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

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by

**Edouard Kujawski, PhD, Associate Professor, Naval Postgraduate
School**

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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 10th, 50th, and 90th 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 function¹ (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 parameters².

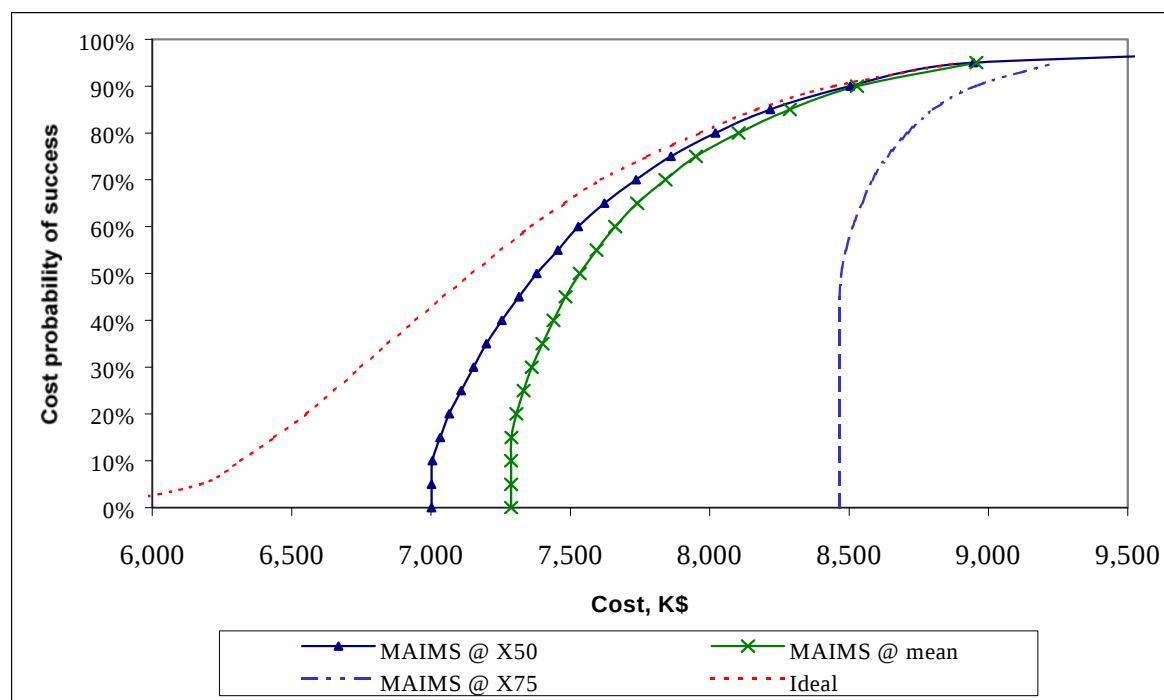


Figure 1. Illustrative Impact of Different Budget Allocation Strategies on Project Cost

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:

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

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.

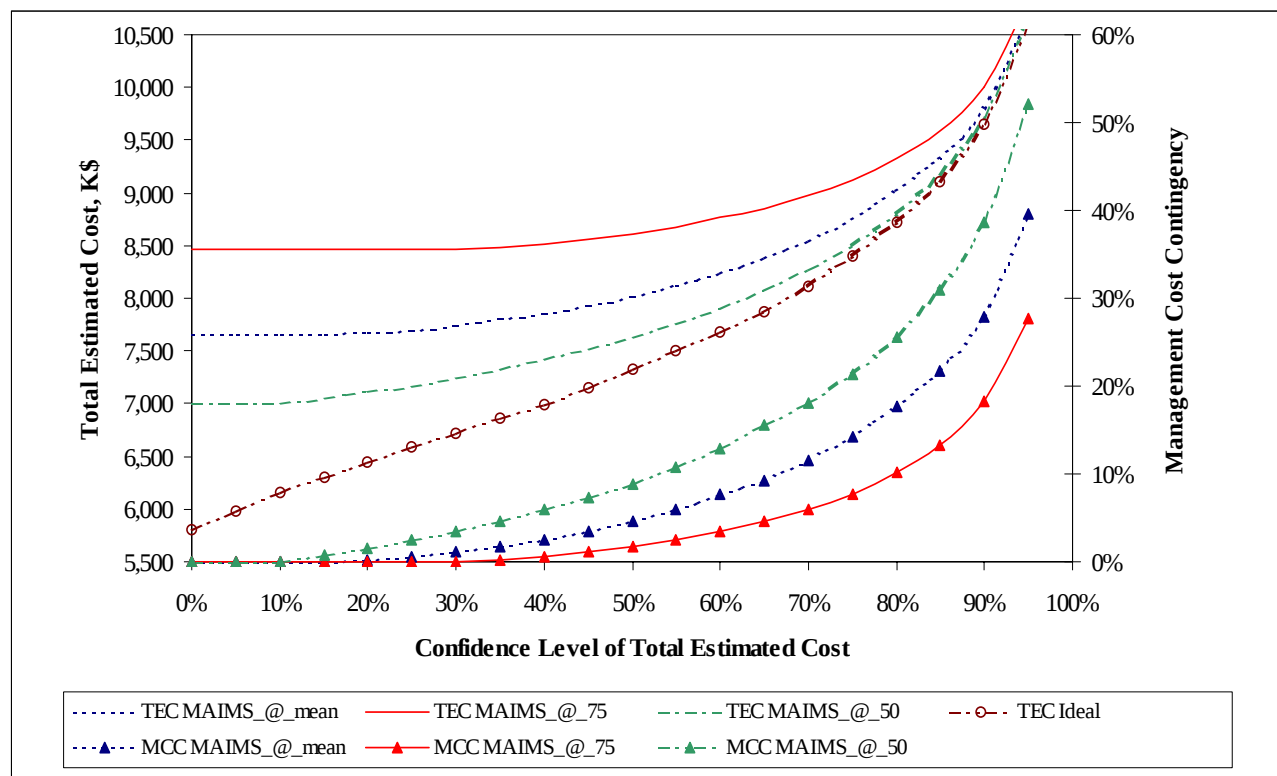


Figure 2. Impact of Different Cost Management Strategies on the Cost and Contingency for the Project in Figure 1

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 100th 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 project³ 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. He⁴ 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
Mean	20%	7,673	0	0%	20%	6,445	-1,220	-16%	0%
	50%	8,071	406	5%	50%	7,348	-317	-4%	0%
	80%	8,987	1,322	17%	80%	8,626	961	13%	73%
50% CL	20%	7,111	0	0%	20%	6,445	-557	-8%	0%
	50%	7,692	690	10%	50%	7,348	346	5%	37%
	80%	8,771	1,769	25%	80%	8,626	1,624	23%	77%
75% CL	20%	8,466	0	0%	20%	6,445	-2,021	-24%	0%
	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.



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Acquisition Research Program: Creating Synergy for Informed Change

Dynamic Cost-Contingency Management **A Method for Reducing Project Cost While Increasing** **Probability of Success**

Ed Kujawski, Ph.D.
Associate Professor
Systems Engineering Department
Naval Postgraduate School

Cost-overrun problem: Déjà-vu

"Their judgment was based more on wishful thinking than on sound calculations of probabilities."

Thucydides, 431 B.C.E.

- Thucydides' observation is very insightful and still appropriate today
- ☞ Projects that come-in under cost do not necessarily deserve kudos
 - They may have carried excessively safe budgets!



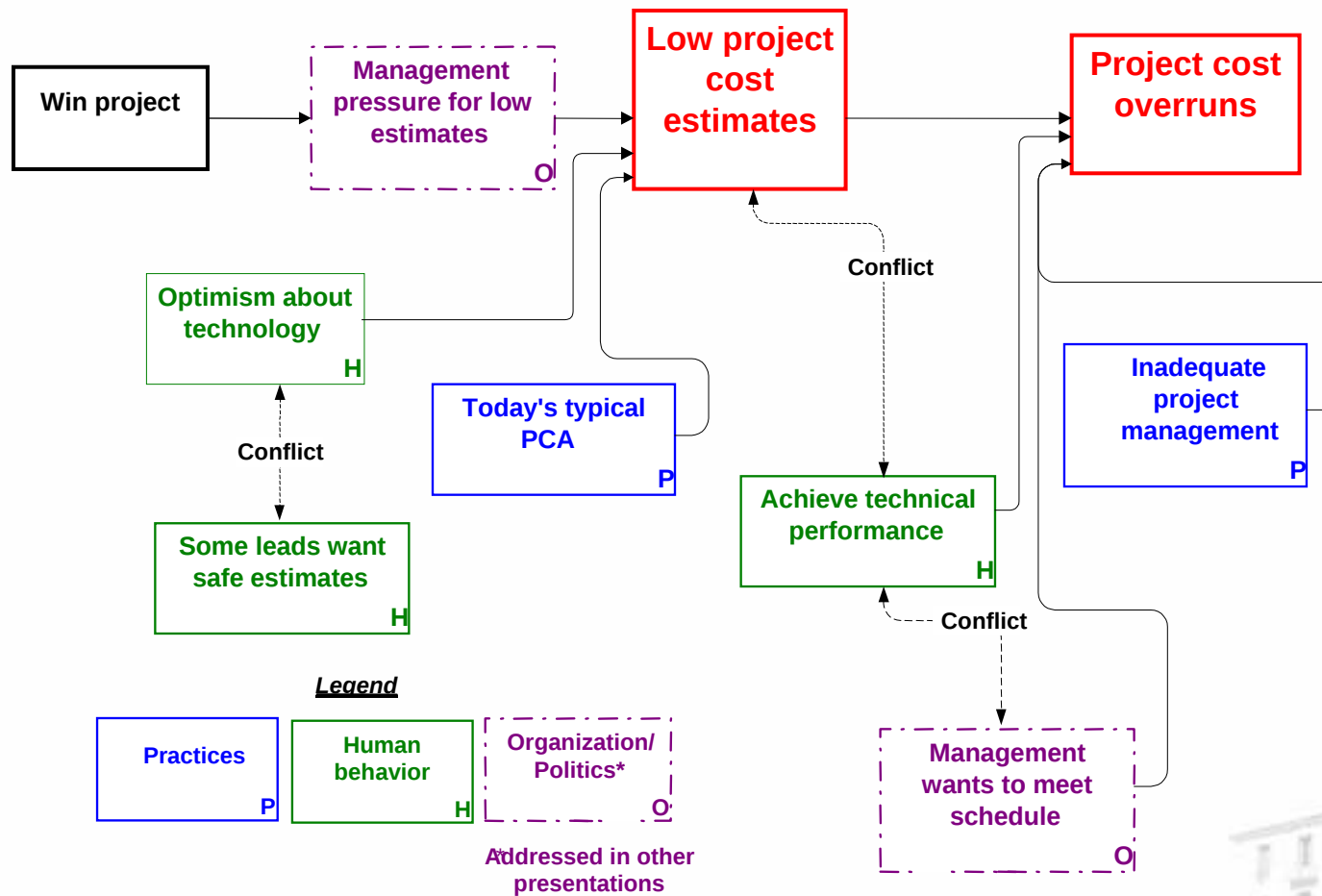
Cost overrun causes “Top 10” list

Common threads among “top 10” lists

- **Institutional and organizational culture**
 - Procurement process, management pressure, poor project definition...
- **Real Vs. idealized human behavior**
 - Psychology is relevant to economics, decision-making, management,...
 - The “100% rational” person is a theoretical model that differs from reality
- **Inadequate analysis - Today's typical Probabilistic Cost Analysis**
 - Ad-hoc data elicitation, improper distributions, omitted and/or limited dependencies, omitted high-risk events & decision points
 - Shift from deterministic to probabilistic approach is NOT silver bullet
 - Monte Carlo simulation is only a mathematical tool: GIGO
- **Poor management practices**
 - Lack of appreciation of probabilistic concepts and psychological influences in budget allocation and control of management reserve



Current project reality leads to cost overruns



Psychology can teach us much about cost overruns

➤ Overconfidence

- R&D folks are intrinsically optimistic about new technologies
 - ☞ *"For heaven's sake, spread those fractiles! Be honest with yourselves! Admit what you don't know!" [Alpert and Raiffa, 1982]*

➤ Negative human behavior – MAIMS Principle

- *"Money Allocated Is Money Spent."* [C. Gordon, 1997]
 - Task underruns are rarely available to protect against tasks overruns. Task overruns are passed on to the total project.

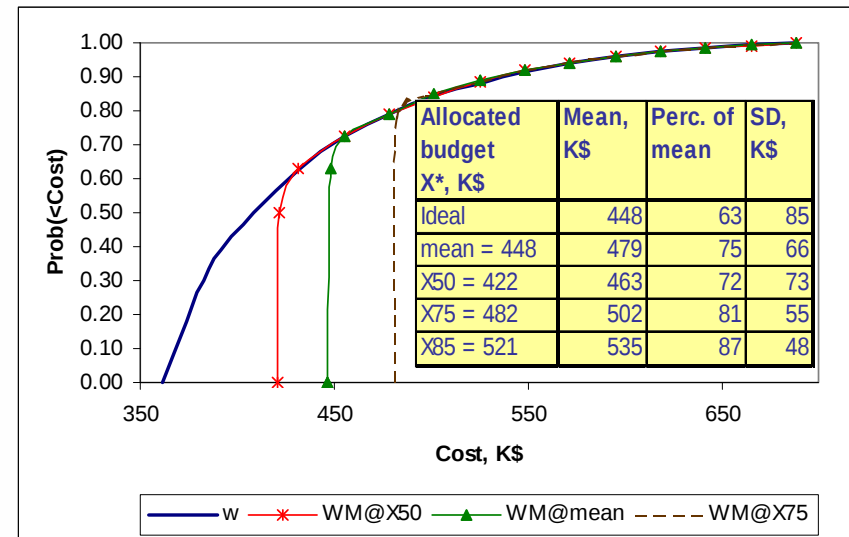
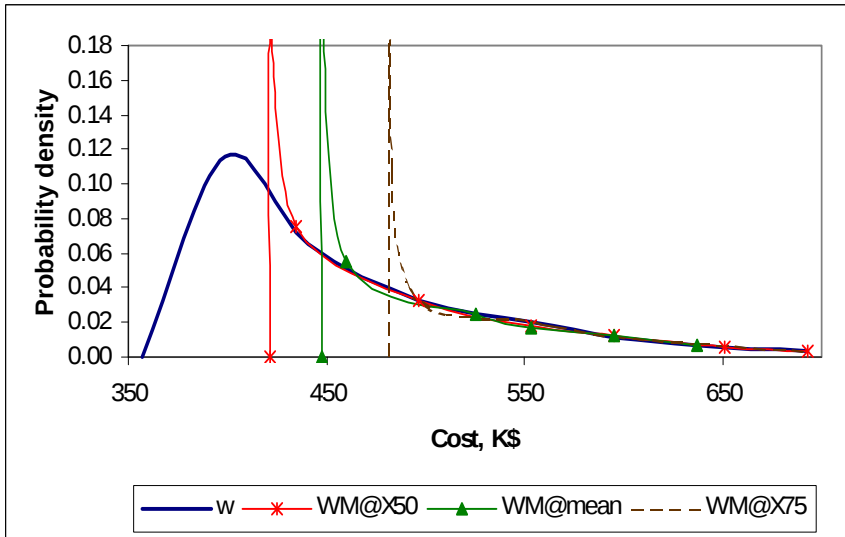
➤ Mistakes of reason

- *"Too many details tend to cloud the big picture."*
 - Total project cost is not simply the sum of cost elements. Project risks are likely to affect multiple elements.
- ☞ *"Implicitly trusting the most readily available information or anchoring too much on convenient facts." [Russo and Schoemaker, 1990]*

Realistic cost analysis requires a systems perspective
Integrate psychological influences, valid mathematical models,
and sound management techniques



MAIMS significantly impacts project cost



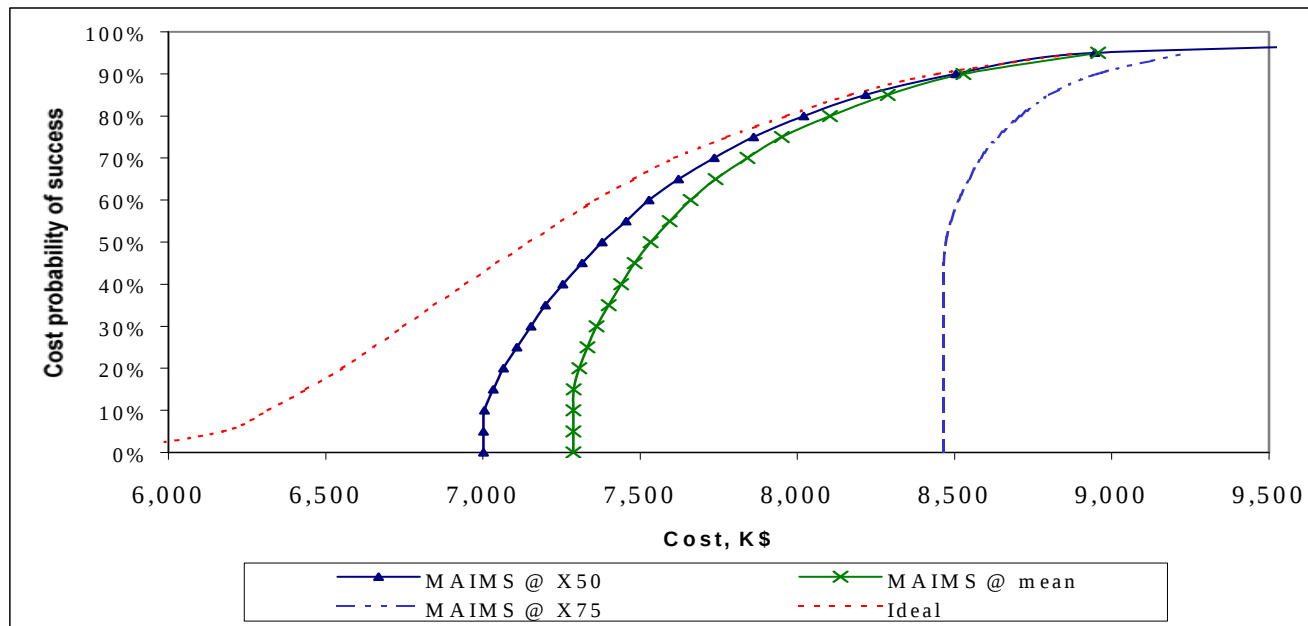
Properties of MAIMS - Modified probability distributions

- Minimum value: allocated budget, x^*
- Spike (Dirac delta function) at x^*
- Identical to original cost element for values $> x^*$

MAIMS impact increases with increased budget allocation



Budget allocation impacts project cost and probability of success



Mythical Project

- "100% Rational" team
- Each cost manager spends only as necessary to satisfy requirements
- Actual cost may be less than budgeted costs

Real Project

- Human & organizational influences
- MAIMS principle: No cost manager spends less than his/her budget
- Actual cost increases with higher allocated budget



It's NOT your textbook contingency anymore!

- Cost contingency depends on desired probability of success and cost management strategy

$$MCC(PoS, PBC_1, \dots, PBC_n) = TEC(PoS, PBC_1, \dots, PBC_n) - PBC$$

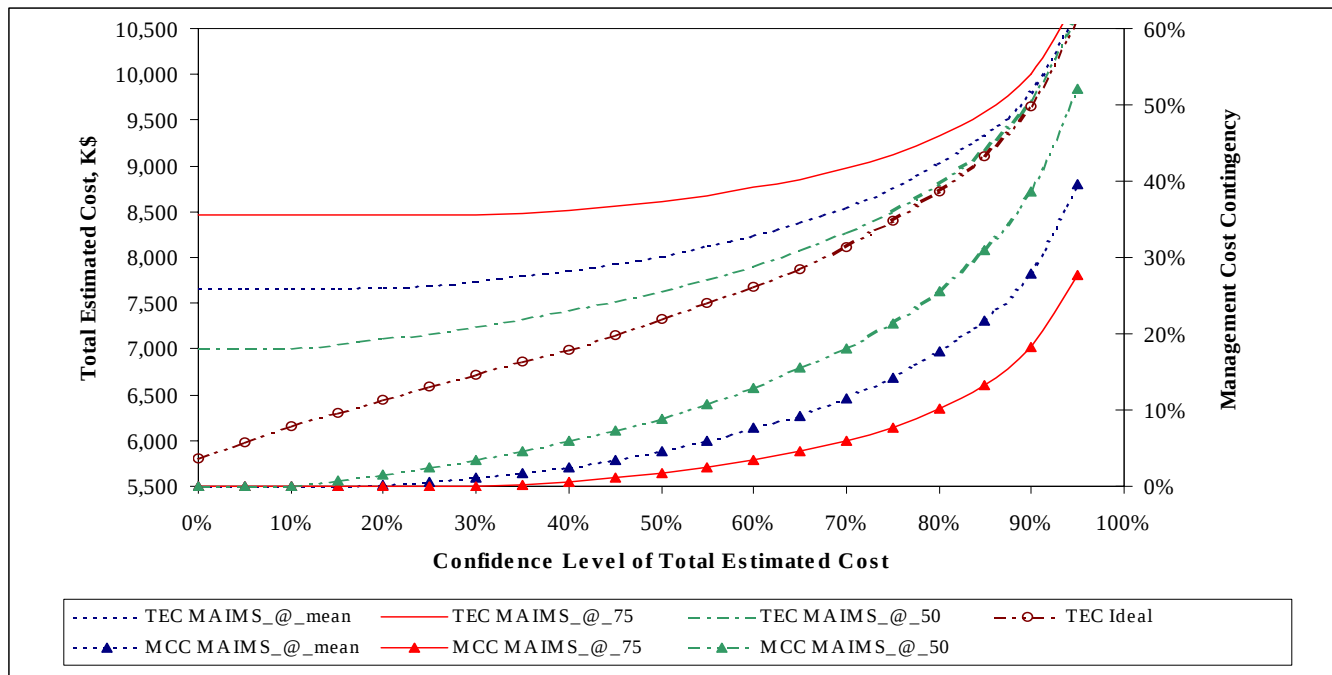
- MCC: Management Cost Contingency
- TEC: Total Estimated Cost
- PoS: Probability of Success
- PBC_i : Baseline Budget for Cost element C_i
- PBC: sum over all cost elements

- Major differences with both deterministic practice and today's typical PCA

- MCC is not a fixed percentage of PBC
- MCC incorporates depends on the management strategy
- MCC is an interactive and iterative process
 - Analysts, engineers, managers



Contingency, cost, & success are NOT directly related



- High cost NEED NOT provide (1) high PoS or CL and/or (2) high contingency
- Low contingency DOES NOT necessarily equate to low cost
- High contingency DOES NOT necessarily equate to high cost and/or padding

Realistic budget allocation, adequate contingency, and dynamic allocation are critical to optimal cost and probability of success.



Fable of a project cost overrun

- Agency X issues a RFP
 - Requests cost at 50% CL
- Contractor A prepares bid
 - Possesses limited sophistication; not cognizant of MAIMS principle
 - Performs today's typical PCA
 - P50: 7,348 K\$
 - Min: 5,633 K\$
- Cont. A submits bid of 7,348 K\$
 - Confident of success. Thinks cost estimate has a 30% margin.
- Contractor A is winner
- Project starts & budgets allocated
 - Cost element baseline at mean:
7,665 K\$

- Much time is spent reallocating and prorating budgets
 - Budget cost elements at 50% CL
 - Baseline cost: 7,002 K\$
 - Management reserve: ~ 5%



The outcome

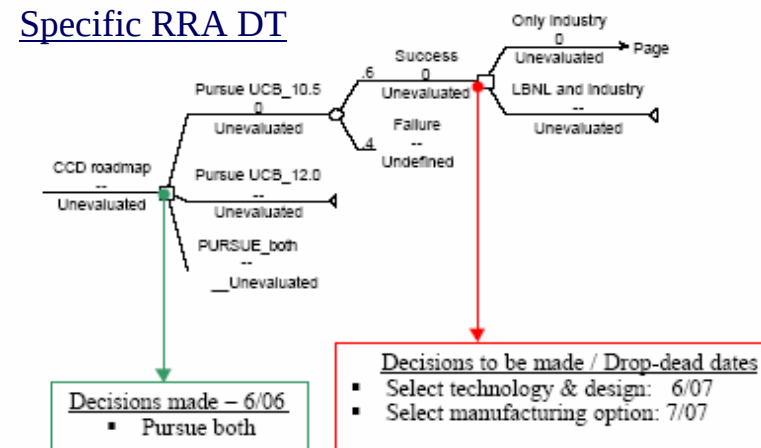
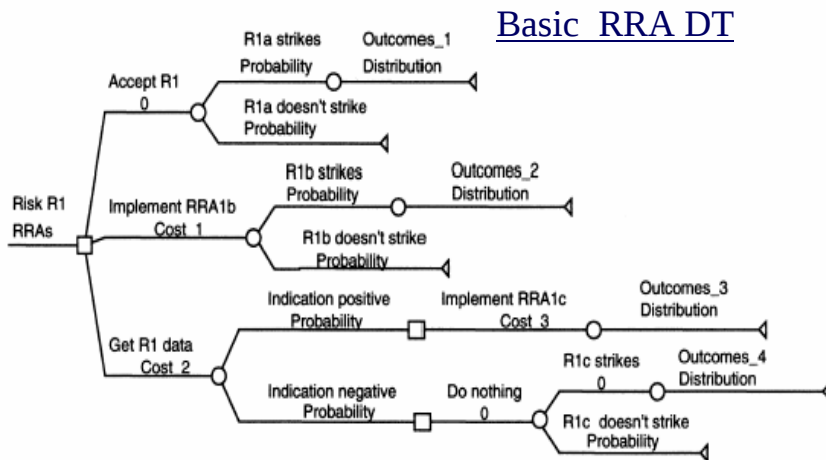
Everybody works very hard.
But the project runs out of budget and is cancelled

- Epilogue
 - Another project has succumbed to the MAIMS principle
 - Today's typical PCA models a mythical project
 - Contracting agencies & contractors use proposed approach



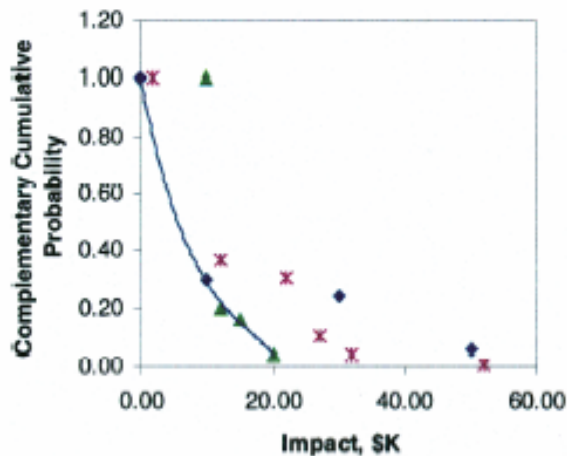
High technical risks require individual risk mitigation plans

- ☞ Technical risks often associated with high-consequence events
- Detailed engineering analysis more suitable than statistical analysis
 - Identify possible Risk Response Actions (RRA)
 - Accept risk as is, Immediately implement RRA, Obtain addition information
 - Develop risk-specific RRAs including critical decision points
 - Scenarios and Decision Trees (DT)
 - Assess risk reduction profile
 - Technical performance parameters, Cost and Schedule earned-value system



The efficient management of technical risks requires a portfolio approach

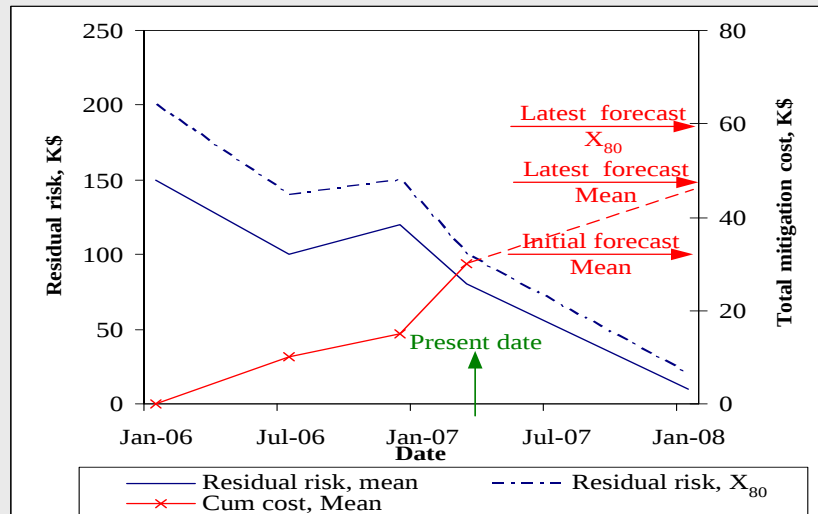
- ➡ Proposed approach based on Markowitz' s efficient portfolio selection principle
- The PMO manages high technical risks as a whole rather than focus on the individual risks per se
 - Systematic development and implementation of Efficient RRA Set
 - Lowest total project cost for a given probability of success
 - System-level oversight
 - Dynamic allocation of contingencies for RRAs
- Contingencies held and managed at the project-wide level
 - Protection against MAIMS principle



Example of an Efficient Contingency Frontier



Risk monitoring & reserve analysis avert surprises



- Risk exposure metric
 - Baseline risk (unmitigated)
 - Residual risk over time (mitigated)
 - Cost of mitigation over time
- ➡ Clearly reveals progress and value of RM effort

- Risk metrics track RM effectiveness and value throughout LC
 - Risk exposure metric - one of many useful quantitative risk metrics
 - Technical Performance Measurements (TPM) for KPPs
- Risk monitoring and metrics should be produced continually
 - Integrated with other PM activities and databases
- Reserve analysis compares contingency reserves to residual risk
 - Assures adequate contingency reserves for remaining risks



Implementation is the challenge!

- Efficient project cost management requires a rigorous framework supported by probabilistic risk analysis and decision-making under uncertainty.
- Some R&D is required
 - Integrated analysis of performance, cost, and schedule
 - Tool for dynamic budget allocation.
- The greatest challenge is the implementation of systems thinking at the personnel, organizational, and institutional levels.

Dynamic cost-contingency management is well worth the additional effort.
The benefits are likely to be significant.

