Costing a Ballistic Schedule

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Executive Summary

This paper delves into an imminent solution of Integrated Cost & Schedule Risk Analysis (ICRSA) assessment to address recurring concerns in the DoD involving cost overruns and schedule delays resulting from program practices and schedule dynamics. Development programs face persistent challenges falling victim to strategic misrepresentation and optimism bias, as well as making development investments without sufficient knowledge of risks, costs, and schedules.

Leveraging insights from NASA's Joint Cost & Schedule Confidence Level (JCL) and a DoD program office perspective. This paper advocates for the value of this technique by presenting a case study involving a DoD program, showcasing the lessons learned during the implementation of ICSRA and the subsequent attainment of a JCL. The primary objective is to provide real world insight based on lessons learned, quantitative analysis, and creative problem solving on the efficacy, utility, and power of the ICRSA and JCL.

Problem

The development of modern weapon systems encompasses everything from hypersonic missiles to stealth aircraft to orbiting satellites. The complexity of weapon systems harbors a hidden enemy: cost and schedule delays. As Deshmukh and Collopy (2010) observe, “these intricate weapons, aircraft, ships, and space programs often balloon in cost, exceeding their initial estimates by a staggering 40% or more. This isn't just a budgetary headache; it's a strategic bottleneck, hindering the development of crucial capabilities and leaving defense planners scrambling to bridge the financial gap.”

Eremenko (2009) paints a similar picture in the aerospace industry, where the allure of cutting-edge technology often translates into spiraling costs. The longer schedules and intricate systems inherent in these programs, he argues, acts like a multiplier, inflating the initial price tag by at least 100% by the time the program reaches completion. This cost explosion not only puts a strain on budgets but also diverts resources from vital areas, potentially impacting training, research, and other critical military functions.

Program overruns have long troubled governments and businesses alike. While the reasons are complex, recent research by Love et al. (2011) suggests that factors beyond optimism bias and strategic misrepresentation contribute to cost overruns in social infrastructure programs. Research as cited by Flyvbjerg et al. point to two fundamental reasons: strategic misrepresentation and optimism bias.

Strategic misrepresentation, a term denoting deliberate misrepresentation, characterizes the practice of presenting an overly positive assessment of a program's viability to garner approval. In the face of pressure to demonstrate tangible outcomes, individuals such as politicians and planners often engage in exaggeration of benefits while downplaying associated risks. Conversely, optimism bias presents a more subtle yet equally detrimental challenge. This cognitive bias reflects the human inclination to overestimate the likelihood of success and underestimate potential challenges. Decision-makers, influenced by their own optimistic projections, set timelines and cost estimates that lack a realistic assessment of unforeseen obstacles.

In 2003, the first Weapon Systems Annual Assessment by the Government Accountability Office (GAO) sounded the alarm: programs were dragging their feet in delivering essential capabilities. Back then, concerns revolved around unreliable cost estimates and unproven designs. Fast forward to 2022, and the same issues still hinder many programs (GAO-22- 105230)

In 2008, the report stated programs were taking longer, costing more, and delivering less. In 2015, over half of both research and development programs and procurement programs were overbudget. In the 2023 report, a staggering 58% of Major Defense Acquisition Programs were running behind schedule, as the GAO states: "Over half of the 26 major defense acquisition programs GAO assessed that had yet to deliver operational capability reported new delays." (GAO-23-106059, page 2)

Major Programs have experienced schedule delay to the original baseline to reach Initial Operational Capability. The list of delayed programs includes: Zumwalt-class destroyers, F-35 fighter jets, and KC-46 tanker planes – all lagging months, even years, behind schedule. Some, like the DDG 1000 Zumwalt, are stuck in a time warp, delayed over 14 years compared to their initial plans. See figure 1, as of June 2023 GAO-23-106059)

Figure 1: IOC Program Delays

Program Name	Months Delayed	Years Delayed
DDG 1000 Zumwalt Class	176	14.67
MQ-4C Triton	92	7.67
Next Generation Operational Control System	83	6.92
Integrated Air and Missile Defense	80	6.67
CH-53K King Stallion -1	79	6.58
KC-46A Tanker Modernization	76	6.33
CVN 78 Gerald R. Ford Class	75	6.25
Small Diameter Bomb Increment II	74	6.17
F-35 Lightning II	62	5.17
VC-25B Presidential Aircraft	37	3.08
F-15 Eagle Passive Active Warning Survivability System	37	3.08
Infrared Search and Track	35	2.92
Ship to Shore Connector	34	2.83
T-AO 205 John Lewis Class	31	2.58
Next Generation Jammer Mid-Band	24	2.00
MQ-25 Stingray	23	1.92
HH-60W Jolly Green II	18	1.50
MH-139A Grey Wolf	17	1.42
T-7A Red Hawk	12	1.00
FFG 62 Constellation Class	12	1.00
LGM-35 Sentinel	12	1.00

(Figure 1: GAO-23-106059)

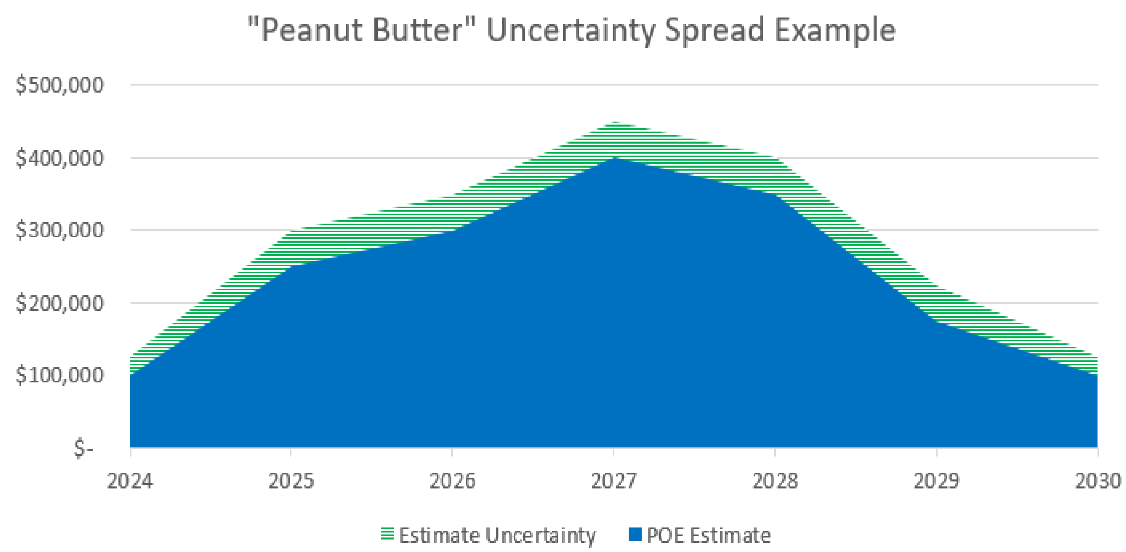
GAO identified that insufficient knowledge before investment decisions is a major factor keeping these programs stalled. Programs jump into expensive development without fully understanding the risks, costs, and timelines. As the GAO puts it, they're "making investment decisions without sufficient knowledge, which can increase the risk of delays," (GAO-23-106059, page 2) setting themselves up for failures.

The U.S. Department of Defense (DoD) faces a persistent challenge: inaccurate cost and schedule estimates for its complex acquisition programs. Programs often fall victim to strategic misrepresentation and optimism bias, assuming smooth sailing without considering potential hurdles. Consequently, initial cost estimates fail to account for potential cost growth, and program timelines prove vulnerable to unforeseen delays, leading to cost overruns and operational disruptions.

This pervasive issue often stems from the lack of Integrated Cost & Schedule Risk Analysis (ICSRA) during early stages of development. Several factors contribute to the absence of robust ICSRA within the DoD. One critical obstacle lies in the incomplete or unreliable nature of the Integrated Master Schedule (IMS). Often plagued by missing logic, unrealistic timelines, and inflexible constraints, the IMS fails to provide a solid foundation for accurate cost projections. Additionally, conducting a complete DCMA 14-point assessment – a rigorous audit of the IMS – can be a resource-intensive and time-consuming process, further discouraging program managers from utilizing ICSRA.

The traditional approach to incorporating schedule uncertainty into cost estimate models involves a tendency to evenly distribute uncertainty funds across the original period of performance—a method informally known as "peanut butter spread." This practice falls short of providing an accurate reflection since it doesn't include the potential for schedule delays.

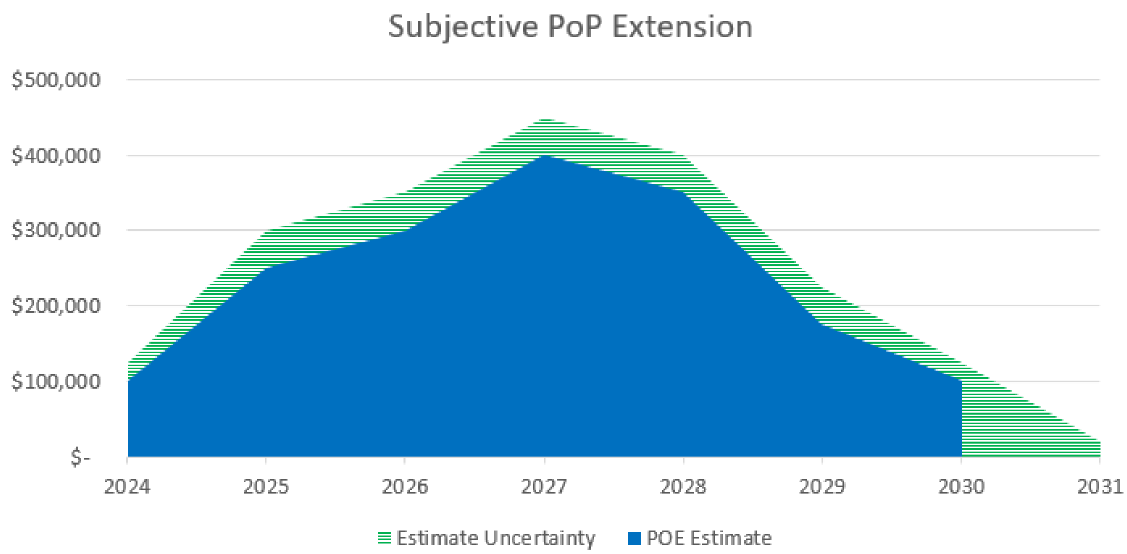
Figure 2: “Peanut Butter” Uncertainty Spead Example



(Figure 2: Simulated Graph, not actual data)

Another common method for incorporating schedule uncertainty in cost estimate models often employs a subjective method that relies on inputs from subject matter experts, who provide assessments of complexity and the likelihood of schedule delays. However, this approach lacks objectivity and introduces a biased and subjective phasing. It also tends to incorporate an extended period of performance.

Figure 3: Subjective PoP Extension



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ICSRA capabilities involve quantitative outputs that present probabilistic schedules and activity durations, as opposed to relying solely on the subjective judgment of a subject matter expert. This approach allows for the quantitative visualization of the impact of schedule growth on cost-dependent activities. In contrast to traditional methods or subjective approaches, an ICSRA, result in higher quality estimates that are more reasonable, realistic, and comprehensive. With ICSRA, funding is more accurately phased into the year of future requirements.

The advantages of ICSRA lie in its ability to produce improved quantitative and realistic results. According to David Hulett, recent evidence suggests that NASA has achieved greater success in meeting cost and schedule targets by implementing JCL assessments, thereby producing more realistic and attainable estimates. However, there are drawbacks, including the agility required for updates and the time-consuming nature of the process. Traditional methods, while easy to model, suffer from inaccurate phasing. However, the subjective approach does generate quick results and leverages subject matter expert (SME) inputs. Yet, it retains significant disadvantages, such as potential SME bias and inaccuracies in phasing.

The GAO found that over the past several years, NASA has made positive changes that have helped contribute to the improved performance of its programs. For example, NASA instituted the Joint Cost & Schedule Confidence Level (JCL) process. This information allows the Congress sufficient information to conduct appropriate oversight and ensure earlier accountability. This will bring more attention to and focus on conducting early, reliable estimates of program costs. (GAO13-276SP)

Solution

Risk and uncertainty analysis is a crucial component to allocate capital for costs and schedule risks. Capital allocation involves distributing financial resources to various aspects of a program, and understanding the potential risks allows for a more informed and strategic distribution. By conducting a risk analysis, program managers can identify and quantify uncertainties and potential disruptions to both cost and schedule. This information becomes instrumental in allocating sufficient capital to address identified risks, ensuring that the program is adequately funded to mitigate and manage these uncertainties. Without a thorough risk analysis, capital allocation decisions may be misguided, leading to inadequate financial provisions for potential risks and, consequently, program failure or delays.

(Conning, 2014) Found that financial crisis, recent frequency of natural catastrophes, and regulatory developments have all put the spotlight on the need for better understanding of risk and risk management. In addition, Conning adds that after the 2008 fiscal crisis it has heightened attention to risk. Companies have discovered they cannot count solely on traditional approaches to navigate operational investment and emerging risk. The attention to risk attribution has not only been important in the private industry but also in federal government programs.

Effective risk analysis also enables a comprehensive understanding of the potential financial impacts associated with program risks. By quantifying the potential costs and schedule implications of identified risks, program managers can make more informed decisions about the allocation of capital. This includes setting aside reserves or contingency funds to address unforeseen events that may impact program timelines or lead to cost overruns. Without a detailed risk analysis, there is a higher likelihood of underestimating the financial impacts of uncertainties, resulting in insufficient capital allocation and potential program disruptions.

Integrated Cost & Schedule Risk Analysis (ICSRA) and Joint Confidence Level (JCL) play interconnected roles each representing a facet of the same process. While used interchangeably, it encapsulates different aspects of the analysis. ICSRA embodies the methodology process, employing loading the schedule with cost applying uncertainties, and identifying potential risks. JCL, on the other hand, serves as the quantifiable outcome of this analysis, a single metric that reflects the program's estimated likelihood of achieving its cost and schedule objectives.

Joint Confidence Level, also known as an Integrated Cost and Schedule Risk Analysis, is a concept used by NASA in program cost and duration estimates, particularly in risk analysis. The Joint Confidence Level represents a statistical measure that combines the uncertainty associated with both cost and schedule estimates in a program. It provides decision-makers with a probability distribution for the joint occurrence of cost and schedule outcomes.

A Joint Confidence Level analysis involves building a cost-loaded schedule model, assigning probabilistic uncertainty distributions to resource costs and activity durations, and incorporating uncertainties and risks associated with resource costs, activity durations, and other relevant factors. These risk activities are defined by their likelihood of occurrence and probabilistic impact distribution on program cost and duration. Monte Carlo simulation is then used to generate program cost and duration values, resulting in a joint probabilistic distribution.

The heart of the JCL analysis lies in the utilization of Monte Carlo simulation. This simulation technique generates a multitude of program cost and duration values by considering the probabilistic nature of the assigned uncertainties and risks. Monte Carlo simulation involves running the program model through numerous iterations (typically ten thousand), each time using random values drawn from the specified probability distributions. The result is a rich dataset representing a spectrum of potential program scenarios. The culmination of this process is a joint probabilistic distribution, providing decision-makers with insights into the range of program cost and duration estimates. The JCL values derived from this distribution serve as key indicators for decision points, facilitating the more informed and realistic approach to program management.

The output of the analysis is a joint probabilistic distribution that represents the likelihood of different combinations of program cost and duration. Decision-makers can then examine specific confidence levels (such as 50%, 70%, etc.) to understand the range of potential program outcomes and make more informed decisions regarding program planning, resource allocation, and risk management.

Understanding the nuanced interplay between impact levels and associated probability distributions is crucial for refining decision-making processes. This emphasis on prioritization stems from the recognition that the distributions significantly influencing a 50% JCL value may differ from those exerting a 70% impact for example. Even though JCL results are insightful and provide better cost estimates there are still certain limitations that hinder decision makers to fully adopt this method.

One primary concern is the lack of meaningful results in terms of the dollar or duration impact, rendering decision-makers with less insight into the risk activities. The complexities involved in capturing and quantifying the diverse array of uncertainties and risks in program management have led to lack of actionable insights. Furthermore, the existing techniques employed in JCL tools are prone to either underestimating or overestimating the impact of specific risks. This discrepancy can lead decision-makers away from a clear and accurate understanding of the potential consequences in terms of program costs and duration.

Addressing these research questions is crucial for advancing the field of JCL analysis and ensuring its efficacy in decision-making processes. Developing a technique that not only prioritizes uncertainties based on their impact but also considers the varying impact levels at different confidence levels is essential for enhancing the utility and accuracy of JCL tools. This research endeavor seeks to refine existing methodologies, offering decision-makers more reliable insights into the intricacies of program uncertainties and risks, and empowering them to make strategic, well-informed decisions.

Application/ Process

In preparation for a critical milestone phase, that sets the program sought to incorporate the JCL process. The unidentified program office initially received a planning schedule from the contractor's proposal that displayed a workable, logical structure, yet it exhibited a notable amount of float. While the schedule's logic was sound, the abundance of float made it challenging to discern the critical path of Integrated Master Schedule (IMS) tasks, especially when attempting to link them to discrete program risks. The presence of excess float introduced ambiguity in identifying task dependencies and understanding their potential impact on the overall schedule. This complexity posed difficulties for the program office in effectively tying program risks to specific tasks and forecasting the potential schedule implications of these risks, i.e., the JCL approach.

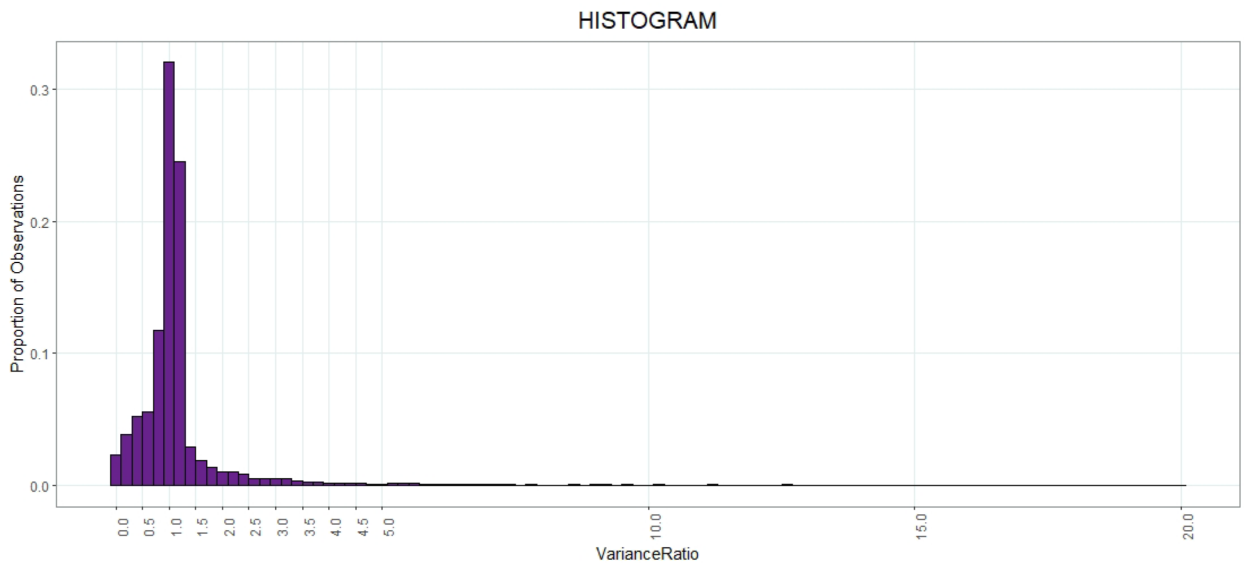
Moreover, the IMS solely incorporated tasks within the contractor's scope, limiting the holistic view of the program. This restricted perspective hindered the program office's ability to comprehensively evaluate the interdependencies between different elements of the program, potentially overlooking critical linkages that could impact the overall schedule with other programs. The need to gain a more inclusive understanding of the program's intricacies became apparent, prompting the program office to explore strategies for incorporating a broader spectrum of tasks and considerations into the IMS.

In addition to the challenges posed by the float and scope limitations, the Joint Analysis of Cost and Schedule (JACS) software tool employed demonstrated functional constraints. While the software was effective in presenting a logical schedule structure, it lacked the agility required for prompt updates whenever the program office estimate (POE) underwent revisions. This lack of responsiveness in the software posed a significant hurdle, given the dynamic nature of program estimates. Consequently, any adjustments to the POE imposed corresponding updates manually to the JACS tool. The time-consuming nature of this process placed a substantial burden on program managers, engineers, and the cost and schedule team, requiring extensive efforts to synchronize program estimates, schedule updates, and uncertainty parameter adjustments effectively.

Months of meticulous work were required, employing established engineering build-up methodologies, robust cost-estimating relationships, and rigorous cross-checks against analogous programs. Each approach presented its own challenges, necessitating careful data analysis, sensitivity testing, and thorough risk identification. Ultimately, the program office delivered a comprehensive and highly defensible estimate.

To quantify schedule uncertainty and inform program planning, the program office conducted a comprehensive Schedule Risk Analysis (SRA) leveraging data from a highly analogous program. This predecessor program provided a rich dataset exceeding 15,000 completed tasks, offering a robust foundation for estimating potential schedule deviations. Utilizing a Variance Ratio metric – the ratio of actual task duration to baseline duration – the team garnered valuable insights into the frequency and magnitude of historical task slippages. These insights were then systematically incorporated into the SRA schedule, meticulously mapped to the analogous program's relevant organizational breakdown structures (OBS) for precise alignment. The resulting probabilistic model, informed by extensive data analysis and rigorous methodological application, yielded a critical finding: the initial program timeline, particularly the proposed end date for the critical milestone phase, exhibited a concerningly low probability of successful completion.

Figure 4: Overall Analogy Performance



(Figure 4: Simulated Graph, not actual data)

Figure 5: Schedule Uncertainty of other analogous programs OBS

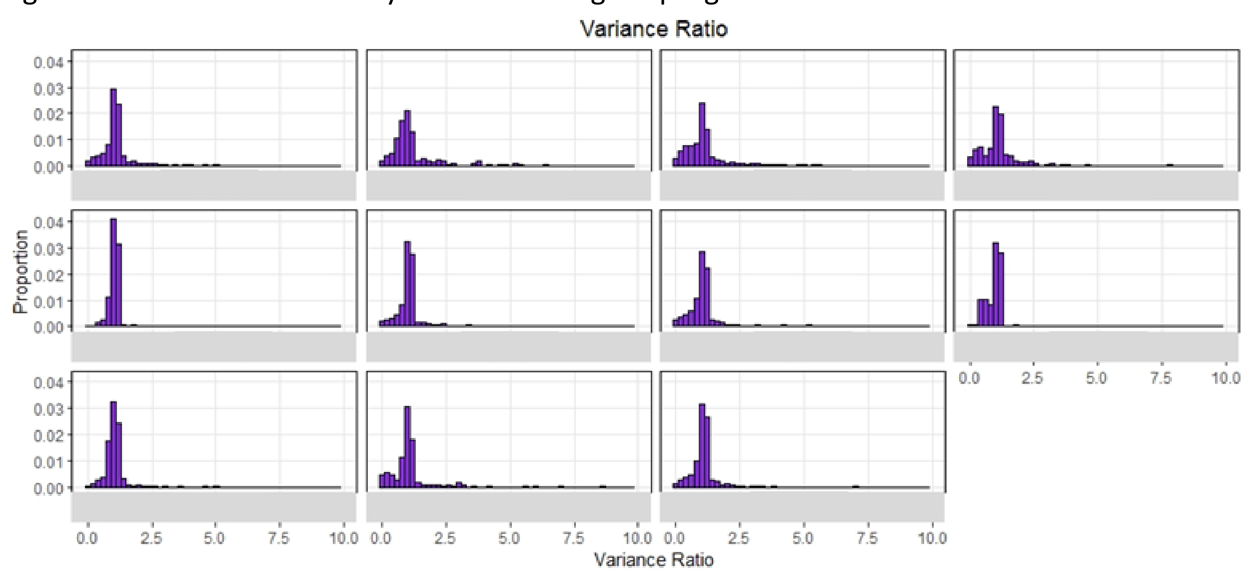


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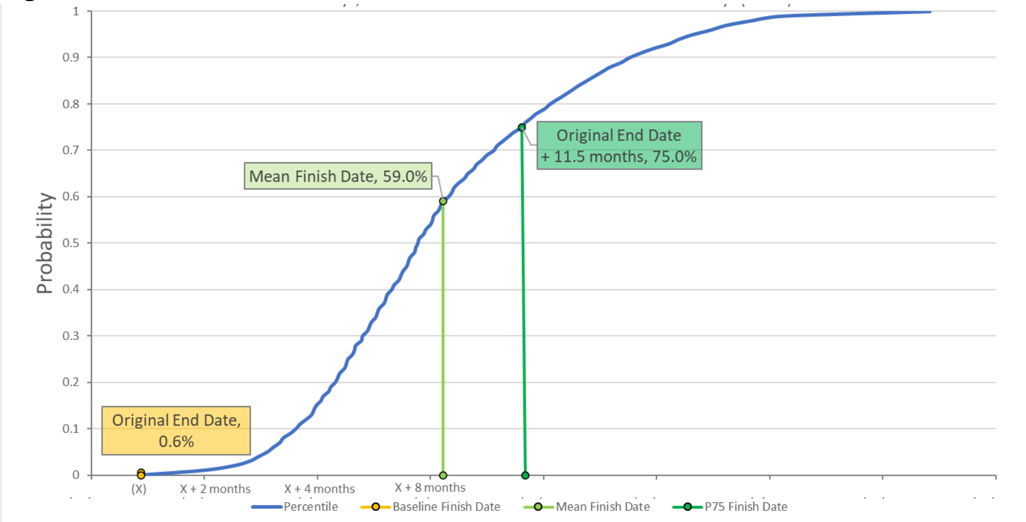
Figure 6: S-Curve



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The first crucial step in mapping cost breakdown structures (WBS) elements to the program schedule was establishing a clear understanding of their temporal relationships. This involved differentiating between time-independent (TI) and time-dependent (TD) costs within each WBS element.

Time-dependent costs are directly influenced by the program's duration. Examples like labor overheads (LOE) tend to accrue steadily over time, with their total cost directly proportional to the hours worked. Conversely, time-independent costs are largely unaffected by the program's timeline. Procurement of materials, for instance, often involves fixed costs regardless of the program's pace.

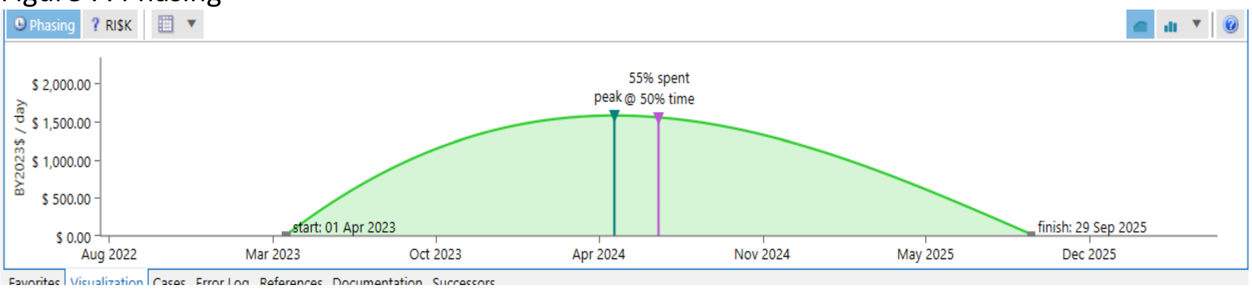
To accurately map costs to the schedule, the program team, including program cost subject matter experts (SMEs) and personnel, meticulously assessed each WBS element. They determined the proportion of each element's total cost that fell into the TI and TD categories. This resulted in a nuanced picture, with some tasks exhibiting a 70/30 or 80/20 split between TI and TD costs, while others displayed a 60/40 or 70/30 distribution.

This granular understanding of the time-dependent nature of costs allowed for a precise alignment with the program schedule. By factoring in the TI and TD components, the team could accurately predict cost accrual over time and identify potential cost risks associated with schedule changes. This detailed mapping served as a vital foundation for effective program cost management and informed decision-making.

To accurately reflect the flow of funding phasing throughout the program lifecycle, the model adopted a phased approach aligned with the cost estimate's outlay. This meant dividing the program into distinct phases, each mirroring the anticipated phasing patterns. The specific phasing scheme leveraged established models like the bell curve, ramp-up, ramp-up/steady state/ramp-down, and front/back loaded options.

The Bell curve, for instance, might be used for programs with a concentrated spending period in the middle, followed by gradual tapering off in both directions. Alternatively, a ramp-up approach might be suitable for programs with initial investment followed by a steady increase in expenditures as activities gain momentum. For programs with distinct phases of activity, the ramp-up/steady state/ramp-down model could be employed, while front/back loaded models cater to situations where the bulk of spending occurs at the beginning or end of the program.

Figure 7: Phasing



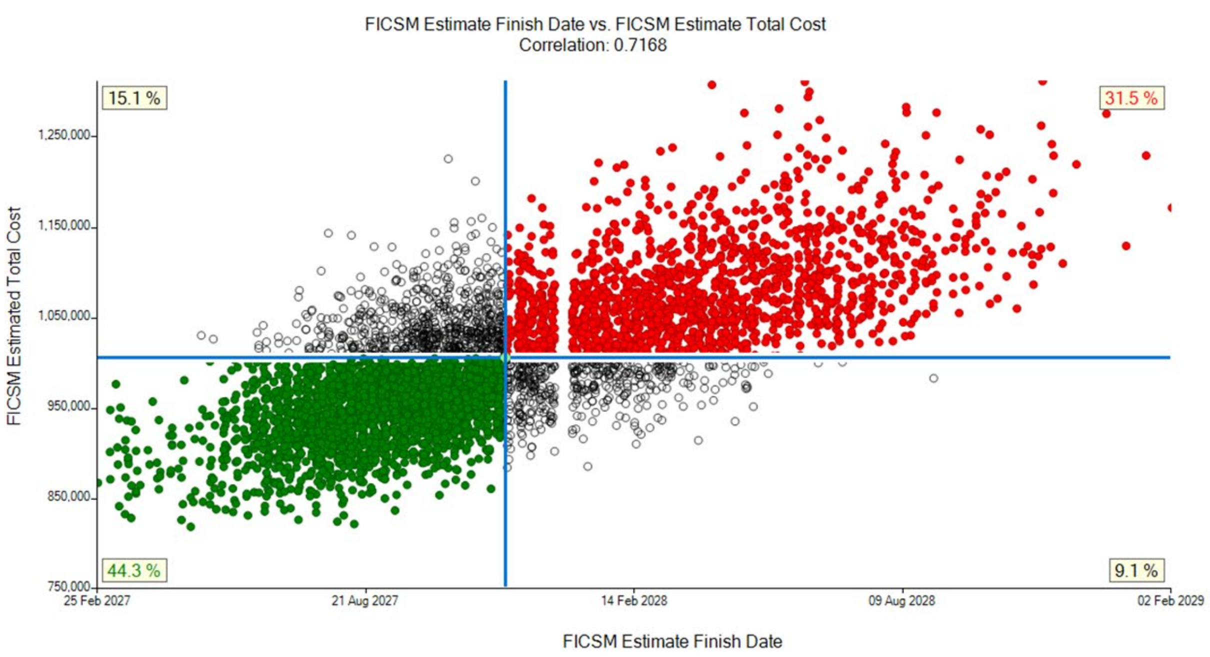
(Figure 7: Simulated Graph, not actual data)

By aligning the model's phases with the anticipated outlay patterns, the team ensured a realistic representation of resource allocation throughout the program. This approach not only facilitated accurate budget planning and forecasting but also provided valuable insights for resource management and risk mitigation strategies.

Full results were obtained through the execution of a Monte Carlo simulation, encompassing the computation of cost and schedule outcomes across ten thousand iterations. For each iteration, a JCL of finish dates and costs were calculated, considering the influence of uncertainties and associated risks. These results were visually presented in a scatter plot, providing a comprehensive overview of the distribution of possible outcomes.

Within the context of the JCL Full Results, the probability of completing EMD by the SRA mean finish date was assessed. Additionally, the mean JCL cost associated with these outcomes was determined. The analysis revealed a joint confidence level of 44.3%, signifying the probability that the program would be completed within the specified time frame and at the calculated cost based on the mean values derived from the Monte Carlo simulation iterations. This comprehensive examination through the Monte Carlo simulation and subsequent analysis contributes to a more nuanced understanding of the program's potential outcomes, accounting for the inherent uncertainties and risks involved.

Figure 8: JCL Full Results

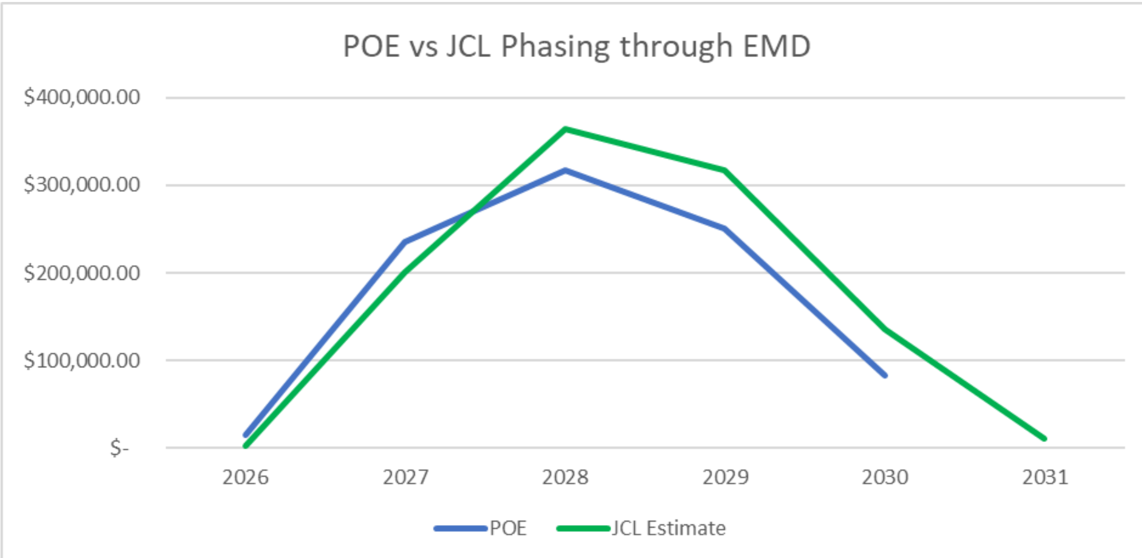


(Figure 8: Simulated Graph, not actual data)

The transition from the baseline schedule to a more realistic schedule was marked by notable shifts in program probabilities and associated costs. The probability of successfully completing contract by the point estimate finish date, coupled with the mean POE cost, demonstrated a confidence level of less than 0.5%. This outcome underscored the challenges and uncertainties associated with adhering to the initial schedule and cost projections.

In contrast, the analysis revealed that the probability of completing EMD aligned with the SRA mean finish date, set at the original end date plus 9 months, and the mean Joint Confidence Level (JCL) cost was at a reasonable confidence level of 44.3%. This adjustment in the schedule and associated cost projections indicated a more realistic assessment, acknowledging the complexities inherent in the program.

Figure 9: POE VS JCL Phasing



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The impact of these findings prompted a decisive program intervention. At the juncture of being two-thirds through the contract proposal process, the government team made the strategic decision to stop the proposal evaluation; and resubmit a bid aligned with the revised schedule. This abrupt change in strategy reflected the program's commitment to align expectations with the newly established, more realistic parameters. This decision highlighted the program's adaptability and proactive approach in responding to evolving circumstances to enhance the program's overall likelihood of success.

Conclusion

The process of integrating cost and schedule risk analysis shifted the emphasis from focusing solely on the outputs of program plans to a more comprehensive consideration of inputs. A key aspect of this improved program planning lies in the strengthened management of risks. Rather than treating risk management as a peripheral consideration, it becomes an integral part of the planning process. This integration contributes to more effective risk identification and mitigation strategies, thereby bolstering the overall resilience of the program.

One of the notable benefits derived from this integrated approach is the improvement in forecasting capabilities. The synergy of cost, schedule, and risk components provides a nuanced understanding of the program's dynamics. This comprehensive insight, in turn, empowers the program team to estimate costs and schedules more accurately, reducing the likelihood of unforeseen challenges disrupting the program's trajectory. Moreover, the integration facilitates early risk identification, allowing the program team to pinpoint potential risks and issues at the nascent stages of the program lifecycle. This early awareness provides a valuable opportunity for proactive intervention and mitigation strategies, mitigating the impact of potential setbacks.

The integrated approach also supports trade space analysis, enabling a thorough examination of alternatives and conducting "what if" drills. This analytical capability offers a strategic advantage in evaluating various scenarios, fostering informed decision-making throughout the program's lifecycle. The result is a dynamic and adaptable planning framework that enhances the program's ability to stay on course and avoid schedule or cost breaches. In essence, this approach transforms program planning into a proactive and strategic tool, ensuring that the program is well-equipped to navigate the complexities inherent in its execution.

The program case study has yielded significant insights that extend beyond the specific program examined, carrying implications for a broader spectrum of DoD programs. The key findings underscore the transformative potential of Integrated Cost & Schedule Risk Analysis and Joint Confidence Level in mitigating the challenges posed by ballistic schedules, offering a path towards enhanced predictability and success in program execution.

JCL shows great promise towards addressing the perennial issues associated with cost and schedule overruns. The case study demonstrates its effectiveness in providing a robust framework for addressing uncertainties, enabling more accurate forecasting, and fostering proactive risk management.

It is imperative that DoD programs recognize and adopt ICRSA & JCL to improve Acquisition Program Baselines. The evidence presented strongly advocates for a shift in the conventional mindset towards a more integrated and risk-informed approach, setting the stage for transformative improvements across DoD initiatives.

In closing, the potential to improve cost estimates of ballistic program schedules into successful endeavors lies within the embrace of JCL. By going beyond the conventional status quo and embracing these methodologies, the DoD can not only navigate the complexities inherent in its programs but also emerge with a new standard of excellence and efficiency. Making these positive changes it will help contribute to improved reliable cost estimates.

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