rEVaMp: Risk Elicited Earned Value Management Procedure - A Systematic Framework for Accounting for Project Uncertainties

By

Parthasarathy Seshadri

Bachelor of Engineering (Chemical Engineering), Annamalai University, INDIA

Masters of Engineering (Chemical Engineering), Indian Institute of Science, INDIA

Ph.D. (Chemical Engineering), Monash University, AUSTRALIA

Submitted to the System Design and Management Program in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Management

at the
Massachusetts Institute of Technology
January 2009

© 2009 Parthasarathy Seshadri
All rights reserved

The author hereby grants to MIT permission to reproduce and to distribute publicly paper and electronic copies of this thesis document in whole or in part.

Signature of Author

Parthasarathy Seshadri
System Design and Management Program
January 2009

Certified and Accepted by

Pat Hale, Thesis Supervisor
Senior Lecturer, Engineering Systems Division
Director, Systems Design and Management Fellows Program
Disclaimer: The opinions and conclusions contained herein are solely the author's and should not be attributed to any third parties.
rEVaMp: Risk Elicited Earned Value Management Procedure - A Systematic Framework for Accounting for Project Uncertainties

By Parthasarathy Seshadri

Submitted to the System Design and Management Program on January 15, 2009 in Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering and Management

Abstract:

**Background:** Project and program budget estimation and execution within the estimated budget are critical functions in any organization, in particular those dealing with fixed cost contracts. During planning, the functional organization estimates the baseline cost and schedule by considering the project as a number of interacting tasks and rolling up resource estimates for completing these tasks and the senior management allocate contingency or management reserve to account for project risks. During execution, project organization measures the project performance against the baseline cost and schedule to prevent cost overruns. One of the methods for monitoring project performance is the Earned Value Management (EVM) methodology which uses conceptually simple parameters like Cost Performance Index (CPI) and Schedule Performance Index (SPI) to monitor and articulate project performance and to compute estimated cost at completion (EAC).

**Motivation:** The budgeting approach as outlined above does not explicitly account for emerging project uncertainties and as a result contingency allocated by the organization at the planning stage may not be sufficient, as the allocation is based on prior experience and does not take the
impact of the emerging risk on the project into account. During planning differences in perceptions of risks with regards to requirements, work scope, maturity of technology, engineering effort and organizational capacity introduce uncertainties. During execution, uncertainties emanate from emerging risks, utilization of past performance to predict EAC and assignment of “earned value” to partially completed tasks. Accounting for these uncertainties could result in a wide range of valid EAC values each associated with a unique likelihood (probability or confidence level). From a project risk management perspective, establishing and constantly monitoring this ‘likelihood’ value will help organizations to accurately measure performance and proactively implement risk mitigation strategies to keep the project in check and to clearly articulate project performance status across the organization.

**Approach:** This thesis extends EVM for incorporating uncertainties and establishing parameters for articulating project performance in a systematic manner. During project planning “Risk Elicited Earned Value Management Procedure” systematically captures embedded costing assumptions and quantifies the impact of task level uncertainties to determine the likelihood of a project meeting the baseline cost using Monte Carlo methodology; such risk quantification will help organizations in contingency allocation for addressing known risks and unknown risks. In this thesis, total contingency amount will be split into two parts - hard and soft values. The hard management reserve (HMR) allocated by the senior management is primarily for addressing known risks and soft management reserve (SMR) is primarily for addressing any unknown risks that typically emerges during the course of project execution.

The senior management would also like to challenge the organization to improve its performance by not completely funding the project but would like to know its impact on the likelihood so as to prevent unduly burdening the organization. During execution, the same risk elicitation procedure can be used to estimate the likelihood that a project meets the EAC calculated by
EVM and in addition, establish what it would take to meet the challenge imposed by the management. Additional emerging risks and refinement in risk mitigation strategies can be incorporated to improve the confidence level on the estimated likelihood. In essence, the new procedure provides a systematic framework for deliberations between functional and project organizations in developing a robust risk management strategy and the likelihood can be used to articulate project status to senior management.

Results: The case studies indicated that the risk elicited approach yields additional parameters that would allow the organization to evaluate the impact of the underlying risk profile and project performance on cost and schedule and help establish confidence levels on the estimated cost and schedule. The approach also helps benchmark organizational performance against management expectations.

Conclusions: The systematic risk elicitation approach outlined in this thesis improves the process of project cost estimation and project execution by making the process more transparent and instilling accountability across the organization. This transparency ensures that the entire organization – functional, project and senior management – have the same understanding about costing methodology. The process establishes confidence levels on the estimated cost and schedule at completion which were not available to the organization previously. This additional information will help the organization with prioritizing risks, securing allocation of adequate funding and contingency amounts and assuring the senior management that the organization is not unduly challenged minimizing employee frustration and burn-out. The framework provides a quantitative means to compare the effect of emerging risks and mitigation plans on project performance. The case studies also demonstrated that the approach has the ability to indicate problems even at the project planning stage by establishing confidence levels that can be used to
evaluate robustness of project costing and articulate status of the project during its execution in an objective manner.

**Thesis Supervisor:** Prof. Pat Hale, Senior Lecturer, Engineering Systems

**Title:** Director, Systems Design and Management Fellows Program
Acknowledgements:

The author would like to thank all who have contributed to the project and research documented in this thesis.

I am grateful to my parent company United Technologies Corporation for their continued support for the System Design and Management Program.

I would like to extend my sincere thanks to my advisor Mr. Pat Hale for his guidance and for the personal support when I needed it most during the course of the project.

I am thankful to Mr. Jim Patrick, Vice President – Air Management Systems, Hamilton Sundstrand and Mr. Jothi Purushotaman, Vice President – Operations, United Technologies Corporation for their suggestions and encouragement.

I would like to acknowledge the support provided by my employer Hamilton Sundstrand and my managers Mrs. Diane Drew, Mr. Tom Zywiak and Mr. Doug Christians during the course of the program. I am also very grateful to Mrs. Cricket O’Donnell for her support with the logistics.

I would like to express my gratitude to all professors, as their guidance and knowledge that I gathered from them is what made this thesis possible.

Finally, the author gratefully acknowledges the logistic support and resources made available to him by MIT System Design and Management Program.
Dedication:

I dedicate this thesis to three very special people in my life, my parents and my wife Padmaja.

The sacrifices my parents made to provide me with the opportunities and values they imbibed are what made me succeed.

For a married man with two young children, the decision to go back to school after would not have worked out but for the support that I received from my family. I am incredibly blessed with a wife who has sacrificed a lot to provide the support that I needed and always there when I needed her. I would not have accomplished academically but for her ability to maintain a cohesive family through her love and affection, despite the hardship of managing the untimely hours from my work life and academic adventure.

As my parents celebrate their golden wedding anniversary, I dedicate my thesis to my parents, as a token of my love, affection and gratitude and to my wife Padmaja for her love and unwavering support.
# Table of Contents

1 Introduction ......................................................................................................................... 17
  1.1 Thesis Overview ................................................................................................................. 18
    1.1.1 Problem Statement ........................................................................................................... 18
    1.1.2 Hypothesis ..................................................................................................................... 19
    1.1.3 Approach ....................................................................................................................... 20
    1.1.4 Conclusions ................................................................................................................... 21

2 Project Description .............................................................................................................. 22
  2.1 Project Planning Process Overview ................................................................................... 22
  2.2 Motivation – Gaps in Existing Project Planning Processes .............................................. 22
    2.2.1 Existing Methodologies for Handling Uncertainties ....................................................... 23
  2.3 Project Performance Monitoring ....................................................................................... 34
    2.3.1 Earned Value Management System ............................................................................. 34
  2.4 Project Motivation .............................................................................................................. 42

3 Risk Elicited Earned Value Management Approach ................................................. 46
  3.1 Description ....................................................................................................................... 46
    3.1.1 Establish Baseline Cost ................................................................................................. 46
    3.1.2 Establish Project Risk Profile ...................................................................................... 46
    3.1.3 Establish Baseline Performance .................................................................................... 49
    3.1.4 Establish Risk Elicited Earned Value Management Parameters .................................. 54
    3.1.5 Realign Risk Profile ....................................................................................................... 59
  3.2 Establish Risk Elicited Probability of Completing Critical Path Tasks ........................ 59
  3.3 Establish Risk Elicited Probability of Meeting Project Schedule .................................. 60
    3.3.1 Risk Elicited Earned Value Management Schedule Parameters ................................. 64
  3.4 Monte Carlo Methodology to Establish Risk Elicited Parameters ............................... 66

4 Results .................................................................................................................................. 67
  4.1 Case Study Assumptions ................................................................................................. 67
  4.2 Case Study 1: Risk Elicited Performance of a Multi-Year Project .............................. 68
  4.3 Case Study 2: Risk Elicited Performance of a Software Project ................................. 78
  4.4 Case Study 3: Risk Elicited Schedule Performance of a Software Project ................... 83
  4.5 Usefulness of Risk Elicited Parameters ......................................................................... 87
5 Conclusions ..................................................................................................................89

6 Implications for Major Stakeholders ...........................................................................92
6.1 Functional Organization ..................................................................................................92
6.2 Project Organization .......................................................................................................93
6.3 Senior Management .......................................................................................................93
6.4 Funding Agencies ..........................................................................................................94

7 Future Work ..................................................................................................................95

Reference ..........................................................................................................................97

Appendix A: Sample of the Risk Elicited Calculation Excel Output for a Reporting Period ..........................................................................................................................99
This page intentionally left blank.
List of Figures

Figure 1: Factors affecting the cost estimation and cost overruns ........................................... 19
Figure 2: Earned Value Management Graphical Interpretation .................................................. 40
Figure 3: Alignment of Budgeted Cost with Risk Profile ......................................................... 51
Figure 4: Interpreting Estimated Risk and Cost Alignment with Maturity ............................ 51
Figure 5: Risk Driven Management Reserve ............................................................................ 53
Figure 6: Risk Elicited Earned Value Management Cost Parameters ................................... 56
Figure 7: Risk Elicited Earned Value Management Schedule Parameters ............................. 63
Figure 8: Case 1 Baseline Project EVMS Information .............................................................. 69
Figure 9: Case 1 Baseline Information on Risk Elicited Parameters ...................................... 70
Figure 10: Project Cost Information at the end of 1st reporting period .................................... 71
Figure 11: Estimated FY 04 Project Completion Cost given Performance and Risk Profile .... 71
Figure 12: FY 04 Confidence Level Profiles for Project Meeting the Estimated Cost ............... 72
Figure 13: FY 04 Contingency Profile as a Percentage of FY 04 Baseline Cost ....................... 73
Figure 14: Estimated FY 05 Project Completion Cost given Performance and Risk Profile .... 74
Figure 15: FY 05 Confidence Level Profiles for Project Meeting the Estimated Cost ............... 75
Figure 16: FY 05 Contingency Profile as a Percentage of FY 05 Baseline Cost ....................... 75
Figure 17: Estimated FY 06 Project Completion Cost given Performance and Risk Profile .... 76
Figure 18: FY 06 Confidence Level Profiles for Project Meeting the Estimated Cost ............... 77
Figure 19: FY 06 Contingency Profile as a Percentage of FY 06 Baseline Cost ....................... 77
Figure 20: Case 2 Baseline Project EVMS Information ............................................................. 79
Figure 21: Case 2 Baseline Information on Risk Elicited Parameters ..................................... 80
Figure 22: Case 2 Project Completion Cost given Performance and Risk Profile ...................... 81
Figure 23: Case 2 Probability of Meeting Cost given Performance and Risk Profile ............... 82
Figure 24: Case 3 Baseline Probability of Meeting Schedule given Performance and Risk Profile .................................................................................................................. 83
Figure 25: Case 3 Probability of Meeting Schedule given Performance and Risk Profile ........ 84
Figure 26: Case 3 Expected Project Duration given Performance and Risk Profile ................. 85
Figure 27: Case 3 Expected Future Burn Rate to Meet Original Schedule ............................ 86
Figure 28: Project Personnel Required for Meeting Original Schedule .................................... 87
Figure 29: Risk Elicited Earned Value Management in a Learning Organization .................. 91
This page intentionally left blank.
List of Tables

Table 1: Risk Elicitation Template.......................................................................................... 49
This page intentionally left blank.
1 Introduction

In every organization, project and program budget estimation and execution within the estimated budget are critically important, in particular those dealing with fixed cost contracts. Typically, during project planning phase, the functional organization estimates the baseline cost and schedule by considering the project as a number of interacting tasks and rolling up resources for completing these tasks. During execution, to prevent overruns, the project organization measures the project performance against the baseline cost and schedule. At the completion of the project, effectiveness of the project manager and his organization is measured by the diligence with which technical, financial and schedule objectives are met. Depending on the project, one of these objectives typically would be met at the expense of others. However, the project manager’s task is complicated by the fact that most often, various assumptions are made in multiple dimensions – technological, engineering and manpower resource – to arrive at the initial project cost estimate. Typically, organizations apply a contingency amount to account for any shortfall due to these assumptions based on their prior experience. Estimation of this contingency is often more of an art than science and may not truly reflect the embedded risks in the project, since the organization does not know its true extent of their impact. In addition, if these are multi-year projects like those in the large aerospace systems, personnel movement during the course of the project causes a knowledge drain with regards to the embedded assumptions in the initial cost estimate. Thus, when re-planning occurs (re-scheduling to bring the project in line with resources and schedule), additional assumptions that may or may not be in tune with the original assumptions are made, causing the whole process to be very inefficient.

One of the methods for monitoring project performance is the Earned Value Management (EVM) methodology which uses conceptually simple parameters like Cost Performance Index
(CPI) and Schedule Performance Index (SPI) to monitor and articulate project performance and compute estimated cost at completion (EAC).

1.1 Thesis Overview

The thesis is split into three sections. The first section describes the current methodology of project planning and monitoring and identify the scope of improvement, in capturing the impact of uncertainties percolating into the planning process due to embedded assumptions. It also discusses the advantages and disadvantages of other alternative methodologies that are currently being used in some industries to improve the accuracy of cost estimation. The second section outlines the systematic procedure for incorporating risk in project planning and also for monitoring the health of the project during the course of its life. The third section applies the new procedure to test cases and demonstrates how the key parameters can be used for tracking the health of the project.

1.1.1 Problem Statement

The accuracy of cost estimation for any project depends on how well the uncertainties – requirements, technology, engineering, resources and processes – are captured during planning stage. Existing methodologies of cost estimation hinge very heavily on past experience and assumptions are made based on previous programs and adjusted for prevailing constraints; the senior management would prefer a lower cost estimate to win the competitive bidding, the functional organization would prefer a larger cost estimate to cover any short falls, etc. Wide variations in human perception of any embedded risks also contribute to the inaccurate cost estimate. Figure 1 is a variation of the process diagram from [1] that clearly articulates various conflicting factors that cause problems in existing cost estimation and project execution processes.
In addition, on long term projects, personnel changes are unavoidable, and failure to capture the rationale for many of the embedded assumptions that went into the cost estimation also cause major problems during any late stage re-planning efforts.

1.1.2 Hypothesis

The primary hypothesis is that providing a systematic framework for quantifying the risks will help [2] those involved in the project to estimate the project cost more accurately by addressing most, if not all, of the factors identified in Figure 1. As with the existing cost estimation practice, the systematic framework starts by dividing the project into a set of interacting tasks. The framework requires that task level risks are identified to quantify uncertainties, to define the project risk profile at that instant in time. In the first pass, as aggregation of risks occurs at the...
project level, task level risks need not be precisely quantified, but nevertheless should be captured to make sure that these risks are made visible providing a foundation for subsequent deliberations. This framework allows for the systematic capture of all the embedded risks along with the corresponding rationale forces everyone involved in the cost estimation process to consciously consider the project tasks to identify all types of embedded risks. If an embedded risk for a task is not captured during planning but identified as a risk during execution, it will clearly highlight a process failure that can be corrected for subsequent projects. This explicit risk elicitation step adds significant value to the organization by improving overall project planning, cost estimation, execution and performance evaluation by instilling accountability and transparency.

1.1.3 Approach

The primary objective of the approach is to elicit all the embedded assumptions typically made during project planning and make them transparent across the organization. Some of these assumptions introduce risks into the project and some may offer opportunities to reduce cost, for example, reuse of existing processes, software and hardware. In addition to risk elicitation, at the project planning stage, the new approach also requires quantification of these risks and opportunities. As these are identified and quantified at the atomic task level, aggregation of the risks and opportunities over the entire project make the final value less sensitive to atomic level variations. Hence, at the planning stage, capturing the risks is more important than quantification, which can be refined during deliberations; and at the end of deliberations, a project risk profile could be established that will be transparent to the functional and project organizations, senior management and/or other stakeholders like the funding agencies. Once the project risk profile is established, scenario analysis using Monte Carlo simulation can be done to
evaluate the robustness of the project costing, given the risk profile. The senior management and/or the funding agencies could use this information to allocate management reserve as needed. As the project is executed, the project risk profile and the project performance could be used to establish quantitative parameters that can be used to objectively articulate the project status to the senior management and/or stakeholders.

1.1.4 Conclusions

The systematic approach provides a framework for capturing risks and uses the prevailing risk profile to establish additional parameters by extending the earned value management calculations to establish confidence levels for the project staying under budget and under schedule. These confidence levels cannot be adequately established by existing project management approaches. The resulting parameters can be used to objectively evaluate the project status, evaluate the impact of mitigation plans and emerging risks, and offer very useful information to all the stakeholders and increase the robustness of the decision making process. The systematic process also aids the organization in learning from prior mistakes through transparency, deliberation, accountability and documentation.
2 Project Description

2.1 Project Planning Process Overview

The initial project planning in most organizations falls on the program office and heavily depends on the functional organization to cost the proposal. The functional organization carries out design trades to identify a system configuration that meets customer requirements and, based on the trades, identifies resources to satisfy the customers’ needs. During this process, functional organization also captures high-level risks that may have an impact on the project. Most often, identified risks pertain only to the individual domains of participating organizations’ interests. From a psychological viewpoint, most people find it difficult to visualize extremes and have a propensity to tread the middle ground. Some of these issues are highlighted as human behavior in Figure 1. Typically, upon securing project funding and agreeing upon schedule, a formal project organization would be constituted for executing the project.

2.2 Motivation – Gaps in Existing Project Planning Processes

One of the major gaps in the project planning process is that, in many organizations, the project execution teams, while responsible for the delivery of the customer milestones within the allocated budget, are not part of the original cost estimation process, and thus suffer from a lack of details about the embedded assumptions that have been made during project planning. Capturing embedded assumptions made by the functional organization along with the details on who made the assumptions, rationale for the assumptions and impact of those assumptions on the project would help the project organization plan its execution better.

Another major flaw in the existing resource estimation process is that, in many organizations, the final estimate is treated as a deterministic value and does not explicitly consider embedded
and/or emerging uncertainties. To quote a vice president from my company, “one area we struggle (with) is how to incorporate risks/variation in our planning which is both as accurate as possible based on past performance and aggressive based on changes we need to take (baseline estimates are based on history) so that we remain competitive. It is a fine balance between using history and driving/expecting change with credibility in the plan. Then it is more difficult to interpret EVMS results as the variance is more of a reporting (hard to differentiate where the plan was wrong driving the variance versus the efficiency of the process)”. This statement again reinforces the conflict depicted in Figure 1 and articulates the difficulty that an organization faces in quantifying the risks. In addition, the quote also highlight the effect the inaccurate project costing has on the effectiveness of the Earned Value Management tool that is commonly used for determining the health of a project.

2.2.1 Existing Methodologies for Handling Uncertainties

2.2.1.1 COSYSMO

The Constructive Systems Engineering Cost Model (COSYSMO) is a parametric model that can help organizations understand the economic implications of implementing systems engineering on projects [3] and was developed at the University of Southern California as a research project with the help of BAE Systems, General Dynamics, Lockheed Martin, Northrop Grumman, Raytheon, and SAIC. COSYSMO estimates the quantity of systems engineering labor, in terms of person months, required for the conceptualization, design, test, and deployment of large-scale software and hardware projects. User objectives include the ability to make proposal estimates, investment decisions, budget planning, project tracking, tradeoffs, risk management, strategy planning, and process improvement measurement. The academic COSYSMO model is
developed in MS Excel and requires *calibrations* to reflect organization’s definitions, maturity of systems engineering implementation and organizational metrics.

As with any model, COSYSMO has a set of embedded assumptions and violating any of these assumptions could lead to inaccurate results. In addition, the user must be aware of the contextual definitions of the COSYSMO terminology

1. Definitions of the cost drivers,
2. Associated counting rules for the size drivers,
3. Output of the model,
4. How it relates to general systems engineering context (i.e., process, labor categories) in their organization.

Beyond the assumptions surrounding the user, the model has additional embedded assumptions. Stating these assumptions from the user guide [4]:

- the organization using the model defines systems engineering in a way that is compatible with the INCOSE (International Council of Systems Engineers) definition
- a predetermined set of systems engineering activities and life cycle phases exist in the organization and aligned closely aligned with the standards
- the model will be used to estimate effort from the contractor perspective
- the organization, not its subcontractors, is performing a majority of the systems engineering work
- reuse of requirements and interfaces is minimal
- the organization using the model develops systems for the defense or aerospace domain similar to those developed by the six organizations that participated in the industry calibration
The implications of these assumptions are significant and, if not carefully considered, can lead to erroneous results. These assumptions indicate the importance of calibrating the model with specific domain data, in particular when applied to non-defense and non-aerospace domains. Some of these assumptions require a change in organizational culture, for example, implementation of systems engineering within an organization is really a costly affair, at least in the short term, and not all companies have the resources or the process maturity to sustain such an activity across the organization. In addition, in the current global economy, under increasing pressure to reduce cost, more and more companies are outsourcing and off-shoring non-core engineering, technology and development work, and some of these are related to systems engineering. Even if these outsourcing and off-shoring initiatives can be accounted for, companies are continuously exploring alternative lower cost countries, moving from China, and India to Thailand, Vietnam, and Philippines etc and the model require recalibration each time that occurs and could restrict its usage across the wide spectrum of industries in a cost effective manner.

2.2.1.1 COSYSMO Cost Drivers

One of the hallmarks of COSYSMO is its systematic generic framework for identifying cost drivers for any project and is independent of the industry and will be discussed further.

1. Understanding of Requirements

The requirements for any project needs to be firm and must be understood as such, because any change in requirements will have an impact on the scope and hence will have an effect on the cost required to fulfill the requirements. The end customer must be engaged even before the signing of the contract to ensure that what the contract says is exactly what it means. Most often embedded assumptions on the customer side emerge as additional requirements that were not considered as part of the original project planning
and increase the scope of the project, hence increasing the cost and extending the schedule. Although, most of the large and complex projects employ configuration control to manage requirement change, despite the best effort, impact of the change does not permeate throughout the organization. For example, in Airbus A380 development [5], when the airlines changed the power requirements, weight implications of that change were clearly understood and engineers changed the wiring material from copper to aluminum to satisfy customer power requirements while meeting the weight constraint. However, impact of this change on the wire harness design was not identified until it was very late.

2. System Architecture

The system architecture should have some flexibility built in to handle any unavoidable emerging requirements due to operational constraints, as any inflexibility requires additional rework to ensure these constraints are adequately addressed to make the system robust and reliable. Typically, companies build such flexibility into the system as design margins, but the system’s usefulness can be seriously limited by system architecture in one of the three key dimensions - hardware, software or interface. This rework typically occurs at late stages as the necessity for change will be identified during verification testing and requires a large amount of resources to ensure robustness of the re-architected system. A good system architecture localizes the impact of structural changes through careful design de-coupling and design modularity to prevent strong interdependencies across interfaces as permeation of the change across the interfaces requires more resources to correct the changes. On the other hand, modularization increases the number of interfaces, resulting in higher system architecture development cost.
3. Level of Service Requirements

In most contracts, customers would be given some leverage in making late changes to the contract which will have an impact on the project. If the organization is not careful, the extent of such changes could have a serious impact on project cost. For example, Airbus allowed customers to change the in-flight entertainment specification of the A380 that, in turn, changed the electrical loads during the production stage, leading to wiring changes causing at least six month delay in their production schedule [5].

4. Migration complexity

The cost of unlearning pre-existing knowledge could be costly, in particular when solutions to problems that demand out of the box ideas and pre-existing knowledge prevents project personnel from coming up with such solutions as they spend time and effort in exhausting all traditional solutions before attempting the out-of-the-box ideas. In addition, the extent of the gap between pre-existing knowledge and what is required to fulfill the current project needs often are not realized during project planning and can cause cost overruns. Legacy system components and workflow may affect new system implementation requiring new technology, component upgrades, increased performance at the interfaces, and new business processes. Even deploying off-the-shelf products for other customers require changes at the interfaces, which typically are not considered during planning stage.

5. Technology Risk

Technology Risk represents the opportunity cost due to the technology readiness, maturity, and potential obsolescence of the technologies being implemented. Immature or
obsolescent technology requires more Systems and Design Engineering effort. It may also involve more preliminary testing effort during the course of development as well as requiring addition verification and validation testing. In addition, more in-depth analysis is often required, as any pre-existing knowledge may not be sufficient to fill the knowledge gap. In addition, new technologies also require additional certification testing to satisfy the regulatory constraints. Additional engineering changes may also emerge as the technology implementation matures during the course of the project.

6. Documentation Match to Life Cycle Needs

The extent of documentation should not be underestimated, and most often project costing fails to account for this properly. In particular, as this is one of the last remaining tasks left before delivery and personnel from the project typically get reassigned to new projects, documentation will be left to a skeleton staff who may not be proficient in the design and operation of the system. The reassignment of project personnel and the relative low priority assigned to documentation can result in delays and inaccuracies. In particular, if the product has a very long life cycle, appropriate documentation is absolutely essential, not only to trouble shoot technical problems, but also to support any legal and regulatory challenges that may happen during the course of the product life. The fuel tank explosion in the TWA flight 800 Boeing 747 required nearly 25 year old simulation and design data to be reviewed for documentary evidence to prove that the companies involved in the design accounted for all the possibilities as stipulated by the prevailing regulations. During the course of the project, the roadmap of decision-making also requires documentation to capture the rationale for making certain decisions and prevent “reinventing of the wheels”.
7. Number and Diversity of Installations/Platforms

The number of different platforms that will use the system that is being developed and number of installations that may require the system also impact the total life cycle cost. The complexity of the operating environment that the system would endure (territorial flexibility, mobility, portability, data security and data assurance) will affect the extent of engineering and technological effort required. The number of new platforms (development effort) should be added to the number of platforms being phased out (decommissioning and disposal effort) in order to account for total life cycle labor cost. The development cost will be higher if all the “-ilities” are taken into account – customizability, reusability, scalability, and modularity, flexibility and heterogeneity of the platforms. Effort required to standardize the system components may or may not increase cost, depending on whether the components are available off-the-shelf or require development. Initial project cost estimation should consider these “-ilities” very clearly so that accurate estimate of the engineering effort required can be ascertained.

8. Number of Recursive Levels in the Design

This captures the impact of the increase in complexity as the number of levels of design related to the system being developed (one standard definition can be found ISO/IEC 15288) and the amount of required SE effort for each level. The development cost increases as the complexity of interactions that needs to be considered in conducting trade-off analysis to make these recursive levels reusable, scalable and modular.

9. Stakeholder Team Cohesion

This includes the cost of the organizational culture in terms of communication across the value chain, their shared vision and commitment to towards the success of the project in terms of its effectiveness. The leadership, diversity of stakeholders, approval cycles,
group dynamics, IPT framework, team dynamics and amount of change in responsibilities all play a role in the costing either directly or indirectly. It further represents the heterogeneity in stakeholder community of the end users, customers, implementers, and development teams. If the business processes does not follow standard procedures and does not follow the standard systems engineering principles then the cost of development will be higher than a project that follows the streamlined systems engineering processes.

10. Personnel / Team Capability

This captures the ability of the organization to respond to technological and engineering challenges associated with any project. Any gap in critical skills needs to be closed as soon as possible and a road map must be put in place to train new personnel with organizational processes to make them productive at the earliest, as the impact of work quality and the subsequent rework along with the permeation of unnoticed problems have profound impact if caught downstream and is one of the major causes of cost overruns.

11. Personnel Experience/Continuity

The organization should ensure that knowledge continuity exists in any project to account for the movement of personnel from attrition and retirement through appropriate level of documentation to capture the rationale for the design decisions and put in place a transition plan to capture critical knowledge. With long term projects, movement of personnel is unavoidable and many organizations fail to create knowledge transfer roadmaps, in particular, for people who are close to retirement. This discontinuity causes more rework during execution than what has been planned for.

Outsourcing, a cost saving measure, is another source of knowledge drain, if the organization is not very careful. The negative effect will not be felt by the current project,
but potentially subsequent projects, as outsourcing of a particular function causes the organization to lose that capability and the associated learning and knowledge. Cheaper outsourcing, while saving cost in the short term, can cause knowledge drain in the long term. Fortunately, most organizations attempt to retain core knowledge and outsource only non-core activities. Another continuity aspect that should be borne in mind: the selection of software and hardware used for design and analysis to ensure consistency.

12. Process capability

The ability of the organizational processes - to prevent problems from occurring, to detect the problems when they occur and to learn from the mistakes - and prevent the same problem from re-occurring in the future - is a critical cost driver. The processes must have checks and balances to ensure mistakes are caught sooner, and should have the ability to identify the root causes and develop mitigation measures. As the organizational processes are standardized, standard operating procedures should be put in place to ensure that the work is carried out diligently to prevent any errors. The processes should be transparent across the project organization to instill accountability and traceability, as lack of them creates rework costing the organization valuable resources.

13. Multi-site coordination

In the global economy and with significant outsourcing, the importance of communication cannot be overstressed. Many companies are finding that the cost of coordination is rapidly increasing and can diminish the anticipated cost savings from outsourcing. Many aerospace companies are turning to off-shoring instead, by pushing the work to one of their off-shore subsidiaries. The differences in culture, time-zone and work ethics cause substantial stress for employees of the parent organization, if not appropriately handled, decreasing their productivity. The extent to which information
exchange is formalized for traceability and adherence to legal and regulatory requirements, in particular with regards to the defense contracts, adds additional cost and is often overlooked during the project planning stage, placing restrictions on the extent of anticipated savings from outsourcing.

14. Tool Support

The adequacy and availability of tools to fulfill the project needs is paramount, as the effectiveness of personnel in analyzing complex problems hinges on these tools. Non-availability of tools could cause the organization to adopt short-cuts which may turn out to be very expensive in the long run. For example, in Airbus 380 development, wiring harnesses developed for copper wires were not altered because different versions of the CATIA design software used by various divisions did not have an aluminum property database, causing expensive rework [5].

2.2.1.2 Scenario Analysis – Monte Carlo Method

The software like Crystal Ball and @ Risk use Monte Carlo methodology to estimate the likelihood that a project could stay below the estimated cost and are commercially available as Excel add-ins. In addition to the most likely cost estimate, the uncertainties are bracketed by the minimum and maximum cost for each of the tasks, and any value in between these minimum and maximum values could be a possible variable. For each task, a random cost value between the minimum and maximum limits is assigned, and rolled up for all tasks to estimate the total project cost. This process is repeated many times to create a large number of scenarios. The cumulative distribution of occurrence of the rolled up cost is plotted against the cost value to estimate the likelihood. A number of distributions are available—the most common that is used for the cost calculation is the triangular distribution. This approach is being piloted in many areas, including sale pricing, airline ticket pricing and for project planning.
2.2.1.3 DSM Analysis

DSM, Design Structure Matrix, is a method that models the organizational process structures used in executing a project and helps identify inherent loops in organizational processes which can cause multiple rework cycles. These potential iterations are often not captured by existing project planning methodologies or by project management software like Microsoft Project. Not accounting for these structurally-induced rework cycles is a major cause of delays in projects and cost overruns. While these structure-induced rework cycles are “planned rework”, unfortunately are not properly accounted for during the “planning stage” and cause surprise delays to projects.

For a product development project, the project cost estimation process starts with the product development process that divides the product development in a number of stages and each stage is further subdivided into a number of tasks. The resources required to carry out a task are then rolled up to calculate the total project cost. The product development process as captured is typically linear, though such linearity is almost never observed in practice, as these structural rework cycles introduce non-linearity. The rework cycle gets shorter and shorter as the team learns from the mistakes with repetitive cycles. In addition to these structure-induced rework cycles, “unplanned” rework cycles emanate from mistakes and errors, and are beyond the scope of the DSM analysis. However, understanding the structural loops will help the organization to estimate the project cost more accurately than would be achieved by assuming a linear product development process and help address some of the cost estimation issues identified in Figure 1.

The DSM analysis provides a sound basis for the initial cost estimation and complements the procedure advocated in this thesis. Unfortunately, many organizations do not have standardized processes for their product development and lack organizational maturity in establishing the task-to-task interactions to effectively use DSM and identify the structural rework cycles prevalent in their organizational processes.
2.3 Project Performance Monitoring

Project performance monitoring is another critical element of project management, as performance can be used to measure organizational effectiveness, both in terms of the maturity of the processes and capabilities of personnel. If the organization consistently meets initial performance goals, this suggests that the organization has mature and robust processes in terms of understanding the requirements, estimating the scope of work, scheduling planned work and carrying out as per plan to deliver what was promised during the planning stage. It also demonstrates the ability of the organization to identify and quantify project uncertainties and highlights its capacity to address emerging uncertainties. Performance can be measured in many dimensions – whether the project stays below the original estimated cost, whether project gets completed before the promised end date, by the quality of the work completed and level of customer satisfaction. From a strategic point of view, performance can also be measured by the strength of the relationship between the organization and funding stakeholders.

2.3.1 Earned Value Management System

The Earned Value Management System (EVMS) was introduced by agencies of the US Federal Government in the 1960’s and, as per the Department of Energy (DOE) manual [6], EVMS is an integrated set of policies, procedures, and practices to support program and project management as a decision-enhancing tool and a critical component of risk management with an intent to improve the project, program and contractor performance and maximize the value delivered while satisfying the objectives of the funding agency. Funding agencies stipulate when EVMS is mandatory for project status reporting; for example, if the total project cost of any DOE project exceeds $20M, the project must use EVMS for project status reporting. DOE projects exceeding $20M also require certification.
2.3.1.1 Purpose

EVMS is a systematic methodology that can be used for effectively integrating the work scope, cost and schedule into a single method to enable benchmarking the project performance against the baseline estimates. This allows for tracking the planned value that was estimated to be performed as per budget against the earned value of actual work performed and the actual cost incurred and provides a standard performance measure for benchmarking against the baseline cost and schedule. The benchmarking enabled by EVMS identifies the cost and schedule variance as measured against the baseline and provides a systematic means for identifying, reviewing, approving, and incorporating changes to the baseline estimate. Monitoring project performance over the entire life cycle helps identification of problems, corrective actions, and management re-planning and also calculating cost at completion given the current status of the project. This allows the organization to manage their resources to ensure that project meets its intended technical objectives as needed.

The cost variance observed during project execution could be due to many factors.

(a) Rate changes (i.e., labor, overhead),

(b) Vendor discounts or price increases,

(c) Quantity discounts (during supply chain)

(d) Material cost changes, and

(e) Requirement changes.

The schedule variance could be attributed to

(a) Poor baseline schedule (does it reflect reality?),

(b) Subcontractor/vendor cannot deliver when needed,

(c) More/less effort than planned,

(d) Insufficient resources (staffing),
(e) Labor disputes/work stoppage,
(f) Resource availability (is it there when I need it?), and
(g) Requirement changes.

Most of these causes could be directly mapped onto the fourteen dimensions for project uncertainties identified in COSYSMO (Section 2.2.1.1.1). The uncertainties arising due to labor rate changes and labor disputes primarily impact multi-year projects, most organizations have labor processes and contingency plans to address these uncertainties and could also be mapped into the dimensions identified in Section 2.2.1.1.

The key parameters that EVMS uses for its calculations are [6],

1. Planned Value (PV) of work to be performed or the budgeted cost for work scheduled (BCWS),
2. Earned Value (EV) of actual work performed or the budgeted cost for work performed (BCWP), and
3. Actual Cost (AC) of work performed (ACWP).

EVMS uses the following indices to effectively articulate the project status to the stakeholders [6]. These indices measure how efficiently a project has been executed when compared to planned baseline until the present time. These indices must be closely monitored and they could predict the future performance.

1. Schedule Performance Index (SPI) indicates how much work the project has accomplished against the planned work. It provides the answer to the question “How the project is doing against the plan?” Monitoring of both current and/or cumulative month data is necessary to assess and establish a trend of how the project is performing.
2. Cost Performance Index (CPI) indicates how much benefit that the project is achieving for every dollar spent. Basically, CPI provides the answer to the question “Is the project
achieving the best bang for the buck?” As with the SPI, monitoring of both current and/or cumulative month data is necessary to assess and establish a trend for the project status.

3. To Complete Performance Index (TCPI) indicates the budget necessary to complete for work remaining versus the estimate for work remaining. TCPI_{BAC} indicates the level of efficiency that must be achieved for the cost at completion to equal the BAC. TCPI_{EAC} indicates the level of efficiency that must be achieved for the cost at completion to equal the EAC.

4. In addition, work remaining (WR), budget remaining (BR), and estimate to complete (ETC) should be checked to assess if adequate resources are available to complete the project.

EVMS calculations are neatly summarized in EVMS Gold Card (Appendix B [6]) and will be reproduced for completeness in Section 2.3.1.5.

2.3.1.2 Strengths

The indices used by EVMS articulate the project status in both cost and schedule dimensions and in meeting technical objectives. In addition, EVMS is systematic and procedurally very simple to understand and follow, and provides a common language across the organization as well as the funding agencies. As EVMS indices indicate organizational effectiveness in fulfilling technical objectives, funding agencies can evaluate the performance of different organizations involved in the project on the same scale. Even within each organization, performance of various functional organizations can be evaluated by the senior management on the same scale.

2.3.1.3 Weaknesses

The initial step of setting up EVMS for each project is tedious and costly. During the initial stages of a project, in the current project planning methodology, the extent of the capture of
embedded risks as part of project costing is unknown, and hence quantifying a planned value for each stage of the project may not be accurate and could result in lower performance indices. Establishing accurate earned value for different stage of a task is also a difficult activity. The small and medium sized companies may not have sufficient resources to fully implement EVMS, and may not be doing it but for the insistence from the stakeholders providing the funding.

The single greatest weakness of EVMS is that even if project status is healthy as measured by EVMS indices (Section 2.3.1.1), it does not guarantee the tasks that were completed are on the critical path, as completion of the critical path tasks alone determines whether the project is on target in meeting the cost and schedule targets. A project manager at one of my previous companies who was managing a multi-million dollar project confided that he always aimed to meet SPI and CPI by carrying out appropriate tasks, regardless of whether completion of such tasks actually improves the status of the overall project. He said that not meeting the EVMS indices would reflect poorly on his performance as a project manager and was the prime reason for this singular concentration. In this case, the true intent of the EVMS indices SPI and CPI aimed for measuring the status of project is being misused to measure project manager’s performance and will not reflect the true status of the project until it is too late. Another reason is that the project personnel have the optimistic perspective that many of the problems will go away eventually, as more information becomes available.

The schedule performance is expressed in dollar value and towards the end of the project, earned value and planned value approach each other and hence, the reliability of the estimated schedule performance could be questionable and earned schedule concept has been put forward to circumvent this [7], but has not yet achieved the same level of traction as the Earned Value Management.
2.3.1.4 Uncertainties in EVMS

The variance between the actual performance and plan occur due to many factors that are listed in Section 2.3.1.1 and are a sub-set of fourteen cost driver dimensions identified by COSYSMO (Section 2.2.1.1.1). In addition, EVMS uses the past performance to determine future performance and does not take emerging risks into account in its analysis. A project which is on right track till the current EVMS period, could encounter a task that is on critical path that could derail its performance. Under that scenario, using the past performance could underestimate the future performance required to fulfill the technical objectives. In addition, inter-dependence of tasks make delineation of partially completed tasks, into what fraction is completed, what has not been completed, whether what is deemed as completed actually contributes to the earned value, very difficult to determine. An additional consideration is whether the indices, CPI and SPI, should have equal weight in determining the EAC—a compromise has been suggested using 0.8 CPI + 0.2 SPI in the EAC calculation.
2.3.1.5 Earned Value Management System Calculations [Appendix B, Ref 6]

![Diagram of Earned Value Management](image)

**Figure 2: Earned Value Management Graphical Interpretation**

**VARIANCES** Favorable is Positive, Unfavorable is Negative

- **Cost Variance**
  
  \[ CV = BCWP - ACWP \]
  
  \[ CV \% = \left( \frac{CV}{BCWP} \right) \times 100 \]

- **Schedule Variance**
  
  \[ SV = BCWP - BCWS \]
  
  \[ SV \% = \left( \frac{SV}{BCWS} \right) \times 100 \]

- **Variance at Completion**
  
  \[ VAC = BAC - EAC \]

**PERFORMANCE INDICES:** Favorable is > 1.0, Unfavorable is < 1.0

- **Cost Efficiency**
  
  \[ CPI = \frac{BCWP}{ACWP} \]

- **Schedule Efficiency**
  
  \[ SPI = \frac{BCWP}{BCWS} \]
OVERALL STATUS

% Schedule  = (BCWS\textsubscript{cum} / BAC) * 100

% Complete  = (BCWP\textsubscript{cum} / BAC) * 100

% Spent  = (ACWP\textsubscript{cum} / BAC) * 100

ESTIMATE AT COMPLETION #

\begin{align*}
\text{EAC} & = \text{Actuals to Date} + \left[ \frac{\text{(Remaining Work)}}{\text{(Efficiency Factor)}} \right] \\
\text{EAC}_{\text{CPI}} & = \text{ACWP}\textsubscript{cum} + \left[ \frac{\text{(BAC} - \text{BCWP}\textsubscript{cum})}{\text{CPI}\textsubscript{cum}} \right] = \text{BAC} / \text{CPICUM} \\
\text{EAC}_{\text{Composite}} & = \text{ACWP}\textsubscript{cum} + \left[ \frac{\text{(BAC} - \text{BCWP}\textsubscript{cum})}{\text{(CPI}\textsubscript{cum} \times \text{SPI}\textsubscript{cum})} \right] \\
\end{align*}

TO COMPLETE PERFORMANCE INDEX (TCPI) #

\begin{align*}
\text{TCPI}_{\text{EAC}} & = \frac{\text{Work Remaining}}{\text{Cost Remaining}} \\
& = \frac{\text{(BAC} - \text{BCWP}\textsubscript{cum})}{\text{(EAC} - \text{ACWP}\textsubscript{cum})} \\
\text{TCPI}_{\text{BAC}} & = \frac{\text{Work Remaining}}{\text{Cost Remaining}} \\
& = \frac{\text{(BAC} - \text{BCWP}\textsubscript{cum})}{\text{(EAC} - \text{ACWP}\textsubscript{cum})} \\
\end{align*}

<table>
<thead>
<tr>
<th>BCWS</th>
<th>Budgeted Cost for Work Scheduled</th>
<th>Value of work planned to be accomplished = PLANNED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCWP</td>
<td>Budgeted Cost for Work Performed</td>
<td>Value of work accomplished = EARNED VALUE</td>
</tr>
<tr>
<td>ACWP</td>
<td>Actual Cost of Work Performed</td>
<td>Cost of work accomplished = ACTUAL COST</td>
</tr>
<tr>
<td>BAC = TAB</td>
<td>Budgeted Cost At Completion</td>
<td>Total budget for total contract</td>
</tr>
<tr>
<td>EAC</td>
<td>Estimated Cost At Completion</td>
<td>Estimate of total cost for total contract</td>
</tr>
<tr>
<td>TCPI\textsubscript{EAC} or TCPI\textsubscript{BAC}</td>
<td>To Complete Performance Index</td>
<td>Efficiency needed from ‘time now’ to achieve the EAC or BAC</td>
</tr>
</tbody>
</table>
2.4 Project Motivation

In my professional life as a systems engineer, I was associated with many projects involving product development in countries that are culturally different, in companies of different sizes, and with different process maturity levels. However, one factor united them all; the projects in every one of these organizations were affected by the underestimation of the impact of embedded risks and invariably causing cost and schedule overruns. The activities involved varying degrees of concurrent development of both technology and engineering and invariably the impact of technology risks was underestimated by the functional organization (refer Figure 1). The personnel movement in these multi-year projects also caused lot of problems in traceability with regards to embedded risks, and have almost always lead to resentment between project and functional organizations during re-planning iterations in determining what risks have been included and what risks have not been included before. Because the risk profile was not clearly established, the senior management was also unable to determine whether the funding that had been allocated was being utilized properly.

The functional organization responsible for estimating the cost of a project that undergoes concurrent technology and engineering development typically overestimate the maturity of the technology and this optimistic view skews the estimated cost to a lower value. As the critical path for project completion can change dynamically during the course of the project, any risk associated with these tasks should be given higher priority. In addition, the original intent of the customers are not actually captured in a set of requirements, and organizations spend more time in satisfying the requirements, only to learn that the solution was not what the customer had in mind. This results in design changes (unplanned rework) very late in the design cycle. Depending on the type of risk and time of its discovery, these unplanned rework (emerging risks) could seriously limit mitigation options available to the organization because of resource and
schedule constraints. In some projects, in securing the business, customers were given latitude in
effecting requirement changes without due consideration to the impact that it might have on the
design. For example, in Airbus A380 development, Airbus allowed the airlines to make changes
to the in-flight entertainment system increasing the power requirements as the plane was being
built and imposed design changes to the wiring costing them lot of resources and delays [5].

Another major impediment is unintentionally caused by the explicit commitment from senior
management to create standardized processes; invariably they do not follow that commitment
with separate funding and resources, and use the same resources working on the project to
develop better processes by capturing what they have learned during the course of the project.
Although this vision appears good in theory, it seldom works in practice, in particular in a matrix
organization. The functional organization responsible for developing better organizational
processes does not have any budget and evaluate the performance of associates. The project
organization controls the budget but does not have any incentives to improve organizational
processes on their budget, due to the erroneous belief that these process improvements drain
resources but do not add tangible value to the current project, despite the benefits with the
planned rework cycles and reduction in unplanned rework. Although the senior management,
project and functional organizations broadly agree on processes standardization and its strategic
importance to the organization, stakeholder cohesion between them is uneven at best. The
personnel working on the project typically get caught in the middle and become frustrated by the
mixed signals sent by the various stakeholders. In the worst case, the associates will be “damned
if they did or damned if they did not” develop better processes. This frustration leads to burnout,
lack of motivation, and loss in quality of workmanship, leading to further loss in productivity
and eventually increasing the project cost. Even adopting an existing product line supposedly
requiring minimal effort derails organizations, as the differences at the interfaces get overlooked
during project planning. The products that were supposed to be off-the-shelf installations requiring minimal hardware and software changes cost organizations large amounts of resources to make certain that the interface constraints are satisfied.

Another weakness in the existing processes is the qualitative approach of using a risk cube to evaluate risk with color coded status GREEN (risk has been eliminated), YELLOW (risk still remain, but mitigation measure identified) and RED (risk still remain and no mitigation measure has been identified). In some organizations where I have worked, due to time constraints only those items that are identified as critical would be discussed during reviews - in this case, the risks that are colored RED. However, if the project organization identifies a mitigation measure, the color code change from RED to YELLOW and the risk falls off the agenda notwithstanding the embedded risks (say, technology development) in the identified mitigation measure. The progress on the mitigation measures in reducing the original risk under these conditions would not come to surface until it is too late.

The cost overrun seems to be independent of the culture, size, process maturity, and degree of concurrent development. This author believes that there is an underlying systemic cause that needs to be given a closer scrutiny and may require an improved approach that elicits embedded risks in a systematic manner and address all the prevalent issues in existing processes. The approach should instill transparency and accountability across the organization - functional organization for project costing, capturing the assumptions and quantification of risks, project organization for project execution and deliverables, given the estimated cost and risk profile. The senior management should be held responsible for providing adequate funding, given the project deliverables and prevailing risk profile and for stakeholder cohesion.

To ensure wider acceptance, the approach should be generic but simple enough to be adopted by organizations across the diverse business landscape. In addition, many organizations have
already spent valuable resources on implementing EVMS within their organization. If the new approach extends EVMS instead of replacing it, it would save valuable resources in re-training personnel and gain approval from senior management for its implementation.
3 Risk Elicited Earned Value Management Approach

3.1 Description

The risk elicited earned value management approach systematically extends the EVMS calculations (Section 2.3.1.5) to account for the prevailing uncertainties in the project. This approach addresses many of the weaknesses identified in project planning and project status monitoring and provides additional insight into the status of the project. The following sections develop the new approach in detail.

3.1.1 Establish Baseline Cost

Any project can be subdivided into a number of interacting atomic tasks. For each atomic task, identify nominal resources (manpower and cost) required to complete all the tasks. Roll costs for all these atomic tasks to estimate budgeted cost at completion (BAC) or the nominal project cost. As is the current practice task in most companies, the functional organization is entrusted with this task. However, the process differs in handling embedded risks; as individuals perceive embedded risks differently, every effort must be taken to prevent ad-hoc inclusion of the impact of any embedded risks in project costing. The ad-hoc process of including embedded risks is one of the serious limitations in current project planning methodology (Section 1.1.1) and requires refinement, as error in the planned cost estimation propagates through to performance monitoring.

3.1.2 Establish Project Risk Profile

In the second step, the project risk profile must be established in a systematic manner—this approach offers a significant improvement over the ad-hoc process of including embedded risks. For each atomic task, the functional organization must identify opportunities (that could reduce
project cost) and threats (that could increase project cost) and express these costs as absolute or percent deviations from the nominal cost estimated in Section 3.1.1. The effect of such opportunities and threats at the task level should be as independent as possible to prevent double book-keeping of these across multiple tasks. This can be accomplished if most of the planned rework cycle (Section 2.2.1.3) due to the structure of the organizational processes is captured explicitly as separate tasks. If the opportunities and threats for each task are independent, then the sum of the deviations will indicate the total potential for cost savings or cost overruns from the nominal cost. In essence, opportunities establish the lower bound for the project cost and represent the optimistic scenario and threats establish the upper bound for the project cost and represent the pessimistic scenario. However, where the project cost ultimately ends up subject to these low and upper bounds is uncertain and depends on many factors like organizational performance, and emergence of additional risks.

Systematic preemptive elicitation of threats and opportunities at the planning stage by the functional organization removes most, if not all, of the doubts in the minds of those performing the cost estimation as to whether these risks and opportunities are included in the nominal cost or not, and allows the project organization and senior management to rationally analyze such uncertainties and objectively evaluate the quantification of their impact on the project. This systematic bookkeeping of uncertainties and their impact makes the budgeting process transparent, eliminates double bookkeeping, and allows for deliberations and subsequent refinement as needed. This process also instills accountability across the organization, as non-identification of risks, and under- or over-estimation of their impact can be challenged during deliberations, thus motivating everyone to come up with a defendable, rational estimate. At this stage, while it is not essential, it is also a good practice to collect the risks according to their impact – cost and/or schedule. Most of the risks and opportunities will impact either cost or
schedule, however, a handful of tasks will affect both; e.g., in a product development project, a technology risk impacts both cost and schedule as it requires more money and time to reduce the risk by achieving an appropriate technology maturity level for incorporation into a product. The functional organization could divide the impact into cost risk and schedule risk which could then be subsequently deliberated.

A template for capturing the risk profile is given below (Table 1). Each task is sub-divided into a set of independent activities. For each activity, a nominal cost estimate and rationale for nominal, minimum (to capture opportunities) and maximum (to capture risks) costs is recorded, along with the functional organization and person responsible for providing this information (as well as for providing updates). For each task, the uncertainties can be captured in the fourteen cost driver dimensions adapted by COSYSMO (Section 2.2.1.1.1), but need not be limited to these drivers. Additional drivers that are specific to the organization and/or the project can be included as needed. It is imperative that this template is kept as a living document that should be updated to redefine the project risk profile before any project re-planning.

The quantified risks can be rolled up to the task level, which can be further sorted and analyzed to reduce the time required to identify key tasks requiring further scrutiny. Once the key tasks are identified, more effort can be focused on determining the prime cost driver activities. The intent of the multi-level step is not to overwhelm the personnel and to simplify overall risk elicitation process.
<table>
<thead>
<tr>
<th>Task 1</th>
<th>Nominal</th>
<th>Min</th>
<th>Max</th>
<th>Nominal</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 1-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 1-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 1-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 1 Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 2</td>
<td>Nominal</td>
<td>Min</td>
<td>Max</td>
<td>Nominal</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Activity 2-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 2-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 2-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 2-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 2 Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 3</td>
<td>Nominal</td>
<td>Min</td>
<td>Max</td>
<td>Nominal</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Activity 3-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 3-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 3-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 3-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 3 Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Risk Elicitation Template

3.1.3 Establish Baseline Performance

In the new approach, responsibility for establishing the baseline performance rests with the project organization. The project organization must work closely with the functional organization to become aware of all costing assumptions and the prevailing risk profile, and work with the functional organization to refine the values as needed and articulate the same to the senior management. In addition, engaging project organization and senior management at this stage provides an independent check on the cost and risk estimation performed by functional organizations and instills accountability, transparency. After all, the project organization is responsible for delivering the project on cost and schedule and senior management is responsible for providing the funding and both have a vested interest in scrutinizing the costing and risk profile estimated by the functional organization. The project organization must exercise prudence
with regards to the details of the risk profile information furnished to the senior management and much of the detailed information collated in Section 3.1.2 should be abstracted. The senior management is more interested in the robustness of the underlying data collected in Section 3.1.2 and organizational adherence to the established standard process that instills transparency, accountability and improved reliability of the derived metrics. They will primarily focus on the higher level metrics derived in this section that would enable them understand the project status and help them make strategic decisions with regards to resource allocations.

The project organization should use the optimistic, nominal and pessimistic cost numbers provided by the functional organization, and establish the overall cost vs. cumulative probability chart using Monte Carlo methodology. This approach aggregates the impact of uncertainties on the project by computing the cumulative impact of cost savings from “task level opportunities” and cost overruns from the “task level threats” on the overall project cost. The frequency of occurrences of the aggregated total project cost establishes the cumulative probability that a project below a given cost (Figure 3) and encompasses the set of opportunities, threats and nominal cost of all the atomic tasks within a project, and can be used to establish baseline probability (likelihood or confidence level) of achieving the nominal cost (BAC).

Figure 3 could be used to demonstrate the organizational capacity in estimating project cost accurately, given the risk profile. If the probability that project meeting the estimated cost falls below a low threshold, the senior management could question accuracy of the estimated cost or the validity of the risk profile.
The extent of the low risk threshold depends on the maturity of the industry, organization and underlying technologies (Point 1 in Figure 4). For example, projects that require new technology
development may have a higher risk profile and management may choose to question low nominal cost estimate. In large and mature manufacturing industries like automotive and aerospace industries, if the probability of meeting the estimated nominal cost is low, then the senior management could question the risk profile established during project planning.

As all the required information has been captured in a systematic manner (Section 3.1.2) subsequent deliberations can take place in a more meaningful manner to resolve the difference between management expectations and established nominal cost given the risk profile. On the other hand, if the analysis shows that the probability of meeting estimated nominal cost is high (Point 2, in Figure 4) and are at odds with either the underlying maturity of industry, organization or technology, it also allows the senior management to target questions as appropriate to refine the estimated cost, risk or both to ensure alignment.

This systematic deliberative process is a significant improvement over the project planning processes existing in many companies, as it allows for the data driven, rational reconciliation of the risk profile, maturity and estimated cost and facilitates accountability. Even if the organization is forced to underbid to secure a contract, the ramifications of such an underbid will be transparent to all stakeholders within the organization and the negotiators can use this information strategically.
Typically, senior management stipulates an “acceptable risk” to challenge the organization and to secure the contract through competitive bidding process. In many companies, assessed complexity of the project determines management reserve or contingency, and typically 15-20% of planned cost is applied to the estimated nominal cost as contingency, but there is no established rule on how much is adequate. As complexity and prior experience do not articulate prevailing project risk profiles very well, senior management typically can not determine adequacy of contingency except through collective intuition.

In the new approach described in this thesis, with threats and opportunities systematically identified and quantified as illustrated in Section 3.1.2, a more meaningful management reserve can be estimated and the initial nominal value used in Section 3.1.1 can be benchmarked and
revised if needed. This risk-elicited approach is procedurally much better than the current approach as it ensures that management reserve is determined by the quantified risk profile and knowing the risk elicited probability the senior management can challenge the project team when necessary, in a more meaningful and informed manner (Figure 5). In addition, from Figure 5, senior management immediately knows the impact of management reserve on the risk-elicited probabilities, giving them the confidence that the project team is provided with sufficient resources to meet its technical objectives. As both project and functional organizations are involved in identifying the risk profile, and senior management is aware of the risk profile, any emerging risks that fall outside the scope of project planning stage will stand out and can be confidently brought to the attention of the senior management to get appropriate adjustment to the management reserve or make other program adjustments.

Once the risk profile and nominal planned cost are identified, baseline EVMS parameters such as BCWP and BCWS for the project can be established so that fractional project completion and earned value can be computed as the project is being executed and its performance can be monitored.

3.1.4 Establish Risk Elicited Earned Value Management Parameters

As the project is being executed, the classical Earned Value Management calculations can be carried out (Section 2.3.1.5) to identify key EVM parameters like AWCP, CPI and SPI, using nominal planned cost and planned schedule and baseline BCWP and BCWS established in Section 3.1.3.

Uncertainties in the Estimated Cost at Completion (EAC) can be quantified, if risks in “remaining work” are quantified. To use the methodology outlined in Section 3.1.2 effectively, absolute deviations from the nominal planned cost must be converted into fractional deviations
denoting the maximum and minimum bounds, then these fractional deviations can be used to quantify risks into “remaining work”. For example, for a task costing $1000, with a minimum of $900 and a maximum of $1200, fractional values will be 1.0, 0.9 and 1.2 respectively.

The Risk Elicited Estimated Cost at Completion (RE-EAC) can be obtained by rolling up the actual cost spent on the tasks and the risk elicited cost required for completing the remaining work for all the tasks. Because the impact of schedule and cost variance needs to be accounted to accurately assess the project status, the RE-EAC is calculated as described as described in the following paragraphs.

For each task/activity, risk elicited estimated cost at completion is calculated by

\[ \text{RE-EAC}_{\text{composite}, i} = \text{ACWP}_{\text{cum}, i} + \text{RND} \times \left( \frac{\text{BAC}_i - \text{BCWP}_{\text{cum}, i}}{\text{CPI}_{\text{cum}, i} \times \text{SPI}_{\text{cum}, i}} \right) \]

where RND is a value that falls between the minimum and maximum fractional cost with respect to the nominal cost for each task \( i \) established in Section 3.1.2.

Rolling up the estimated cost for all tasks that constitute the project using the above equation will result in one plausible scenario. The risk elicited probability that project stays under the estimated EAC could be obtained from a large number of Monte Carlo simulations by changing RND value between the fractional minimum and maximum values for all the tasks. The cumulative probability chart is obtained from the frequency distribution of the risk elicited EAC calculated from the Monte Carlo simulations. This chart can then be used to establish the probability that the project stays below a given EAC value. Overlaying BAC on this plot also illustrates the probability of meeting the planned baseline cost.

From the new risk elicited EAC vs. cumulative probability plot (Figure 6), probabilities of meeting the original BAC (Section 3.1.1) or revised BAC+MR (Section 3.1.3) can be found out. As the project progresses, cost necessary to meet the baseline confidence levels can also be found from the plot.
Figure 6: Risk Elicited Earned Value Management Cost Parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{BAC,0}$</td>
<td>Baseline Probability of Meeting the Planned Cost (Budgeted Cost At Completion)</td>
</tr>
<tr>
<td>$P_{BAC,1}$</td>
<td>Probability of Meeting the Planned Cost (Budgeted Cost At Completion) at the end of the 1st Reporting Period</td>
</tr>
<tr>
<td>$P_{BAC+MR,0}$</td>
<td>Baseline probability the project stays under the budgeted cost at completion + the hard management reserve</td>
</tr>
<tr>
<td>$P_{BAC+MR,1}$</td>
<td>Probability the project stays under the budgeted cost at completion + the hard management reserve at the end of the 1st Reporting Period</td>
</tr>
<tr>
<td>$BAC_{PMR0,0}$</td>
<td>Baseline Risk Elicited Cost required for project completion at a confidence level PMR0 established by the hard management reserve.</td>
</tr>
<tr>
<td>$EAC_{PMR0,1}$</td>
<td>Risk Elicited Cost required for project completion at baseline confidence level established by the hard management reserve at the end of the 1st Reporting Period</td>
</tr>
</tbody>
</table>
3.1.4.1 Risk Elicited Earned Value Management Cost Parameters

This section explains the significance of the seven Risk Elicited EVM Cost parameters and how to interpret them.

\( P_{BAC,0} \) determines the ability of the organization in aligning estimated cost and estimated project risk profile and maturity of its cost estimation processes. As discussed in Section 3.1.3, any misalignment would result in very low or very high values, which could indicate a problem and require extensive deliberations across the organization to ensure correction. Such deliberations not only improve the accuracy of the estimates, but also improve cost estimation processes. The accuracy of future performance prediction hinges on the integrity of the baseline.

\( P_{BAC, n} \) gives the probability of the meeting the budgeted cost at completion at the end of the \( n^{th} \) reporting period. If this probability is higher than \( P_{BAC, 0} \) the organization is ahead when compared with their planned baseline, otherwise, the project is falling behind.

\( P_{BAC+MR, 0} \) determines the confidence levels that senior management or stakeholders place in the organization in meeting the project performance through the assignment of *hard management reserve*. In other words, \( 1 - P_{BAC+MR, 0} \) determines the challenge that the senior management want the organization to overcome in addressing the identified risk profile in delivering to the technical milestones. The *hard management reserve* must take many factors – like the nature of the known risk profile (engineering and technological) – and available resources like time and personnel.
\( P_{BAC+MR, n} \) represents the probability that the organization could meet senior management or stakeholder expectations at the end of the \( n^{th} \) reporting period. If this probability is higher than \( P_{BAC+MR, 0} \) the organization is ahead in meeting senior management or stakeholder expectations.

\( BAC_{PMR0, 0} \) determines amount of funding agreed upon by the senior management or stakeholders to challenge project organization in fulfilling project objectives. The challenge level \((1.0 - PMR0 \text{ or } 1.0 - P_{BAC+MR, 0})\) determined by hard management reserve and is established by senior management by considering various factors such as the maturity of the technologies, organizational processes, historical performance, market constraints, and strategic constraints.

\( EAC_{PMR0, n} \) determines the amount of funding that the organization could consume to keep the challenge on par with the original baseline for the \( n^{th} \) reporting period. If this value is higher than the sum of the budgeted cost at completion (BAC) and hard management reserve, then the organization must improve its effectiveness in carrying out all the outstanding tasks and are clearly falling behind in meeting the senior management or stakeholder expectations.

\( P_{EAC, n} \) represents the probability that the project could meet the estimated cost at completion as calculated by the EVM analysis at the end of \( n^{th} \) reporting period, given the existing project risk profile and performance. If this value is lower than the corresponding \( P_{BAC+MR, n} \), then, the project is failing both in terms of cost and in addressing project risks.

Monitoring these seven parameters at the end of each EVM reporting period establish how the organization is faring in meeting allocated nominal budget and risk elicited budget. This information can be used to objectively measure organizational effectiveness in carrying out the project and its ability to anticipate project risks and prioritize mitigation plan.
3.1.5 Realign Risk Profile

During the course of the project, the risk profile changes as more information becomes available, with intensity of some risks diminishing and new risks emerging; original uncertainties identified in Section 3.1.2 decrease or even vanish and new threats and opportunities may appear. As stipulated in Section 3.1.2, realignment of the project risk profile must precede any project re-planning to ensure the new baseline reflects reality. Hence, opportunities and threats should be realigned to reflect prevailing risks, and they must be quantified for all remaining work in each of the remaining individual atomic tasks. While this can be done on a continuous basis, it is a costly exercise, and to keep the task manageable, it should be done only at stipulated intervals over the course of the project, preferably at the end of key stage gates in the project. Regardless of when it is done, it is important that project risk profile is adjusted during the course of the project to ensure calculated risk adjusted EAC reflects the prevailing risk profile.

In a product development project, stage gates such as concept design review, preliminary design review, detailed design review, verification test readiness review, validation test readiness review, field implementation, maintenance and supportability review can be used as points at which the project risk profile is reevaluated to change the prevailing risk as more and more information falls into place at each of the stage gates. The reevaluation can be carried out using the template discussed in Section 3.1.2 using same procedure. It is also important that, despite the changes to the risk profile, the original risk profile must be documented to help any future project cost estimation process.

3.2 Establish Risk Elicited Probability of Completing Critical Path Tasks

Section 2.3.1.3 articulated that the current health of the project as measured by EVM does not guarantee that the project is not on the critical path. One way to address this is to carry out the
risk elicited approach specifically targeted towards the critical path tasks. A project management tool such as MS Project can be used to identify critical path tasks and the risk elicited EVM process outlined in Section 3.1.1 to Section 3.1.5 can be repeated only for these critical path tasks/activities to establish the risk elicited probabilities and to ensure that prevailing risk profile of critical path tasks is in alignment with that of the project and will not impede project completion. If these risk elicited probabilities for the critical tasks are not improving as the project is being executed, it will preemptively indicate that the current organizational performance in completing these critical tasks and the prevailing risk profile, would not allow the project meet its cost and schedule objectives. Monitoring risk elicited probabilities for the critical tasks, in addition to the project level probability, will allow the project organization to prioritize resources for critical tasks to improve performance and/or, more importantly, decrease associated risk profile. In essence, this probability will establish whether, over the reporting period, deployed resources achieved the intended objectives of decreasing the risk profile to ensure the project is kept on track, by instilling accountability.

3.3 Establish Risk Elicited Probability of Meeting Project Schedule

In most projects, the senior management not only is interested in excellence in meeting cost and technical performance goals; they also want to know whether the project organization will meet the schedule. In some projects, not meeting the schedule has wider ramifications such as cost penalties and organizational reputation. For example, Airbus had to pay penalty to airlines for missing their A380 delivery schedule and, in addition, also suffered cancellations of orders [5]. At the moment, Boeing is suffering from the same problem with the delay in 787 deliveries, and potential customers are waiting on the sidelines before placing firm orders with some airlines considering other alternatives [8]. Delays may also impact the ability of the organization in securing future contracts and, even when contracts are won, a history of delays decreases the
future leverage that the organization may have on the customers. Both Boeing and Airbus have experienced multiple delay announcements that have tested the patience of both airlines and investors, and the impact of these announcements has progressively become more and more serious, eroding trust. Under these conditions, senior management would like to know an estimate of the confidence level that the organization has in meeting the promised schedule. In other projects, increasing funding may not be an option, but there may be some flexibility in schedule, and the stakeholders can be engaged early if the probability of meeting the schedule could be improved through reallocation of resources.

The risk elicitation process as outlined in the preceding sections can also be extended to schedule with minor modifications to determine the probability that the project meets the baseline schedule or, as with the cost, can be used to estimate the probability (say 90%) that the project will not exceed a given schedule. Based on the schedule performance, the estimated cost at completion for each task/activity $i$ can be found by the following equality

$$EAC_{\text{Schedule}, i} = ACWP_{\text{CUM}, i} + [(BAC_i - BCWP_{\text{CUM}, i}) / SPI_{\text{CUM}, i}]$$

t_{\text{Schedule}, i}$ the time required to complete task $i$ given the current risk profile and schedule performance can then be found from:

$$t_{\text{Schedule}, i} = EAC_{\text{Schedule}, i} / CBREV$$

where CBREV is the cost ‘burn rate’ that is actually earning value and can be calculated by dividing the planned cost by the project duration, $t_{\text{project}}$:

$$CBREV = BAC / t_{\text{project}}$$

It must be noted that the actual cost burn rate (amount of money spent over the project duration) may be higher because of a lower cost performance, but most of the additional money is not earning value and should not be used in this calculation for estimating the schedule as the “true” schedule is determined only by the earned value.
Rolling up the time required for all the tasks in the project will then give the actual amount of time required to complete the project. It is simpler to use $t_{\text{project}}$ as the calendar days, so that the estimated time can also be expressed in calendar days. The same approach taken in Section 3.1.4 can be adopted to determine the probabilities using the Monte Carlo methodology by eliciting the impact of risk, using a random parameter $\text{RND}$. $\text{RND}$, which varies between the minimum and maximum relative deviations identified in Section 3.1.2, will be incorporated into the equation only for completing the left over tasks as follows:

$$EAC_{\text{Schedule},i} = ACWP_{\text{CUM},i} + \text{RND} \times \left(\frac{\text{BAC}_i - \text{BCWP}_{\text{CUM},i}}{\text{SPI}_{\text{CUM},i}}\right)$$

This modified equation allows the building of the cumulative probability charts to estimate the probability of meeting the schedule. It must be noted that, in this case, the complementary probability i.e. probability of missing the deadline may of more interest from the senior management perspective ($P' = 1 - P_{\text{project meeting schedule}}$).

Figure 7 shows how to obtain key risk elicited schedule parameters from the cumulative plot. In the plot, BS is the budgeted schedule, BMS is the budgeted schedule with management reserve and the ES is the EVMS estimated schedule at the end of the 1st EVMS reporting period ($S_{P,1}$).
Estimated Project Duration or Finish Date

Figure 7: Risk Elicited Earned Value Management Schedule Parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{BS,0}$</td>
<td>Baseline Probability of Meeting the Planned Schedule using Baseline Cost with planned burn rate</td>
</tr>
<tr>
<td>$P_{BS,1}$</td>
<td>Probability of Meeting the Planned Schedule (Budgeted Cost At Completion) at the end of the 1st Reporting Period with planned burn rate</td>
</tr>
<tr>
<td>$P_{BMS,0}$</td>
<td>Baseline probability the project meets the Planned Schedule Based on budgeted cost BAC and hard management reserve with the planned burn rate</td>
</tr>
<tr>
<td>$P_{BMS,1}$</td>
<td>Probability that the project meets the Planned Schedule Based on budgeted cost BAC and hard management schedule reserve with planned burn rate at the end of the 1st Reporting Period</td>
</tr>
<tr>
<td>$S_{BMS,n}$</td>
<td>Risk Elicited Schedule estimated at the end of the n th EVMS reporting period, that is required for satisfying the baseline confidence level ($P_{BMS,0}$)</td>
</tr>
</tbody>
</table>
3.3.1 Risk Elicited Earned Value Management Schedule Parameters

This section explains the significance of the seven Risk Elicited EVM Schedule parameters and how to interpret them. Most of these are similar to the cost parameters established in Section 3.1.4.

P_{BS, 0} represents the ability of the organization to align schedule and resource estimate, project risk estimate and the maturity of its schedule estimation processes. As discussed in Section 3.1.3, any misalignment will result in very low or very high values which could indicate a problem and require deliberations across the organization to ensure correctness. The accuracy of estimated future schedule performance hinges on the integrity of the baseline.

P_{BS, n} represents the probability of meeting the schedule at completion at the end of the n\(^{th}\) reporting period. If this probability is higher than P_{BS, 0} the organization is ahead when compared to their planned baseline.

P_{BMS, 0} determines the confidence level that senior management places on the organization in meeting the project schedule. In other words, 1 - P_{BMS, 0} determines the probability that the project could miss the schedule and indicates the challenge that the senior management places on the organization in overcoming the identified risk profile while delivering technical and cost milestones. The challenge level must take many factors like the nature of the risk profile – engineering and technological – and available resources like the time and personnel.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR_{BMS, n}</td>
<td>Risk Elicited Future Period Burn Rate required to meet the original schedule</td>
</tr>
<tr>
<td></td>
<td>given the prevailing risk profile and performance, and can be calculated by</td>
</tr>
<tr>
<td></td>
<td>S_{BMS, n} / t_{project}</td>
</tr>
<tr>
<td>P_{S, 1}</td>
<td>Risk elicited probability that the project meet the estimated schedule at the</td>
</tr>
<tr>
<td></td>
<td>end of the 1(^{st}) EVMS period</td>
</tr>
</tbody>
</table>
\( P_{BMS, n} \) represents the probability that the organization could meet the senior management expectations at the end of the \( n^{th} \) reporting period. If this probability is higher than \( P_{BMS, 0} \) the organization is well on their way to meeting the schedule expectations.

\( S_{BMS, n} \) determines the schedule that the project organization should keep to achieve the \( P_{BMS, 0} \) probability of meeting schedule, i.e., to keep management challenge on par with the original baseline. If this value is higher than the budgeted schedule including the management reserve at the budgeted burn rate, it indicates that the organization must improve its efficiency in carrying out the project and are clearly falling behind in meeting senior management expectations.

\( CBR_{BMS, n} \) is the burn rate required to meet the original schedule for completing the remaining tasks given the prevailing risk profile and project performance and in labor intensive projects, is useful for human resource re-planning activity. In labor intensive projects, by establishing an average wage rate for the project personnel, this burn rate can be translated into number of full-time personnel equivalent required to complete the tasks and meet the original schedule. The estimated headcount and burn rate has the same confidence level as that of \( S_{BMS, n} \).

\( P_{S, n} \) is the probability that the project could meet the schedule estimated by the EVMS calculations at the end of the \( n^{th} \) reporting period. If this probability is higher than \( P_{BMS, 0} \), then the organization is well on its way to meeting the budgeted schedule.

Monitoring these seven parameters at the end of each EVM reporting period establishes how the organization is progressing in meeting the schedule, given the budget and the risk profile. This information can be used to measure organizational effectiveness in carrying out the project and its ability to anticipate project risks and prioritize mitigation plan, particularly when it comes to the tasks that are on the critical path.
3.4 Monte Carlo Methodology to Establish Risk Elicited Parameters

In Sections 3.1.4 and 3.3.1, the risk elicited parameters were defined and in Section 3.1.3 outlined the procedure for calculating these probabilities using Monte Carlo approach. It usually involve large number of scenario analysis by randomly choosing cost or schedule value within the minimum-to-maximum range as stipulated by prevailing task or activity-level risk profile and typically done using software.

The aim of the risk elicitation approach outlined in this thesis is to extend Earned Value Management, and during project execution needs to be repeated for each reporting period. Most organizations already have templates in place for carrying out their Earned Value Management calculations in MS Excel and even stand-alone project management software like MS Project uses MS Excel as the standard export interface to articulate project planning and status reporting. Monte Carlo analysis software like Crystal Ball and @Risk are MS Excel Add-ins, and use MS Excel as their user interface. For these reasons, MS Excel is chosen as the preferred platform for carrying out the Monte Carlo calculations for Risk Elicitation as well.

For the purpose of demonstrating the Risk Elicitation approached, a slightly modified version of MS Excel add-in developed by Prof. Paul A. Jensen [9] is preferred over the commercial packages. Although a bit slower than the commercial packages, this package is preferred as it offers the following flexibilities:

(a) The calculations and plots for each reporting period can be done in a single worksheet and the entire project can be kept in a single Excel file, facilitating easy bookkeeping and easy referencing.

(b) VBA source code is freely available to enable improvements

(c) The add-in provides additional VBA methods for easy extraction of the risk elicited parameters directly from the cumulative distribution.
4 Results

4.1 Case Study Assumptions

The intent of this thesis is to develop a systematic framework and the purpose of the case studies is to demonstrate how to apply the risk elicitation approach to real projects and to demonstrate how the interpretation of the results systematically helps early identification of potential problems and aids the project organization in prioritizing risks. Given that intent, due to logistical constraints in setting up a meaningful project, eliciting and quantifying all the risks and performing EVM analysis over a period of time, EVM data for the case studies were obtained from public domain. The case study will assume a risk profile to demonstrate how to derive the risk elicited parameters and how these parameters could be used to preempt problems that hinder the organization in addressing the issues. However, taking data from any existing project has its limitations; it suffers from lack of cohesive risk elicitation and quantification of risks as part of project planning. In addition, the published report has only the EVM analysis, but not the underlying project status information and can not be used for establishing the risk elicited probabilities on critical tasks. The new approach recommends that the risk elicitation needs to be done very early on in the project as indicated in Section 3.1.2, otherwise will suffer from the same issues identified in Section 2.3.1.3 and 2.3.1.4.

In using published project data for demonstrating how to derive the risk elicited parameters and how to use the parameters to preempt issues, the following approximation was made: The upper limit for the risk profile is established using allocated contingency amount and the minimum and maximum deviations were assigned such that the total uncertainty stays below the contingency amount. To remove any personal bias, a random number was used to create these deviations, subject to the maximum contingency value. As the purpose of this thesis is to develop a
systematic framework and the intent of the Case Studies is to show how to use the approach in real situations and to demonstrate how the approach can help identify potential problems and help the project organization prioritize risks, this assumption is reasonable as it does not impact the integrity of the approach, and shifts only the absolute values.

4.2 Case Study 1: Risk Elicited Performance of a Multi-Year Project

The first case used to demonstrate the risk elicited approach is a university project, for which Earned Value Management Reports are available [10]. As the risk profile for this particular project is not available, as articulated in Section 4.1, contingency amount was taken as a measure of risk and is used to calculate the upper bound for the risk profile. To prevent any bias, risk profile itself is calculated by randomly choosing a value between 0 and this maximum bound. This particular project reallocated the available contingency amount during the course of the project, indicating a change in the risk profile. The risk profile is realigned to conform to the new contingency amount by reevaluating new random values subjected to the new maximum amount. The information about the maximum possible cost savings (opportunities) is not available. For demonstration purposes, for each of these tasks a value between 0 and 2.5% was randomly assigned. Ideally, the maximum and minimum for calculating the risk profile needs to be established as per Section 3.1.2, and must be part of the project planning and project cost estimation process.
The funding arrangement for this project was unique in the sense that the project is funded by a national lab and available contingency amount was adjusted during the course of the project without full budget re-planning. Hence, total available budget was ensured to be adequate for completing the project. As the project proceeded, funding agency adjusted the contingency amount as needed. In most organizations, change in contingency amount is generally accompanied by a full budget re-baseline. For the purpose of the demonstrating the risk elicitation approach, an intermediate *hard management reserve* (HMR) was assumed that has a 90% probability of meeting the cost target (PMR0 = 90%). Figure 9 depicts the established baseline scenario. Given the assumed risk profile, the probability that the project stays below the established baseline cost of $21.194 M is about 4.5% and to increase this confidence level to 90%, a funding of $22.45 M is required, indicating a $1.25 M contingency.

**Figure 8: Case 1 Baseline Project EVMS Information**

The funding arrangement for this project was unique in the sense that the project is funded by a national lab and available contingency amount was adjusted during the course of the project without full budget re-planning. Hence, total available budget was ensured to be adequate for completing the project. As the project proceeded, funding agency adjusted the contingency amount as needed. In most organizations, change in contingency amount is generally accompanied by a full budget re-baseline. For the purpose of the demonstrating the risk elicitation approach, an intermediate *hard management reserve* (HMR) was assumed that has a 90% probability of meeting the cost target (PMR0 = 90%). Figure 9 depicts the established baseline scenario. Given the assumed risk profile, the probability that the project stays below the established baseline cost of $21.194 M is about 4.5% and to increase this confidence level to 90%, a funding of $22.45 M is required, indicating a $1.25 M contingency.
Figure 10 depicts the project cost information at the end of the first reporting period. The risk elicited performance parameters indicate that the project is doing better than the baseline established in Figure 9, as the probability that the project stays under the $22.45 M has increased to 95.1% and funding required for maintaining the 90% challenge decreases to $22.3 M. Given the prevailing risk profile and the project performance, at the end of the 1st reporting period, the chance of meeting the budgeted cost is virtually zero. Subsequent charts will depict the trend line changes in these performance indicators.
Figure 10: Project Cost Information at the end of 1st reporting period

Figure 11: Estimated FY 04 Project Completion Cost given Performance and Risk Profile
Figure 11 depicts the cost information as estimated from the classical EVM analysis and the risk elicited cost that has a 90% confidence level, for a partial time frame in fiscal year 04 (FY 04). If the estimated cost at completion (EAC) stays below the green line indicating the baseline cost estimate, then the project is performing better than the baseline estimate and its status can be considered green. If the estimated cost at completion (EAC) goes above the red line indicating the 90% challenge initially imposed by the senior management, suggest that the project is falling behind the management expectations, requiring mitigation measures to bring it back on track. As the EAC and risk elicited costs are always above the baseline, the project is always behind the baseline, from a trend line point of view, risk elicited cost is a leading indicator of problems when compared to the EAC estimated from EVM alone.

Figure 12: FY 04 Confidence Level Profiles for Project Meeting the Estimated Cost
Figure 12 depicts the confidence level that project could meet cost targets, given the prevailing project performance and risk profile. The probability that the project stays under the budgeted cost is virtually zero after the first reporting period. The EAC estimated from the EVM analysis also has very low probability of meeting the cost target. This probability value was not available to the project organization without the risk elicitation approach outlined in this thesis and knowing this low probability would have allowed objective deliberations across the organization in deriving mitigation measures. Figure 13 provides the history of contingency amount expressed as a percentage of the baseline cost.

**Figure 13: FY 04 Contingency Profile as a Percentage of FY 04 Baseline Cost**

From Figure 12, the risk elicited cost ($\text{EAC}_{90\%}$, $\text{EAC}_{0}$ is the cost that has the 90% probability of meeting the cost target at the baseline for that fiscal year) has a zero probability of meeting the cost target between Nov-03 and Jan-04, and provides a strong basis to the project organization
either to re-baseline the project or have deliberations on how to improve project performance by reprioritizing risks to align future performance to bring the project back on track. Combining the information from Figures 11, 12 and 13 and using the risk elicited cost, the project could have been re-baselined in Nov-03 instead of Jan-04, giving more time for the organization to take corrective actions. Approaching the funding agency with this data would have allowed an objective evaluation that could have resulted in an increase in hard management reserve or an increase in overall contingency amount.

Figure 14, Figure 15 and Figure 16 depict the risk elicited parameters for (FY 05), the baseline cost of $38.5 M is the cumulative planned cost for FY 04 and FY 05.

![Diagram](image)

**Figure 14:** Estimated FY 05 Project Completion Cost given Performance and Risk Profile
Figure 15: FY 05 Confidence Level Profiles for Project Meeting the Estimated Cost

Figure 16: FY 05 Contingency Profile as a Percentage of FY05 Baseline Cost
Considering Figure 14, Figure 15 and Figure 16, it is interesting to note that between Feb 05 and Jun 05, despite the fact that EAC estimated by the EVM analysis was increasing, the baseline cost and contingency amount remained the same. The risk elicitation approach indicate that the baseline cost and the risk elicited cost for this fiscal year is not sufficient to complete the project as indicated by the zero probability after the first reporting period in this fiscal year. Even EAC estimated by EVM has only a 30% probability of success and places undue stress on the organization and establishing this confidence level a priori would have allowed the project organization to articulate the status better to seek more funding as the probability of meeting the cost is essentially zero from Nov-04 or internally discuss how to improve the performance to address the short-fall. The contingency amount did increase after Nov-04, but not sufficiently high to cover the short-fall (Figure 16) and remain same during Feb-05 and Jun-05.

![Figure 17: Estimated FY 06 Project Completion Cost given Performance and Risk Profile](image)

Figure 17: Estimated FY 06 Project Completion Cost given Performance and Risk Profile
Figure 18: FY 06 Confidence Level Profiles for Project Meeting the Estimated Cost

Figure 19: FY 06 Contingency Profile as a Percentage of FY 06 Baseline Cost
Similar to the FY 05 numbers, FY 06 numbers (Figure 17 and Figure 18) also indicate that the project is consistently behind baseline cost. It is also worth noting that despite the project not meeting cost targets, allocated contingency amount as a percentage drops during the course of the fiscal year. As highlighted before, given the risk profile and performance, if the risk elicited probabilities of meeting the cost target were available to the project organization, it would have allowed them to seek extra funding from the agency and negotiated for a better contingency amount (Figure 19) and develop mitigation measures sooner to internally improve the performance. Depending on the nature of the risk, funding increase sought could be in the form of hard management reserve (HMR) or soft management reserve (SMR).

4.3 Case Study 2: Risk Elicited Performance of a Software Project

The second case study that will be used to demonstrate the risk elicited approach is a short term software project in which schedule is the overriding factor when compared to cost as evidenced by the EVM parameters for this project depicted in Figure 20, showing the cumulative ACWP is higher than the cumulative BCWS or BCWP.
As with Case 1, reasonable values for the risk profile were assumed, such that the total contingency amount is below 15%. The cost savings from opportunities is assumed not to exceed 10%. As before, triangular distribution is assumed for each of the tasks for carrying out the Monte Carlo simulations to establish the probability profiles. The performance hurdle imposed by the management is assumed to be 10%, in other words, the project has a 90% probability of meeting the cost target with the hard management reserve and the short-fall must be overcome by the project team through performance improvement. For the assumed risk profile, Figure 21 establishes the baseline risk elicited parameters, the probability that the project would stay below the baseline cost estimate of $2.194 M is only about 16.7%. Given the risk profile, a funding of $2.328 M is required to increase the confidence level to 90%.
Figure 21: Case 2 Baseline Information on Risk Elicited Parameters

As the project proceeds, the earned value management calculations could be performed using the planned cost, scheduled cost and actual spending. The prevailing risk profile is then used to establish the estimated cost required for completing the project, given current project performance, and the results are depicted in Figure 22 and Figure 23.
This project did not undergo any re-baseline during the course of its execution and hence the analysis is simpler. In Figure 22, if the cost required is below the baseline estimate (BAC, green line) then the performance of the project is better than the baseline and if the cost exceeds the challenge imposed by the hard management reserve (BAC$_{90\%}$, red line) then the project is falling behind the challenge. In between these two extremes, it can be concluded that the project may be heading into problem which could be managed without re-planning. The estimated cost at completion (EAC) from EVM has a lower value compared to the risk elicited EAC because it does not account for the prevailing risk profile. Hence, it can be concluded that the risk elicited cost could preempt problems faster than EVM estimate, allowing organization more time to identify and implement remedial measures.
The risk elicitation approach preempts the problem by about two months and the organization could have known the problem in April instead of June. In this case study, as the project ends at the end of the year, both the risk elicited cost and EAC estimated by the EVM would coincide, which is understandable considering the impact of risk profile on project performance diminishes as the project nears its conclusion.

Figure 23 depicts the probability that the project could meet the planned cost, the EAC from EVM (performance alone), and the BAC+MR (initial risk). Because of the prevailing risks, the project still has only about 30% chance of meeting the EAC estimated by EVM and, as expected, reaches 100% at the end of the project completion which is in accordance with the lack of sensitivity of project to the risk profile as the project nears its completion.

**Figure 23:** Case 2 Probability of Meeting Cost given Performance and Risk Profile
4.4 Case Study 3: Risk Elicited Schedule Performance of a Software Project

The risk elicitation approach can also be used to evaluate the schedule performance of projects (Section 3.3), where monitoring schedule may be more important. The software project that was analyzed in Section 4.3 is taken as the test case for demonstrating this.

![Graph](image)

**Figure 24:** Case 3 Baseline Probability of Meeting Schedule given Performance and Risk Profile

Figure 24 establish baseline probabilities, given the risk profile the project has only a 16.9% probability of meeting the original schedule of 365 days. Similar to the *hard management reserve* for cost, given the schedule risk profile, the stakeholders or senior management could agree to a maximum allowable slip in schedule, which acts as a buffer and is similar to the *safety time* allocated in the Critical Chain Method [11, 12]. If a maximum schedule slip of 20 days is allocated, then the project has 85% chance of meeting it and as with cost, and the remaining 15% difference is imposed upon the project team as a challenge that they must overcome through
performance improvement in meeting project objectives subject to the schedule constraint. Now as the project is executed, the schedule performance could be evaluated. If the schedule risk profile is not available for a project, the buffer can also be calculated using hard management reserve and the planned burn rate.

![Graph showing schedule performance over time](image)

**Figure 25: Case 3 Probability of Meeting Schedule given Performance and Risk Profile**

Figure 25 highlights that at the planned budget burn rate in earning value, given the risk profile and project performance, by Apr-06, the chance of meeting the original project schedule is close to zero and even the 20 extra days reserved as management schedule reserve also will not be enough by Aug-06. Knowing this information earlier helps the organization to prioritize their risk mitigation plans and project performance improvement plans including resource allocation.

Figure 26 establishes the confidence levels for the estimated project duration as the project is being executed and compares the same for schedule estimated by classical EVM calculation and
that calculated by the risk elicitation approach that has a 85% probability of meeting the schedule target and establishes the confidence level that is placed on the estimated duration values. The trends and absolute values helps the organization and stakeholders to workout the mitigation plans including allotment of additional resources to ensure that the project is brought back on track sooner.

Figure 26: Case 3 Expected Project Duration given Performance and Risk Profile
Figure 27 provides the profile of the estimated future burn rate for completing the remaining work in the remaining period – an indicator for the allocation of resources both in terms of personnel and cost – to earn value and meet the original project schedule, given the risk profile and performance. The actual burn rate may vary depending on how the project is doing in terms of its cost performance. For this project the EVM data in Figure 20 indicates that the Cost Performance Index is less than 1 and hence the estimated future burn rate will be higher than that given by Figure 27. In a labor intensive project, the burn rate established in Figure 27 help with human resource allocation to meet the original schedule. Assuming an average individual wage rate of $400 / day for project personnel, Figure 28 translates the burn rate in Figure 27 into number of full-time equivalent personnel (HC_{85\%}, n or HC_{EVM}) required for meeting original
schedule. As of Apr-06, to complete the project in time, given the schedule performance and risk profile require 17 people (85% probability, \( HC_{85\%} \)).

![Project Personnel Required for Meeting Original Schedule](image)

**Figure 28: Project Personnel Required for Meeting Original Schedule**

### 4.5 Usefulness of Risk Elicited Parameters

The results from these case studies indicate that the risk elicitation approach outlined in thesis could be used to quantitatively monitor project performance in both cost and schedule dimensions. The risk elicited parameters objectively help with early problem identification and quantify the impact of remedial measures and ensure that entire organization is held accountable for the delivery of project objectives, organizational performance and effective value creation to the stakeholders. Knowing the risk elicited parameters, the organization has the following options to address the problems:
• Re-baseline the project in accordance with the prevailing risk profile and performance
• Revisit risk profile to ensure the all risks are accounted for (a must for re-planning)
• Increase *hard management reserve*, in other words, decrease the management challenge imposed on the project.
  
• Increase *soft management reserve*

The risk elicited parameters provide the organization an objective body of evidence to demonstrate that the project is in trouble, as the underlying assumptions – risks and impact of the risks – are transparent and previously agreed upon by the entire organization. This objectivity makes the entire organization accountable in bringing the project back on track.

Given the transparency, project organization has the responsibility to explain why the project performance was not as expected. If any of the new risks identified during project execution that can not be classified as an emerged risk (say, due to a requirement change by the customer) but were not captured during initial planning, then the functional organization will be held accountable for revising organizational processes used for evaluating the project risks at the planning stage to prevent such omissions in the future; the person responsible for the omission should be notified and re-trained as needed. If the new risks have truly emerged during the course of project execution, the senior management has the responsibility to increase *hard management reserve* (in other words, decrease management challenge) and/or increase *soft management reserve*, so as not to place undue burden on the organization. If the project is externally funded, then this information can be used to impress upon the external funding agency to review the current funding and contingency.
5 Conclusions

The risk elicitation approach outlined in this thesis improves the process of project cost estimation and performance monitoring during execution by making the process more transparent and by instilling accountability across the organization. It provides a systematic framework for capturing the impact of risks that could affect the project performance and is flexible enough to account for any emerging risks as the project is being executed. This approach closes one of the major gaps in the project planning process by explicitly capturing all the assumptions and quantifying their impact on project costing. This transparency ensures that the entire organization – functional, project and senior management – have the same understanding about costing methodology and its assumptions and help the organization in prioritizing risks while developing mitigation plans. This new approach computes risk elicited probabilities and establishes confidence levels on the estimated cost and schedule for project completion; this important quantitative information, not previously available to the organization, makes articulating project status more robust. The importance of these confidence levels can not be overstressed as this approach articulates project status quantitatively and supports securing adequate funding and contingency during negotiations with stakeholders funding the project. It also assures the senior management that the organization is not unduly challenged and minimizes employee frustration and burn-out that may lead to unanticipated productivity losses.

Internally, the project and functional organization can use the confidence level to leverage resources from senior management. Knowing the confidence level and its sensitivity to the additional resources, senior management could address the problem in an informed manner – either by increasing hard management reserve (decreasing the imposed challenge) or by increasing the soft management reserve. Over a period of time, as the organization undertakes
many projects using the same standardized process, project costing and risk elicitation knowledge is captured and documented, thus improving the capability of the organization in accurately estimating the project cost and executing the project to plan.

The case studies also demonstrated the risk elicited parameters preemptively indicate problems at the project planning stage by establishing confidence levels that can be used to evaluate the robustness of project costing and articulate the status of the project during its execution. Broadly speaking, the risk elicitation approach makes the qualitative project cost and schedule risk management into a quantitative process, such that rather than reporting “the project is in on course or project is in trouble” or the color coded RED-YELLOW-GREEN charts, now the status can be reported as “the project has a 90% probability of meeting the cost or schedule or to meet the project objectives, there is a 80% probability that we need X million dollars or Y months or Z full time equivalent personnel, given the prevailing performance and risk profile”.

This quantification allows for objective deliberations between functional, project organizations and with other stakeholders including funding agencies, senior management, and customers with regards to project status, project funding and to the extent of contingency amount. The quantitative approach allows for better decision making as the impact of the decisions can also be quantified and removes any persistent ambiguousness usually prevalent in qualitative statements.

Although, it is imperative that the risk elicitation is to be done systematically from the project planning stage to reap its full benefits, this may be difficult to achieve in many long term projects. However, analytical sections of the risk elicitation approach for establishing the risk elicited performance parameters can still be applied at any point in a project execution cycle, provided prevailing risk profile can be identified and quantified. Given the risk profile, the risk
elicited parameters can still be calculated and benchmarked from at that point in time as the starting values and can be continued to be monitoring for subsequent reporting periods.

Above all, this streamlined risk elicited project costing and monitoring conform to the systems engineering principles as depicted below (Figure 29) by systematically eliminating uncertainties in communication, capturing knowledge through documentation and in creating a learning organization that builds upon the gathered knowledge. Broadly speaking, the risk elicitation process can be mapped on to the DMAIC (Define, Measure, Analyze, Improve and Control) and DFSS (Design For Six Sigma) methodologies that are being used for process design and product design improvements respectively [13]. Over a period of time, the systematic process will help create an organization that can play to its strength with regards to project planning and execution in a seamless manner and minimize the impact of many of the organizational issues causing poor performance that were depicted in Figure 1.

![Figure 29: Risk Elicited Earned Value Management in a Learning Organization](image-url)
6 Implications for Major Stakeholders

6.1 Functional Organization

The new risk elicitation approach increases accountability placed on the functional organization and provides a deeper insight into risks, requiring the capture and documentation of all the risks and assumptions in a systematic manner. In addition, it requires the functional organization to quantify both positive (opportunities) and negative (threats) impact of the risks and assumptions and also the nature of the impact whether it will impact cost and/or schedule. This information will be shared across the organization and the transparency helps the functional organization in their discussions with other stakeholders and establishes confidence levels in meeting the cost and schedule, aiding resource planning. Often, the functional organization is responsible for quality of workmanship, robustness of the organizational processes and welfare of the employees, including professional advancement; this new quantitative process allows them carve out adequate resources and develop contingency plans to ensure the employees are not unduly overstressed causing performance degradation.

In parallel, the new approach also make the functional organization more accountable and any omissions in terms of assumptions and risks require justification as to why they were not identified during project planning phase. As the risks and assumptions are explicitly captured and documented, it allows for reviews within the organization and enables revisions to ensure that the risks and assumptions are quantified properly. The methodology instills a process that reduces the chance of unintended omissions, thus improving effectiveness of the overall project planning and execution process.
6.2 Project Organization

The risk elicitation process as outlined in this thesis requires the early involvement of the project organization in project planning, immediately following project costing performed by the functional organization; as the project organization evaluates the project costing to establish the confidence levels quantitatively, it allows them to engage the functional organization through rational deliberations. This interactive process ensures that the project organization has a full comprehension of the risks and their impacts on the project and allows them to engage senior management during the process to highlight confidence levels. The confidence levels can be leveraged to make changes to resource allocation, risk prioritization, and contingency levels. As the new process continuously monitors project performance and translate performance data into probabilities, quantitatively articulating the project health to the stakeholders becomes easier. Any emerging, unforeseen problems stand out and clearly highlighted, aiding deliberations between all the stakeholders to identify ways to improve the performance. Any changes to the risk profile and re-planning undergo the same transparent review process. The process also computes the confidence levels on the estimated cost of completion as calculated from the EVM process, and helps articulate the hurdle in meeting the project objectives.

6.3 Senior Management

From senior management perspective, the primary intent of the risk elicitation approach is to ensure that planning closely reflects execution. The systematic approach facilitates a learning organization that builds trust and transparency and, over the course of many projects, improves both project cost estimation and project execution processes. In the long run, this will allow the senior management to develop confidence in the estimated cost and schedule numbers and secure new business contracts based on these numbers. In the global market place, as all organizations
aggressively compete for projects, knowing that the underlying cost estimation is robust and that the organization is ready to meet the challenge is a significant advantage. The systematic approach also allows the functional and project organizations to clearly articulate various scenarios to the senior management in terms of probabilities, including the ramifications of lowering the cost for the sake of securing the project.

The systematic approach also standardizes the process for capturing emerging risks and articulates accountability to capture omissions, pinpointing personnel training shortfalls. Dividing the contingency into two parts, for addressing known risks – *hard management reserve* and for addressing unknown risks – *soft management reserve*, also helps the senior management evaluate organizational performance in identifying and quantifying project risks. In addition, establishing probabilities for meeting the agreed schedule also helps senior management in confidently negotiating penalty clauses that are typically put in place in large projects. The process also computes the confidence levels on the estimated cost of completion as calculated from the EVM process, and help the senior management understand the hurdle that needs to be overcome in meeting the project objectives.

### 6.4 Funding Agencies

The funding agencies also would benefit from the risk elicited approach, as they could have access to the risk profile, along with the budget proposal that would also include baseline confidence levels. During execution, the risk elicited confidence levels would become part of the Earned Value Management System report, allowing them to objectively evaluate the estimated cost and estimated schedule required for project completion.
7 Future Work

The case studies were based on the projects that had already been completed for which the EVM data was available and demonstrated how the new approach could be used to establish the risk elicited parameters to enable rational decision making process. However, the usefulness of risk elicitation process during project planning by functional organization and the subsequent evaluation of the project costing by project organization and deliberative reconciliation of risk, cost, and schedule has not yet been demonstrated and should be undertaken as part of the planning phase of a new project.

After such a demonstration has been completed, following extension could be considered to further augment risk elicitation. The project risks typically have two mutually independent but complementary dimensions (a) probability of the risk occurrence (b) severity of risk impact, each of which may have different underlying drivers, requiring different mitigation plans. For example, possibility of a change in requirement and impact of the change in requirement have different drivers, and each may require a different mitigation plan to be put in place. In this thesis, to simplify the analysis, the effect from these two dimensions is combined into a single deviation. Once the usefulness of the risk elicitation during project planning is established, further development should divide risk elicitation during planning into these independent dimensions. This division will allow the organization to understand the underlying drivers and develop separate mitigation plans to reduce the impact from both of these dimensions, as mitigating risk in one of the dimension may not achieve the anticipated benefit. While it is generally true that executing the mitigation plan in one dimension may be sufficient to eliminate the risk, it may not be true all the time and that it may be easier to executing the mitigation plan in one of the dimension when compared to other dimension. But such finer resolution will only
be possible, if the organization is aware of the underlying factors in both dimensions and quantification of the impact of these underlying factors.
Reference


5. Airbus A380 Problems
   a. http://www.businessweek.com/globalbiz/content/jun2006/gb20060630_996152.htm
   b. http://www.amtonline.com/article/article.jsp?siteSection=1&id=3230
   c. http://www.spiegel.de/international/0,1518,438408,00.html

6. Earned Value Management System (EVMS), DOE G413.3-10, 2008


8. Boeing 787 Problems
   e. http://www.businessweek.com/magazine/content/06_25/b3989049.htm
   http://www.me.utexas.edu/~jensen/ORMM/frontpage/jensen.lib/index.html

10. Monthly EVM reports on National Compact Stellarator Experiment
    (http://ncsx.pppl.gov/CPR/CPR.html)


## Appendix A: Sample of the Risk Elicited Calculation Excel Output for a Reporting Period

<table>
<thead>
<tr>
<th>WBS Tasks</th>
<th>Random Variable</th>
<th>Distribution</th>
<th>lower limit (a)</th>
<th>mode (m)</th>
<th>upper limit (b)</th>
<th>Likely</th>
<th>ACWP</th>
<th>BCWS</th>
<th>BCWP</th>
<th>CPI</th>
<th>SPI</th>
<th>Likely Pending</th>
<th>Risk ElicitedCost</th>
<th>EVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Project Management</td>
<td>CV_1</td>
<td>Triangular</td>
<td>90.0%</td>
<td>100.0%</td>
<td>110.0%</td>
<td>$134,034.51</td>
<td>$20,620.22</td>
<td>$12,204.83</td>
<td>$20,126.18</td>
<td>0.066</td>
<td>1.647</td>
<td>$113,829.33</td>
<td>$95,039.31</td>
<td>$92,440.84</td>
</tr>
<tr>
<td>1.2 System Requirements</td>
<td>CV_2</td>
<td>Triangular</td>
<td>95.0%</td>
<td>100.0%</td>
<td>115.0%</td>
<td>$122,166.16</td>
<td>$111,041.16</td>
<td>$79,331.40</td>
<td>$61,083.08</td>
<td>0.550</td>
<td>0.770</td>
<td>$61,083.08</td>
<td>$263,693.85</td>
<td>$255,255.45</td>
</tr>
<tr>
<td>1.3 Software Requirements</td>
<td>CV_3</td>
<td>Triangular</td>
<td>95.0%</td>
<td>100.0%</td>
<td>120.0%</td>
<td>$204,742.11</td>
<td>$6,940.07</td>
<td>$30,512.08</td>
<td>$30,711.32</td>
<td>4.425</td>
<td>1.007</td>
<td>$174,030.79</td>
<td>$48,968.38</td>
<td>$46,012.02</td>
</tr>
<tr>
<td>1.4 Detailed Design</td>
<td>CV_4</td>
<td>Triangular</td>
<td>90.0%</td>
<td>100.0%</td>
<td>125.0%</td>
<td>$290,974.28</td>
<td>$98,574.28</td>
<td>$290,974.28</td>
<td>$316,062.96</td>
<td>1.000</td>
<td>1.000</td>
<td>$290,974.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 Test Planning</td>
<td>CV_5</td>
<td>Triangular</td>
<td>95.0%</td>
<td>100.0%</td>
<td>125.0%</td>
<td>$174,062.04</td>
<td>$100.00</td>
<td>$174,062.04</td>
<td>$170,756.36</td>
<td>1.000</td>
<td>1.000</td>
<td>$174,062.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6 Technical Infrastructure</td>
<td>CV_6</td>
<td>Triangular</td>
<td>95.0%</td>
<td>100.0%</td>
<td>105.0%</td>
<td>$183,072.30</td>
<td>$100.00</td>
<td>$183,072.30</td>
<td>$186,067.03</td>
<td>1.000</td>
<td>1.000</td>
<td>$183,072.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.7 Development Testing</td>
<td>CV_7</td>
<td>Triangular</td>
<td>92.5%</td>
<td>100.0%</td>
<td>105.0%</td>
<td>$183,072.30</td>
<td>$100.00</td>
<td>$183,072.30</td>
<td>$173,532.12</td>
<td>1.000</td>
<td>1.000</td>
<td>$183,072.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.8 Verification &amp; Validation</td>
<td>CV_8</td>
<td>Triangular</td>
<td>90.0%</td>
<td>100.0%</td>
<td>125.0%</td>
<td>$877,985.12</td>
<td>$100.00</td>
<td>$877,985.12</td>
<td>$673,360.96</td>
<td>1.000</td>
<td>1.000</td>
<td>$677,985.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.9 Deployment</td>
<td>CV_9</td>
<td>Triangular</td>
<td>95.0%</td>
<td>100.0%</td>
<td>125.0%</td>
<td>$182,529.03</td>
<td>$100.00</td>
<td>$182,529.03</td>
<td>$185,332.24</td>
<td>1.000</td>
<td>1.000</td>
<td>$182,529.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.10 Materials/ODC</td>
<td>CV_10</td>
<td>Triangular</td>
<td>95.0%</td>
<td>100.0%</td>
<td>105.0%</td>
<td>$41,950.00</td>
<td>$100.00</td>
<td>$41,950.00</td>
<td>$42,786.59</td>
<td>1.000</td>
<td>1.000</td>
<td>$41,950.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WBS Tasks</th>
<th>Likely</th>
<th>ACWP</th>
<th>BCWS</th>
<th>BCWP</th>
<th>CPI</th>
<th>SPI</th>
<th>Likely Pending</th>
<th>Risk ElicitedCost</th>
<th>EVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Project Management</td>
<td>$134,034.51</td>
<td>$20,620.22</td>
<td>$12,204.83</td>
<td>$20,126.18</td>
<td>0.066</td>
<td>1.647</td>
<td>$113,829.33</td>
<td>$95,039.31</td>
<td>$92,440.84</td>
</tr>
<tr>
<td>1.2 System Requirements</td>
<td>$122,166.16</td>
<td>$111,041.16</td>
<td>$79,331.40</td>
<td>$61,083.08</td>
<td>0.550</td>
<td>0.770</td>
<td>$61,083.08</td>
<td>$263,693.85</td>
<td>$255,255.45</td>
</tr>
<tr>
<td>1.3 Software Requirements</td>
<td>$204,742.11</td>
<td>$6,940.07</td>
<td>$30,512.08</td>
<td>$30,711.32</td>
<td>4.425</td>
<td>1.007</td>
<td>$174,030.79</td>
<td>$48,968.38</td>
<td>$46,012.02</td>
</tr>
<tr>
<td>1.4 Detailed Design</td>
<td>$290,974.28</td>
<td>$290,974.28</td>
<td>$316,062.96</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 Test Planning</td>
<td>$174,062.04</td>
<td>$174,062.04</td>
<td>$170,756.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6 Technical Infrastructure</td>
<td>$183,072.30</td>
<td>$183,072.30</td>
<td>$186,067.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.7 Development Testing</td>
<td>$183,072.30</td>
<td>$183,072.30</td>
<td>$173,532.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.8 Verification &amp; Validation</td>
<td>$877,985.12</td>
<td>$877,985.12</td>
<td>$673,360.96</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.9 Deployment</td>
<td>$182,529.03</td>
<td>$182,529.03</td>
<td>$185,332.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.10 Materials/ODC</td>
<td>$41,950.00</td>
<td>$41,950.00</td>
<td>$42,786.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WBS Tasks</th>
<th>Likely</th>
<th>ACWP</th>
<th>BCWS</th>
<th>BCWP</th>
<th>CPI</th>
<th>SPI</th>
<th>Likely Pending</th>
<th>Risk ElicitedCost</th>
<th>EVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Project Management</td>
<td>$2,194,587.83</td>
<td>$136,901.47</td>
<td>$122,148.31</td>
<td>$111,999.57</td>
<td>0.806</td>
<td>0.917</td>
<td>$2,062,588.26</td>
<td>$2,127,363.18</td>
<td></td>
</tr>
</tbody>
</table>