NPS-AM-07-035

EXCERPT FROM THE

PROCEEDINGS

OF THE

FOURTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM

THURSDAY SESSIONS

Dynamic Cost-contingency Management: A Method for Reducing Project Costs While Increasing the Probability of Success

by

Edouard Kujawski, PhD, Associate Professor, Naval Postgraduate School

4th Annual Acquisition Research Symposium of the Naval Postgraduate School:

Acquisition Research: Creating Synergy for Informed Change

May 16-17, 2007

Prepared for: Naval Postgraduate School, Monterey, California 93943

Acquisition Research program
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL

The research presented at the symposium was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

To request Defense Acquisition Research or to become a research sponsor, please contact:

NPS Acquisition Research Program
Attn: James B. Greene, RADM, USN, (Ret)
Acquisition Chair
Graduate School of Business and Public Policy
Naval Postgraduate School
555 Dyer Road, Room 332
Monterey, CA 93943-5103
Tel: (831) 656-2092
Fax: (831) 656-2253
E-mail: jbgreene@nps.edu

Copies of the Acquisition Sponsored Research Reports may be printed from our website www.acquisitionresearch.org

Conference Website:
www.researchsymposium.org

Proceedings of the Annual Acquisition Research Program

The following article is taken as an excerpt from the proceedings of the annual Acquisition Research Program. This annual event showcases the research projects funded through the Acquisition Research Program at the Graduate School of Business and Public Policy at the Naval Postgraduate School. Featuring keynote speakers, plenary panels, multiple panel sessions, a student research poster show and social events, the Annual Acquisition Research Symposium offers a candid environment where high-ranking Department of Defense (DoD) officials, industry officials, accomplished faculty and military students are encouraged to collaborate on finding applicable solutions to the challenges facing acquisition policies and processes within the DoD today. By jointly and publicly questioning the norms of industry and academia, the resulting research benefits from myriad perspectives and collaborations which can identify better solutions and practices in acquisition, contract, financial, logistics and program management.

For further information regarding the Acquisition Research Program, electronic copies of additional research, or to learn more about becoming a sponsor, please visit our program website at:

www.acquistionresearch.org

For further information on or to register for the next Acquisition Research Symposium during the third week of May, please visit our conference website at:

www.researchsymposium.org

THIS PAGE INTENTIONALLY LEFT BLANK

Dynamic Cost-contingency Management: A Method for Reducing Project Costs While Increasing the Probability of Success

Presenter: Edouard Kujawski is an associate professor in the Systems Engineering Department at the Naval Postgraduate School. His research and teaching interests include the design and analysis of high-reliability/availability systems, risk analysis, and decision theory. He received a PhD in theoretical physics from MIT, following which he spent several years in research and teaching physics. He has held lead positions at General Electric, Lockheed-Martin and the Lawrence Berkeley National Laboratory. He has contributed to the design of particle accelerators and detectors, space observatories, commercial communication systems, the Space Station, and nuclear power plants. He was a participant and contributor to the Lockheed Martin LM21 Risk Management Best Practices and the original INCOSE *Systems Engineering Handbook*. He is a member of the San Francisco Bay Area Chapter of INCOSE and has served on the board of directors.

Edouard Kujawski, PhD, Associate Professor
Department of Systems Engineering
Naval Postgraduate School
Monterey, Ca 93943
Phone: (831) 656-3324 (Office),
(510) 289-1144 (Mobile)
E-mail: ekujawsk@nps.edu

Abstract

In the real world, “Money Allocated is Money Spent" (MAIMS). As a consequence, cost underruns are rarely available to protect against cost overruns, while task overruns are passed on to the total project cost. The combination of the probabilistic aspects of project costs and the MAIMS principle have important implications for budget allocation and the management of contingencies. Project costs depend not only on the desired probability of success but also on budget allocation and contingency management. This is in contrast with both deterministic practices that allocate a percentage of the project baseline cost for contingency as well as today's de-facto probabilistic cost analyses that provide a cost contingency independent of the budget-allocation strategy. The realistic modeling of cost uncertainties and the MAIMS principle provide a framework for developing a viable cost-management strategy for allocating baseline budgets and contingencies. Based on this analysis, the project manager can maintain a realistic project-wide contingency and dynamically distribute it to the individual risks on an as-needed basis. Projects that implement dynamic cost-contingency management based on these principles are likely to achieve a higher probability of success and cost less.

Introduction

Real-world experience and intuition both suggest that project costs depend on many factors, including technical, organizational, and behavioral considerations. Thucydides got to the very root of the cost-overrun problem over 2000 years ago when he stated, “Their judgment was based more on wishful thinking than on sound calculation of probabilities” (Augustine, 1997, p. 255).

In the 1990's, the Lockheed Missiles and Space Co. carried out a study which concluded that the following deficiencies in cost modeling and contingency management have been major contributors to both project high costs and overruns (Gordon, 1997):

- Hidden incentives in procurement
- Hidden incentives in management styles
- Failure to coordinate cost analysis and cost management
- Use of invalid mathematics such as arithmetically summing uncertain cost elements instead of using statistical methods
- Overlooking the "Money Allocated Is Money Spent" (MAIMS) principle

The MAIMS principle accounts for the fact that projects rarely underrun their allocated budgets. It is the money analog of Parkinson's Law, "Work expands to fill the time allotted." The principle is also in concordance with Goldratt's observation that negative human behavior is a major cause of the project-scheduling problem. Goldratt (1997) developed the Critical Chain Project Management (CCPM) as a management philosophy and solution that simultaneously reduces project duration and protects against schedule risk. A key principle of CCPM is to aggregate task buffers at the project-level for use where and when needed. But it also proposed the following guidelines for sizing buffers: (1) cut task duration estimates in half, and (2) add approximately 25% of the original estimate to the project buffer. These guidelines appear to be rather arbitrary, and many technical managers are uncomfortable with them. A number of simple alternatives to estimate and sum buffers have been proposed (Newbold, 1998; Schuyler, 2001). We think that their use is no longer justified because of the availability of simple Monte Carlo simulation tools such as @Risk® and Crystal Ball®.

The premise of this paper is that a credible Probabilistic Cost Analysis (PCA) needs to integrate findings on human behavior with mathematically valid models and sound management techniques to obtain realistic cost estimates and achieve project success. A key recommendation is that in order to deliver successful projects at an optimal cost project, management needs to allocate "reasonable" budgets to the cost-account managers and dynamically manage the cost-contingency funds as a risk portfolio at the program/project level.

Proposed Modifications to Today's Typical PCA

Assessing Uncertain Cost Elements

R&D and complex engineering projects rely heavily on engineering/expert judgment for the assessment of uncertain cost elements. Unfortunately, these subjective assessments are often performed in a rather ad-hoc manner, and they have been identified as a critical source of error in probabilistic risk analyses (Keeney & von Winterfeld, 1991). The Direct Fractile Assessment (DFA) method has been investigated in numerous psychological experiments and found to provide one of the most reliable and least bias-prone procedures for eliciting uncertain quantities (Alpert & Raiffa, 1982). We recommend that experienced analysts and domain experts determine the 10^{th}, 50^{th}, and 90^{th} percentiles for uncertain cost elements. While other percentiles may be used, these seem to be highly practical (Dillon, John, & von Winterfeld, 2002).

Fitting Cost Elements with Realistic Probability Density Functions (PDF)

Uncertain cost elements are more appropriately modeled as continuous than discrete random variables. We favor the use of the three-parameter Weibull distribution because it is an open-ended function that can assume a wide variety of shapes (Kujawski, Alvaro, & Edwards, 2004). It is also more flexible than the three-parameter lognormal even though both are characterized by three independent parameters. The use of more complex PDFs seemed unwarranted for fitting three subjectively assessed percentiles. Analysts and assessors should always validate that they feel comfortable with the shape of the fitted distribution.

Incorporating the MAIMS Principle

The MAIMS principle plays a significant role in PCA. Once a cost element is allocated a budget, x* it becomes a random variable with minimum value x* rather than the lower range of the original PDF. The cost element is then given by a PDF with a delta-like function[1] (or spike) at x* that accounts for all random values less than or equal to x* and the original distribution for values greater than x*. The associated Complementary Distribution Function (CDF) has a step-function behavior at x* and is identical to the original CDF above x*. The effect on the cost element is that its mean increases and its standard deviation decreases with increasing values of x*. As a result, the MAIMS principle plays a significant role in budget management.

Modeling Specific Risks

The above PDFs provide a macroscopic rather than a microscopic view of the project cost risk. They effectively model those factors or project characteristics that are ever present and contribute to cost uncertainties. But complex projects often involve a number of critical decisions and high-impact risks which call for explicit risk-mitigation actions. A detailed PCA should incorporate both the macroscopic and microscopic views to ensure that all risks and cost uncertainties are addressed and that the risk-reduction activities are transparent (Chapman & Ward, 1997). The analysis of specific risks and risk-response actions requires a microscopic view and is best carried out using tools such as decision trees, influence diagrams, or other discrete representations (Kujawski, 2002a).

Modeling Correlations

Cost elements are correlated because project characteristics (such as complexity, criticality, management, staff, and processes) are likely to impact multiple cost elements at the subsystem and system levels. Also, the realization of any one risk is likely to influence other risks and to increase their probabilities and/or consequences. Kujawski, Alvaro, and Edwards (2004) have developed a Two-Level Correlation Model (TLCM) which greatly reduces the number of parameters needed to specify a mathematically valid and physically realistic correlation matrix. In its simplest form, it models correlations among cost elements of the same and different subsystems with only two parameters, ρ_{int} and ρ_{ext}.

Application to a Representative Design and Engineering Project

To investigate the concepts and issues discussed in the previous sections, we consider a hypothetical project with three level-2 cost elements (project/system-level and two

[1] Caution: The MAIMS-modified PDFs are not the same as the Crystal Ball® and @Risk® truncated PDFs.

subsystems) each with three level-3 cost elements. Figure 1 depicts different budget-allocation strategies for a given set of PDFs and TLCM parameters[2].

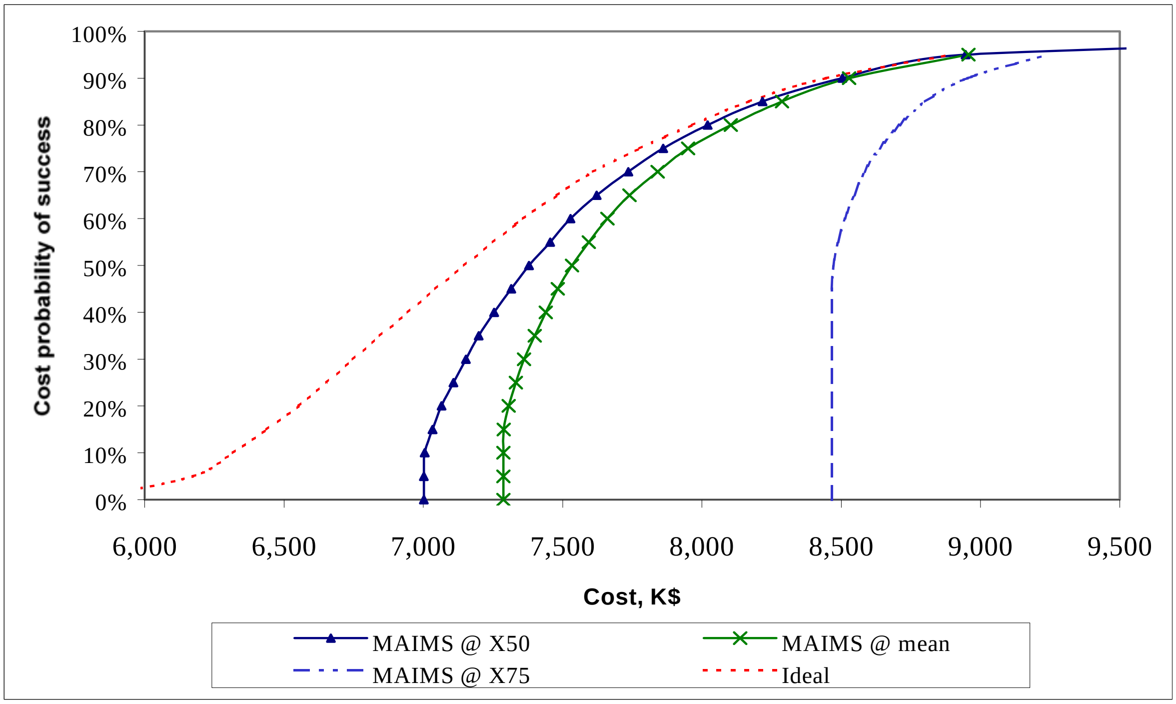

Figure 1. Illustrative Impact of Different Budget Allocation Strategies on Project Cost

Note: The cost elements are modeled with Weibull distributions fitted to the 10th, 50th, and 90th fractiles. The cost correlations are modeled using the two-level correlation model with parameters of 0.6 and 0.4.

The “ideal curve” corresponds to the model where the project staff rationally spends money only as necessary to satisfy the project requirements. In this ideal world, the actual costs may be less than the budgeted costs, and the savings are available to support other project elements on an as-needed basis. In the MAIMS_@_X50 and MAIMS_@_X75 curves, all cost elements are allocated equal percentiles of 50% and 75%, respectively. The MAIMS_@_mean curve corresponds to the case in which each cost element is allocated its mean or expected value. Each cost element is then budgeted at a percentile that depends on the shape of the assessed PDF. The MAIMS effects increase with higher allocated budgets and are substantial over a wide range of Probability of Success (PoS) values of interest to PCA.

Budget Allocation, Contingency, and Project Cost

Our objective is to integrate the presented concepts into a sound methodology for determining an optimal as well as realistic Total Estimated Cost (TEC) and budget-allocation/management strategy for a given PoS. The combination of cost uncertainties and the MAIMS principle complicates the situation. As we have shown, the TEC depends not only on

[2] The calculations were performed using Crystal Ball® and 10,000 trials.

the desired PoS but also the budget allocation and the management of contingencies. The project cost cannot be estimated until the cost management strategy—including budget allocation—is specified. We like to think that this contains a flavor of the Heisenberg Uncertainty Principle.

Much has been written on cost contingency; but there is still much confusion (Baccarini, 1999; INCOSE, 2003). To shed additional light on the subject, we express the Management Cost Contingency (MCC) in a form that exhibits its dependence on the PoS and the cost management strategy:

$$MCC(PoS, PBC_1,\ldots, PBC_n) \equiv TEC(PoS, PBC_1,\ldots, PBC_n) - PBC.$$

PBC_i is the baseline budget for cost element C_i, and PBC is the probabilistic sum of all the project cost elements. The above relationship contrasts with both (1) the deterministic practice that allocates a percentage of the PBC as MCC, and (2) today's typical PCA that provides a MCC that is independent of the budget-allocation strategy. Figure 2 depicts the TECs and MCCs corresponding to Figure 1.

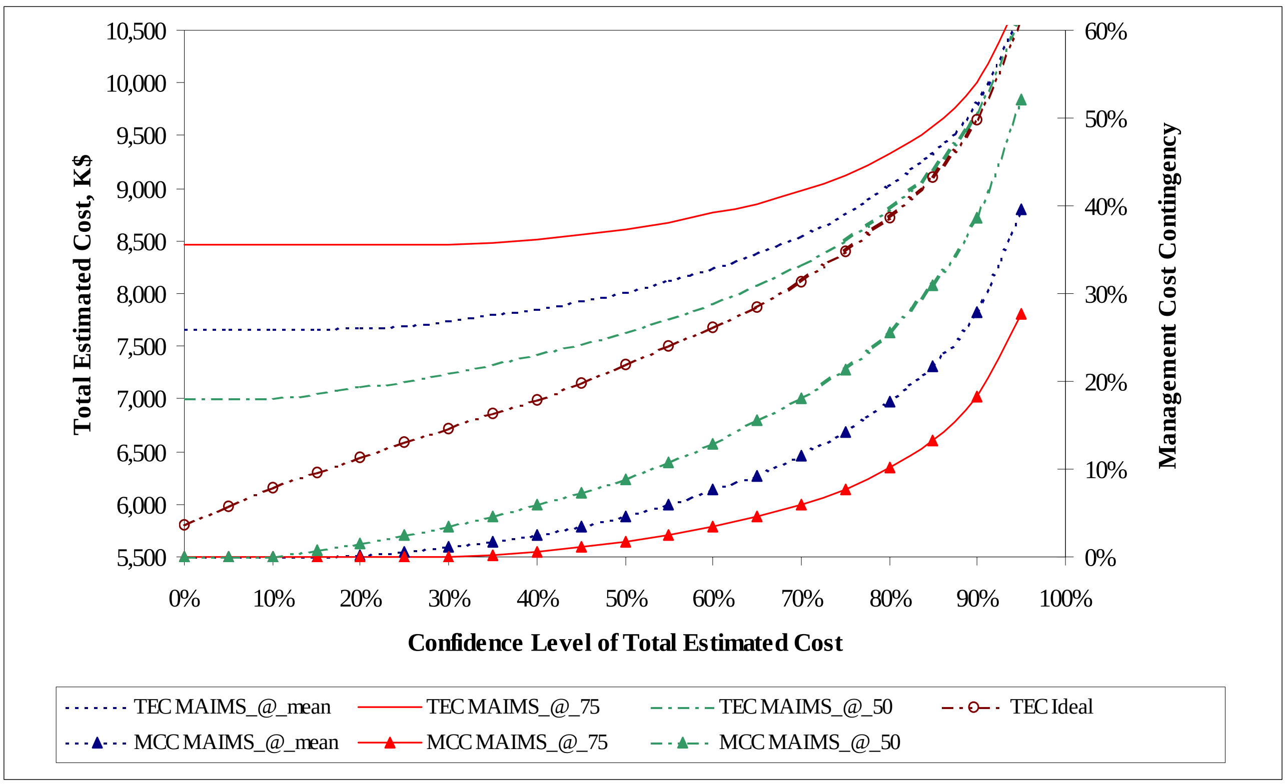

Figure 2. Impact of Different Cost Management Strategies on the Cost and Contingency for the Project in Figure 1

Figure 2 contains valuable information for both the procuring activity and the contractor. The budget management strategy has a significant impact on the TEC for a given PoS. The effects of the MAIMS principle increase with increasing budget allocations and are substantial for all but the very highest PoS values. The MAIMS principle has little impact at the very high confidence levels (CL > 95%) because each contributing cost element must then be near its maximum or 100^{th} percentile value. These results have important implications for cost management. For example, sizeable cost reductions are achieved by allocating budgets to the cost elements at the 50% CL rather than the 75% CL. The standard PCA that assumes an "ideal" project provides a false sense of confidence; it may be a major source of cost overruns even for projects with high contingencies.

Why Projects Even with High Cost-Contingencies Often Fail

Consider a hypothetical request for proposal for the project[3] depicted in Table 1. To level the playing field, the procuring activity specifies that all bids should provide the 50% CL cost. Contractor A has a certain level of sophistication. He[4] prepares a typical PCA with every bid; but he is not cognizant of the MAIMS principle. He performs today's typical PCA and obtains the CDF in Fig. 2 labeled "TEC Ideal" and a P50 TEC of 7,348 K$. Based on this analysis, Contractor A submits a bid of 7,348 K$ and rationalizes that the proposal is conservative given that the P50 value is 30% above the low estimate of 5,633 K$. But because of the MAIMS principle, Contractor A's risks are significantly greater than he thinks. Once the contract is awarded, management proceeds to baseline and allocate budgets to the cost elements at their mean values. Given that the cost elements are budgeted at their mean values, the TEC is really given by the CDF in Fig. 2 labeled "PEC MAIMS_@_mean," the P50 TEC is 8,071 K$, and the PBC of 7,665 K$ is the lowest achievable cost. To management's surprise, this value is 317 K$ less than the proposal bid of 7,348 K$. Because of the MAIMS principle, there is a negligible likelihood that Contractor A, given his practices, can deliver the project for the submitted bid of 7,348 K$. Table 1 summarizes this and several other scenarios.

Management	**Strategy**	**MAIMS-Modified PCA**				**Typical PCA**			
Budget Allocation	**Desired PoS**	**TEC $K**	**MCC $K**	**MCC %**	**Real PoS**	**TEC $K**	**MCC $K**	**MCC %**	**Real PoS**
	20%	7,673	0	0%	20%	6,445	-1,220	-16%	0%
Mean	50%	8,071	406	5%	50%	7,348	-317	-4%	0%
	80%	8,987	1,322	17%	80%	8,626	961	13%	73%
	20%	7,111	0	0%	20%	6,445	-557	-8%	0%
50% CL	50%	7,692	690	10%	50%	7,348	346	5%	37%
	80%	8,771	1,769	25%	80%	8,626	1,624	23%	77%
	20%	8,466	0	0%	20%	6,445	-2,021	-24%	0%
75% CL	50%	8,613	147	2%	50%	7,348	-1,118	-13%	0%
	80%	9,330	864	10%	80%	8,626	160	2%	52%

Table 1. Some Summary Data for the Different Cost Management Strategies Depicted in Figure 2

Similarly, when considering specific technical risks, the common-sense and mathematically valid solution for efficient-cost risk management is to maintain a project-wide contingency and to distribute it to the individual risks on an as-needed basis. This approach to

[3] This is the same illustrative project used for Figures 1 and 2.

[4] Gender neutral

managing project technical risks may be thought of as a variant of modern portfolio theory (Markowitz, 1991). The implication to managing project is that less attention should be given to the individual risks (substituted for stocks) and more to the project (substituted for portfolio) as a whole (Kujawski, 2002b). CCPM formalizes analogous concepts and their implementation for project schedule planning and management.

Concluding Remarks

This paper develops a practical and sound framework for quantifying the influence of human behavior on project cost and efficiently managing project risks and cost contingencies. The key elements include:

- The incorporation of the “Money Allocated Is Money Spent” (MAIMS) principle. The probability distribution of each cost element is modified by setting all cost values less than the allocated budget to the allocated budget in the MCS.
- The realistic assessment of cost uncertainties and technical risks using proven methods such as the Direct Fractile Assessment method, event trees and/or influence diagrams.
- The realistic treatment of correlations among cost elements.
- The probabilistic treatment of the cost elements and explicit representation of technical risks. The analysis is readily performed using commercially available Monte Carlo simulation Excel add-ins.
- The implementation of a project-wide cost contingency to ensure the contractually agreed-to or acceptable probability of success.
- Contingencies held and managed at the project-wide level. They should not be allocated at the task-level and held by individual subsystem managers.
- A dynamic allocation algorithm with system-level oversight for managing project risks. However, individual technical risks are still managed by the responsible technical performers. A database for tracking risks would provide a powerful tool for accurately watching and forecasting contingency allocations and for controlling adverse behaviors.

All seven principles are necessary to ensure that adequate contingencies are available to mitigate all project risks and not just selected ones. Projects that implement all seven principles are more likely to succeed and cost less.

The author acknowledges that it takes effort to develop these more realistic models and that all models are only approximations to reality. The single greatest challenge to the development and use of improved probabilistic cost analysis and dynamic budget allocation is the implementation of systems thinking at the personnel, organizational, and institutional levels. But given the magnitude of the cost overrun problem, there is no excuse for accepting the status quo; the benefits are likely to be significant.

References

Alpert, M., & Raiffa, H. (1982). A progress report on the training of probability assessors. In D. Kahneman, P. Slovic, & A. Tversky (Eds.), *Judgment under uncertainty: Heuristics and biases* (pp. 294-305). Cambridge: Cambridge University Press.

Augustine, N. R. (1997). *Augustine's laws.* Reston: American Institute of Aeronautics and Astronautics.

Baccarini, D.J. (1998). Cost contingencies—A review. *Australian Institute of Quantity Surveyors Refereed Journal* 2(1), 8-15.

Chapman, C., & Ward, S. (1997). *Project risk management: Processes, techniques and insights*. West Sussex: John Wiley & Sons.

Dillon, R.L., John, R., & von Winterfeld, D. (2002). Assessment of cost uncertainties for large technology projects: A methodology and an application. *Interfaces* 32(4), 52-66.

Goldratt, E.M. (1997). *Critical chain.* Great Barrington: North River Press.

Gordon, C. (1997). *Risk analysis and cost and cost management (RACM): A cost/schedule management approach using Statistical Cost Control (SCC*). Retrieved April 10, 2007, from http://www.geocities.com/mtarrani/RiskAnalysis_and_CostManagementOverview.pdf.

INCOSE. (2003, January). *Figuring out contingency budgets*. Internet thread, Risk Management Working Group. Retrieved April 10, 2007, from http://www.incose.org/rmwg/RMWG.

Keeney, R.L., & von Winterfeld, D. (1991). Eliciting probabilities from experts in complex technical problems. *IEEE Transactions on Engineering Management,* 38 (3), 191-201.

Kujawski, E. (2002a). Selection of technical risk responses for efficient contingencies. *Systems Engineering* 5(3), 194-212.

Kujawski, E. (2002b). Why projects often fail even with high cost-contingencies. *Systems Engineering* 5(2), 151-155.

Kujawski, E., Alvaro, M.L., & Edwards, W.R. (2004). Incorporating psychological influences in probabilistic cost analysis. *Systems Engineering* 7(3), 195-216.

Markowitz, H. M. (1991). *Portfolio selection: Efficient diversification of investments*. Malden, MA: Blackwell.

Newbold, R. (1998). *Project management in the fast lane: Applying the Theory of Constraints*. Boca Raton: St. Lucie Press.

Schuyler, J. R. (2001). *Risk and decision analysis in projects*. Newton Square: Project Management Institute.

2003 - 2006 Sponsored Acquisition Research Topics

Acquisition Management

- Software Requirements for OA
- Managing Services Supply Chain
- Acquiring Combat Capability via Public-Private Partnerships (PPPs)
- Knowledge Value Added (KVA) + Real Options (RO) Applied to Shipyard Planning Processes
- Portfolio Optimization via KVA + RO
- MOSA Contracting Implications
- Strategy for Defense Acquisition Research
- Spiral Development
- BCA: Contractor vs. Organic Growth

Contract Management

- USAF IT Commodity Council
- Contractors in 21st Century Combat Zone
- Joint Contingency Contracting
- Navy Contract Writing Guide
- Commodity Sourcing Strategies
- Past Performance in Source Selection
- USMC Contingency Contracting
- Transforming DoD Contract Closeout
- Model for Optimizing Contingency Contracting Planning and Execution

Financial Management

- PPPs and Government Financing
- Energy Saving Contracts/DoD Mobile Assets
- Capital Budgeting for DoD
- Financing DoD Budget via PPPs
- ROI of Information Warfare Systems
- Acquisitions via leasing: MPS case
- Special Termination Liability in MDAPs

Logistics Management

- R-TOC Aegis Microwave Power Tubes
- Privatization-NOSL/NAWCI
- Army LOG MOD

- PBL (4)
- Contractors Supporting Military Operations
- RFID (4)
- Strategic Sourcing
- ASDS Product Support Analysis
- Analysis of LAV Depot Maintenance
- Diffusion/Variability on Vendor Performance Evaluation
- Optimizing CIWS Lifecycle Support (LCS)

Program Management

- Building Collaborative Capacity
- Knowledge, Responsibilities and Decision Rights in MDAPs
- KVA Applied to Aegis and SSDS
- Business Process Reengineering (BPR) for LCS Mission Module Acquisition
- Terminating Your Own Program
- Collaborative IT Tools Leveraging Competence

A complete listing and electronic copies of published research within the Acquisition Research Program are available on our website: www.acquisitionresearch.org

Acquisition research Program
Graduate school of business & public policy
Naval postgraduate school
555 DYER ROAD, INGERSOLL HALL
MONTEREY, CALIFORNIA 93943

www.acquisitionresearch.org