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Dynamic Cost Risk Assessment for Controlling the Cost of Naval Vessels

22 September 2008

by

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Abstract

Naval vessels, like most large-capital projects/programs, have a long history of cost growth and overruns. To get a handle on this problem, NAVSEA's Cost Engineering and Industrial Division, NAVSEA 05C, has introduced Probabilistic Cost Risk Analysis (PCRA) into the Department of Defense (DoD) Planning, Programmatic, Budgeting, and Execution System (PPBES). The quantification of cost in terms of Cumulative probability Distribution Functions (CDF) or "S-curves" provides a macroscopic view of project/program risk. Risk curves alone do not provide adequate visibility into the individual project risk drivers; therefore, they are insufficient for planning and managing Risk Reduction Activities (RRA). Complex projects typically involve a set of high-consequence, project-specific risks that require detailed analysis and for which risk response actions need to be developed and implemented. The analysis of specific risks and RRAs requires a microscopic view. We present a practical and mathematically sound approach using scenarios and Monte Carlo simulation within the framework of decision trees and risk curves. The approach is detailed using a realistic but simplified case of a project with three technical risks.

Keywords: Probabilistic Cost Risk Analysis (PCRA), Planning, Programmatic, Budgeting, and Execution System (PPBES), Cumulative probability Distribution Functions (CDF), Risk Reduction Activities (RRA), Monte Carlo simulation

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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.

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1. Introduction

Cost growth has been a major problem for the US Navy. Over the past four decades, the growth of US Navy ship costs has exceeded the rate of inflation. In the past 50 years, annual cost escalation rates for amphibious ships, surface combatants, attack submarines, and nuclear aircraft carriers have ranged from 7 to 11% (Arena, Blickstein, Younossi & Grammich, 2006). Along with real cost growth, the DoD has had significant problems with cost estimates. By and large, the DoD and the military services have underestimated the acquisition cost new weapon systems. A recent study by RAND (Arena, Leonard, Murray & Younossi, 2006) indicates that there is a systematic bias toward underestimating weapon system costs and substantial uncertainty in estimating the final cost of a weapons system.

The DoD recognizes that uncertainty is an important part of cost estimating. During a 2007 seminar with a naval aviation program official, the Assistant Secretary of the Navy for Research, Development and Acquisition, Dr. Etter (Burgess, 2007, p. 42), stated:

> Program managers not only need to know a realistic cost estimate for their program, they need to know the percent probability of achieving that target. For example, a ship with a 40% chance of coming in on budget has a 60% chance of being over budget. Such a situation should prompt the project manager to seek help from the acquisition community.

There is an ongoing major shift in R&D and complex engineering projects/programs from deterministic to probabilistic approaches. (For convenience, in this report we use project to refer to both project and program.) Probabilistic Cost Risk Analysis (PCRA) provides the proper framework for handling the many different elements of cost uncertainties, including project-specific, high-consequence risks. These risk drivers must be identified, assessed, mitigated, and controlled through formal risk management, which is an essential and critical discipline, implemented in today's DoD projects. The *Risk Management Guide for DoD Acquisition* (2006, p. 3) reads:

> Risk management is a continuous process that is accomplished throughout the life cycle of a system. It is an organized methodology for continuously identifying and measuring the unknowns; developing mitigation options; selecting, planning, and implementing appropriate risk mitigations; and tracking the implementation to ensure successful risk reduction. Effective risk management depends on risk management planning; early identification and analyses of risks; early implementation of corrective actions; continuous monitoring and reassessment; and communication, documentation, and coordination.

The DoD risk management process is consistent with the American Association of Cost Engineers (AACE) approach, which includes identifying and analyzing risk factors or drivers, mitigating the risk drivers when appropriate, estimating their impact on plans and monitoring and controlling risk during execution (Hollmann, 2006). Figure 1 depicts PCRA as an integral part of the risk management process. To be effective, PCRA should interface with each of the risk management activities and be regularly updated to reflect the risk registry, risk mitigation plans, and their status integrated with the project’s Earned Value Management System (EVMS) (NDIA-PMSC, 2005).

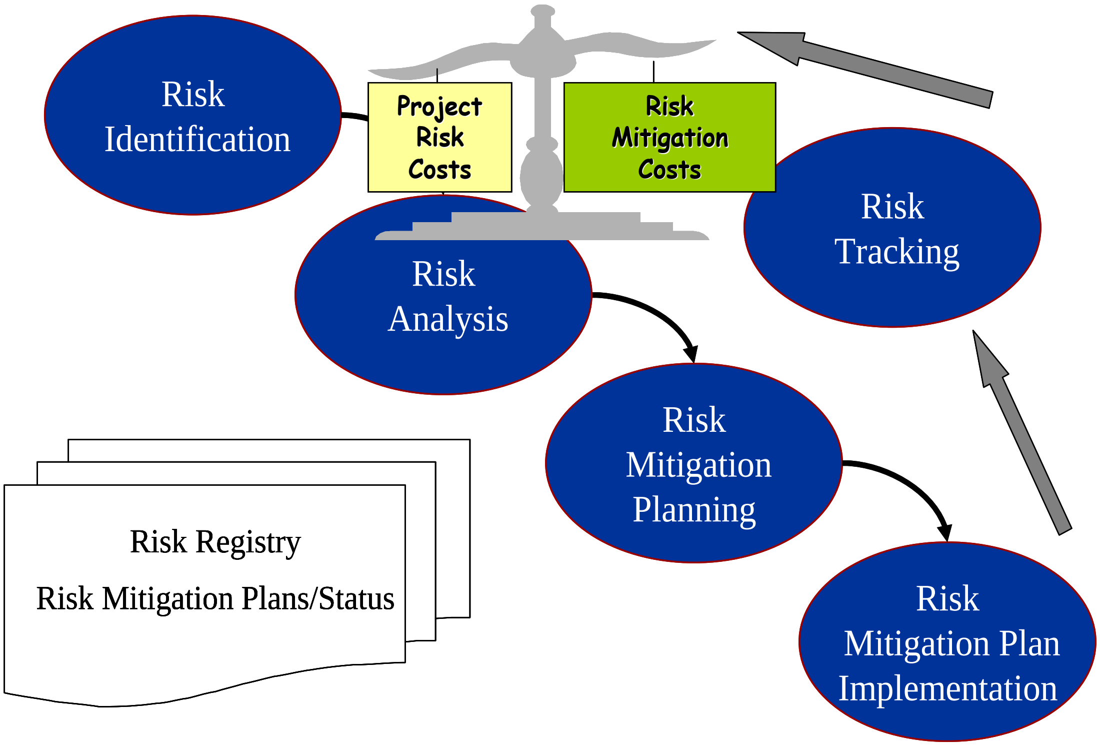


Figure 1. Probabilistic Cost Risk Analysis as an Integral Part of the Risk Management Process
(Adapted from *Risk Management Guide for DoD Acquisition,* 2006)

The emphasis on risk management supports efforts to reduce lifecycle costs of system acquisitions. An often-neglected concept in project risk management is the consideration of the entire project lifecycle. Analysis of risk over the lifecycle of a system can yield substantial benefits. Conversely, ignoring important stages of the lifecycle can lead to substantial problems in terms of risk for product development at the beginning of the lifecycle and for product upgrade or replacement at the end (Pennock & Haimes, 2001).

Many sources of cost uncertainty in naval vessel construction such as economic/business factors (rates-wages, overhead, vendor/supplier stability, inflation indices, multi-year assumptions, etc.), learning/rate/curve assumptions, and cost-reduction initiatives are well understood within the framework of a macroscopic perspective. These are effectively modeled with classical Probability Distribution Functions (PDF) such as the triangular, Beta, lognormal, and Weibull distributions. These PDFs, however, do not model some of the negative influences of the acquisition process and human behaviors such as the MAIMS principle, “Money Allocated Is Money Spent” (Kujawski, Alvaro, & Edwards, 2004). The MAIMS principle is the money-analog of Parkinson's Law. It captures the fact that cost under-runs are rarely available to protect against cost overruns while task overruns are passed on to the total project cost. The PDF for each cost element is modified to set all random values less than its allocated value to the allocated value. This has important implications for contingency and risk management (Kujawski, 2007). A realistic probabilistic analysis requires more than PDFs. There are dependencies or correlations between cost elements; these need to be modeled using correlation matrices (Book, 2001). However, even accounting for these additional effects, macroscopic factors constitute only a fraction of current typical project risk drivers and, therefore, cost uncertainty.

The development and acquisition of naval vessels, like most complex engineering projects, is also susceptible to project-specific risk drivers, such as low Technology Readiness Level (TRL); high design, manufacturing, and complexity; significant requirement changes; sizeable quantity changes; large funding uncertainty; severe acts of nature; and serious accidents. It is tempting to assume or claim that the classical PDFs that cost or risk analysts typically elicit for cost also quantify the project-specific, high-consequence risks. Sometimes these analysts go through the effort of identifying and discussing risk drivers, but when it comes to quantifying the risks and estimating contingency, they simply apply high/low ranges to WBS elements without thinking about how a particular risk driver affects one or more cost elements. We think it is invalid and counterproductive to do this because it leads to (1) the loss of valuable information and visibility into important risks and (2) a reduced focus and ability to track risk mitigation actions. Best practices implement the identification of risk drivers and events as the kick-off activity of cost risk analysis. Hollmann (2007) explicitly accounts for the risk drivers using their Expected Values (EV) in addition to the macroscopic classical PDFs. He refers to this approach as the Driver-Based Monte-Carlo (DBM). This represents a significant improvement over today’s typical Monte Carlo analysis. However, the use of EV is a major limitation for use in a truly probabilistic framework in which decisions are based on a given probability of success.

The analysis of specific risks and risk response actions (RRA) requires a microscopic view and is best carried out with tools such decision trees (DT), influence diagrams, or other discrete representations. This microscopic perspective offers many benefits. It is a powerful risk analysis method to explicitly model high-consequence risks and RRAs, thereby providing a tool for making better decisions. It also assists subject-matter experts (SMEs) to think about credible, high-consequence events and better deal with overconfidence or optimism biases. However, the microscopic view is too cumbersome to individually analyze every risk and source of cost uncertainty. It complements and needs to be integrated within the PCRA. The total project cost is then best modeled as the sum of a macroscopic baseline cost and microscopic risk cost as depicted in Figure 2.

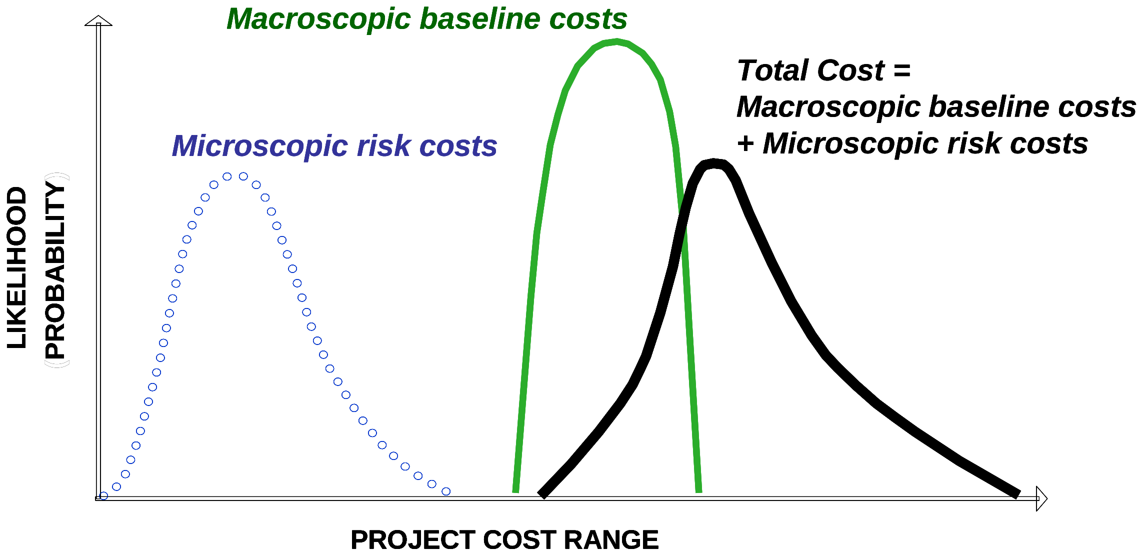


Figure 2. Total Project Cost as the Sum of the Macroscopic Baseline Costs and Microscopic Risk Costs
(Adapted from Federal Transit Administration, 2004)

In this report, we develop a practical and realistic integrated microscopic/macroscopic PCRA method as an integral entity of the DoD risk management process, as follows:

1. The cost and/or risk analysts (simply referred to as analyst below) and the SMEs jointly identify the individual risks using the standard DoD risk-identification process.

2. The analyst and the SMEs jointly screen the identified risks for further analysis and risk mitigation.

3. The analyst and SMEs jointly identify realistic RRAs for the screened risks.

4. The analyst models each risk and its RRAs using a DT.

5. The analyst works with the SMEs to quantify the value of the decisions and outcomes for each DT using discrete and continuous distributions. We favor the Direct Fractile Assessment (DFA) method for data elicitation and fitting the associated cost elements with a three-parameter Weibull distribution.

6. The analyst quantifies the DTs using Monte Carlo simulation. Risks and RRAs are then modeled in terms of risk curves. We, thereby, avoid relying on the minimum expected risk value, which is a serious shortcoming of standard decision analysis.

7. The analysis is readily performed using commercial Excel add-ins (such as Crystal Ball®, @Risk, etc.) or more specialized tools (such as DecisionPro, Analytica, etc.)

8. The analysis is updated regularly and key milestones throughout the project life-cycle to effectively monitor and control the performance and selection of RRAs as old risks are retired and new risks arise.

With the proposed approach, project managers and team leads can dynamically determine the optimal temporal set of decision gates for a given probability of success, thereby reducing cost while increasing the probability of project success.

Section 2 discusses the dynamic picture of project risks and the need for total risk management. Section 3 presents the use of Generalized Decision Trees (GDT) and illustrates their application for the analysis of a single risk with two RRAs as the project evolves. Section 4 extends the approach to multiple risks and illustrates the method for the realistic but simplified case of a project with three technical risks. We close the report with some recommendations for further development.

2. From Risk Assessment to Total Risk Management

"Risk management" is an overloaded term. It is used to denote both (1) the activities following risk assessment and (2) the entire process of risk assessment and its management. Following Haimes (1991), we use the term "total risk management" for the latter. The standard quantitative risk assessment paradigm focused on the following triplet of questions articulated by Kaplan and Garrick (1981):

1. What can go wrong?
2. What are the associated likelihoods?
3. What are the consequences?

Once these critical questions have been answered, the greater challenge for risk management is to address and control the following three issues articulated by Haimes (1991):

1. What can be done and what options are available?
2. What are the tradeoffs in terms of costs, benefits, and risks?
3. What are the impacts of current decisions on future options?

Successful risk management requires that the above three critical issues be properly and continuously addressed to reflect the dynamic character of project risks depicted in Figure 3. The sources and consequences of risks continue to evolve and change over time. As more information is obtained about a particular risk, the RRA options might change, thus, it is necessary to constantly monitor risk. In general, at any point in time there will be a mix of acceptable and unacceptable results. The performance of the RRAs needs to be monitored and controlled to ensure they are adequately mitigating risk. Concurrently, management reserves need to be reviewed on a periodic basis and dynamically allocated where needed to ensure project success (Kujawski, 2007). Waldof (1998) in his risk management guide writes, “Risk management efforts that fail do so because the risk control actions did not keep up with a changing program situation” (p. 33). The proposed dynamic risk assessment and management approach provides a mathematically valid as well as practical framework for dealing with this challenge.

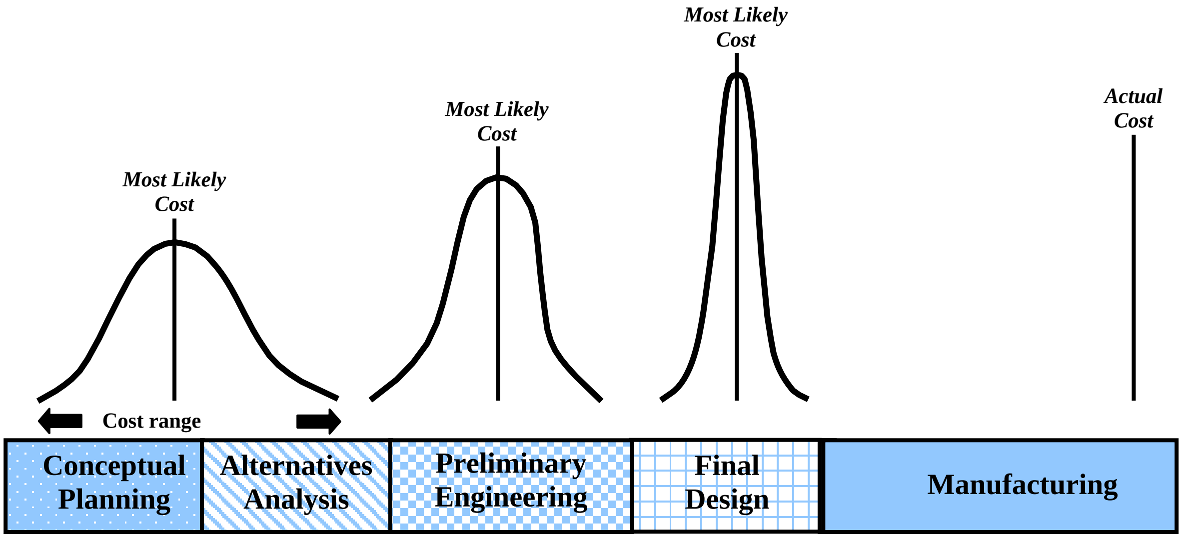


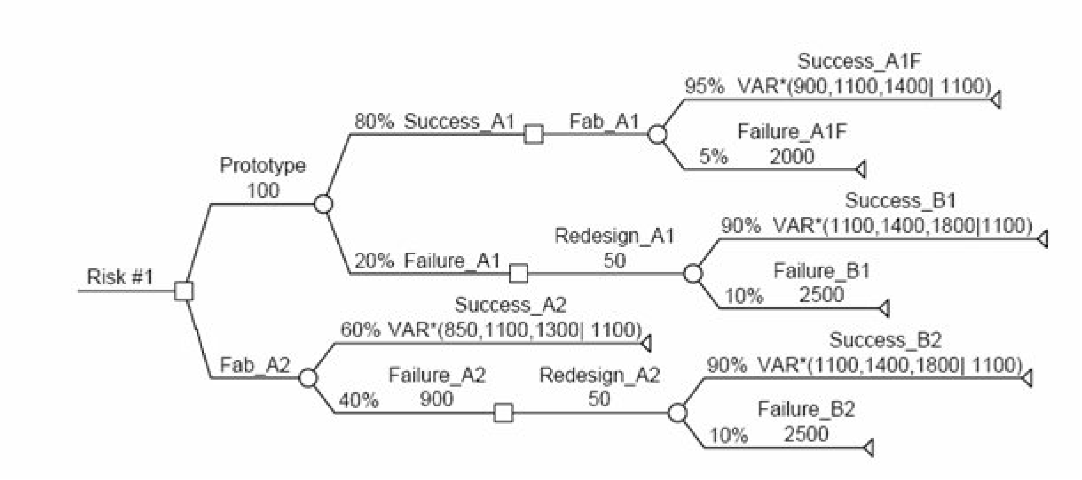
Figure 3. The Dynamic Picture of Project Cost Risk
(Adapted from Federal Transit Administration, 2004)

3. Generalized Decision Trees for Modeling and Analyzing Risk Response Actions–Single Risk Case

We model and analyze each screened risk and the associated candidate RRAs using a generalized GDT. In a GDT, PDFs rather than discrete branches are associated with the chance nodes, and the outcomes are analyzed using Monte Carlo simulation (Kujawski, 2002). This provides a powerful technique for dealing with the complex situations typical of today's DoD projects. It avoids bushy trees and generates risk curves, thereby removing the reliance of decision-making based on expected value.

3.1. Illustrative Example #1—Selecting the Initial RRA Selection

To illustrate the approach, we consider the single risk depicted in Figure 4. To be concrete and without loss of generality, we associate Risk #1 with the fabrication of a complex module or system and the following two RRAs: (1) Directly fabricate the module, or (2) Build a prototype and then fabricate the module. The GDT follows the standard DT representation. The decision nodes and chance nodes are depicted as squares and circles, respectively. The ordering of the decision nodes corresponds to different temporal deterministic events in the development and fabrication cycle of the module. The branches that originate with decision nodes represent the available RRAs. The branches that originate with chance nodes represent the possible probabilistic outcomes. A descriptive label, a probability, and a cost distribution are associated with each branch. These probability and cost values are conditional on the RRAs and may also be conditional on the outcome of other risks in case of interdependencies.



NOTE: In this hypothetical case, the values may be thought of as $K.

Figure 4. Generalized Decision Tree for Risk #1

Figure 4 depicts the fabrication of a hypothetical first of a kind system. To mitigate the associated risk, the project considers two initial candidate risk response actions.

The data in Figure 4 is as follows: The cost PDFs are three-parameter Weibull PDF fitted to the 10th, 50th, and 90th percentiles determined in accordance with the DFA method. The baseline cost is assumed to be $1,100K. The cost risk is then given by the Value At Risk (VAR) relative to this value. For example, VAR*(900, 1,100, 1,400 | 1,100) denotes the cost risk distribution associated with the three-parameter Weibull PDF with the 10th, 50th, and 90th percentiles equal to $900K, $1,100K, and $1,400K, respectively, given a baseline cost of $1,100K.

We evaluate each RRA in Figure 4 using the Excel Monte Carlo simulation add-in Crystal Ball®. The selection of a RRA is a deterministic event, and only the associated outcomes can be realized. It would, therefore, be inappropriate to weigh or combine the outcomes of the two RRAs since they are mutually exclusive. The PDFs and risk profiles for each individual RRA at the start of the project are depicted in Figures 5a and 5b, respectively. The PDFs are multimodal and cannot be represented using any of the PDFs commonly used in risk analysis (Vose, 2006).

The peak for the "prototype" RRA corresponds to the outcome in which the fabrication of the module fails. The PDF for the "direct fabrication" RRA has two modes corresponding to the sequence of events in which the first fabrication and the subsequent fabrication following redesign both fail.

The Complementary Cumulative Distribution Functions (CCDF) or risk curves shown in Figure 5b provide a more global picture. The exceedance probability is the probability of exceeding a given consequence or (1—the probability of success). For example, looking at the VAR(Fab_A2) curve, one reads that there is approximately a 30% probability that the cost will exceed $1,500K. Equivalently, one can state that there is a 70% probability that the cost will be less than $1,500K. The risk curve and the Cumulative Distribution Function (CDF) carry identical information content. Since we are focusing on specific risks and VAR, we favor the risk curve or CCDF because, in our opinion, it provides a better view of the residual risk and management reserve than the S-curve (or CDF) that typically represents the total cost (including the baseline and risk cost elements).

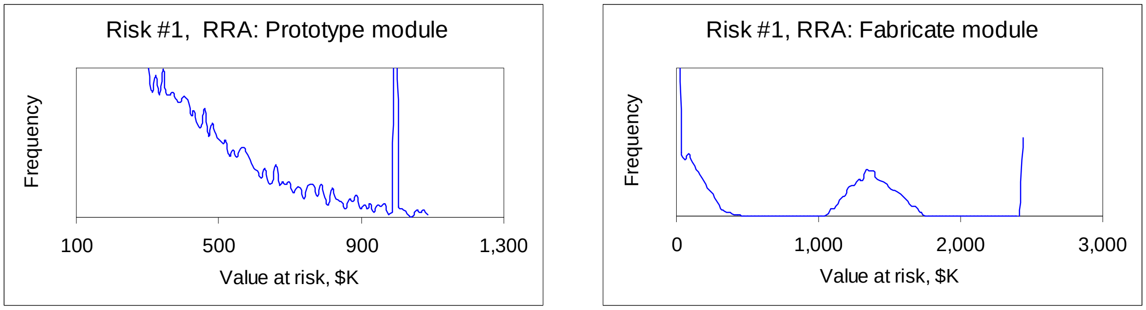


Figure 5a. Probability Distributions corresponding to the Two RRA Options for Risk #1

Given the different scales, the two PDFs are shown separately for greater visibility

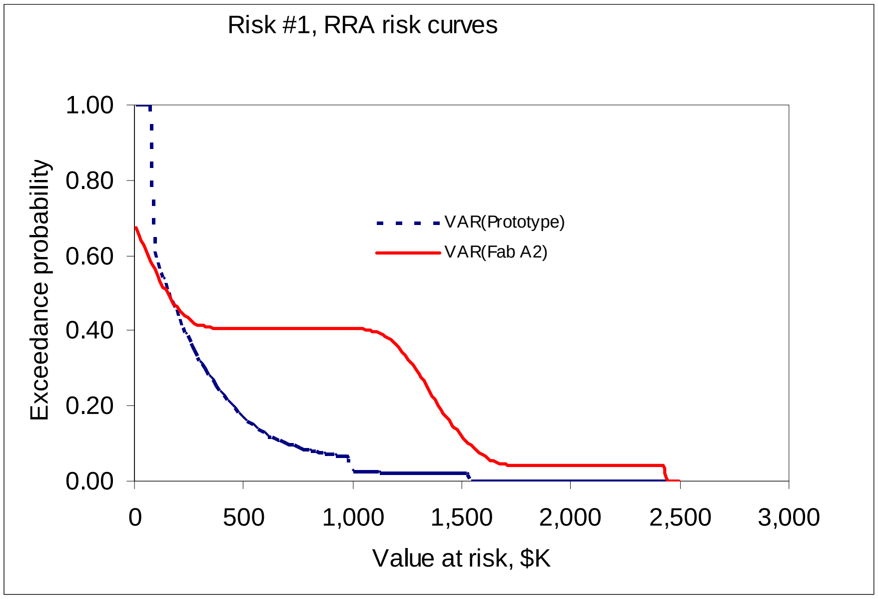


Figure 5b. Risk Curves for the two RRA Options for Risk #1

Please consider Figure 5b. For any given value on the “Value at risk”-axis, the risk curve that corresponds to the lowest exceedance probability represents the lower risk. Figure 5b illustrates that the prototype risk curve is significantly lower than the fabrication risk curve and, thus, has less risk. In this hypothetical but realistic situation, the investment of $100K for building a prototype provides a significant return on the investment as measured by the significant risk reduction. To be more precise, the prototype RRA presents a lower cost risk for all values greater than $200K. For the manager trying to decide if it is worthwhile to invest in the prototype option, the answer is to invest as long as the anticipated benefits from the prototype (whether it be cost savings, time savings, information, etc.) exceed $200K and/or if the low-probability/high-consequence costs of direct fabrication are unacceptable.

3.2. Illustrative Example #1—Analyzing the Dynamic Character of Risk

As discussed in the previous section, we use risk GDTs to model the evolution of the potential RRAs. Figure 6 depicts the Risk #1 risk curves at the start of implementation of the “Prototype” RRA (dash line) and after the successful demonstration of the prototype (solid line). The latter risk curve moves to the left of the original risk curve and is steeper, which reflects a reduced risk. These two risk curves represent the value of the unmitigated risk exposure at two different points in time, thereby providing a metric for the risk exposure as the project evolves. This information is essential for tracking the residual risk exposure versus the cost of the expended RRAs and modifying the RRAs as needed to ensure mission success. As expected, the residual risk following a successful prototype is less than the original risk. In contrast, a risk curve that moves to the right of the original risk curve means that the risk exposure is increasing and the selection of RRAs needs to be re-considered.

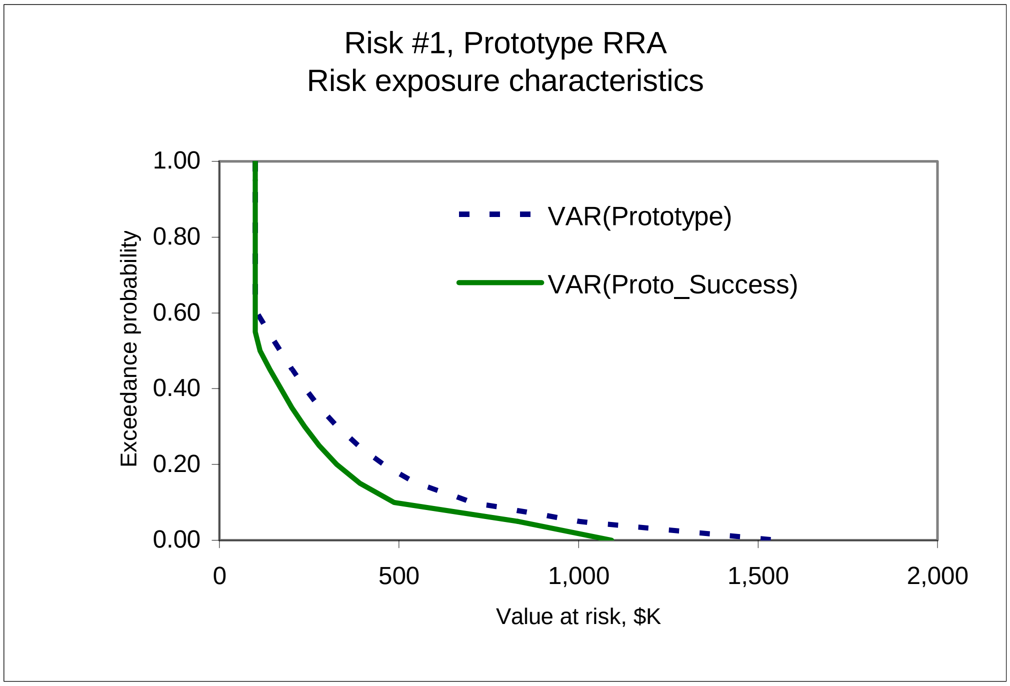


Figure 6. Risk Exposure Characteristics for Risk #1 with the Development of a Prototype at the Start of Risk Mitigation and after Successful Demonstration

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4. The Quantification of Multiple Project Risks

Consider a project with *n* credible, high-consequence risks $\{R_i\}$. Each risk, R_i, is characterized by a probability of occurrence p_i and a spectrum of possible outcomes with a PDF $L_i(x)$, where *x* is a random variable that represents the magnitude of the associated cost or loss. One may then think of this set of risks as a risk portfolio or repository (Kujawski & Miller, 2007) with a generalized discrete PDF $R_S(x)$ given by:

$$R_S(x) \equiv \left\{ \left\langle p_1, L_1(x) \right\rangle, \left\langle p_2, L_2(x) \right\rangle, \ldots, \left\langle p_n, L_n(x) \right\rangle, \left\langle 1 - \sum_{i=1}^{n} p_i, 0 \right\rangle \right\} \qquad (1)$$

As depicted in Figure 2, the total project cost is a random variable that consists of the sum of the *m* base cost elements and the explicitly identified risk costs. Depending on the state of knowledge of the data, the base cost elements BC_i may be modeled as either point estimates or continuous PDFs. The total project cost TC is then the probabilistic sum of the *m* base cost elements and *n* risk-driver costs:

$$TC(x) = \sum_{i=1}^{m} BC_i(x) + \sum_{i=1}^{n} p_i L_i(x) \qquad (2)$$

Equations (1) and (2) provide visibility into the link between the credible, high-consequence risks $\{R_i\}$ and the total project cost risk curve. Monte Carlo simulation tools such as Crystal Ball® and @Risk can also provide tornado charts that conveniently quantify the importance of the various risk drivers and their link to the overall cost risk. Projects can use this information to rationally identity risks. This is in sharp contrast with: (1) the use of point estimates that are at best ambiguous because overly confident staff provide low cost estimates, while others may inflate their cost estimates to make it easier to achieve success, (2) decision-making based on qualitative assessments, and (3) the consideration of only S-curves, which only provide a macroscopic and somewhat “black box” view of project risk and cost uncertainty.

4.1. Illustrative Example #2—A Project with Multiple Risks

Consider the hypothetical project with the following three independent risks: Risk #1 is depicted in Figure 4; Risks #2 and #3 are depicted in Figure 7a and 7b, respectively. This example is both rich and simple enough to illustrate: (1) several diverse RRAs and their analysis, (2) the dynamic nature of the risk picture, and (3) the monitoring of individual risks and allocation of management reserves. The approach readily extends to dependent risks by incorporating probability and outcome values that reflect causality effects or correlations among the risks.

Risk #2, which is depicted in Figure 7a, may be thought of as a prime contractor who subcontracts the engineering and fabrication of a complex module and considers the following two options: (1) subcontract to a single contractor A, denoted by the branch PDR_A associated with the initial node; (2) carrying two subcontractors and selecting the best one for fabrication at the Preliminary Design Review (PDR). We need to uniquely identify each branch. The PDR_A sequence represents the decision to proceed with a single contractor. The PDR_AB sequence represents the decision to proceed with two contractors and, at PDR, to select the best one for manufacturing. By selecting two contractors with different offerings, the prime significantly reduces the probability of PDR failure. The RW branches represent the different costs associated with rework. Each of these branches is modeled with a three-parameter Weibull distribution specified in terms of the 90th, 50th, and 10th percentiles provided by SMEs or based on relevant historical data.

Risk #3, which is depicted Figure 7b, may be thought of as a prime contractor who considers two different Verification and Validation (V&V) strategies as a means for risk reduction. The branch VVS_1_(Start or CDR) represents the use of the standard approach with planned expenditures of $300K. The branch VVS_2_ (Start or CDR) represents the use of a more thorough V&V strategy with planned expenditure of $1,000K. The branch RW_(1 or 2 and PDR or CDR) represents the rework for V& V strategies 1 and 2 following the PDR and CDR, respectively. The rework is assumed to be inversely related to the V&V effort and it is modeled with a three-parameter Weibull distribution, as previously discussed.

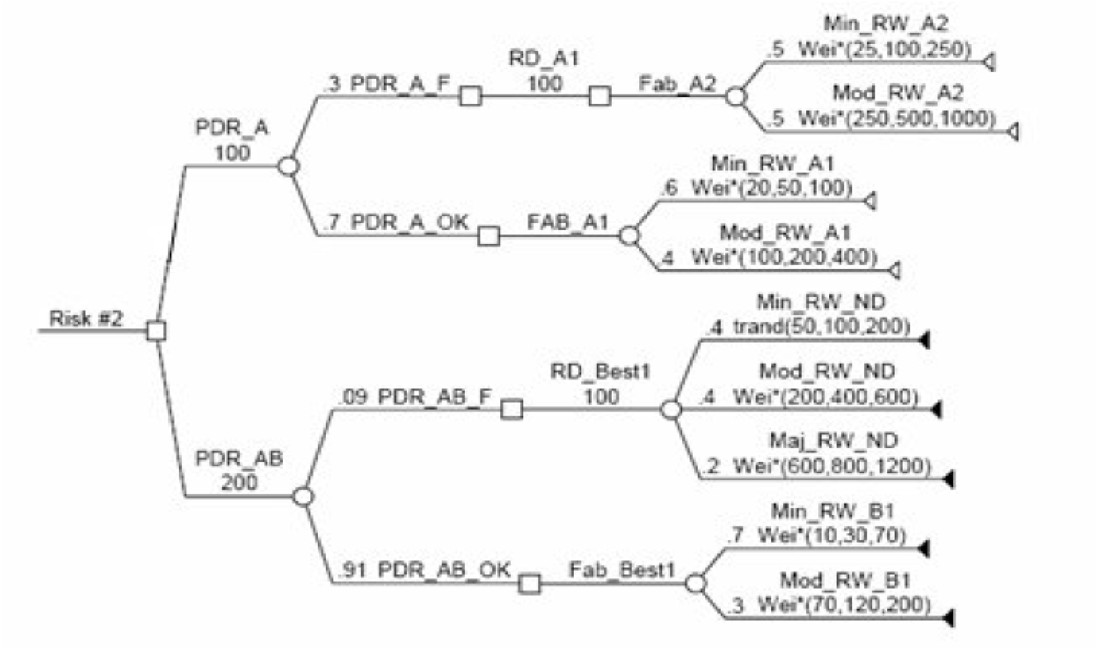
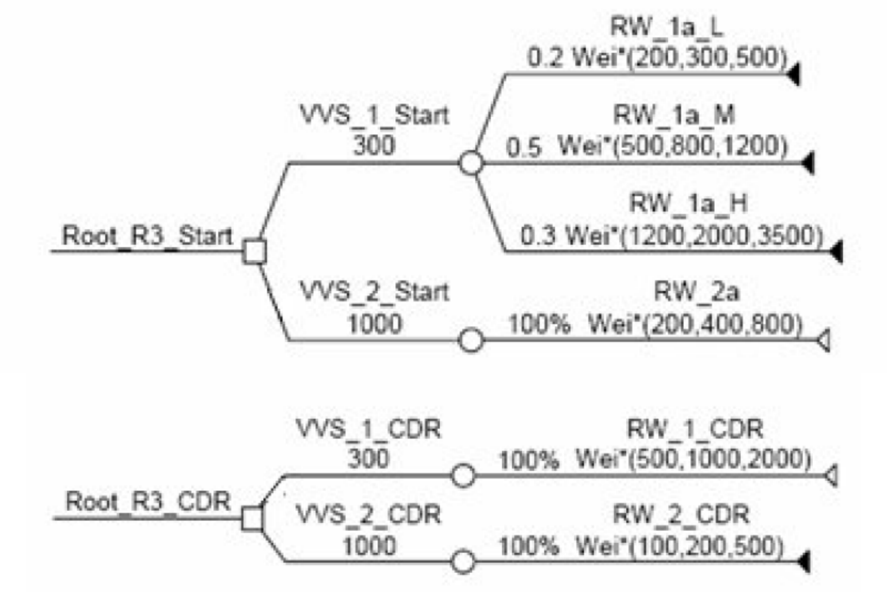


Figure 7a. Generalized Decision Tree for Risk #2 with Two Initial Candidate Risk Response Actions



NOTE: The start (or PDR) and CDR periods are shown separately to simplify the representation of the sequence of events.

Figure 7b. Generalized Decision Tree for Risk #3 with Two Initial Candidate Risk Response Actions

Given the above illustrative project with three risks each and two potential RRAs, there are eight possible initial Total Project RRAs (TPRRA) that the project may opt to implement. As previously discussed, the risk picture is dynamic and it may give rise to a large combinatorial number of outcomes as the project evolves. For example, consider Risk #1 with development of a prototype as a risk reduction option. The prototype may fail or succeed, and the fabrication of the final module may fail or succeed. The full representation of the set of all possible outcomes for even this project is overwhelming and of limited value for a research report. We therefore limit ourselves to reporting an interesting subset of the complete analysis, as follows:

1. We consider only two of the eight TPRRAS.
    - a. Strategy 1. Use of the lowest cost-mitigation option for each risk, which is equivalent to proceeding as normal (i.e., do not implement specific RRAs for any of the three risks). This is the approach that a risk-seeker project manager would favor.

    b. Strategy 2. Use the most effective RRA for each risk. This corresponds to: (1) developing a prototype for Risk #1; (2) proceeding with two contractors for Risk #2; and (3) implementing the more thorough V&V effort for Risk #3. This is the approach that a risk-averse project manager would favor.

2. For each strategy, we assume the best possible outcomes for the first probabilistic nodes, which for convenience we identify by the time of occurrence T1:

    a. The Risk #1 prototype and the Risk #2 review PDR_AB succeed.

    b. Risk #3 has no gates. The risk reduction is directly accounted in the magnitude of the rework.

3. For each strategy, we assume the worst outcomes for the probabilistic nodes for the first probabilistic nodes, which for convenience we identify the time of occurrence T1:

    a. The Risk #1 prototype and the Risk #2 review PDR_AB fail.

    b. Risk #3 has no gates. The risk reduction is directly accounted in the magnitude of the rework.

Figures 8 and 9 depict the initial and residual risks under strategies #1 and #2 assuming the best and worse T1 outcomes, respectively. These data provide bounds for the risk range that may threaten the project following implementation of the initial set of RRAs. Figure 10 depicts this useful information, thereby avoiding the need to analyze the full combinatorial set of RRAs. The dynamic picture of risk and the value of monitoring risk are further discussed in the next section.

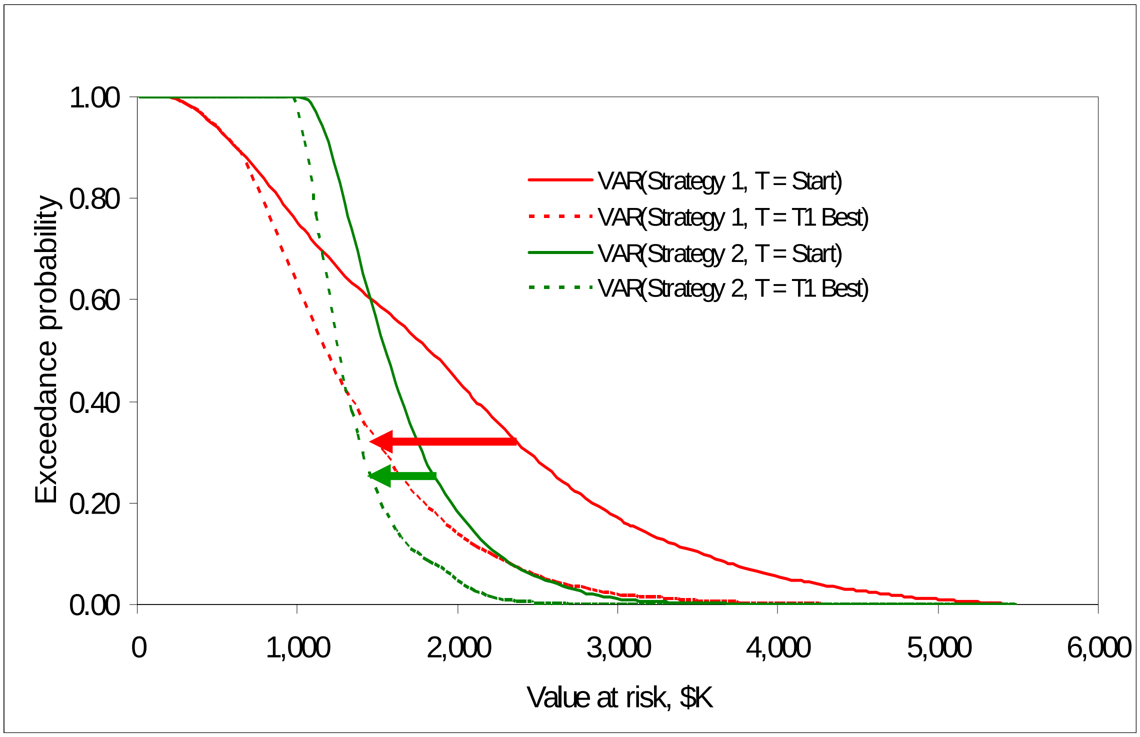


Figure 8. Risk Exposure Characteristics for Risk-seeking Strategy #1 and a Risk-averse Strategy #2 Assuming the Best Possible Outcomes at the 2nd Decision Points; i.e., Good Luck Prevails on the Project for the Initial Set of Risk Response Actions

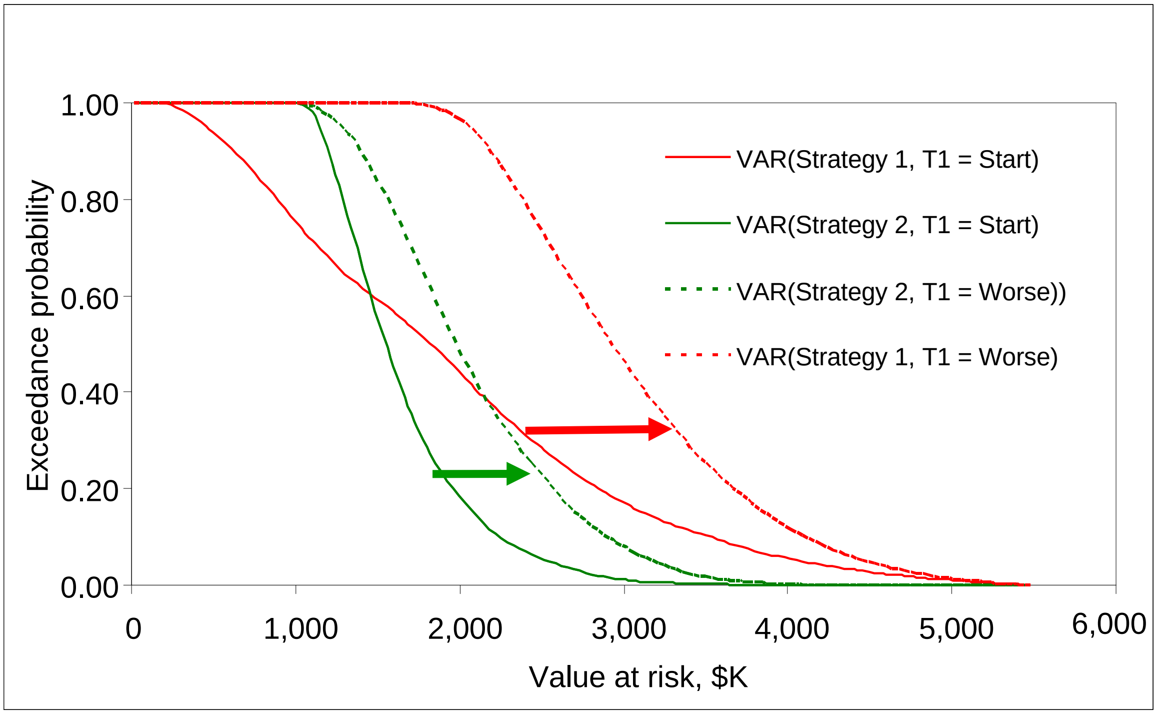


Figure 9. Risk Exposure Characteristics for Risk-seeking Strategy #1 and a Risk-averse Strategy #2 Assuming that Assuming the Worse Possible Outcomes at the 2nd Decision Points; i.e. Murphy's Law Prevails on the Project for the Initial Set of Risk Response Actions

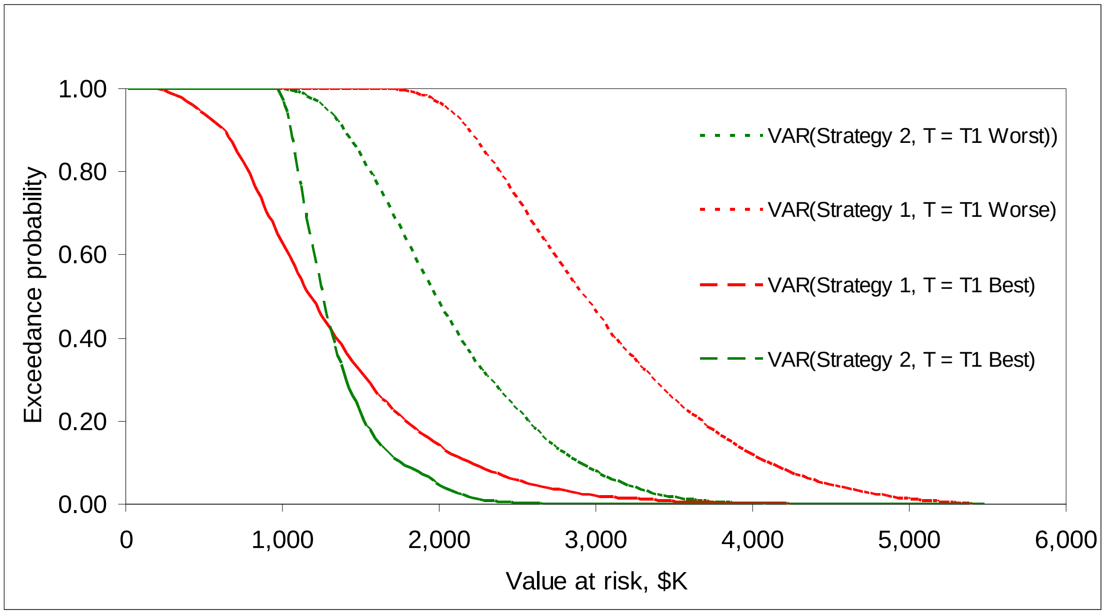


Figure 10. Bounds on the Project Risk Following Implementation Risk-seeking Strategy #1 and a Risk-averse Strategy #2

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5. The Value of Analyzing Risk Dynamism

Figures 8 and 9 illustrate the value of monitoring the performance of the RRAs and other risks. When the best outcomes are realized, both strategies reduce risk. As depicted in Figure 8, both T1 curves move to the left and become narrower than the start risk curves. Likewise, if the worst outcome prevails as assumed in Figure 9, then both strategies actually increase the cost risk exposure of the project. Thus, graphing risk curves over time provides a metric to measure the success of risk mitigation efforts.

Figures 8, 9, and 10 provide additional information that can help the project rationally choose the preferred o strategy. Under the best-case scenario (Figure 8), at the start of the project, Strategy #1 offers a lower risk exposure below $1,500K, while Strategy #2 offers a lower risk exposure above that value. Both strategies are equal in terms of exceedence probability (60 %) at the “breakeven” point of $1,500K. What does the project gain by extending the analysis to time T1? It gains the information that the “breakeven” point is lower ($1,200K) and the risk at that point is also lower (40%). So, which one is the best choice? The optimistic project manager most likely assumes that the best outcome would be realized, thereby making a choice based on the expected benefits. As long as the expected benefits of the RRA are greater than $1,200, he/she would choose Strategy #2. But of course, there is no such assurance, so we must examine the worst-case scenario.

Figure 9 shows the results of implementing each strategy over time assuming the worst outcome (Murphy’s Law). As expected, the risk-seeking Strategy #1 significantly increases the project cost risk exposure when things go bad, but the more conservative Strategy 2 is much less sensitive to bad outcomes. In fact, at T1, Strategy # 2 dominates Strategy 1 (i.e., it has a lower risk for any value.) For pessimists, the choice is simple: Strategy #2 is especially effective in providing insurance against the worst outcomes.

Which strategy is chosen depends on the decision-maker's risk aversion. Is he/she an optimist or a pessimist? In either case, if the expected benefits of risk mitigation exceed $1,200K, Strategy #2 is the best choice. We believe examining risk information in this way provides useful insight and helps project managers make better choices.

6. Conclusions

6.1 Lessons Learned

This report presents a method for evaluating and tracking project-specific risks at the microscopic level. This type of analysis, as opposed to the macroscopic-level risk analysis, is essential for risk management. While the macro level provides some information about total cost risk, the micro level allows the project manager to plan and control risk response actions that influence total cost risk.

This report also demonstrates the use of GDTs to model the evolution of the potential RRAs and risk curves to evaluate the risk. We believe risk curves are better than the expected-value results usually given by traditional decision tree analysis because they contain all the risk information both in terms of probabilities and value at risk. Risk curves derived from Monte Carlo simulation on GDTs are particularly useful when analysts are comparing different risk-mitigation strategies. The “breakeven” points help the risk manager understand the conditions under which each strategy is most appropriate. Combined with scenario analysis, it offers an opportunity to make cost-benefit tradeoffs among strategies. This thorough approach allows management to consider what they mean by “acceptable” risk and explicitly models the tradeoff between risk and benefits of any given RRA. Tracking the performance of RRAs over time is key to understanding the dynamic nature of risk management and can reveal necessary changes in strategy.

6.2 Future Research and Implementation

The cost risk analysis and management developed in this report is both rich and simple enough to illustrate: (1) the portfolio aspect of several diverse RRAs and their analysis, (2) the dynamic nature of the risk picture, and (3) the monitoring of individual risks and allocation of management reserves. The approach readily extends to dependent risks using different probability and outcome values that reflect causality effects among the risks. The authors think that it provides the detailed information that program managers need and want when they face hard decisions on programs. There is a cost for this type of analysis, but it is small considering the potential benefits. The proposed approach is both practical and mathematically valid and can be implemented using commercially available tools such as Crystal Ball® and @Risk.

The next phase is to further develop the methodology and an integrated tool so that a program manager can select a portfolio of risk reduction activities that maximizes the cost-benefit of such activities. The dynamic nature of the approach will allow the program manager to monitor and manage the performance of risk reduction activities over time and optimize the allocation of risk management resources over the life-cycle of the project/program. The challenge is to start implementing these more refined cost models and risk management practices.

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