Proceedings of the Annual General Donald R. Keith Memorial Conference
West Point, New York, USA
April 29, 2021
A Regional Conference of the Society for Industrial and Systems Engineering

A Comparative Analysis Supporting Risk-Based Cost Contingency Planning for Army System Development

Fred Cooper, Marvin Flewellen, Joshua Heiman, and Daniel Pryor

Department of Systems Engineering
United States Military Academy
West Point, NY

Corresponding author's Email: joshua.heiman@westpoint.edu

Author Note: CDT Pryor is an Engineering Management major and CDT Flewellen and Heiman are Systems Engineering majors, and CDT Cooper is an Operations Research major. All four cadets have taken various courses involving stochastic system modeling and critical analysis of data. We would like to thank Dr. Patrick Driscoll and Mr. James Richards, our sponsor at the U.S. Army Engineering, Research, and Development Center (ERDC), for their support throughout this project.

Abstract: Cost estimating for Army major defense acquisition programs (MDAP) is a well-documented and detailed process. Yet cost overruns continue to occur that reach Nunn-McCurdy breach levels, threatening potential program cancellation. Cost contingency funding, a budgetary insurance of sorts, offers a potential remedy for this if internal and external risks are explicitly identified and linked to cost estimates. This project introduces a Monte Carlo based approach that links Army work breakdown structure (WBS) cost estimates to major recurring DoD and industry cost risks to examine the effectiveness of policy options for risk-based cost contingency budget choices. Using credible future scenarios to trigger risks during the RDT&E phase of Army system development, the results suggest that a policy involving a balance between cost risk contingency funding and management accountability could provide breach insulation while tying additional program dollars to risk events, thereby enforcing fiscal responsibility.

Keywords: System development, Contingency budgeting, Risk, Cost analysis, Simulation.

1. Background

In early 2020, the U.S. Army Engineering, Research, and Development Center (ERDC) initiated an internal research and development project exploring the possibility that untapped information may exist during the pre-milestone A. Cost overruns on defense contracting in general has been a long-established phenomenon that occurs with such regularity that one might conjecture are simply an unrecognized normal consequence of the defense acquisition process in the modern information age. A wealth of research followed that sought to identify root causes in program management, cost estimation, and external drivers offered some explanation for why cost overruns were occurring and potential fixes that might reduce or eliminate these from occurring. Despite major reforms in the Federal Acquisition Regulations, the DoD Acquisition Process, and regulations focused on military weapons systems (WSARA, 2009), the problem persists.

The literature supports a near universal conclusion that identifying a comprehensive set of risk factors for cost overruns at an early stage of system development, engineering and construction projects plays an important role in eliminating or controlling them by adopting preventative measures (Durdyev, 2020), one of which is cost contingency budgeting.

Cost contingency budgeting, while commonplace in non-DoD construction project management and in-use by other U.S. government agencies such as the National Science Foundation and the Federal Highway Administration has scarce mention GAO and little practice among Army system development beyond 'bumping up' total cost estimates to compensate for shortfalls in information and program experience. Neither of these organizations allow for the use of management reserves, but rather require any cost contingency estimates be directly associated with identified risk elements, thereby keeping in line with industry best practices as well.

It appears then that if cost contingency funding is to be used to suppress emerging cost growth over budget, then a comprehensive set of risk elements must be tied to estimates, and these risk elements should be assessed using best practices amongst the risk analysis community which by necessity must include appropriate stochastic methods for addressing the uncertainty naturally associated with these same risks. This paper represents the results of a complementary project attempting to understand the current role of and future potential for risk analysis-based contingency budget estimating for acquisition programs. To address this aspect of acquisition processes, it will be helpful to identify current best practices for major projects in industry and compare them to those in force in Army acquisition with the hope of accomplishing knowledge transfer in both directions to aid and inform future practices.

In Section 2, we first briefly highlight important processes and elements of the defense acquisition process that are or could be associated with risk-based contingency estimating. In Section 3, we introduce a system-thinking viewpoint of the defense acquisition process in general and cost estimating and risk analysis using familiar systems engineering artifacts. Then, we compare core estimating techniques and cost overrun phenomena with those used and observed in industry best practices. Section 4 introduces a stochastic simulation model for culling possible system-of-system cost overrun drivers that leverages an experimental design framework within a Monte Carlo model to determine which environmental elements have the most impact on cost overruns. Using an example Army missile program WBS/CES as a baseline and then adding industry risk elements and correlation considerations as a proof-of-concept for the overall approach. Despite changes to program baselines over time, the fact that no significant relationship exists between baseline instability and cost overruns, narrowing considerations to risk events (Christensen, 1998).

2. Acquisition in Brief

Properly addressing the issue of budget contingency in this setting requires a brief review of Army acquisition hoping to leverage a more holistic perspective endemic to systems engineering to yield results that might offer possible systemic remedies. An MDAP is defined as a program estimated to require research, development, test, and evaluation (RDT&T) costs of more than $480 million or procurement costs of more than $2.79 billion (in FY2014 constant dollars) (CRS, 2016).

2.1 Dynamics of Army Acquisition

Although several potential pathways exist to support Army acquisition, our primary concern herein are with acquisition programs involving multi-year, proactive to need system develop plans that exercise a complete set of budgeting actions, rather than rapid response acquisitions that tend to be more commercial-off-the-shelf (COTS) solutions.

The Army's acquisition system is further nested within the Defense Acquisition System. The Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASAALT) oversees all Army acquisitions, retaining gateway approval at specific milestones in a program's development. Most important for our purposes are the activities undertaken early in a program prior to milestone A, which typically occurs at the end of the Material Solution analysis phase.

As documented and described in Army Regulation 1-1, the DoD's Planning, Programming, Budgeting, and Execution (PPBE, 2016) is the process by which annual resource allocations occur. The Army's version of the PPBE process takes direction from and provides input to the DoD PPBE process, which represents an aggregation of each service's forecast for annual budget. Army acquisition programs reside at the intersection of these three processes. For material systems, Milestone B normally represents the initiation of an acquisition program because a system must reach a required level of technology maturation to progress past this milestone.

It became apparent early in the project that a host of internal and external influences and their interactions were historically driving cost overruns throughout the system development process. The interplay of these factors extends beyond program office boundaries to include U.S. economic conditions, Congressional priorities, threat evolution, and the pace of technological advances among others, complicates cost estimating. To help understand how these interactions were taking place, several systems engineering representations were created.

2.2. Systems Engineering Representations

The purpose of the systemigram in context to the problem of cost overruns in the acquisition process is to attempt to capture and map all connections between common entities that have been linked to cost overruns. In this case, the entities, or nodes, are color coded to represent whether they are an external factor, internal factor, or could be either based on the exact circumstances. All connections and nodes in the systemigram are derived mainly from interviews conducted throughout the early stages of our research from experts in the Department of Defense acquisition industry and early research conducted by our team. It is nearly impossible to represent all possible factors that can influence a future cost overrun. Nonetheless, it served a useful tool to make it easier to understand and document our research and findings by helping to identify key nodes that exposed risk factors that ultimately were included in our stochastic model.

ISBN: 97819384962-0-2

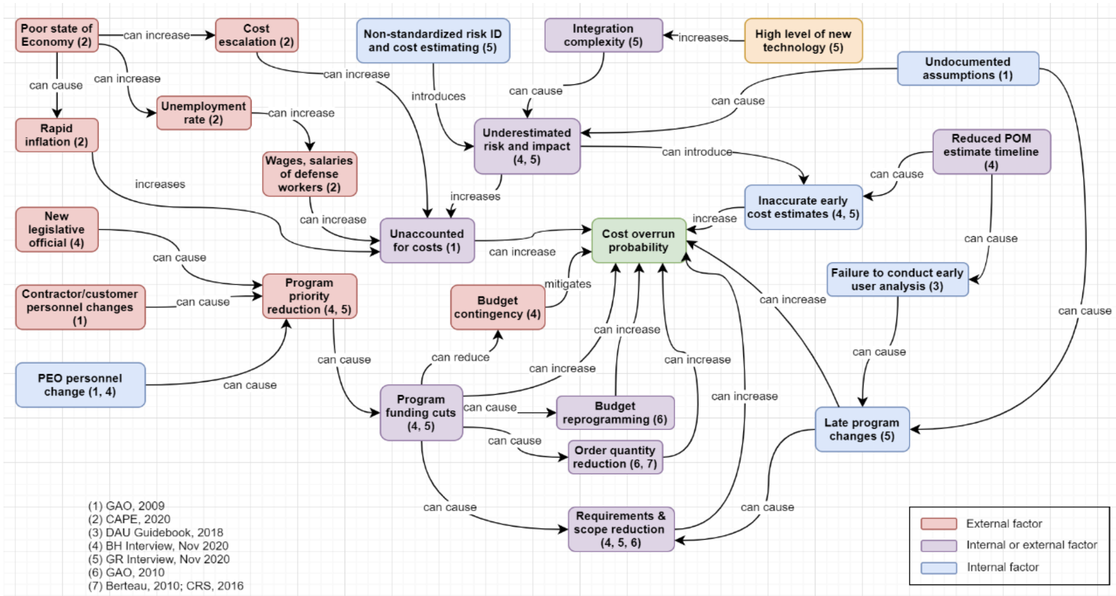

Figure 1. Systemigram Representing Select Dynamic Interactions Influencing Cost Overruns

When risk events or unexpected costs occur, two things can happen: a cost overrun, or a rescoping or changing of requirements of a program. However, these are not mutually exclusive events. If a program must rescope or change requirements at some point during the acquisition process due to factors such as inadequate user feedback, it motivates additional activities by the program office that incur unexpected and unplanned for costs. Moreover, rescoping in this manner reduces system capabilities to that point that Army enthusiasm for the program can wither, threatening it with cancelation.

A similar observed effect of these dynamics occurs when program priorities are altered because of leadership changes at a higher level than the program office. When a new official takes office or priorities get changed, budgets get shifted and moved between programs within the Department of Defense. The problem with this is that a change of budget for a program induces a reprogramming activity seeking to shift funding between programs to where it is perceived to be needed the most, frequently resulting in lesser priority program cancellations to spring loose sufficient funding to buoy critical programs experiencing cost overruns.

3. Risk-Based Contingency Cost Analysis

A program's approved cost estimate should be used to create the program's budget spending plan, which describes how and at what rate the program funding will be spent over time (GAO, 2020). In general, program costs increase dramatically due to three factors: wage and price increases of defense resources, less production orders within programs, and the large technological advances between programs (GAO, 2020). These rising costs have not been adequately captured in budgets as DoD has noticed significant increases in cost overruns (CAPE, 2020). It is worthwhile to briefly examine the ways in which the Army performs cost analysis, and to compare these with industry best practices.

Simulation-based cost estimating also produced notable success in predictive cost modeling. Specifically, Monte Carlo simulation methods have been used in industry work to create accurate models of cost. (Taye, 2019). This leads us to believe that other simulation-based predictive cost models such as bootstrapping could be useful.

The Monte Carlo simulation method is a very direct, flexible, and powerful way to learn about a system by simulating it with random sampling (Bonate, 2001). In this specific study, questionnaire surveys were analyzed by using a Relative Important Index (RII) ranking on factors identified in the survey and significance of data checked by using a t-test at a 95% confidence interval. This model showed that the real cost of most projects increases by up to 10% over its budget and some up to 80% over budget (Taye, 2019). While that conclusion may not be useful in the context of our problem, we may discover that simulation-based modeling may be at least important in identifying key factors that tend to lead to cost overruns.

One dimension pertinent to this project is the process of estimating a risk-based *cost contingency budget* to augment baseline program cost estimates where they are created in the lifecycle of an Army acquisition program.

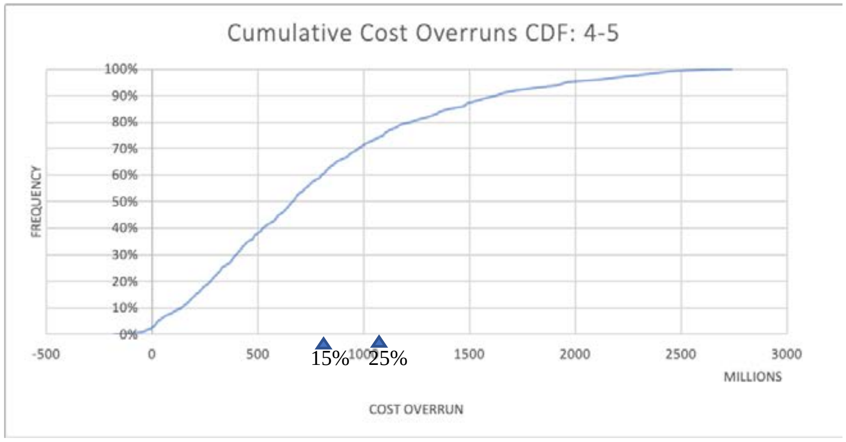

Figure 2: Base Model Cumulative Distribution Function (CDF)

It appears to be universally recognized, though not practiced, that using stochastic simulation is a best practice when estimating risk-based cost contingency budgets (AACE, 2019) for projects of long duration (> 18 months). However, it is common among DoD cost analysts to apply uncertainty distributions directly to WBS cost element without necessarily linking to specific risk events. Without this association, contingency funding becomes a pool of dollars to draw from as overruns occur in a first-come-first-served manner without synchronization with program risk management priorities. In contrast, risk-based contingency budgeting possesses natural linkage to specific risk event associations, thereby offering a degree of protection from priority violating spending. Interestingly, both the Association for the Advancement of Cost Engineering (AACE) and the Project Management Institute (PMI) recommend that risk events include escalation and currency values, recognizing that escalation is not negated by an NPV discount rate and it tends to be more volatile than inflation.

Further complicating this situation, risk events often are correlated with one another in a similar way that WBS-based cost estimates are between cost elements. When such a correlation is not accommodated within modeling and analysis, a cost contingency will underestimate funding. Failing to identify inter-risk or inter-cost element correlation also denies a program office the ability to capitalize on efficient mitigation strategies, that is, implementing single strategies that ripple across risk events or cost elements creating more 'bang for the buck' than independent actions would.

4. Modeling and Analysis

Using an example Army ground missile system, we first identified all DoD and industry risk factors from our previous research that applied to the example missile program. Next, we determined subjective likelihood that the risk event occur and impact that it would have on the cost of the program if it were to occur for each WBS/CES element in the program we studied. We scaled the likelihood and impact on a discrete 1-5 scale (1 being low, 5 being high) to quantify the probability and affect each element had on cost overrun. We incorporated a risk crosswalk to interpret both the overall and average impacts of these elements. This provided us with a quantitative way to compare risk events against each other.

A Monte Carlo Simulation paired with Stochastic effects would allow us to preserve the impacts of individual Risk Events on total cost overrun while also accounting for each of the Risk Event's uncertainties. In our base model, we only included risk events on WBS/CES elements that were deemed to have a medium-high likelihood that they occur and a medium-high impact on the total cost.

Where each of the risk events applied in the WBS/CES structure, we applied a binary statement based on the likelihood we determined for the element regarding the specific risk event. If the statement triggered, the model would calculate 1,000 runs on that Risk Event's impact on the WBS/CES element's cost, creating a distribution of all the model runs. If the statement did not trigger, the model would leave out the impact of that risk event on the WBS/CES element's cost. The total cost of each WBS/CES element therefore is a cumulative effect of each risk event's impact on that specific WBS/CES element. The total cost overrun for the program therefore was calculated as the sum of all WBS/CES element's distributions. The more risk events occurred with any run of the model created a more normal distribution of total cost overrun output. This leads us to believe that risk-based cost contingency planning may be an effective way of planning for the uncertain effects of risk in major Army Acquisition Programs.

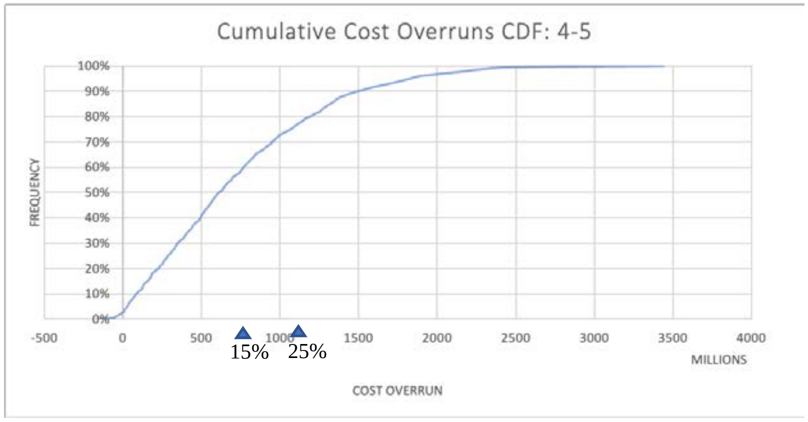

Figure 3: Worst Case Scenario Model Cumulative Distribution Function (CDF)

Figure 2 represents the base model output of 1,000 runs where each run produces a cumulative cost overrun for the entire Army ground missile program. The Nunn-McCurdy breach levels are calculated from the base acquisition program baseline estimate, which becomes the zero point on the horizontal axis. In this way, for each scenario and combination of risk factors, the probability of cost overruns reaching any particular level, including those associated with significant (15%) and critical (25%) Nunn-McCurdy breaches can be assessed. Subsequently each of the policy options can be examined for their implications and effectiveness assuming that known future conditions lead to identifiable risk realizations.

Figure 3 represents our “worst case” scenario model output in which all three environmental factors - the pace of technology development, future military threats, and the state of the economy – significantly influence the likelihood that risk events occur and thus push cost overrun probabilities higher. Where each applied, risk likelihoods automatically adjusted, causing model cost overrun probabilities to change in response for each combination of risk factor runs being explored. Using scenarios to trigger common sets of risks in this manner also explicitly tests important risk event correlations that are typically diagnosed only in hindsight. For the worst-case scenario, 47% of cost overrun results were greater than the significant breach level (15% over APB: $710.5M) and 24% were over a critical breach (25% over APB: $1,184M). The best-case scenario resulted in 43% at or over critical breach and 21% at or over significant breach. These runs included both industry and DoD risk events. Without industry risk factors included, the percentages change to 4% and 1%, respectively, illustrating how failing to include appropriate industry risk events could dramatically understate contingency funding estimates. Moreover, it is not just the number of risk events that matter; it is the pattern of linkage to WBS elements that is critical.

Three budget policy options for requesting contingency funding were analyzed. All options have the intention of shifting the point at which Nunn-McCurdy counting begins. As a first option, Army requests 25% over the APB estimate. This policy would provide a buffer to the critical breach level but might question the management abilities of the program office. Alternatively, Army could adopt the current National Science Foundation contingency budgeting policy (NSF, 2017) in which the first 10% of cost overrun would be absorbed by the PEO internally by cross-leveling funds within a common portfolio. The most attractive option balances funding needs with management responsibility: Army requests 15% contingency funds to cover overruns to the significant breach level leaving the rest for program management. The modeling results, explicitly linked to specific risk events, would provide detailed support to budget requests by highlighting subsets of risk events that rapidly accumulate cost overruns.

5. Conclusion

This project introduced a Monte Carlo based approach linking Army work breakdown structure (WBS) cost estimates to major recurring DoD and industry cost risks to examine the effectiveness of policy options for risk-based cost contingency budget choices. A select number of credible future scenarios were used to trigger risk occurrence during the RDT&E phase of Army system development, resulting in cost overruns that would, without policy intervention or budget buffering, mandate Nunn-McCurdy breach reporting to Congress. However, with an effective budget policy in-place that is based on risk-based cost contingency planning and effective program management, modeling results suggest a potential for insuring programs against cost overruns so easily reaching breach levels while enforcing fiscal responsibility among program managers.

Additionally, incorporating future scenarios into stochastic cost estimating, much like those used for Army capability planning, provides Army acquisition officials with a adaptable means for considering realistic influences on program cost estimates that extend beyond those reflected in similar system historical data. While the modeling excursions used for this work were limited to a representative ground missile system, the process nonetheless appears to offer unique features not currently codified in budget processes. Model output differences between scenarios also suggests that correlation between risk events can be described and analyzed by examining similar effects on model output with varying scenarios. Scenarios that result in statistical findings of no significant differences can be grouped, thereby reducing the number of potential excursions needing exploration by the model.

This project aimed to develop a risk-based stochastic costing model as a proof of concept because of using representative program cost data. However, the risk-based stochastic cost estimating process demonstrated can easily be validated against past programs incurring Nunn-McCurdy breaches if sufficient acquisition program baseline data were available.

Finally, to be successful amidst the continuing dynamics enveloping system development and acquisition, this stochastic risk modeling approach should be updated as more accurate cost data emerges during a program's lifecycle and major external risk drivers shaping the environment become evident. Since the development and acquisition process involves multiple organizations over time, cost analysis can easily become siloed and disjointed, a condition ripe for disagreement on estimates and risk events much like what occurs currently. Rather than relying on analysis handoff between organizations, a means of centralizing program costing in a common repository should be explored so that all appropriate agencies involved with a program – including prime contractors – can provide timely updates to match the dynamic conditions within which a program exists. A risk-based contingency planning process such as this cannot be a one-time event conducted to simply meet a programmatic requirement.

6. References

Association for the Advancement of Cost Engineering (AACE) International. 2019. *Guide to Quantitative Risk Analysis, AACE* Professional Guidance Document 02, RP 68R-11, TCM Framework.

Bonate, Peter. 2001. "A brief introduction to Monte Carlo simulation," *Clinical Pharmacokinetics*, 40, 15-22. 10.2165/00003088-200140010-00002.

Christensen, D.S., J.A. Gordon. 1998. "Does a rubber baseline guarantee cost overruns on defense acquisition contracts?," *Project Management Journal*, Vol 29, 43-51.

Congressional Research Service (CRS). 2016. *The Nunn-McCurdy Act: Background, Analysis, and Issues for Congress*, CRS Report: R41293, Washington, DC. Director, Cost Assessment and Program Evaluation (CAPE). 2020. FY2019 Annual Report on Cost Assessment Activities, U.S. Department of Defense, Washington, DC.

Director, Cost Assessment and Program Evaluation (CAPE). 2020. "FY 2019 Annual Report on Cost Assessment Activities." Department of Defense.

Durdyev, S. 2020. "Review of construction journals on causes of project cost overruns," *Engineering, Construction, and Architectural Management*, Emerald Publishing Ltd, ahead of print, https://doi.org/10.1108/ECAM-02-2020-0137

National Science Foundation (NSF). 2017. *Large Facilities Manual*, Budget, Finance, and Award Management Office, Washington, DC.

Taye, G. 2019. Simulation Modeling of Cost Overrun in Construction Project in Ethiopia. *International Journal of Recent Technology and Engineering* (IJRTE). Vol. 8, Issue 4, 12685-12691.

U.S. Government Accountability Office (GAO). 2020. *Cost Estimating and Assessment Guide*, GAO-20-195G, Washington, DC.

U.S. Department of the Army. 2016. *Planning, Programming, Budgeting, Execution*: AR 1-1, Washington, DC.

Weapon System Acquisition Reform Act (WSARA). 2009. 10 U.S.C. § 101, United States Congress, Washington, DC.

ISBN: 97819384962-0-2