last decade, a number of aid contractors have been bought by defense contractors. The aid contractors continue to contract only or principally with the United States Agency for International Development, but their organizations contract with other government agencies.

Given this level of complexity, even if the OMB complied with the Transparency Act obligation to identify the parent of the contractor, the objective of allowing the public to understand who is ultimately benefiting from a government contract would not be met. Similarly, this complexity and the lack of easily available public information make it very unlikely that contracting officers, competitors, the public, or even contractors themselves could identify OCIs without substantial improvements in government data collection.

Conclusions

Policy debates continue about how government contracting officers should best handle OCIs when they encounter them, but the government does not have and is not collecting the information necessary to detect OCIs in the first place. While the FAR lists a number of ways for contracting officers to detect OCIs, including asking other people in their offices, these methods are very unlikely to result in detection given the complexity, opacity, and international character of many organizational relationships.

Ownership relationships are not the only type of relationships that could generate an organizational conflict of interest, but detection of OCIs based on other types of relationships is even more difficult. Organizations may have contractual relationships that could give rise to conflicts, such as teaming and subcontracting relationships, and subcontracting relationships can be tiered several layers deep. Neither the government nor the public has good access to information about these relationships. Usaspending.gov has started making available information on first-tier subcontracts, but without the information needed to link them to their primes. Organizations can also be characterized by interlocking ownerships where, although companies are legally separate, they are owned or managed by the same individuals. The GAO has pointed to several cases in which owners of debarred firms continued to receive government awards by spinning off new companies or disguising the true owner of the company (GAO, 2009). Identifying interlocking ownership could not be accomplished without a unique identifier for people—and the United States has firmly rejected the idea of creating such an identifier out of privacy concerns and fear of giving too much power to the government (see Electronic Privacy Center, 2008). Finally, the question of how to identify the relevant activities of related entities remains unanswered. If the contractors themselves cannot do it, it seems very unlikely that anyone else can.

When it comes to OCI, policymaking is outstripping the realities of available information. In the absence of adequate information, the policy debates on OCI avoidance and mitigation risk being largely theoretical. The questions of what kind of information is needed to identify OCIs, who should collect this information, and who should have access to it must be addressed in the elaboration of OCI policy. At the same time, the need for information about the identity, relationship, and activities of government contractors is part of a much larger discussion regarding the balance between security, liberty, privacy, protection from misuse of government power, and the assurance of accountable and efficient government operation.

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Endnotes

1. For purposes of this article, the term “organizational structure” refers to a contractor and its affiliates, including parents and subsidiaries.
2. This personal communication (letter dated July 21, 2010) from Mitchell Vakerics, policy manager for The Coalition for Government Procurement, replied to Amy Williams, Office of the Under Secretary of Defense (Acquisition, Technology and Logistics), Defense Procurement and Acquisition Policy and Pricing (Defense Acquisition Regulation Systems), issuing comments on the implementation of Section 207 of the Weapons Systems Acquisition Reform Act of 2009, 75 Federal Regulation 20954 (April 22, 2010) “Proposed Rule” on Organizational Conflicts of Interest. Retrieved from http://www.regulations.gov/#documentDetail;D=DARS=2010-0045-0016.
3. Because it is only five digits long, the Commercial and Government Entity (CAGE) Code assigned to each contractor on registration is insufficient given the number of contractors.
4. This personal communication (e-mail) is courtesy of T. Christian Williams, pursuant to his Freedom of Information Act (FOIA) Request No. 197667 submitted to the General Services Administration.

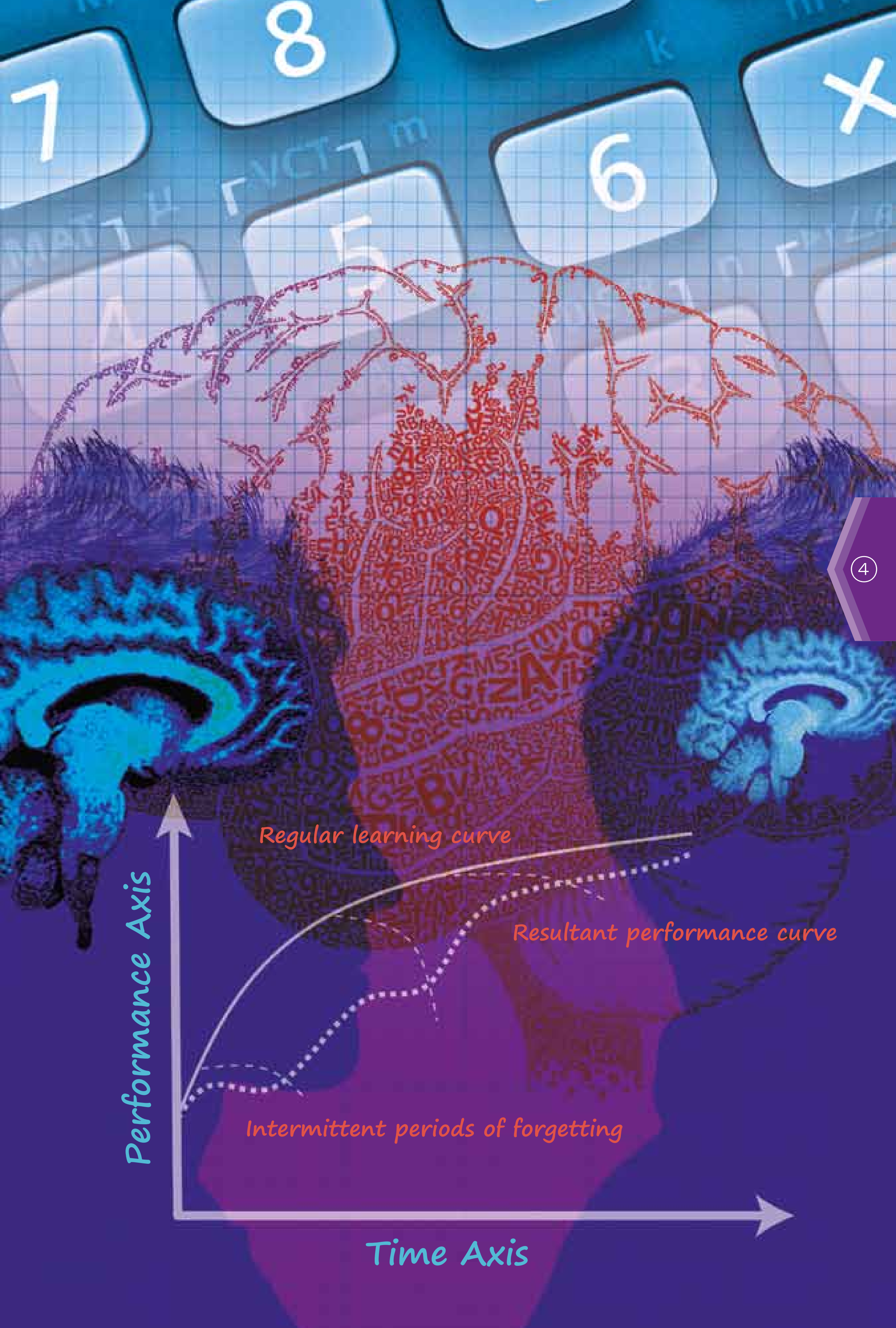
Keywords: *Learning Curve, Half-Life, Learn-Forget Models, Performance, Training, Acquisition*

Half-Life Learning Curves in the Defense Acquisition Life Cycle

Adedeji B. Badiru

Learning curves are useful for assessing performance improvement due to the positive impact of learning. In recent years, the deleterious effects of *forgetting* have also been recognized. Workers experience forgetting or decline in performance over time. Consequently, contemporary learning curves have attempted to incorporate forgetting components into learning curves. An area of increasing interest is the study of how fast and how far the forgetting impact can influence overall performance. This article introduces the concept of half-life analysis of learning curves using the concept of growth and decay, with particular emphasis on applications in the defense acquisition process. The computational analysis of the proposed technique lends itself to applications for designing training and retraining programs for the Defense Acquisition Workforce.

image designed by Diane Fleischer »


Regular learning curve
Resultant performance curve
Intermittent periods of forgetting
Performance Axis
Time Axis

THE ILLITERATE OF THE 21ST CENTURY WILL NOT BE THOSE WHO CANNOT READ AND WRITE, BUT THOSE WHO CANNOT LEARN, UNLEARN, AND RELEARN.
—ALVIN TOFFLER

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Formal analysis of learning curves first emerged in the mid-1930s in connection with the analysis of the production of airplanes (Wright, 1936). Learning refers to the improved operational efficiency and cost reduction obtained from repetition of a task. Learning curves have been used for decades to assess improvement achieved over time due to the positive impacts of learning. Early analytical modeling of learning curves focused on reduction in cumulative average cost per unit as production level doubles. Several alternate models of learning curves have been presented in the literature of the decades. The classical models have been successfully applied to a variety of problems. In recent years, the deleterious effects of forgetting have also been recognized. It has been shown that workers experience forgetting or decline in performance even while they are making progress along a learning curve. Consequently, contemporary learning curves have attempted to incorporate forgetting components into learning curves. An area of increasing interest is the study of how fast and how far the forgetting impact can influence overall performance.

This article presents the concept of half-life analysis of learning curves (Badiru, 2010), using the concept of *growth* and *decay* of learning in the acquisition environment. Half-life is the amount of time it takes for a quantity to diminish to half of its original size through natural processes. Although the common application of half-life is in natural sciences, the computational analysis lends itself to applications to learning curves. Several research and application studies have confirmed that human performance improves with reinforcement or frequent and consistent repetitions. Badiru (1992, 1994) provides a computational survey of learning curves as well as industrial application to productivity and performance analysis. Reductions in operation processing times achieved through learning curves can directly translate to cost savings. In today's technology-based operations, retention of learning may be threatened by fast-paced shifts in operating requirements. Thus, those involved in computational analysis of learning curves may find it of benefit to study the half-life properties of learning curves. Information about the half-life can tell us something about the sustainability of learning-induced performance. This is particularly useful for designing training programs and assessing workers' performance.

Concept of Growth and Decay

Growth and decay occur naturally in many processes. We often speak of "twice as much" and "half as much" as benchmarks for process analysis. In economic and financial principles, the "rule of 72" refers to the length of time required for an investment to double in value. These common "double" or "half" concepts provide the motivation for examining half-life properties of learning curves. The usual application of half-life is in natural sciences. For example, in Physics, the half-life is a measure of the stability of a radioactive substance. In practical terms, the half-life of a substance is the time it takes for the substance to decay to half of its initial size. The longer the half-life of a substance, the more stable it is. This provides a good analogy for modeling learning curves with the recognition of increasing performance or decreasing cost with respect to the passage of time. For purposes of this article, the following key definitions are provided:

- *Half-life* of a *learning curve* is the incremental production level required to reduce cumulative average cost per unit to half of its initial level.

- *Half-life* of a *forgetting curve* is the amount of time it takes for performance to decline to half of its initial level.

Literature on Learning Curves

Although an extensive collection exists of classical studies of performance *improvement* due to learning curves, only very limited attention has been paid to performance *degradation* due to the impact of forgetting. Some of the classical works on process improvement due to learning include Smith (1989); Belkaoui (1976, 1986); Nanda (1979); Pegels (1976); Richardson (1978); Towill, and Kaloo (1978); Womer (1979, 1981, 1984); Womer and Gulledge (1983); Camm, Evans, and Womer (1987); Liao (1979); McIntyre (1977); Smunt (1986); Sule (1978); and Yelle (1976, 1979, 1983). Only in recent years has the recognition of "forgetting" curves begun to emerge, as can be seen in more recent literature (Badiru, 1995; Jaber & Sikstrom, 2004; Jaber, Hemant, & Darwin, 2003; Jaber &

Bonney, 2003, 2007; Jaber & Guiffrida, 2008). The new and emerging research on the forgetting components of learning curves provides the motivation for studying half-life properties of learning curves. Performance decay can occur due to several factors, including lack of training, reduced retention of skills, lapse in performance, extended breaks in practice, and natural forgetting.

The Acquisition Learning Framework

It is a natural process for people to learn, unlearn, and relearn. Capturing this process in a quantitative framework is essential for making effective decisions in any operation, particularly in the defense acquisition environment, where human-machine interfaces are common.

Defense acquisition endeavors often get behind schedule, exceed cost baselines, and/or exhibit poor performance. Many of these problems have their sources in the human elements within the acquisition life cycle. Ward (2010, 2012), using his FIST (Fast, Inexpensive, Simple, and Tiny) model, calls for rapid acquisition using the concept of "80% now is better than 100% later." This perfectly fits the learning curve approach proposed in this article.

Because the degradation of learning does not follow a linear path, it is essential to monitor the various stages of the learning, unlearning, and relearning processes. This article presents an analytical modeling of the stage where a learning profile has degraded to half of its initial value. This is useful for predicting the magnitude and behavior of learning over time. The article points out that the half-life point is of most interest in tracking the degradation path of learning. That half-life point can be used for acquisition training and retraining purposes. With the techniques in this article, something similar to a break-even analysis of learning can be done because the upswing of learning and the downswing of learning conceptually intercept at some point. Of particular note in the decision process is whether that interception point occurs before or after the half-life point. For the purpose of training in acquisition operations, an organization can use the half-life computational technique to estimate what fraction of training retention remains after some point in time and what level of retraining might be needed during the acquisition life cycle.

General Half-Life Profile

Figure 1 shows a graphical representation of performance as a function of time under the influence of forgetting (i.e., performance decay). Performance decreases as time progresses. The objective is to determine when performance has decayed to half of its original level. Based on the law of radioactive disintegration, the Law of Learning Decay is proposed here.

> *The rate of decay of learning due to the effect of forgetting is proportional, at any instant, to the incipient learning level.*

The Law of Learning Decay is formulated mathematically in subsequent sections of this article. A mathematical abstraction of the physical process of learning and forgetting is formulated by considering the rate of change in performance (*P*), which is a function of the learning rate (*L*). While learning itself is difficult to quantify and measure, its output and performance can be measured as a physical quantity of production. The discrete process is approximated by a continuous curve.

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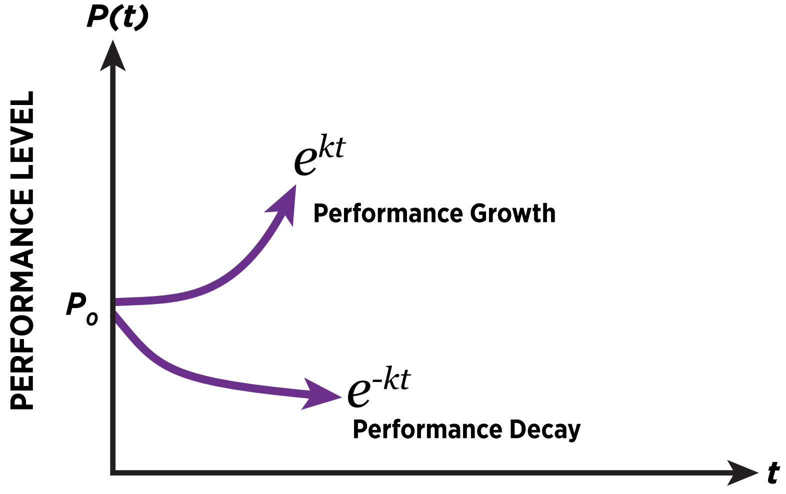
FIGURE 1. REPRESENTATION OF SYSTEM RESPONSE TIME WITH RESPECT TO PASSAGE OF TIME



Thus, the following mathematical formulation emerges: At time *t*, a certain level of learning *L*, yields a certain level of performance denoted as *P*. Denote this transformation as:

$$\mathrm{L} \rightarrow \mathrm{P}$$

The rate of decay of *P* can be written as:

$$\frac{d[P]}{dt} = -k[P],$$

where k = decay coefficient. This has the general form of an initial value problem in first-order linear equations, and it has the following general solution:

$$P(t) = P_0 e^{-kt},$$

4

where P_0 = initial level of performance. The half-life of *P* is computed as the value of *t* at which *P* decays to half of its original level. That is:

$$P(t_{1/2}) = P_0 e^{-kt_{1/2}} = \left(\frac{1}{2}\right) P_0 e^{-kt_0},$$

which is solved to obtain the half-life as:

$$t_{1/2} = \frac{1}{k} \ln 2.$$

To illustrate the application of half-life computations, consider an engineering reactor that converts the relatively stable uranium 238 into the isotope plutonium 239. After 15 years, it is determined that 0.043 percent of the initial amount A_0 of the plutonium has disintegrated. Determining the half-life of the isotope is the point of interest. From Physics, the initial value problem is stated as:

$$\frac{dP}{dt} = kP$$

with $P(0) = P_0$. This has a general solution of the form:

$$P(t) = P_0 e^{-kt}$$

If 0.043 percent of the atoms in A_0 have disintegrated, then 99.957 percent of the substance remains. To find *k*, we will solve:

$$\alpha P_0 = P_0 e^{-15k}$$

where α = remaining fraction of the substance. With α we obtain *k* = 0.00002867. Thus, for any time *t*, the amount of the plutonium isotope remaining is represented as:

$$P(t) = P_0 e^{-0.00002867t}$$

This has a general decay profile similar to the plot of *P*(*t*) in Figure 1. Computation can now be done of the half-life as corresponding value at time *t* for which *P*(*t*) = $P_0/2$. That is:

$$\frac{P_0}{2} = P_0 e^{-0.00002867t}$$

which yields *t* (half-life) value of 24,180 years. With this general knowledge of the half-life, several computational analyses can be done to predict the behavior and magnitude of the substance over time. As another example, consider a radioactive nuclide, which has a half-life of 30 years. Suppose the interest lies in computing the fraction of an initially pure sample of this nuclide that will remain undecayed at the end of a time period, say 90 years. From the equation of half-life, the solution for *k* can be deduced:

$$\frac{P_0}{2} = P_0 e^{-kt_{half-life}}$$

$$k = \frac{\ln 2}{t_{half-life}}$$

Which gives *k* = 0.0231049. Now, we can use this value of *k* to compute:

$$\frac{P_0}{P} = e^{-(0.0231049)(90)} = 0.125$$

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Similarly, let us consider a radioactive isotope with a half-life of 140 days. The number of days it would take for the sample to decay to one-seventh of its initial magnitude can be computed:

$$\frac{P_0}{2} = P_0 e^{-kt_{half-life}}$$

$$k = \frac{\ln 2}{t_{half-life}}$$

Which yields k = 0.004951 and results in:

$$P = 1/7P_0$$

$$\frac{1}{7}P_0 = P_0 e^{-kt}$$

$$t = \frac{\ln 7}{k} = 393 \ days$$

For learning curves, similar computational analysis can be performed to assess the forgetting-induced properties of the curves. Thus, a comparative analysis of the different models can be conducted.

Half-Life Application to Learning Curves

Wright (1936) documented the "80 percent learning" effect, which indicates that a given operation is subject to a 20 percent productivity improvement each time the activity level or production volume *doubles*. The proposed half-life approach is the antithesis of the double-level milestone. Some of the classical learning curve models are:

- *Log-linear model*
- *S-curve model*
- *Stanford-B model*
- *DeJong's learning formula*
- *Levy's adaptation function (Levy, 1965)*
- *Glover's learning formula (Glover, 1966)*
- *Pegels' exponential function (Pegels, 1976)*
- *Knecht's upturn model (Knecht, 1974)*
- *Yelle's product model*

The basic log-linear model is the most popular learning curve model. It expresses a dependent variable (e.g., production cost) in terms of some independent variable (e.g., cumulative production). The model states that the improvement in productivity is constant (i.e., it has a constant slope) as output increases. That is:

$$C(x) = C_1 x^{-b}$$

Where:

$C(x)$ = cumulative average cost of producing x units

C_1 = cost of the first unit

x = cumulative production unit

b = learning curve exponent

Notice that the expression for *C(x)* is practical only for $x > 0$. This makes sense because learning effect cannot realistically kick in until at least one unit ($x \geq 1$) has been produced. For the standard log-linear model, the expression for the learning rate, *p*, is derived by considering two production levels where one level is double the other. For example, given the two levels x_1 and x_2 (where $x_2 = 2x_1$), the following expressions emerge:

$$C(x_1) = C_1(x_1)^{-b}$$
$$C(x_2) = C_1(2x_1)^{-b}$$

The percent productivity gain, *p*, is then computed as:

$$p = \frac{C(x_2)}{C(x_1)} = \frac{C_1(2x_1)^{-b}}{C_1(x_1)^{-b}} = 2^{-b}$$

4

The performance curve, *P(t)*,shown earlier in Figure 1 can now be defined as the reciprocal of the average cost curve, *C(x)*, and as a function of production level, *x*. Thus, we have

$$P(x) = \frac{1}{C(x)}.$$

The application of half-life analysis to learning curves can help address questions such as:

- How fast and how far can system performance be improved?
- What are the limitations to system performance improvement?
- How resilient is a system to shocks and interruptions to its operation?
- Are the performance goals that are set for the system achievable?

Derivation of Half-Life of the Log-Linear Learning Curve

Figure 2 shows a pictorial representation of the basic log-linear model, with the half-life point indicated as $x_{1/2}$. The half-life of the log-linear model is computed as follows:

C_0 = Initial performance level

$C_{1/2}$ = Performance level at half-life

$$C_0 = C_1 x_0^{-b} \text{ and } C_{1/2} = C_1 x_{1/2}^{-b}$$

$$\text{But } C_{1/2} = \frac{1}{2} C_0$$

Therefore, $C_1 x_{1/2}^{-b} = \frac{1}{2} C_1 x_0^{-b}$, which leads to $x_{1/2}^{-b} = \frac{1}{2} x_0^{-b}$,

Which, by taking the (-1/*b*)th exponent of both sides, simplifies to yield the following expression as the general expression for the standard log-linear learning curve model,

$$x_{1/2} = \left(\frac{1}{2}\right)^{-\frac{1}{b}} x_0, \; x_0 \geq 1$$

where $x_{1/2}$ is the half-life and x_0 is the initial point of operation; $x_{1/2}$ is then referred to as the *First-Order Half-Life*.

The *Second-Order Half-Life* is computed as the time corresponding to half of the preceding half. That is:

$$C^1 x_{1/2(2)}^{-b} = \frac{1}{4} C_1 x_0^{-b},$$

which simplifies to yield:

$$x_{1/2(2)} = \left(\frac{1}{2}\right)^{-\frac{2}{b}} x_0.$$

Similarly, the Third-Order Half-Life is derived to obtain:

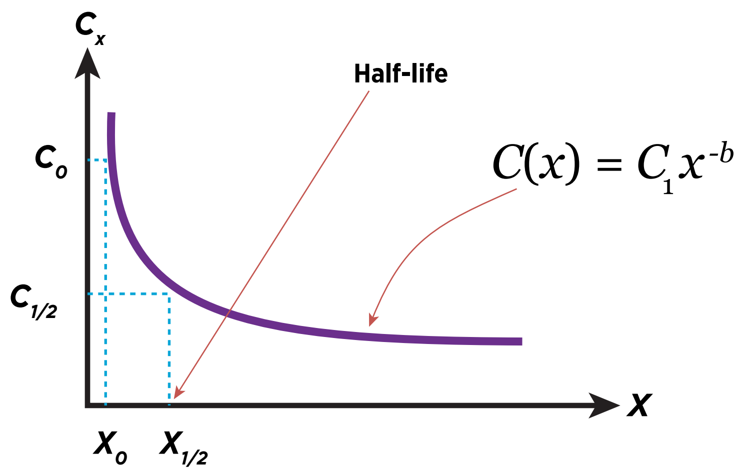
$$x_{1/2(3)} = \left(\frac{1}{2}\right)^{-\frac{3}{b}} x_0,$$

4

In general, the k^{th}-Order Half-Life for the log-linear model is represented as:

$$x_{1/2(k)} = \left(\frac{1}{2}\right)^{-\frac{k}{b}} x_0.$$

FIGURE 2. GENERAL PROFILE OF THE BASIC LEARNING CURVE MODEL



Computational Examples

Figure 3 shows a comparison of learning curve profiles of the log-linear model with b = 0.75 and b = 0.3032 respectively. The graphical profiles reveal the characteristics of learning, which can dictate the half-life behavior of the overall learning process. Knowing the point where the half-life of each curve occurs can be very useful in assessing learning retention for the purpose of designing training programs or designing work.

For $C(x) = 250x^{-0.75}$, the First-Order Half-Life is computed as:

$$x_{1/2} = \left(\frac{1}{2}\right)^{-\frac{1}{0.75}} x_0, \; x_0 \geq 1$$

If the above expression is evaluated for $x_0 = 2$, the first-order half-life yields $x_{1/2}$ = 5.0397, which indicates a fast drop in the value of $C(x)$.The specific case of x_0 = 2 shows $C(2)$ = 148.6509 corresponding to a half-life of 5.0397. Note that $C(5.0397) = 74.7674$, which is about half of 148.6509. The conclusion from this analysis is that if we are operating at the point $x = 2$, we can expect this particular curve to reach its half-life decline point at $x = 5$.

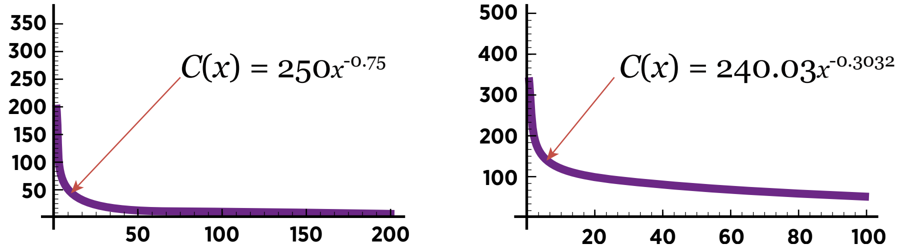
For $C(x) = 240.03x^{-0.3032}$, the First-Order Half-Life is computed as:

$$x_{1/2} = \left(\frac{1}{2}\right)^{-\frac{1}{0.3032}} x_0, \; x_0 \geq 1$$

If we evaluate the above function for $x_0 = 2$, the First Order Half-Life yields $x_{1/2} = 19.6731$. This does not represent as precipitous a drop as the other curve. The half-life analysis can be applied to learning curves to determine when each cost element of interest will decrease to half of its starting value. This information can be useful for product pricing purposes, particularly for technology products that are subject to rapid price reductions due to declining product cost. Several models and variations of learning curves have been reported in the literature (Badiru, 1992; Jaber & Guiffrida, 2008). Models are developed through one of the following approaches:

1. Conceptual models
2. Theoretical models
3. Observational models
4. Experimental models
5. Empirical models

FIGURE 3. COMPARISON OF LOG-LINEAR CURVES FOR *b* = -0.75 AND *b* = -0.3032



Half-Life Derivations for Classical Learning Models

The S-Curve model. The S-Curve (Towill & Cherrington, 1994) is based on an assumption of a gradual start-up. The function has the shape of the cumulative normal distribution function for the start-up curve and the shape of an operating characteristics function for the learning curve. The gradual start-up is based on the fact that the early stages of production are typically in a transient state with changes in tooling, methods, materials, design, and even changes in the workforce. The basic form of the S-Curve function is:

$$C(x) = C_1 + M(x+B)^{-b}$$

$$MC(x) = C_1\left[M + (1-M)(x+B)^{-b}\right]$$

Where:

C(x) = learning curve expression

b = learning curve exponent

M(x) = marginal cost expression

C_1 = cost of first unit

M = incompressibility factor (a constant)

B = equivalent experience units (a constant).

4

Assumptions about at least three out of the four parameters (*M, B,* C_1, and *b*) are needed to solve for the fourth one. Using the *C(x)* expression and derivation procedure outlined earlier for the log-linear model, the half-life equation for the S-Curve learning model is derived to be:

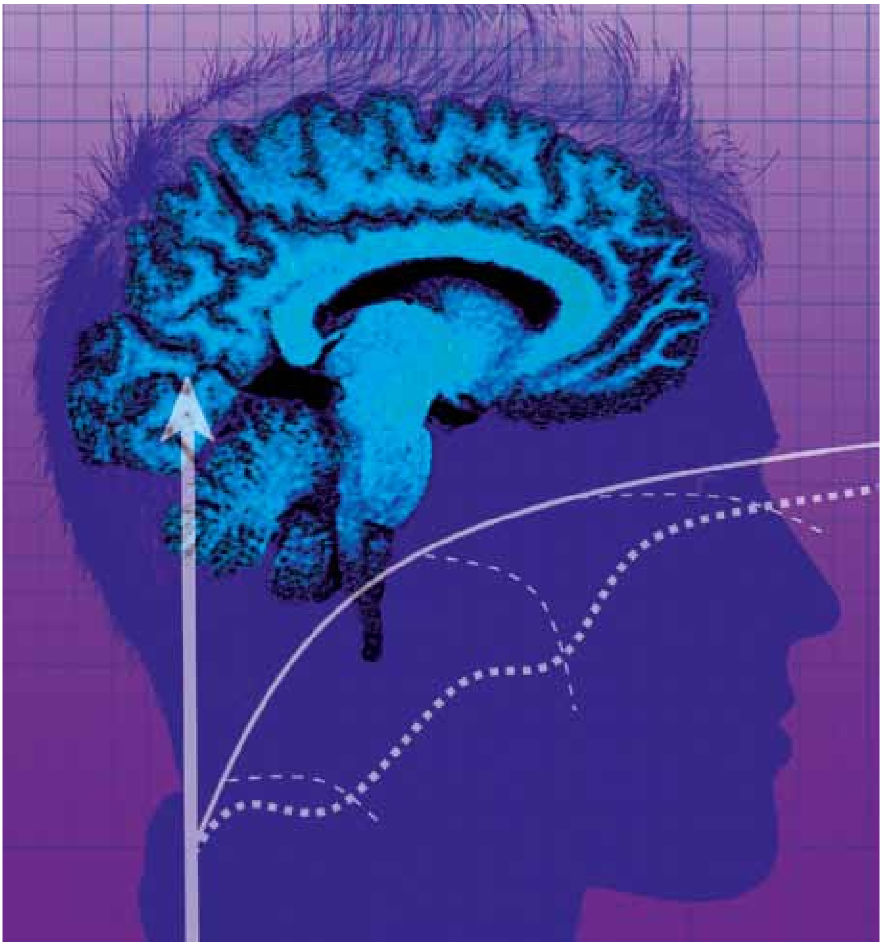
$$x_{1/2} = (1/2)^{-1/b}\left[\frac{M(x_0+B)^{-b} - C_1}{M}\right]^{-1/b} - B$$

Where:

$x_{1/2}$ = half-life expression for the S-Curve Learning Model

x_0 = initial point of evaluation of performance on the learning curve

In terms of practical application of the S-Curve, consider when a worker begins learning a new task. The individual is slow initially at the tail end of the S-Curve. But the rate of learning increases as time goes on, with additional repetitions. This helps the worker to climb the steep-slope segment of the S-Curve very rapidly. At the top of the slope, the worker is classified as being proficient with the learned task. From then on, even if the worker puts much effort into improving upon the task, the resultant learning will not be proportional to the effort expended. The top end of the S-Curve is often called the slope of *diminishing returns*. At the top of the S-Curve, workers succumb to the effects of *forgetting* and other performance-impeding factors. As the work environment continues to change, a worker's level of skill and expertise can become obsolete. This is an excellent reason for the application of half-life computations.



The Stanford-B model. An early form of learning curve is the Stanford-B model, which is represented as:

$$UC(x) = C_1(x + B)^{-b}$$

Where:

$UC(x)$= direct cost of producing the x^{th} unit

b = learning curve exponent

C_1= cost of the first unit when B = 0;

B = slope of the asymptote for the curve;

B = constant ($1 < B < 10$). This is equivalent units of previous experience at the start of the process, which represents the number of units produced prior to first unit acceptance. It is noted that when $B = 0$, the Stanford-B model reduces to the conventional log-linear model. Figure 4 shows the profile of the Stanford-B model with B = 4.2 and b = -0.75. The general expression for the half-life of the Stanford-B model is derived to be:

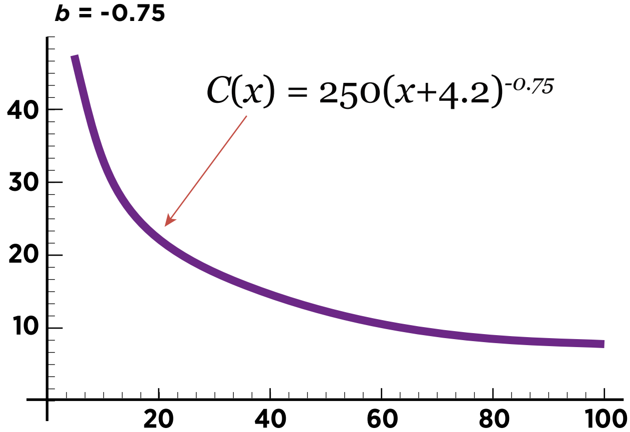
$$x_{1/2} = (1/2)^{-1/b}(x_0 + B) - B$$

Where:

$x_{1/2}$ = half-life expression for the Stanford-B Learning Model

x_0 = initial point of evaluation of performance on the learning curve

FIGURE 4. STANFORD-B MODEL WITH PARAMETERS *B* = 4.2 AND *b* = -0.75



Multifactor Half-Life Derivation

Badiru (1994) presents applications of learning and forgetting curves to productivity and performance analysis. One example presented used production data to develop a predictive model of production throughput. Two data replicates are used for each of 10 selected combinations of cost and time values. Observations were recorded for the number of units representing double production levels. The resulting model has the functional form below and the graphical profile shown in Figure 5.

$$C(x) = 298.88 x_1^{-0.31} x_2^{-0.13}$$

Where:

$C(x)$ = cumulative production volume

x_1 = cumulative units of Factor 1

x_2 = cumulative units of Factor 2

b_1 = First learning curve exponent = -0.31

b_2 = Second learning curve exponent = -0.13

A general form of the modeled multifactor learning curve model is:

$$C(x) = C_1 x_1^{-b_1} x_2^{-b_2}$$

and the half-life expression for the multifactor learning curve was derived to be:

$$x_{1(1/2)} = (1/2)^{-1/b_1} \left[\frac{x_{1(0)} x_{2(0)}^{b_2/b_1}}{x_{2(1/2)}^{b_2/b_1}} \right]^{-1/b_1}$$

$$x_{2(1/2)} = (1/2)^{-1/b_2} \left[\frac{x_{2(0)} x_{1(0)}^{b_1/b_2}}{x_{1(1/2)}^{b_2/b_1}} \right]^{-1/b_2}$$

4

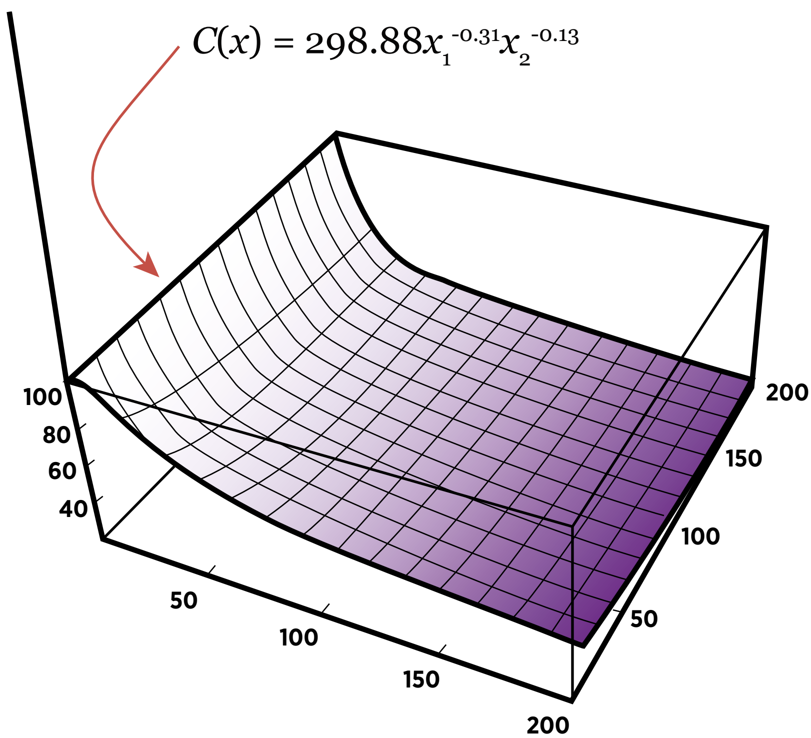
Where:

$x_{i(1/2)}$ = half-life component due to Factor i (i = 1, 2)

$x_{i(0)}$ = initial point of Factor i (i = 1, 2) along the multifactor learning curve

Knowledge of the value of one factor is needed to evaluate the other factor. Just as in the case of single-factor models, the half-life analysis of the multifactor model can be used to predict when the performance metric will reach half of a starting value.

FIGURE 5. BIVARIATE MODEL OF LEARNING CURVE



Incorporation of Forgetting Functions into Learning Curves

Several factors can influence learning rate in practice. A better understanding of the profiles of learning curves can help in the development of forgetting intervention programs and for the assessment of the sustainability of learning. For example, shifting from learning one operational process to another can influence the half-life profile of the original learning curve. Important questions that half-life analysis can address include the following:

1. What factors influence learning retention and for how long?
2. What factors foster forgetting and at what rate?
3. What joint effects exist to determine the overall learning profile for worker performance and productivity?
4. What is the profile of and rate of decline of the forgetting curve?

The issues related to the impact of forgetting in performance and productivity analysis are brought to the forefront by Badiru (1994, 1995) and all the references therein. Retention rate and retention capacity of different workers will determine the nature of the forgetting function to be modeled for the workers. Whenever interruption occurs in the learning process, as in scheduled breaks (Anderlohr, 1969), it results in some forgetting. The resulting drop in performance rate depends on the initial level of performance and the length of the interruption. The following three potential cases illustrate how forgetting may occur:

Case 1: Forgetting may occur continuously throughout the learning process.

Case 2: Forgetting may occur discretely over distinct bounded time intervals.

Case 3: Forgetting may occur over intermittent and/or random time intervals where the time of occurrence and duration of forgetting are described by some probability distribution.

Any operation that is subject to interruption in the learning process is susceptible to the impact of forgetting. Sule (1978) postulated that the forgetting model can be represented as:

$$y_f = x_f r_f^{-b_f},$$

where:

y_f = number of units that could be produced on r^{th} day in the presence of *forgetting*.

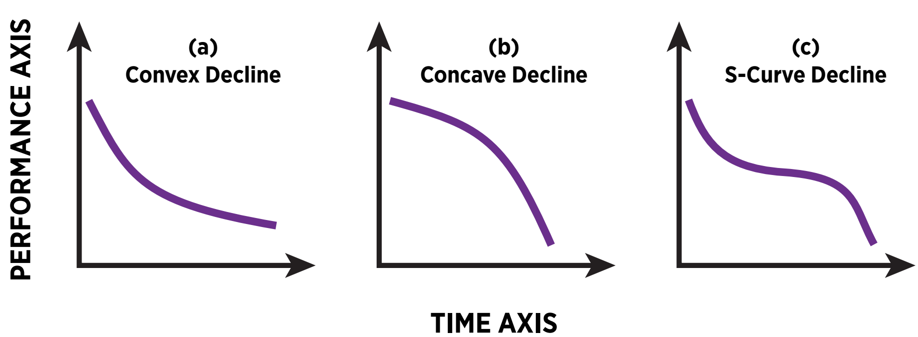
x_f = equivalent production on first day of the forgetting curve.

r_f = cumulative number of days in the forgetting cycle.

b_f = forgetting rate.

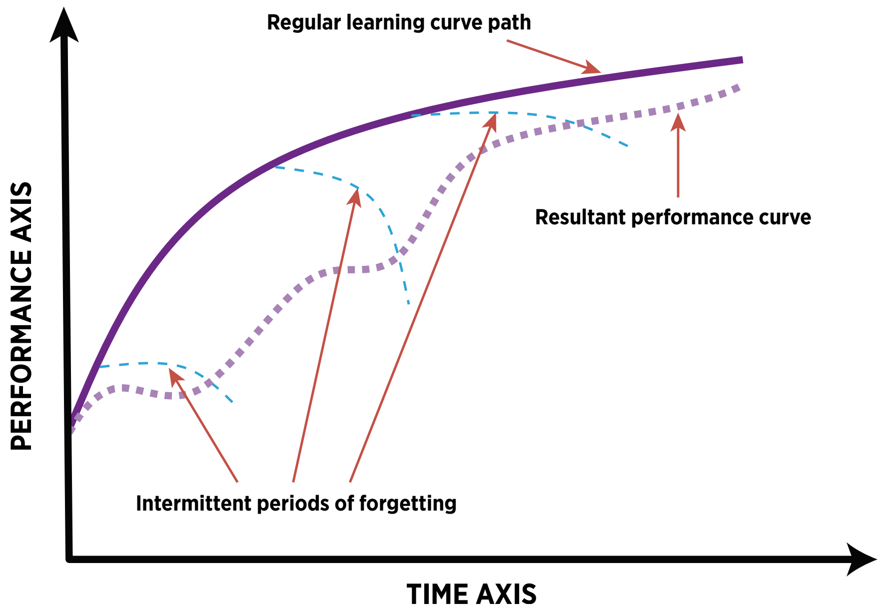
The forgetting function has the same basic form as the standard learning curve model, except that the forgetting rate will be negative, indicating a decay process. Figure 6 shows some of the possible profiles of the forgetting curve. Profile (a) shows a case where forgetting occurs rapidly along a convex curve. Profile (b) shows a case where forgetting occurs more slowly along a concave curve. Profile (c) shows a case where the rate of forgetting shifts from convex to concave along an S-Curve.

FIGURE 6. ALTERNATE PROFILES DECLINING IMPACT OF FORGETTING



The profile of the forgetting curve and its mode of occurrence can influence the half-life measure. This is further evidence that the computation of half-life can help distinguish between learning curves, particularly if a forgetting component is involved. The combination of the learning and forgetting functions presents a more realistic picture of what actually occurs in a learning process. The combination is not necessarily as simple as resolving two curves to obtain a resultant curve. The resolution may particularly be complex in the case of intermittent periods of forgetting. Figure 7 shows representations of periods where forgetting occurs and the resultant learn-forget profile.

FIGURE 7. RESOLUTION OF LEARN-FORGET PERFORMANCE CURVES

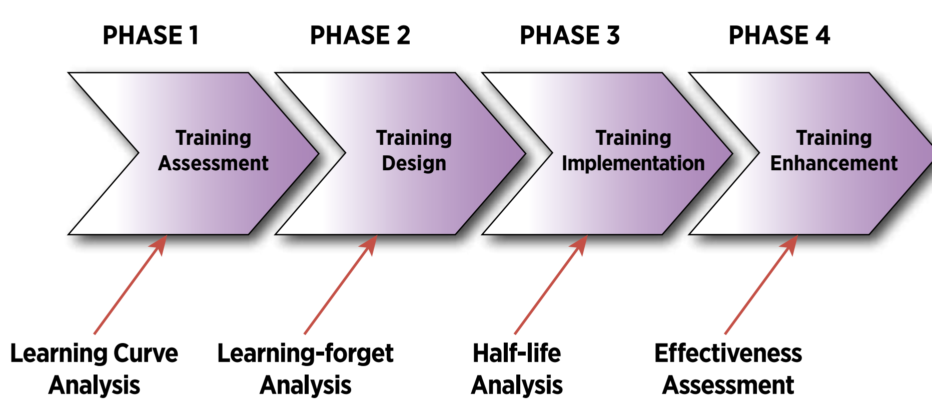


Applications to Training and Worker Effectiveness Analysis

Learning curves are traditionally used for diagnostic and planning purposes in installed operations. The premise of this article is that learning curve analysis, learn-forget modeling, and half-life analysis can be used proactively to design or enhance training programs, thereby improving worker effectiveness. Training is a capital-intensive overhead cost that is often difficult to justify in terms of revenue production. There are two aspects of justifying training programs: effectiveness and efficiency of the training program. Effectiveness refers to the benefits an organization derives from training the workforce to meet organizational objectives. Efficiency refers to the process of determining the resources required for the training versus the expected output. In this process, it is essential to provide the resources required at the right time, in the right form, and in the right quantity. An understanding of the half-life characteristics of the learning process can make the resources allocation process more effective.

In practice, there is a lack of a structured approach to ensuring training effectiveness and efficiency. Sawhney, Badiru, and Niranjan (2004) present a structured model training. The model is adapted here to show where learning curve analysis may be important and how half-life analysis can be incorporated. Figure 8 shows the streamlined training process incorporating learning curve analysis, forgetting analysis, and half-life analysis. The first phase is to assess the alignment of the training program to the organizational strategic goals in light of the learning curve impact. Phase 2 involves specific design of the training program with recognition of the learn-forget phenomenon. Phase 3 addresses training implementation with respect to the limit of the learning effect, half-life properties of learning, and the limit of retention. Phase 4 finalizes the process with training enhancement activities. This can involve resource realignment, output evaluation, and risk mitigation for the subsequent rounds.

FIGURE 8. INCORPORATION OF LEARNING, FORGETTING, AND HALF-LIFE ANALYSIS INTO TRAINING PROCESS



Conclusions

Degradation of performance occurs naturally either due to internal processes or externally imposed events, such as extended production breaks. For productivity assessment purposes, it may be of benefit to determine the length of time it takes a production metric to decay to half of its original magnitude. For example, for career planning strategy, one may be interested in how long it takes for skills sets to degrade by half in relation to current technological needs of the workplace. The half-life phenomenon may be due to intrinsic factors, such as forgetting, or due to external factors, such as a shift in labor requirements. Half-life analysis can have application in intervention programs designed to achieve reinforcement of learning. It can also have application for assessing the sustainability of skills acquired through training programs. Further research on the theory of half-life of learning curves should be directed to topics such as the following:

- Half-Life Interpretations
- Training and Learning Reinforcement Program
- Forgetting Intervention and Sustainability Programs

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In addition to the predictive benefits of half-life expressions, they also reveal the ad hoc nature of some of the classical learning curve models that have been presented in the literature. The author recommends that future efforts to develop learning curve models should also attempt to develop the corresponding half-life expressions to provide full operating characteristics of the models. Readers are encouraged to explore half-life analysis of other learning curve models not covered in this article.

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Professor Adedeji Badiru is head of Systems and Engineering Management at the Air Force Institute of Technology. He is a registered professional engineer, a certified Project Management Professional (PMP), and a Fellow of the Institute of Industrial Engineers. He has BS and MS degrees in Industrial Engineering (IE), an MS in Mathematics from Tennessee Technological University, and a PhD in IE from the University of Central Florida. He has authored several books and journal articles.

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Keywords: *Decision Cost Model (DCM), Decision Tree Node, Cost-Overrun Percentage, Probability, Pearson-Tukey Method*

Decision Cost Model for Contractor Selection

Victor J. Apodaca and Peter C. Anselmo

As U.S. Government facilities age and new facilities are constructed, the need to hire contractors for an increasing number of government construction projects is imperative. The current government technical evaluation for contractor selection is less than optimal. This article introduces an alternative technical evaluation methodology to the current government contractor selection process: a Decision Cost Model (DCM) that can be applied to ensure cost-efficient contractors are selected in awarding construction contracts. Applying the DCM ensures contractors with the lowest expected total cost are recommended for project awards. Also presented are ways DCM can be applied to increase efficiency in the selection process for future government construction projects, while simultaneously meeting taxpayers' expectations of receiving maximum value for their tax dollars.

image designed by Diane Fleischer »

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Applying decision cost analysis provides the U.S. Government an alternative to the existing process for selecting construction contractors. The Decision Cost Model (DCM) proposed in this article evaluates each prospective contractor against computed cost factors and uses the contractor's cost estimates to compute the total expected cost for construction projects. The DCM can be used with any number of contractors and with any number of construction division categories.

The assessment of cost overruns is based on an evaluation of historic data from recent/similar projects undertaken by government contractors. The model considers five recent/similar projects for each contractor. In general, the more recent/similar projects used in the modeling analysis, the better the modeling of total expected cost. In the event a contractor does not have similar project data, the contractor is omitted from the contractor selection pool. The DCM considers cost factors for specific construction division estimates and cost-overrun percentages. Applying the DCM requires the evaluator or project managers to collect historical cost data to compute the division cost factors. In many cases, historical cost data available for the project cost analysis may be limited. However, with expert judgment and careful evaluation of each division cost factor, the program manager (PM) can ensure each contractor is evaluated equitably. Note that just about every division has the potential of cost overruns. Those without a cost overrun indicate the contractor has cost control over the underlying construction division(s), and this control of costs will not negatively impact the total expected cost of the project.

For purposes of this study, the DCM method is applied using the example of three contractors and three cost factors and their computed division cost overrun percentages. The DCM application compares division costs for electrical, structural, and mechanical contractor expenditures. The cost factors are modeled using historical data and expert judgment combined with a probability model to fit a cost-overrun percentage distribution for each cost factor. The Pearson-Tukey method is used to apply cost-overrun probabilities to chance nodes in a three-outcome decision tree (Clemen, 2001). The central idea is to find three representative points in the distribution and assign respective probability values to each outcome. Accordingly, the Pearson-Tukey method allows the PM to pick the most representative points and probability values for each cost factor.

The intent of this article is to demonstrate the development of the DCM decision method and apply the method with an example utilizing real-world data. The DCM method gives an approximation of how division cost-overrun percentages impact the division estimate and the total expected cost for the project (Clemen, 2001). Hence, the DCM method provides a novel way to improve future government contractor selections for awarding government construction projects. The DCM improves the existing contractor selection process by adding an evaluation of potential cost-overruns in computing the total expected cost for a project.

The next three sections of the article describe the current project award process and how the DCM can easily be inserted into the current process; introduce a cost factor data table; and provide a complete description of the DCM and its methodology. Following the DCM methodology, the article discusses applying the DCM in depth, using a real-world example with historical cost data and expert judgment. Finally, the article concludes by reporting the DCM total expected project costs and the author's recommendation for future use of the DCM.

Current Project Award Process

"Best value technically acceptable" is a term used by the government to select a project contractor meeting the technically acceptable criterion at least cost (General Services Administration, 2005). If a contractor has the lowest cost estimate and has met the technically acceptable criteria, then the contractor is awarded the project contract. The current government "best value technically acceptable" criterion does not take into account the impact of potential project cost overruns on the final cost of a government project. This is a shortcoming in conducting feasibility analysis for construction projects.

Government construction projects are projected years in advance of their purposed construction or operation. To understand the needs, requirements, and budget allocation for constructing facilities, government decision makers require more accurate feasibility studies. In general, a feasibility study contains a needs analysis, mission requirements, and cost estimate for the project. Consequently, the feasibility study is instrumental in awarding project contracts. The government cost estimate contained in the feasibility study provides guidance in the solicitation of contractors for the project. Generally, the contractor solicitation for a given construction project will request two forms of cost information: a project cost estimate for a facility meeting the projected needs and performance standards, and the projected contractor's historical cost and performance data relevant to the project. The aim is to forecast the costs required to complete the construction project in accordance with the contract and plans. Construction project estimation is a difficult and time-consuming process. Engineering and contractor experience are needed to complete a good estimate. The PM must assume the roles of both contractor and engineer to ensure sound contracting and engineering principles are adhered to in the construction project.

The government PM represents the taxpayer and is responsible for developing the construction project's Independent Government Estimate (IGE). Because construction projects are projected years in advance of their need, the government PM will prepare a current year IGE for the project. The current year IGE is utilized to perform the technical evaluation and compare the project cost estimates submitted by contractors. The current IGE represents the total estimated cost of the project and division estimated costs. The IGE is developed using *RSMeans,* an industry standard for construction cost estimation. *RSMeans* is a division in Reed Construction Data that provides costs by discipline format, site prep, mechanical, and electrical. The division specializes in providing material, labor, and building cost information to the North America construction industry. (Note that RSMeans cost data are updated annually and delivered in a book or software application.)

The Construction Specifications Institute (CSI) is an organization that maintains and advances the standardization of construction language, as pertains to building specifications. CSI Master Format is an indexing system for organizing construction data and construction specifications. For purposes of this article, the CSI Master Format considers 16 divisions of construction costs. *RSMeans* cost data are available on a software program called *CostWorks* and in *RSMeans* construction cost data manuals. *RSMeans* is a cost data source, which has 45,000 separate cost line items for all areas of construction. Each cost line item represents data collected to represent the mean average of material, labor, and equipment. This cost is gathered from 30 cities throughout the United States. The *RSMeans* database is updated annually, and the data are adjusted to the area of the country where the construction is occurring. For the purpose of construction cost estimation, the *RSMeans* data come in two formats: *RSMeans* 2004, which has a 50-division format, and *RSMeans* 1998, which has a 16-division format. Both formats have the same basic information, with *RSMeans* 2004 separated into the basic information, which is further separated into more specialty divisions.

RSMeans 1998 defines construction disciplines by 16 separate areas identified as divisions:

1. Division 1 is "General Requirements." General Requirements are items such as supervisor, project manager costs, vehicles, and other general items required for construction.

2. Division 2 is "Site Construction." Site Construction is dirt work, surveys, and the site preparation required for building construction.

3. Division 3 is "Concrete." Due to the expense involved in concrete and the volatile market for concrete, this must be identified separately.

4. Division 4 is "Masonry." This section identifies block work in basements, fencing, and subfloor needs.

5. Division 5 is "Metals." This identifies all metal materials used for construction, including siding, studs, and metal work.

6. Division 6 is "Woods and Plastics." This area identifies all doors, hardware, and special Panduit® products (pertaining to tubing, panels, electronic cables, etc.).

7. Division 7 is "Thermal and Moisture Protection." This identifies items involved in insulation, vapor-barrier protection, and sealants.

8. Division 8 is "Doors and Windows." This includes any that may be required to support the project.

9. Division 9 is "Finishes." Finishes include paint, flooring, and molding.

10. Division 10 is "Specialties." Specialties include alarm systems and all other special equipment. This could pose huge variability in project costs.

11. Division 11 is "Equipment." This includes items located inside the building, such as safes, electronics, and any other types of equipment (other than Division 15 Mechanical) that could be considered a permanent item inside the building.

12. Division 12 is "Furnishings." This includes items such as furniture for offices or millwork.

13. Division 13 is "Special Construction." This encompasses items that may fall outside normal construction. This would include fire protection and special electronic needs.

14. Division 14 is "Conveying Systems." This includes special furnishings.

15. Division 15 is "Mechanical." This includes heating, ventilation, cooling, and special operations of doors or ventilation systems.

16. Division 16 is "Electrical." This addresses electrical supplies used for any electrical needs inside or outside the building. It also includes items that may be used to supply power to the building.

Decision Cost Model

The DCM proposed in this article can be implemented at the technical evaluation stage in selecting a contractor for a given construction project. The proposed model computes the total expected costs of a construction project by modeling cost-overrun percentages for each division cost factor combined with the division cost estimate. The DCM utilizes the same contractor historical data and estimates that are used in the current contractor selection process. The key difference between the current contractor selection process and applying the proposed method is allowing a more detailed evaluation of each division's estimate and the impacts of cost-overrun percentages computed from similar projects. The DCM uses the existing estimates and cost factors to determine which contractor offers the lowest expected construction project costs.

The DCM model takes into account all estimated costs, cost-overrun percentages, and PM expert judgment of cost-overrun risk. The DCM uses the same common *RSMeans* format for comparing contractor's cost estimates, thus reducing subjectivity in the selection process. The DCM uses commercially available software to facilitate contractor selection for project awards. By identifying the lowest total cost contractor for the project, the DCM provides expected value information for improving efficiencies in allocating taxpayer funds for government construction projects.

The DCM example used in this article compares three prospective contractors for a real-world project, identified as Contractors 1–3. The cost estimate data used for calculations are "total estimate" and "percent change" in division costs. Based on the 16 potential cost divisions in *RSMeans*, the study assumes the PM has selected three cost-overrun divisions facing cost-overrun risk. The corresponding cost-overrun factors are: cost factor 1–mechanical, cost factor 2–finish, and cost factor 3–electrical.

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To apply the DCM, the PM must specify a probability model for each cost factor under consideration. The beta–general distribution is well suited for cost analysis under uncertainty. The beta distribution is parsimonious and flexible when applying expert judgments. However, in applying the beta distribution in cost analysis, the PM must estimate best-fit parameters. The approach taken in this article is to calculate these parameters by minimization of absolute difference of the probability distribution estimates for various cost-overrun percentages. Accordingly, the following approach is used to pick the best parameter set for cost factors in the [0,1] range $Min\ \sum_{i=1}^{n} d_i$ where $d_i = \left|\int_a^{y_i} f_B(y_i) - \int_a^{y_i} \hat{f}_B(y_i)\right|$ are absolute differences of probability distribution estimates for various cost-overrun percentages, with "*B*" subscript denoting the beta distribution. The y_i values are cost-overrun percentage fractiles, expressed as a number in the [0, 1] range for the factor in question. These cost-overrun percentage fractiles and the PM-assessed distribution fractile, i.e., $\hat{f}_B$ combine actual data and expert judgment.

The objective is to find beta distribution parameters for the lower bound "a" and upper bound "b" denoted by $\propto_1, \propto_2$. This ensures the modeled beta distribution $\hat{f}_B$ is the best approximation for various cost-overrun factors. The probability model combines historical data and expert judgment, thus giving the PM the ability to accurately define the boundary location and scale parameters for each cost-overrun percentage cost factor—location giving the minimum bound and scale giving the range between maximum and minimum bounds. This approach allows the PM to apply expert judgment in specifying the impact of cost-risk affecting each cost factor. The PM can easily modify cost-overrun percentages and fractile parameters to re-calculate cost-risk by introducing new cost-overrun percentages and fractiles from the distribution.

To apply the probability model in the decision analysis, this article uses the Pearson-Tukey method. The Pearson-Tukey method gives the PM the ability to easily compute expected costs and their upper/lower bounds using the discrete-form representation of the beta-general distribution. Using this technique, the division cost-overrun percentage and related probabilities are implemented in a three-chance node decision tree. The three-point approximation uses the .05, .5, and .95 fractiles associated with the realization probabilities of 18.5 percent, 63 percent, and 18.5 percent respectively. The resulting solution gives the total expected costs for the project, whereby each division cost factor value (in the tree) is accounted for in the estimating contractor's total cost for the project. Thus, the DCM shows which contractor has the greatest likelihood of minimizing the total expected project cost (Clemen, 2001).

Cost Factor Data Table

Historic project cost data are summarized in the Cost Factor Data (CFD) Table. The table contains a summary of the contractor's division estimate, initial project cost, actual project cost, computed cost-overrun percentage for each project, and the Pearson-Tukey approximated values. Table 1 is an example of Contractor 1 Mechanical Cost Factor. The top header contains the initial cost, actual costs, and cost-overrun percentage. The pink area contains the Mechanical division five previous projects, initial estimate, actual costs, and cost-overrun percentage. The blue shaded area contains the preliminary computed and expert judgment applied minimum, median, and maximum cost-overrun percentages. The green shaded area in Table 1 contains the Pearson-Tukey approximation and the fractile cost-overrun percentage values and probabilities.

TABLE 1. CONTRACTOR 1 MECHANICAL COST FACTOR DATA TABLE

Mechanical				
		Initial	***Actual***	***% Over***
Renovation 1		39000	65000	0.666666667
Renovation 2		78000	96000	0.230769231
Renovation 3		595000	635000	0.067226891
Renovation 4		26000	32000	0.230769231
Renovation 5		464000	52000	0.120689655
		Expert Judgment		
Upper Bound		0.666666667	0.230769231	
Lower Bound		0.067226891	0.067226891	
Median		0.230769231	0.175729443	
Pearson-Tukey Fractile		Value	Probability	
	0.95	0.3839	0.185	
	0.5	0.175	0.63	
	0.05	0.0468	0.185	

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DCM Methodology

The DCM methodology may be summarized as follows: development of division cost factors, computation of division cost-overrun percentages, and model of cost factors. There must be a preliminary fit regarding a beta-general distribution as well as an application of expert judgment on a case-by-case basis. Consider model minimization beta distribution from the cost factor, cost-overrun percentages, and fractiles. Additionally, there should be a utilization of the modeled output parameters to generate a beta-general distribution. The PM must also apply the Pearson-Tukey method to approximate the cost-overrun percentage and fractile. The DCM methodology is described in the following five-step process to compute cost-overrun percentage distribution:

1. For each of the three cost factors to generate a preliminary beta-general distribution from the observed five cost-overrun percentages, the PM uses expert judgment, as necessary, to

modify division cost-overrun percentage input parameters. The PM will then go to Step 2 with a reasonable fractile and cost-overrun percentage for the cost factor.

2. The PM models the beta distribution parameters. Many different software packages can be used to solve the formula. This example uses an author-developed minimization solver in Excel. The PM observes the fitted distribution and determines if modification to the distribution is needed. The PM uses the computed cost-overrun percentages and Comulative Distribution Function (CDF) curve to estimate the fractile and bounds to create the best distribution to represent each cost factor. The model then computes the beta distribution parameters.

3. The beta-general distribution will be generated by the minimization process as described in Step 2.

4. Application of the Pearson-Tukey method will be used to turn the continuous distribution into a three-outcome chance node for the decision tree.

5. Completion of the decision tree will be accomplished in determining which contractor has the lowest total expected cost for the project. The PM must examine the input contractor's total estimate, cost factor division cost estimate, and the modeled computed cost-overrun percentage as well as the probability parameters, and subsequently figure them into the DCM Influence Table. (See Table 8).

DCM Example

The beta distribution minimization is the key to identifying the total lowest expected cost contractor for the project. The DCM minimization distribution requires a fractile, which is determined to associate with each cost-overrun percentage. The modeled distribution will be demonstrated with real data provided by the contractor. This creates a project cost-risk baseline. Next, the model distribution will be demonstrated with real data and applied expert judgment. Essentially, the applied expert judgment distribution utilizes the same division cost factor fractile determination and cost-overrun percentage method. The DCM example is demonstrated with real cost-overrun percentage data from the Contractor 1 Mechanical cost factor. The only difference with the applied expert judgment example is due to the fact that the PM develops a more accurate prediction of project cost-overrun risk.

In general, fractiles are defined as the points between the range [0, 1] in a distribution. The DCM may use predefined quartiles such as the first quartile = .25, the median = .5, and the third quartile = .75. Although these fractiles may be used for cost-overrun percentage modeling, a more accurate fractile model is needed. Both examples demonstrate a more accurate method for determining fractiles for cost-overrun percentages. The model selects specific cumulative probabilities and associates corresponding fractiles. The cumulative probabilities and the fractile determination method used in the model are estimated from a Cumulative Distribution Curve (CDC) generated from fitted beta general cost-overrun percentage distribution. From the CDC, the PM determines each fractile by estimating CDC distribution of the input p-values to the fitted p-values fractiles (Clemen, 2001). The key idea is to determine the best fractiles using fitted cost-overrun percentages that can be applied to the data set for the computation of the distribution. From the curve of the CDC, the PM estimates the cumulative probability value of the cost-overrun percentage to determine the CDF fractile values for the model.

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For purposes of this computation, the PM will associate each of the five cost-overrun percentage points with five fractile values. Other computation parameters needed are the extreme distribution bounds from the five cost-overrun percentage data. The distribution of the lower boundary will be 0, and the upper boundary will be the cost-overrun percentage plus .1. The CDC estimated the p-value to fitted p-value fractile is inputted into the model. CDF fractiles selected from the CDC are as follows: point .1 is used as the first fractile, the estimated second fractile, the median, a fourth fractile, and the fifth fractile.

A general recommendation for fractile determination is to analyze the computed median and the upper bound $P(X <= x) = .9$. The assumption of the median is the key starting point, and the 90 percent fractile is a reasonable upper boundary because it's a number that construction estimators and/or construction-contract managers can understand. This model makes it possible to determine the fractile values based on the CDC distribution. The model uses a three-step process to compute five fractiles needed to define the alpha 1, alpha 2, and the minimum and maximum boundaries. These parameters are needed to model the beta-general distribution necessary for application of the Pearson-Tukey method.

1. Step 1: Fit the data.

2. Step 2: Estimate the CDC P-values to fitted p-value distribution points and adjust model fractile input to compute fractile. Review match criteria of .1.

3. Step 3: Input computed alpha 1, alpha 2, min and max to fit the Pearson-Tukey distribution.

The first step involves fitting the cost-overrun Contractor 1 with the Mechanical cost-overrun percentage in real data. Contractor 1 Mechanical Division has five historical cost-overrun percentages as follows: .0672, .1206, .2307, .2307 and .6667. The data are limited to five data points with a range of 6.072 percent –-66.67 percent cost-overrun percentage. Note the duplicate 23.07 percent cost-overrun percentage. This may be a concern, but demonstrates how the real data are modeled. The preliminary beta-general cost-overrun data fit the results in Figure 1—28.8 percent median, alpha 1 = .194, alpha 2 .2307, min .067, and max = .6667.

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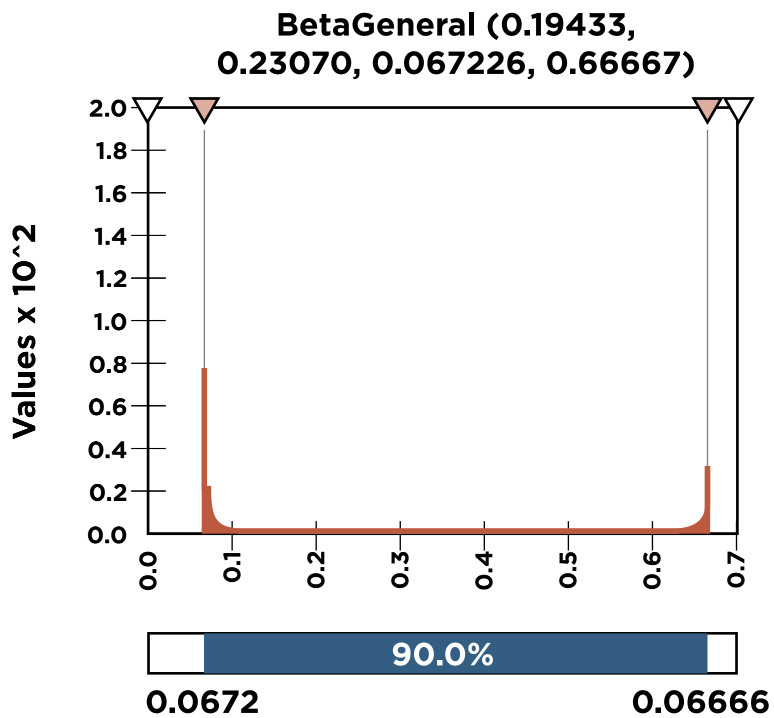
FIGURE 1. CONTRACTOR 1 MECHANICAL COST-OVERRUN PERCENTAGE FITTED REAL DATA.

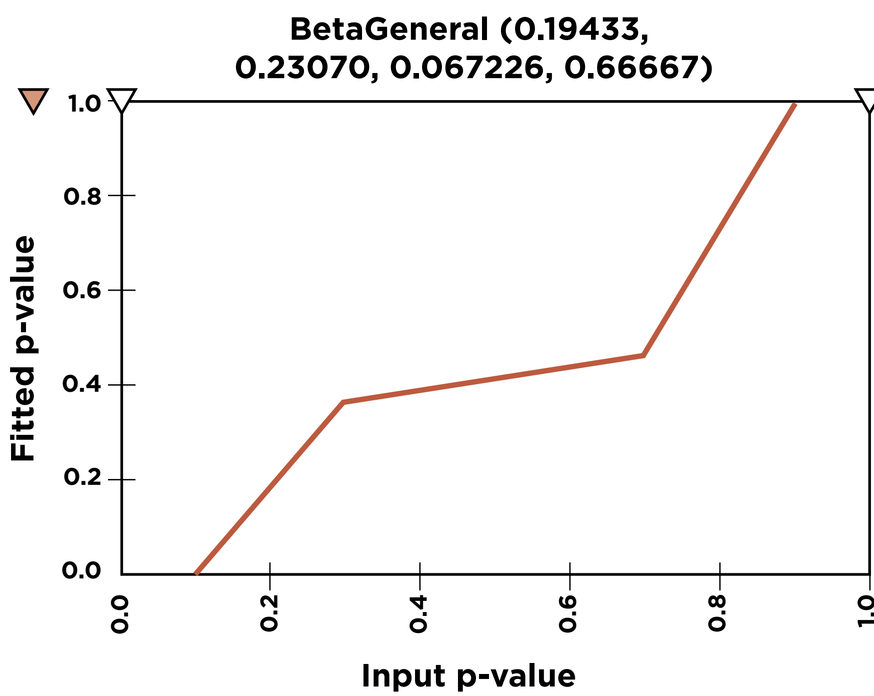


Note. Adapted from "Making Hard Decisions with Decision Tools," by R. T. Clemen, 2001.

The second step is to estimate the CDC p-values to fitted p-value distribution points and adjust model fractile input to compute fractile. Review match criteria of .1. Fit the beta-general distribution, and estimate the five fractile points using the CDC. Determine the fractile data points by estimating each distribution point of the p-value to the fitted p-value point by evaluation of the slope of the CDC. Through evaluation of the Contractor 1 mechanical cost-overrun percentage real data CDC curve, one can estimate the p-value/fitted p-value origin fractile as (0, .1), with the first fractile at (.3, .4), the next fractile at (.7, .5), and the fractile termination at (.9, 1). The points in the parentheses (x, y) are points on the CDC curve. From these estimated points, the first fractile is estimated .1. The next fractile, .2, is estimated from the distribution points between point (0, .2) and (.3, .4) on the CDC. The next two fractiles are .49 and .5, and are estimated between (.3, .4) and (.7, .5) on the CDC curve. The

CDC fractile termination will indicate the fifth fractile to be in the 90 percent quartile. Using this estimation method, the PM can estimate the CDF fractile model values as shown in figure 2 (Clemen, 2001, p. 403).

FIGURE 2. CONTRACTOR 1 MECHANICAL REAL DATA FITTED P-VALUE/INPUT P-VALUE CURVE



Note. Adapted from "Making Hard Decisions with Decision Tools," by R. T. Clemen, 2001.

The PM will model the minimization beta distribution. The PM will input each cost-overrun percentage in progression with the associated fractile into the model; 6.72 percent = .1, 12.06 percent = .2, 23.07 percent = .49, 23.07 percent =.5, and 66.67 percent = .9. The model utilizes a beta distribution, which returns the cumulative beta probability density of the inputted cost-overrun percentage and the inputted CDF fractile. The result is a computed fractile, which the PM compares to the inputted CDF fractile. If the computed fractile is within .01 of the inputted CDF fractile, the PM considers this a computed fractile match. The PM then utilizes the modeled output parameters—alpha 1, alpha 2, and the min and max—to fit the beta-general distribution.

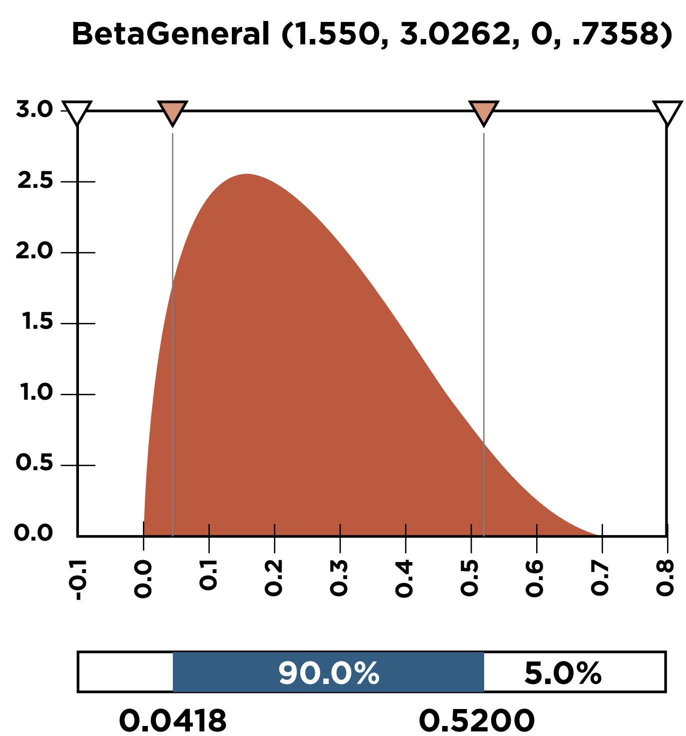
The Contractor 1 Mechanical cost-overrun real example results are alpha 1 = 1.55, alpha 2 = 3.026, min = 0, and max = .73. The parameters are used to fit a beta-general distribution for estimation of the Pearson-Tukey overrun percentage and probability values used in the decision tree. Table 2 displays the model with the beta-distribution computation of the fractile from the cost-overrun percentage and CDF fractile inputs. Note the CDF fractile is computed within the .15 range—a PM-considered match. This will indicate that the alpha 1, alpha 2, and the min and max are ready for the next step—fit the beta-general Pearson-Tukey distribution.

TABLE 2. CONTRACTOR 1 MECHANICAL FRACTILE REAL DATA SOLVER

Step 2:					
	Objective Function		0.133445735		
		alpha 1	**1.550436497**		
		alpha 2	**3.026241986**		
		max	**0.735866163**		
		min	**0**		
0.248449		Overrun %	CDF Fractile	Computed	
		0.0672269	**0.1**	0.1	Fitted
		0.1206897	**0.2**	0.225208	0.249222
		0.230769	**0.49**	0.499879	
		0.230769	**0.5**	0.499879	
		0.66667	**0.9**	0.998237	

The third step involves determining the Pearson Tukey overrun percentage and probability values. The computed model results are as follows: alpha 1 = 1.55, alpha 2 = 3.02, min = 0, and max = .73. Parameters are used to model the beta-general distribution. The Pearson-Tukey method is applied to identify the cost-overrun percentages and 5 percent, median, and 95 percent probabilities for the decision tree. Through application of the Pearson-Tukey method, the PM estimates the 95 percent fractile is equal to the probability of 18.5 percent, with a cost-overrun of 52 percent. The median fractile probability is equal to 63 percent, with a 23.07 percent cost-overrun. The 5 percent fractile is equal to the probability of 18.5 percent, with a cost-overrun of 4.18 percent. These values are entered into the decision tree to compare each contractor's project cost-overrun risk to their project completion. Figure 3 depicts the Contractor 1 Mechanical real data fitted beta-general distribution results from the modeled parameters.

FIGURE 3. CONTRACTOR 1 MECHANICAL REAL DATA DISTRIBUTION



Note. *Adapted from "Making Hard Decisions with Decision Tools," by R. T. Clemen, 2001.*

Fractile Determination with Applied Expert Judgment

Figure 4 reflects the Contractor 1 Mechanical cost-overrun percentage with applied expert judgment. The modeling and fractile determination process are the same as modeling with real data. The main difference is the PM applies expert judgment to the real data to adjust cost-overrun outliers. Because of limited data provided by the contractor, the PM must rely on experience and sound judgment to make any adjustments to the data set. Using expert judgment, the PM modifies distribution parameters to best represent the contractor. The PM accomplishes the modification by careful evaluation of the project scope of work to be performed, division cost-overrun percentage range, and identification of cost-overrun outliers.

The PM must also understand the many factors that impact a cost-overrun risk on a construction project. The PM uses past experience to reasonably evaluate the cost-overrun risk to the project. Some common cost-overrun examples are: unclear documented scope of work, unforeseen problems, project location, and abatement of facility. These examples are common and add enormous cost to a construction project. A prime contractor's project experience on special projects and a prime contractor's experience with the subcontractor also impact the cost-overrun risk. Lower cost-overrun risk occurs when a prime contractor has an established, longstanding relationship with a subcontractor. The project tends to run more effectively with better cost control.

The construction industry identifies the contractor responsible for the overall project as the "prime contractor." The subcontractor works for the "prime contractor." An example of a prime contractor with a limited working relationship with a subcontractor is what the construction industry calls a construction broker. These construction brokers estimate a construction project and hire local subcontractors to complete the project. Because of lower overhead and remote capability, a construction broker's estimate may be lower than other prime contractors. Because of limited working relationships with local subcontractors, the prime contractor broker incurs large project cost-overruns. Other cost-overrun examples include: subcontractor experience, project location (whether the project is in a city or in the middle of a desert), and weather (such as snow, wind, and rain). All these variables influence the PM's expert judgment application to division cost factors.

Every division cost factor is modeled independently of one another. For example, the mechanical cost-overrun percentage does not depend on the cost-overrun (or any other) estimate such as electrical or finish. Division cost factors such as mechanical and electrical are primarily managed by independent subcontractors. The finish division cost factor is also independent from the other cost factors and is primarily managed by the "prime" contractor. The prime contractor is the contractor who is responsible overall for the project and the subcontractors' division impacts.

The DCM process is accomplished in the following Steps 1 through 3.

Step 1

The first step is to review the divisional "real" data and apply expert judgment to determine the most likely cost-overrun percentage and, if needed, determine the least likely cost-overrun percentage. The observation of Contractor 1 Mechanical cost-overrun percentage is that 4 of the 5 cost-overrun percentages are in the range between .067–.2307. The PM has determined that the .6667 cost overrun appears to be an outlier. This cost-overrun is from a lower cost mechanical project where minor changes in cost amplify a larger change in cost-overrun percentage. This mechanical project initial estimate was $39,000, and the final actual cost was $65,000. After review of the contractor's initial proposal, the PM had determined the contractor initially estimated this mechanical division estimate as a repair of the existing mechanical system. The contractor's good-faith estimate was proposed to save materials, labor, and the ability to use the existing system. After further analysis, the mechanical project became a total mechanical replacement, thus reflected in the actual cost, not in the good-faith estimate.

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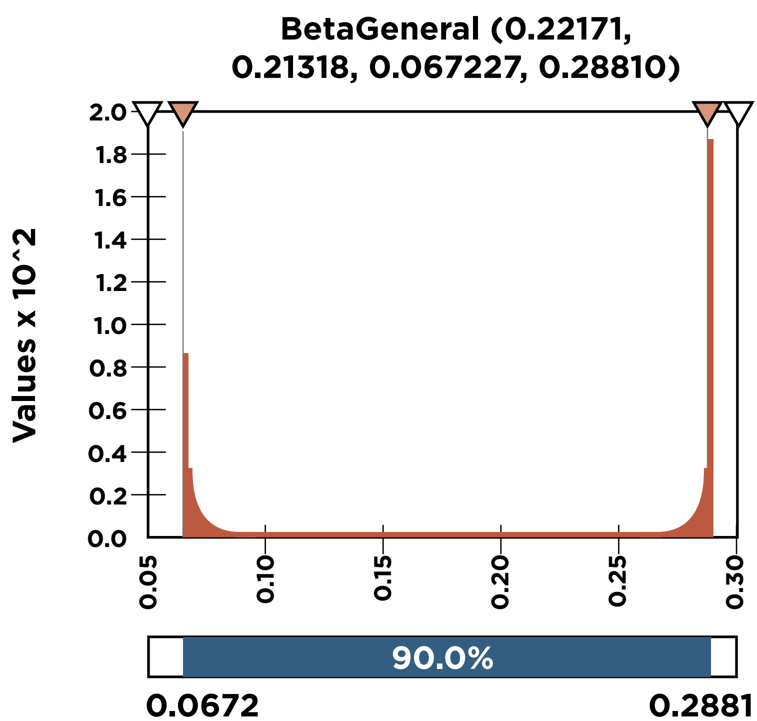
With limited data to evaluate the contractor, and judging from the cost-overrun percentages, 4 of the 5 are less or equal to 23.07 percent cost-overrun percentage. More than likely, a 23.07 percent or smaller cost-overrun may occur, while a cost-overrun of 66.67 percent is least likely. Contractor 1 proposed this mechanical project for $480,000. From the contractor project real data, the contractor's two similar mechanical projects were for $595,000 and $464,000; the contractor had a 6.7 percent and 12 percent cost-overrun respectively. Because of risk to costs, the PM cannot completely discount the 66.67 percent cost-overrun, so the PM will use the complete contractor mechanical real cost-overrun dataset (.067-.66667) to compute the median .2881. The high median is driven by the one high .6667 cost-overrun percentage. The PM will replace the .6667 cost-overrun percentage with the median .2881 and input into the cost-overrun percentage in the 5th fractile of the model. Keep in mind that this will be the only applied expert judgment made to the Contractor 1 Mechanical overrun percentage dataset.

The Contractor 1 Mechanical real cost-overrun percentage (Figure 1) fits beta-general distribution with a computed median .2881. The PM determines this is a better representation of the Contractor 1 Mechanical cost-overrun. Next, determine the fractiles using the developed model and proceed to Step 2.

FIGURE 4. CONTRACTOR 1 MECHANICAL APPLIED EXPERT JUDGMENT REAL DISTRIBUTION

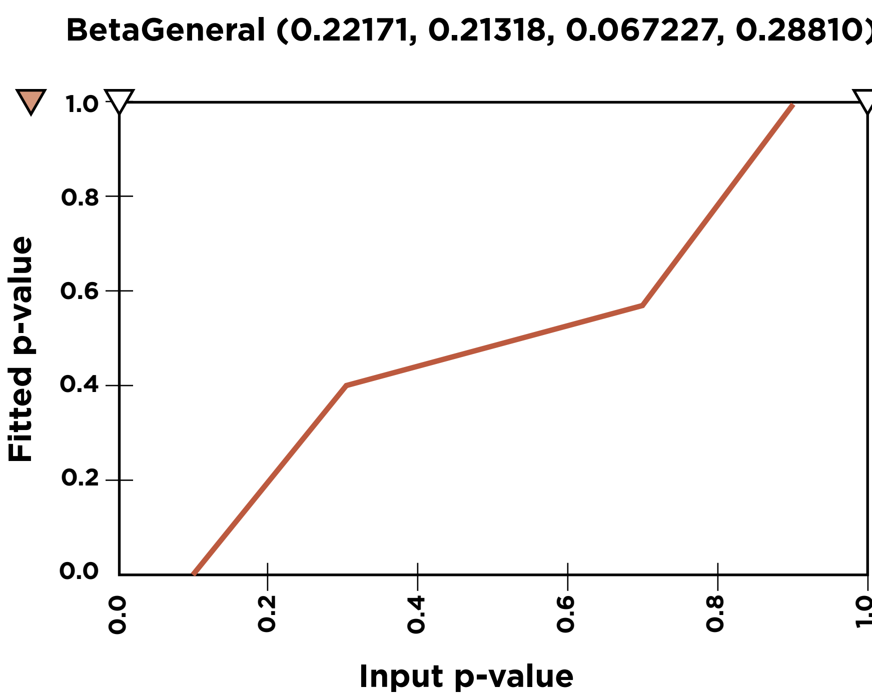


Note. Adapted from "Making Hard Decisions with Decision Tools," by R. T. Clemen, 2001.

Step 2

Estimate the CDC P-values to fitted p-value distribution points and adjust the CDF fractile input to compute the model fractile. In this example, the fractile determination, the PM demonstrates Contractor 1 Mechanical real data with applied expert judgment. From the curve estimate, the p-value/fitted p-value origin fractile is (0, .1), the second fractile point is (.3, .4), the third fractile at (.5, .5), the fourth fractile is (.7, .6), and the fractile termination is (.9, 1). From the CDC estimated points, the model fractiles are estimated to be .1, .3, .55, and .75. The CDC .9 fractile termination is the model fifth fractile. The fractile estimated values are inputted into the CDF fractile model.

FIGURE 5. CONTRACTOR 1 MECHANICAL EXPERT APPLIED DATA P-VALUE CDF



Note. Adapted from "Making Hard Decisions with Decision Tools," by R. T. Clemen, 2001.

Observations on Table 3:

1. Alpha 1 = 2.596, alpha 2 = 6.303, min = 0, max = .585.

2. Application of PM expert judgment, the .6667 cost-overrun is replaced with .2881 median.

3. The 1st fractile .1, .3, .75, and .9 is within the .15 match criterion. The 3rd fractile, .2307, is a duplicate of the 4th fractile, which accounts for the .764 computed median fractile. The .184 fitted

median and .2881 upper bound model the applied expert judgment shape or bounds for the distribution. The PM uses the modeled parameters to fit the beta-general distribution.

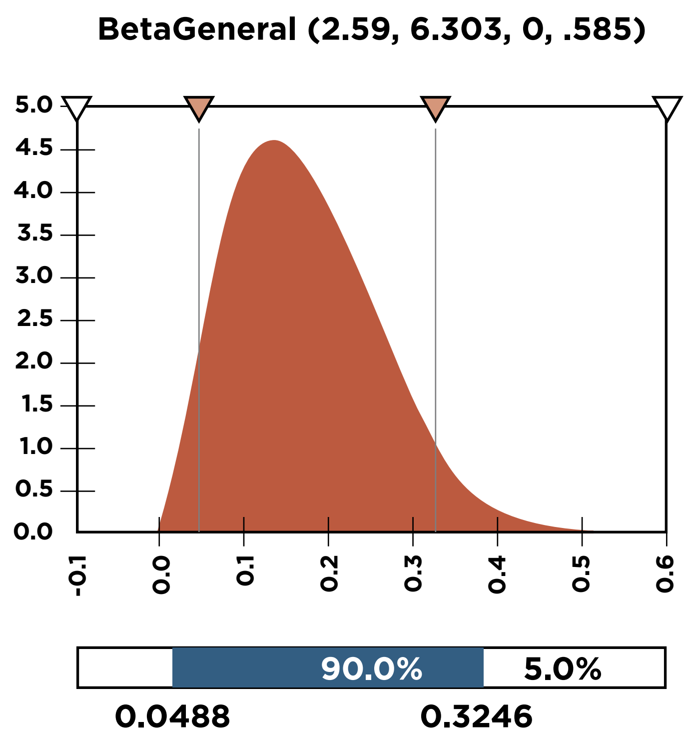
TABLE 3. CONTRACTOR 1 MECHANICAL EXPERT JUDGMENT APPLIED DATA SOLVER

Step 2:	Expert judgment decision to discard upper bound and insert real data fitted median .2881				
	Objective Function		0.243971668		
		alpha 1	**2.596224508**		
		alpha 2	**6.303480736**		
		max	**0.58571502**		
		min	**0**		
		Overrun %	CDF Fractile	Computed	Fitted Dist
		0.0672269	**0.1**	0.1	0.179829619
		0.1206897	**0.3**	0.314529	
		0.2307692	**0.55**	0.764705	
		0.2307692	**0.75**	0.764705	
.6667 replaced with fitted median		0.2881	**0.9**	0.899968	

Step 3

Determine the Pearson Tukey values. The model parameter results are alpha 1 = 2.5906, alpha 2 = 6.303, minimum = 0, and maximum = .585 are used to fit the beta-general distribution. The Pearson-Tukey method is applied to approximate the median, upper, and lower cost-over-percentage and probabilities for the decision tree. The Pearson-Tukey method estimates the 95 percent fractile is equal to the probability of 18.5 percent, with a cost-overrun percentage of 32.46 percent. The median is equal to 63 percent, with a 16 percent cost-overrun. The lower 5 percent fractile is equal to the probability of 18.5 percent, with a cost-overrun percentage of 4.88 percent. These values are entered into the decision tree to compare each contractor project cost-overrun risk to their project estimate. In Figure 6, the Pearson-Tukey cost-overrun percentage and probability values are entered into the decision tree to compare each contractor project cost-overrun risk to their project completion.

FIGURE 6. CONTRACTOR 1 MECHANICAL PEARSON-TUKEY WITH EXPERT JUDGMENT APPLIED DATA



Note. Adapted from "Making Hard Decisions with Decision Tools," by R. T. Clemen, 2001.

In summation, the PM first demonstrated the model with limited real data provided by the contractor. The model was then demonstrated with the application of expert judgment to the same Contractor 1 Mechanical real data. The DCM results show that with the provided real data, and without the application of expert judgment, Contractor 1 would be the suggested contractor for project award with a total project cost of $5,571,137. The DCM results, with applied expert judgment to the real data, demonstrate that Contractor 2 is the suggested contractor for project award, with a total project cost of **$5,438,781**.

DCM Data Summary

The DCM model input and output parameters are in Tables 4-7. Table 4 contains the model parameters for each contractor's real data cost factor distribution shape parameters. Table 5 contains the contractor's real data cost factor Pearson-Tukey cost-overrun percentage and probability values. Table 6 contains the model cost factor distribution parameters for each contractor's real data with applied expert judgment. Table 7 contains the summarized Pearson-Tukey cost-overrun percentage and probability values for contractor's real data cost factor with the applied expert judgment.

Table 4 is the summary of the output model parameters for each contractor. The model parameters computed with real data provided by the contractors. The computed parameters did not have any expert judgment applied. The output parameters are used to define each contractor's division cost factor distribution shape.

TABLE 4. CONTRACTOR'S DIVISION COST OVERRUN MODEL OUTPUT PARAMETER RESULTS (NO EXPERT JUDGMENT APPLIED)

Contractor 1	α_1	α_2	Min	Max
Mechanical	1.550	3.026	0	.735
Finish	.562	4.371	0	.313
Electrical	2.252	14.056	0	.487
Contractor 2	α_1	α_2	Min	Max
Mechanical	1.354	2.665	0	.850
Finish	2.269	3.88	0	.254
Electrical	.968	.959	0	.628
Contractor 3	α_1	α_2	Min	Max
Mechanical	1.052	.976	0	.72
Finish	2.382	5.383	0	.914
Electrical	.641	.698	0	.709

Table 5 is a summary of the Pearson-Tukey cost-overrun percentage and probability for each contractor's real data division cost factor. The Pearson-Tukey cost-overrun percentage and probability approximation will be inputted to create the decision tree.

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TABLE 5. CONTRACTOR'S DIVISION PEARSON-TUKEY REAL DATA COST-OVERRUN RESULTS (NO EXPERT JUDGMENT APPLIED)

Contractor 1	18.5% probability	63% probability	18.5% probability
Mechanical	4.18%	23.07%	52%
Finish	.08%	5.21%	313%
Electrical	1.481%	5.931%	14.2%
Contractor 2	**18.5% probability**	**63% probability**	**18.5% probability**
Mechanical	3.9%	26.3%	61%
Finish	3.03%	10.5%	19.4%
Electrical	2.88%	31.2%	59.2%
Contractor 3	**18.5% probability**	**63% probability**	**18.5% probability**
Mechanical	4.2%	37.8%	72.0%
Finish	7.5%	26.4%	54%
Electrical	1%	32.88%	68.48%

Table 6 is the summary of the output model parameters for each contractor. The model parameters were computed with the application of expert judgment to the real data. These parameters are used to define the cost factor distribution shape.

TABLE 6. CONTRACTOR'S DIVISION COST-OVERRUN MODEL OUTPUT PARAMETERS RESULTS (WITH EXPERT JUDGMENT APPLIED)

Contractor 1	α_1	α_2	Min	Max
Mechanical	1.948	2.024	0	.359
Finish	2.246	3.144	0	.571
Electrical	3.006	10.283	0	.2307
Contractor 2	α_1	α_2	**Min**	**Max**
Mechanical	2.262	8.266	0	.72
Finish	2.004	4.063	0	.439
Electrical	5.086	7.567	0	.261
Contractor 3	α_1	α_2	**Min**	**Max**
Mechanical	2.216	2.146	0	.388
Finish	1.937	2.173	0	.600
Electrical	.641	.698	0	.709

Table 7 contains the summary of the Pearson-Tukey cost-overrun percentage and probability for each contractor's division cost factor real data with applied expert judgment. The Pearson-Tukey cost-overrun percentage and probability approximation are used to create the decision tree.

TABLE 7. CONTRACTOR'S DIVISION PEARSON-TUKEY COST-OVERRUN PERCENTAGE RESULTS REAL DATA WITH APPLIED EXPERT JUDGMENT.

Contractor 1	**18.5% probability**	**63% probability**	**18.5% probability**
Mechanical	4.48%	17.1%	30.06%
Finish	6.05%	23.1%	43.1%
Electrical	1.61%	4.87%	9.87%
Contractor 2	**18.5% probability**	**63% probability**	**18.5% probability**
Mechanical	4.86%	16.2%	33.91%
Finish	3.26%	13.35%	20.86%
Electrical	5.1%	10.3%	16.37%
Contractor 3	**18.5% probability**	**63% probability**	**18.5% probability**
Mechanical	5.94%	19.8%	33.39%
Finish	7.18%	27.9%	50.41%
Electrical	1.01%	33.08%	69.37%

Table 8 contains the Decision Cost Model influence summary with the application of expert judgment to the real data provided by the contractor. The DCM Influence Summary input parameters are initial estimate, division cost factor estimate, and computed Pearson-Tukey cost-overrun percentage and probability. The DCM computed the model and identified that Contractor 2 had the lowest variability of division cost overruns, resulting in the selection of Contractor 2 as the "best value" contractor, with a project estimated expected total cost of $5,438,781.

TABLE 8. DECISION COST MODEL SUMMARY (WITH APPLIED EXPERT JUDGMENT)

Diagram #1	
EV	**-$5,438,781.01**
STDEV	**$88,110.91**
MIN	**-$5,687,267.00**
MAX	**-$5,212,076.00**

INPUTS						
Initial Cost	**Contractor 1** $5,300,000.00	Probability	**Contractor 2** $5,100,000.00	Probability	**Contractor 3** $4,990,990.00	Probability
Cost 1 Mech	$480,000.00		$760,000.00		$750,000.00	
High Overrun	0.3246	0.185	0.3391	0.185	0.3339	0.185
Median Overrun	0.16	0.63	0.162	0.63	0.198	0.63
Low Overrun	0.0488	0.185	0.0486	0.185	0.0594	0.185
Cost 2 Finish	$1,100,000.00		$850,000.00		$1,200,000.00	
High Overrun	0.431	0.185	0.2086	0.185	0.5041	0.185
Median Overrun	0.231	0.63	0.1335	0.63	0.279	0.63
Low Overrun	0.0659	0.185	0.0326	0.185	0.0718	0.185
Cost 3 Electrical	$750,000.00		$930,000.00		$780,000.00	
High Overrun	0.0987	0.185	0.1637	0.185	0.6937	0.185
Median Overrun	0.0487	0.63	0.103	0.63	0.3308	0.63
Low Overrun	0.0161	0.185	0.051	0.185	0.0101	0.185

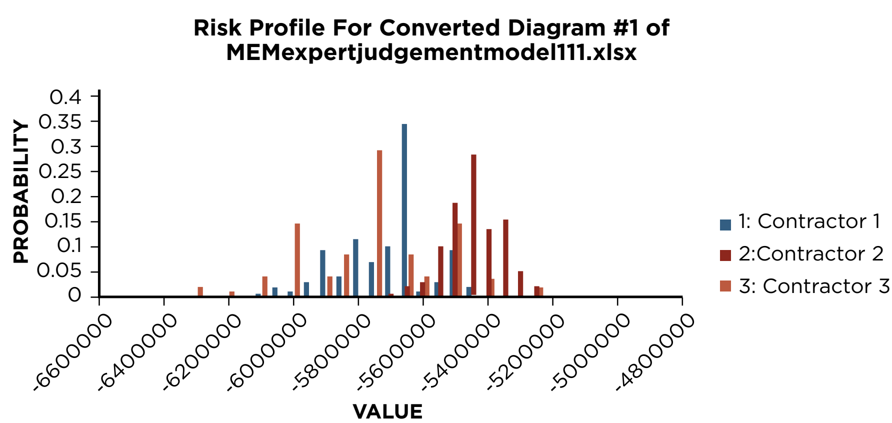
Table 9 contains the Statistics and Risk Profile charts generated from the model. The charts provide an analytical data summary to the end user for this decision. The statistics chart shows the range for each contractor's estimate with the cost factor inputs. The model identifies Contractor 3, who initially had the lowest project estimate, as the contractor with the highest total expected cost of the three contractors. Contractor 3 has a cost range from $5,111,140 to $6,387,421, with a mean cost of $5,742,003. Contractor 1, who had the highest initial estimate, is the second lowest total expected cost contractor. Contractor 1 has costs that range from $5,461,365 to $6,082,365, with a mean cost of $5,720,684. Contractor 2, the model-recommended contractor, had costs that ranged from $5,129,768 to $5,687,267, with the mean cost of $5,438,781.

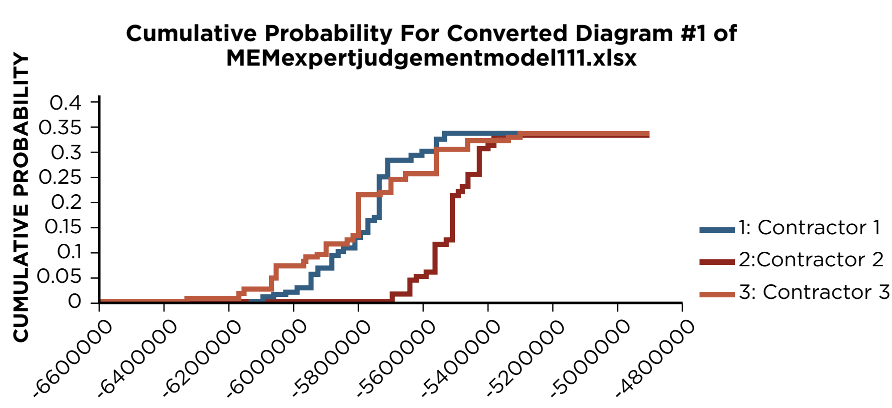
Table 9 also displays total cost variability by contractor. Contractor 1 has the cost standard deviation of $138,554, and Contractor 3 has the highest variability of cost standard deviation of $234,952. Contractor 2 has the lowest cost standard deviation of $88,110. The risk profile chart in Table 9 displays how each contractor's cost probability and overruns are distributed. This gives the decision maker confidence for the decision and provides further support for the selection of Contractor 2.

The total expected cost risk profile for the project demonstrates that Contractor 1 has a 35 percent confidence the contractor will meet the computed "mean" total expected cost of the project, and that Contractors 2 and 3 both have a 30 percent confidence they will meet the computed "mean" total expected cost of the project. The cumulative probability plot shows that Contractor 1 and Contractor 3 are grouped together with total expected cost risk. Contractor 2 has separated from the other two contractors' project selections and offers the lowest total expected cost with the highest confidence.

TABLE 9. CONTRACTOR'S STATISTICS, RISK AND CUMULATIVE PROBABILITY PROFILE

Contractor Selection	*1: Contractor 1*	*2: Contractor 2*	*3: Contractor 3*
STATISTICS			
Mean	-5720684	-5438781	-5742003
Minimum	-6082365	-5687267	-6387421
Maximum	-5461365	-5212076	-5129578
Mode	-5667425	-5432385	-5732314
Std Dev	138554.1	88110.91	234952
Skewness	-0.29076	-0.25133	-0.10148
Kurtosis	2.806697	2.920348	2.873793





Note. Adapted from "Making Hard Decisions with Decision Tools," by R. T. Clemen, 2001.

Figure 7 demonstrates the DCM minimum expected cost solution decision tree. The decision tree will demonstrate how each division estimate is impacted by the computed division cost-overrun percentage and probability. The DCM utilized the top three divisions determined by the PM as cost factors for the decision tree. The DCM demonstrates how the mechanical, electrical, and finish division cost factors have an overall impact on the total cost for the project. The DCM will also demonstrate how the initial estimate from the contractor is not the expected cost provided to the government. To better represent the decision tree in this report, the single decision tree is shown in Figure 7 as Decision Tree Contractor Selections, Parts 1 and 2. The decision tree chance node demonstrates how each Pearson-Tukey chance and percentage impact each division cost for the project, and collectively impact total cost of the project.

FIGURE 7.DECISION TREE CONTRACTOR SELECTIONS PART 1

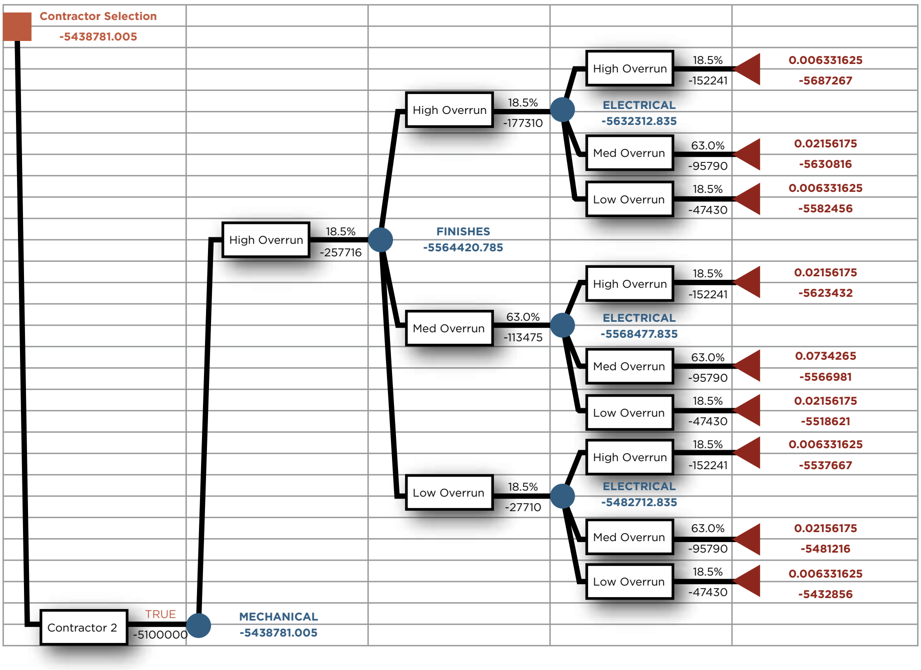
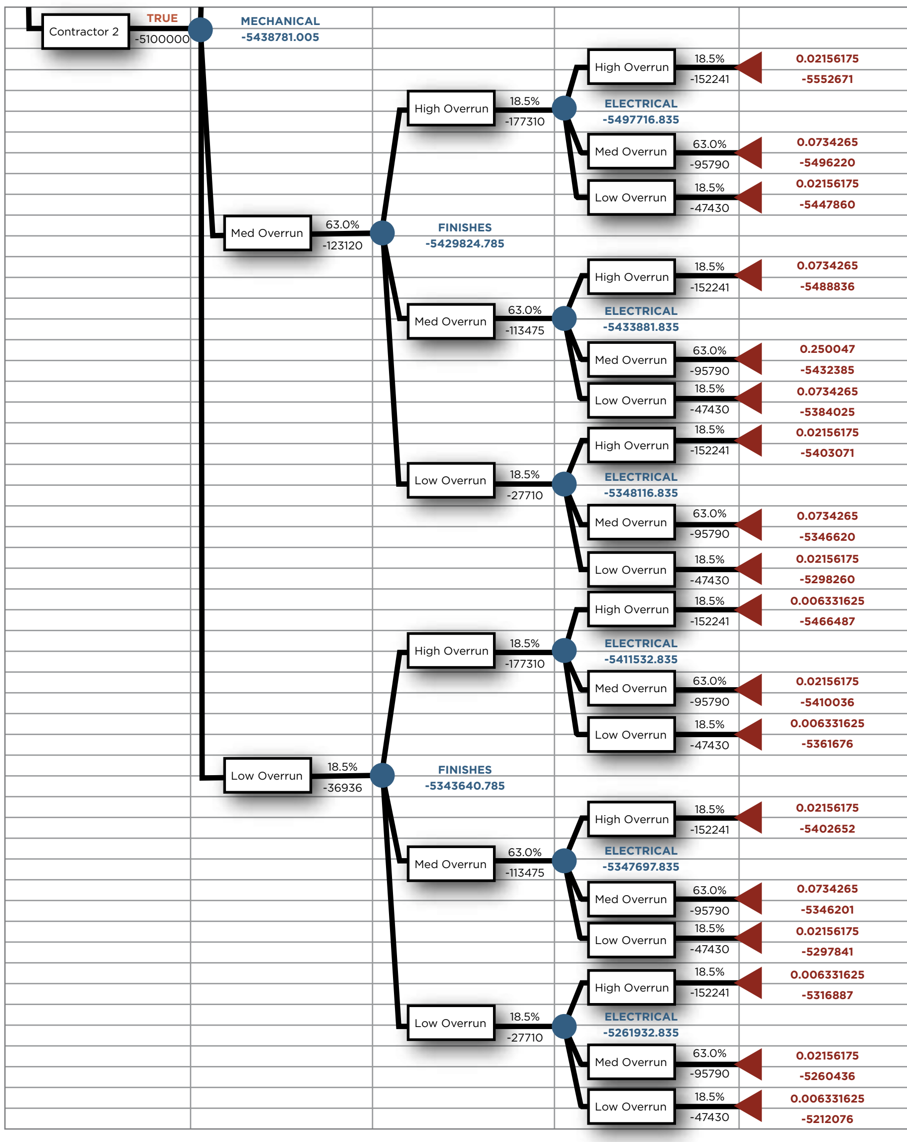


FIGURE 7.DECISION TREE CONTRACTOR SELECTIONS PART 2



Note. Adapted from "Making Hard Decisions with Decision Tools," by R. T. Clemen, 2001.

CONCLUSIONS

In summation, from a pool of certified contractors, the government contracting office solicited estimates for the project. Utilizing RSMeans as a standard format for construction costs, the PM completed a current year IGE, collected five similar project estimates, and final project costs from the three potential contractors. After review of each contractor's project history and computing the division cost-overrun percentage, the PM identified three common cost factors for the DCM.

The PM fit a primary distribution for each of the three division cost-overrun percentages. With the historical project dataset and expert judgment, the PM modeled a minimization beta distribution to best represent each contractor's cost factor. The model computed output parameters used to generate a beta-general distribution. The PM applied the Pearson-Tukey method to approximate the cost-overrun percentage and probability for each cost factor. The modeled cost-overrun percentage and probabilities are imputed into the DCM Influence Table. With the modeled cost overrun percentages and fractiles, the total estimate, and cost factor division estimates, the DCM computed the lowest total expected cost contractor for the construction project.

Initially, each contractor presented a total cost estimate for the construction project. Contractor 1's estimate was $5.3 million, Contractor 2's estimate was $5.1 million, and Contractor 3's estimate was $4.9 million. Contractor 3 appears to be the lowest total cost contractor for the project. With the current contractor selection process, Contractor 3 would have been awarded the construction project. With the same data from the contractor's initial cost estimate, cost factor division cost estimates, modeled cost-overrun percentages, and chance parameters, the DCM model demonstrated that a lower total expected cost decision for the construction project may be made. The DCM provides a valid, data-driven decision process to select the contractor best suited to meet the tax-payers' objective—a value-driven government construction project.

Future application of the DCM is a software program that can be developed and added to *RSMeans* CostWorks to streamline the contractor evaluation process. The DCM is not limited to construction projects. The DCM can be adapted to any problem with defined variables and historical costs. The decision model can be used for private, municipal, state, and federal construction projects.

Annually, many U.S. Government construction projects and funds need to be obligated for projects. The government PM, at times will look at a contractor's project estimates at face value. A common scenario in the government construction process is that a government-certified construction contractor will state, "It will cost $5 million dollars to construct a facility." If the government has the facilities project programmed, and the IGE is within 25 percent of the contractor's estimate, the government will obligate the funds to the construction project. The project will be funded without the knowledge of the contractor's project cost-overrun percentage history and the potential unknowns surrounding project cost overrun.

Under the current government contractor selection process, the government would have awarded the project to Contractor 3, who had the lowest initial estimate of $4.9 million. The DCM demonstrated that Contractor 3 is not the lowest cost, but indeed has the largest cost risk for project award.

The author's experience in construction management and evaluation of project historical cost data indicates the majority of construction projects will have at least a division cost-overrun. Cost-overruns are often termed by the contractor as "modification, change order, or upgrade." On several occasions, a contractor proposes to win a government project by bidding the lowest estimate. The contractor later makes up the difference in modifications or change orders throughout the project, as was demonstrated by DCM in Contractor 3's situation.

The recommendation of this study is for U.S., state, and municipal governments to take careful consideration of construction division cost-overruns before project contractor project award selection. This article demonstrated that by utilizing a good DCM and a common format, a valid, data-driven decision can be made for project award. Using this process will bring more cost-effective contractor selection solutions for the government and construction engineers. Using this DCM, the federal government's stimulus and project funding could be used more efficiently, thus meeting the taxpayers' expectations of responsible government construction spending for their tax dollars.

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Mr. Victor J Apodaca is a Facilities Project Manager with the Department of Homeland Security. His professional interests are facilities project management, construction projects and energy efficiency alternatives. He has a BSBM from University of Phoenix and completing work at New Mexico Tech towards a Master of Engineering Management (MEM). His personal interests are modeling decision analysis for construction projects and real estate investments. He has a passion for the outdoors which includes golf, fishing, hiking and spending time in the mountains with his family.

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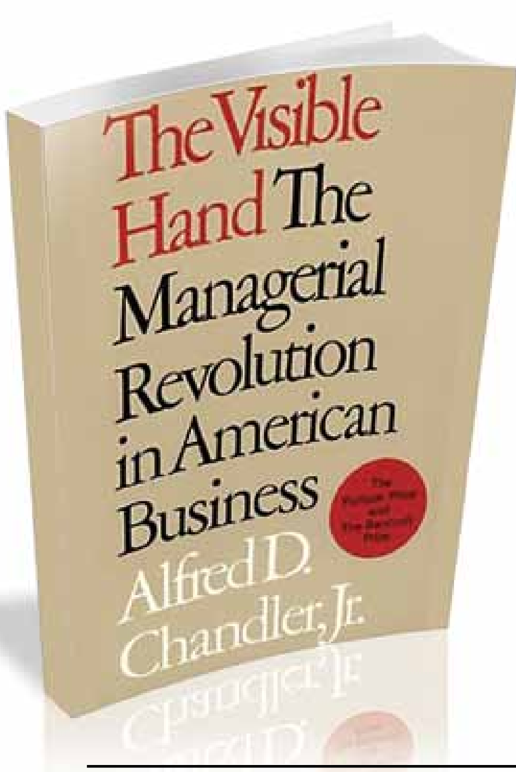

Featured Book

The Visible Hand: The Managerial Revolution in American Business

Author(s):
Alfred D. Chandler Jr.

Publisher:
Belknap Press of Harvard University Press

Copyright Date:
1993

ISBN:
978-0674940529

Hard/Softcover:
Both, 624 pages

Reviewed by:
Dr. Nayantara Hensel, Professor of Industry and Business at National Defense University and a member of the *Defense ARJ* Research Advisory Board. Dr. Hensel's PhD is from Harvard University, where she learned from Dr. Chandler himself.

Review:

Alfred Chandler's *The Visible Hand* contributes significant insights into the historic evolution of the large-scale business enterprise and modern managerial capabilities. This has important implications in understanding how key business functions that are located in smaller business enterprises can be combined to form multiunit business enterprises, which, in turn, can be applied to the defense industry in several ways. First, the historical perspectives in the book can help in assessing whether key functions should be outsourced by the Pentagon or conducted internally. Second, the historical lessons can assist in exploring whether defense companies should outsource activities to smaller firms or whether they should internalize the activities and expand the size and scope of their corporate structure.

The Visible Hand examines the growth of business enterprises in the United States between the 1840s and the 1920s, and the developments in coordination and administration of production and distribution activities (including communication, finance, and transportation). Internalization of these activities into larger business enterprises rather than the continuation of these functions in smaller, diverse companies led to reduced transaction costs in conducting core functions, as well as greater productivity. Chandler focuses on the importance of the creation of managerial hierarchies as well as the development of the formal profession of managers in achieving the internalization of activities and in the formation of large, American companies. Without the development of professional managers, the benefits of improved productivity and lower costs due to the synergies between the functional units and their integration into the broader corporate structure could not have been realized.

Chandler examines the managerial revolution in a variety of industries, including the evolution of the railroad industry in the United States. The analysis examines changes in mass distribution (the development of department stores, chain stores, etc.) as well as changes in mass production. The analysis then examines the integration of mass production and mass distribution functions within modern industrial corporations and vertical integration through mergers in a variety of industries. These historical examples have many parallels with contemporary supply chain management challenges, some of which have been effectively dealt with through acquisition of smaller companies conducting core functions into larger corporate enterprises.

An understanding of how the "visible hand" of management replaced the "invisible hand" of market mechanisms through the evolution of the modern American business enterprise and through the associated development of managerial hierarchies is key in evaluating the challenges currently facing American industries, including the defense sector. When I was a PhD student at Harvard University, I always found that Alfred Chandler's perspectives in his discussions with the students in class provided valuable insights on how historic and contemporary threads were woven together to create the tapestries of particular industries or markets. Today, both the economic crisis and the associated budgetary pressures necessitate improved efficiencies, greater productivity, and reduced costs in the industrial base, and the exploration of economic history in *The Visible Hand* can provide the foundations for some possible solutions.

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