National Aeronautics and
Space Administration

Presentation Abstracts of the 2023 NASA Cost and Schedule Symposium

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Jet Propulsion Laboratory

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2023 Abstract Collection

The Strategic Investments Division would like to welcome you to the 2023 NASA Cost and Schedule Symposium. This document contains the names of the authors and abstracts for the presentations that will be given this year. In the Symposium Agenda you will notice that there is a unique ID number mapped to each presentation. These same ID numbers can be used, within this document, to find the presentation abstract that you are interested in.

This year, with a cadre of excellent presentations and an awards banquet full of worthy nominations, the NASA Cost and Schedule Symposium will be a full and eventful three days!

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01_ Challenges Aggregating Multiple, Interdependent Projects into a Program Quantitative Schedule Risk Analysis Model

Authors: David Hulett, Ian Bailey, Lorrie Tietze

Presenters: David Hulett, Ian Bailey, Lorrie Tietze

Abstract: Some complex programs are structured so that several projects must interact with each other to produce the final integrated deliverable. The constituent projects have their own project schedules, that may be large and detailed, and are typically assigned to different entities or sites that may be in the same umbrella company or government agency.

- The constituent projects are specialized entities, focusing on design, fabrication of various components, integration and production of multiple units for the ultimate customer.
- They have their own deliverables that are required by other projects in the program. Ultimate delivery of the first product, a major program milestone, is built from the efforts of these interdependent entities.
- Each project within the integrated program has its own level of uncertainty and set of risk events. Due to the interdependencies between projects, a delay experienced by one entity, the "giver" of a product is transmitted to another entity, the "receiver" of that same product. If the receiver does not know about the delay early in their own planning, and that delay is probabilistic, the ultimate first-product delay could be weeks to months.
- There are risk events that affect only one of the specialized entities and others that affect several of the entities. The cumulative effect of a risk event impacting multiple entities could be much larger to the overall program than any individual risk event.
- A risk analysis for any giver entity can forecast a delay in giving the receiver needed input. Often the receiver does not know about the delay early in its own planning, so the entities' conduct of risk analysis need to be coordinated and, ideally, analyzed in the order in which the interdependent activities will be conducted. In addition, that delay is probabilistic and may be a few weeks or several months.
- The receiver entity needs to incorporate the delay in its own planning. The knock-on effects of the giver's delay on the receiver's plans need to be represented somehow so the receiver's output (may be to another receiver such as the fabricating entity) will correctly reflect the delay. Alternative ways to communicate the delayed delivery would be to select a date determined by the giver's risk analysis, say the P-70 date, or a duration of the predecessor's work on the product, or a complete probability distribution of the giver entity's possible dates / durations.
- Broader risks impacting multiple entities need to be incorporated into the overall programs' commitments and funding requirements.

The consequence of such an integrated program on the final delivery to the customer needs to be understood and probably mitigated in some way for a better result. Prioritization of the risks must account for risks that affect one project, multiple projects or the entire program. Risk mitigation should affect risks where it provides the most benefit to the final program's delivery to the client.

The risk analysts need to understand which risks have serious effects on the giver-entity's delivery, but also what is occurring with other entities working in parallel in another sequence. The program-level review deals with parallel vs. sequential entity work resulting in the final product's delivery date. Some risks affect more than one entity so the analysis has to reflect the

distribution of the effects of risks at the program level, which is made up of its constituent parts. Strategies for developing a program-level schedule must take into account the size of the projects' schedule, which have thousands of activities. It may not be feasible to build a single interrelated program-level schedule. Other strategies might include developing top-level projects and represent the projects' deliverables to other projects in a summary fashion. The chosen strategy must take into account the maintenance required to ensure that the program schedule is truly and consistently representative of the work in the individual project schedules.

This paper will explore these questions using small, case-study schedules with giver-receiver logic between project in the program:

- Building individual program entities' schedule risk model
- Linking the output of some projects that are inputs to the work of other projects
- Evaluate the integrated program – alternative strategies
- Prioritization of risks for focused risk mitigation across all entities

03_Propulsion Cost Model Update

Authors: Richard Webb

Presenters: Richard Webb

Abstract: This presentation will provide an update on the status of the Propulsion Cost Model (PCM). PCM is a model for estimating liquid rocket engines, nuclear thermal propulsion systems, and solid rocket motors. It can be used as either an add-on to PCEC or as a standalone model. The model, which is being developed and released in phases, greatly expands the existing CASTS estimating capabilities in these areas. We will present an overview of the entire model, with greater depth provided regarding the newly completed solid motor portion in particular. The development of the CERs for the solid portion have been completed, thus completing CER development for the entire model. Integrating the solid CERs into the PCM spreadsheet models and completion of the solid motor Virtual Black Book (VBB) documentation set are the only tasks remaining prior to full release of the model.

The breadth and depth of the solid motor historical cost database have been greatly expanded beyond that included in the original CASTS data set. The depth has been expanded from 18 to 55 historical data points for Flight Unit costs, including additional data points received through a data sharing agreement with the Missile Defense Agency and other REDSTAR sources. With the addition of the new data points, the breadth has been expanded such that the database, formerly comprised of large-diameter solid motor Booster data only in CASTS, has been segregated into 5 categories depending upon the SRM usage and size, including: Boosters, Stages, Upper Stages, Kick Motors, and Sounding Rockets. In addition, the nature of the expanded data set necessitated a change in the primary independent variable from Total Impulse to Gross Weight to better accommodate the wider range of sizes and uses of the motors in the database.
The unrestricted version of the CERs developed for each of the 5 categories will be presented as well as examples of the VBB information to be made available both to the general public (unrestricted) and redacted examples of restricted cost data available to authorized users.

04_Complexity the Right Way

Authors: Andy Prince

Presenters: Andy Prince

Abstract: Over the past several years I have engaged in a (hopefully) good natured discussion with several of my peers over the proper use of complexity factors in cost estimating relationships (CERs). While I still stand by contention that complexity factors should not be used as a parameter in a CER, I theorize that using complexity factors to adjust the output of a CER is a reasonable and sound approach to better cost estimates.
(By the way, this is how cost estimating was often done back in the days of weight-based and other single variable CERs, this method is not new, but possibly has been forgotten)
In my presentation I will share my results from developing and testing complexity factors based on a simple CER and the underlying data. The CER is developed using log-transformed least squares. The CER forms the basis for both developing and testing the complexity factors. Statistics such as r-squared, root mean squared deviation, and mean absolute error are calculated. Use of simulation and cross-validation are explored as ways to test the efficacy of the complexity factors.

05_ MBSE Cost Study

Authors: Brook Cavell, Kirsten Lam

Presenters: Brook Cavell, Kirsten Lam

Abstract: In order to understand the costing and timing nature of Model Based System Engineering (MBSE), The Aerospace Corporation executed a study to cover the following facets of MBSE impact on an acquisition:

- What is the initial cost for setting up MBSE themed support for a project/program?
- What are the over time costs for MBSE for configuration management and curation of the models?
- What key MBSE factors and quantifiers should the government program office consider when reviewing a proposal?
- What are possible +/-/ugly features of MBSE versus traditional system engineering methods?
- What is the LCCE for implementing MBSE?

The objective of the effort was to study the cost estimation of MBSE by gathering information to support key qualifiers/quantifiers to assess costs, ask the questions, and investigate cost drivers derived from the literature review and root cause analysis of the problems including inputs from MBSE experts. This presentation highlights the results of the study and provides preliminary answers to these questions.

06_ An Independent Schedule Risk Assessment (iSRA) – Utilizing Existing Objective Data and Subjective Applied Expertise for a Quantitative, Comprehensive and Credible Schedule Risk Assessment

Authors: Charles Delio, Daniel Donaldson, Matthew Gonzales, Vladimir Karavodin, James Quilliam

Presenters: Charles Delio, Daniel Donaldson, Matthew Gonzales, Vladimir Karavodin, James Quilliam

Abstract: This case study is an effort to document and share with practitioners the results of an independent schedule risk assessment process. This process utilizes both

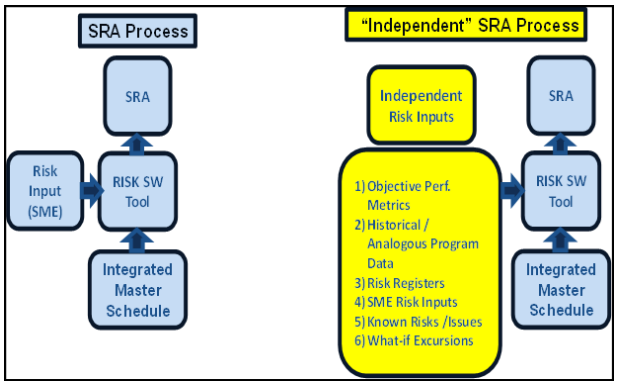
objective and subjective assessment areas for comprehensive, quantitative, and credible SRA results for decision makers.

This case study will provide an in-depth explanation of the principal objective and subjective assessment criteria of the process. The elements of this process will focus first on three (3) primary objective assessment criteria of performance metrics, program risk/s, and historical (analogous) program data. The second part of the comprehensive process will focus on three (3) primary subjective assessment criteria of subject matter expert (SME) risk ratings, known risk issues (not yet formulated) and possible what-if excursions (What-if scenarios).

The results of implementing a comprehensive objective and subjective based process utilizing these six (6) data criteria should greatly enhance the understanding and confidence that leadership and project teams have in the results of this independent comprehensive schedule risk assessment. It will also assure that sound decisions are being made based on the reliance of these crucial schedule risk assessment criteria. This study also establishes a foundation for future research into schedule risk assessment tool results, accuracy and capabilities.

When completed, the attendee will be able to:

1. Comprehend the differing aspects of an independent schedule risk assessment process and the application of this tool as lessons learned for practitioners.
2. Analyze the value of applying the six (6) principal objective and subjective assessment criteria of the independent schedule risk assessment analysis tool.
3. Synthesize the benefits of understanding and utilizing the comprehensive objective and subjective based process versus traditional schedule risk assessment practices and procedures for sound decision making and accurate and reliable schedule risk assessment results**.**



07_ Enhanced Tornado Sensitivity Analysis Process (ETSAP): Prioritizing & Taking Action on the Critical Program Inputs with the Highest Impact on Program Completion

Authors: James D. Quilliam

Presenters: James D. Quilliam

Abstract: This case study is an effort to document and share with practitioners the enhanced tornado sensitivity analysis (ETSAP) process. This process utilizes a comprehensive five (5) step process during a schedule risk assessment to prioritize and provide the critical

program inputs for decision makers to take management action on tasks with the highest impact on program completion.

This will provide an in-depth explanation of the principal assessment criteria of this novel process for practitioners. In order to fully comprehend this process, the case study will focus first on the output charts of a traditional schedule risk assessment. Next, tornado sensitivity attributes with be reviewed along with the importance of utilizing the population of all available tornado sensitivity options. A comparison will be provided on the traditional vs. the enhanced tornado sensitivity process culminating with the ability to extract primary and secondary risks. Once this is accomplished, the enhanced tornado sensitivity analysis process flow will be covered in detail. This will allow for a complete understanding of the process steps. The enhanced tornado sensitivity analysis approach for prioritizing the top risk inputs will then be shared. A detailed representation of the five process steps will be outlined culminating with a summarized overview of the comprehensive process. From this one-page summary comes the listing of the harvested top primary and secondary risk inputs culled from the assessed tornado results as part of the schedule risk assessment simulations.

The results of implementing this comprehensive tornado assessment process utilizing the five (5) step criteria should greatly enhance the understanding and confidence of leadership and project teams. This will allow them to focus on the critical risk inputs that are crucial to the successful completion of their programs. It will also assure that sound decisions are being made based on the reliance of these crucial schedule risk assessment drivers. These primary and secondary level tasks from the tornado sensitivity report are significant since they are most likely to cause a delay to project completion and/or provide an opportunity to reduce the remaining duration of the project. The benefits of this enhanced analysis to uncover these important risk drivers far outweigh the added minimal processing time at the end of a simulation. The enhanced tornado sensitivity analysis provides a listing of the tasks requiring increased management attention and for providing meaningful information when making decisions about which tasks to mitigate in an effort to improve project completion dates. This study also establishes a foundation for future research into schedule risk assessment tool results and insuring data use and credibility.

When completed, the attendee will be able to:

- Comprehend the differing aspects of the enhanced tornado sensitivity analysis (ETSAP) process and the application of this tool as lessons learned for practitioners.
- Analyze the value of applying the five (5) step process during a schedule risk assessment to prioritize the critical program inputs for decision makers in order to take management action on tasks with the highest impact on program completion.
- Synthesize the benefits that the enhanced tornado sensitivity analysis provides in listing the tasks requiring increased management attention and for providing meaningful information when making decisions about improving project completion dates while establishing a foundation for future research into schedule risk assessment tool results**.**

09_ Getting More out of the MS Project IMS

Authors: William Paradis

Presenters: William Paradis

Abstract: Have you ever considered the price paid to construct and maintain an Integrated Master Schedule or IMS? On any given flight project here at NASA, there is one or more Planner/Schedulers who work full time maintaining the IMS over the course of the project? A lot of work goes into the IMS and there is a lot that comes out and providing an early warning system to the project of future project schedule impacts is probably the biggest thing. It is a great tool, it's like an anti-acid tablet helping to relieve heartburn caused by the alternative of not planning. What else can we get out of the MS Project file or how do we get more? The earned value folks frequently come up with new ways to get the schedulers to get more for them making life easier for the earned value analyst but what can schedulers do to get more out of the IMS to make life easier for themselves and the projects they support? I see schedule products get developed as standalone products, hand drawn charts. I see project personnel combing through MS Excel snapshots of the IMS to create one time use charts for upcoming reviews; and many times, I do not think they have to. So, what products or data can be extracted right out of the IMS that would help save time for others on the project to help simplify things? Folks who mine data for schedule, hand draw charts, or develop standalone schedules can benefit from things extracted from the IMS and do not even know it? How can schedulers get more out of the MS Project and be of more help to the project? So many things get tracked and analyzed in parallel that if we put our minds to it; we can become a more value-added resources to the project and to NASA by more fully using the MS Project file. I've prepared a presentation to share some ideas and examples to enlighten schedulers of how to get more out of the MS Project file then they have before and would like to share it with the schedule community; the things I will share in this presentation has proved beneficial to me and my projects and I hope it does the same for you; I hope to see you there.

10_ The Changing Role of NASA Cost Analysis

Authors: John Dotson

Presenters: John Dotson

Abstract: Kennedy Space Center (KSC) has undergone significant changes with the advent of commercial space providers. With the rise of private companies vying for a share of the space market, KSC has been forced to adapt and find ways to remain competitive. One of the key challenges facing KSC today is a reduced budget and a corresponding need to do more with less money.

One approach KSC has taken to address these challenges is to embrace a more cost-effective and efficient business model. This has involved exploring new technologies and processes known as Affordability, such as automation and digitalization, to reduce the time and resources required for operations. Additionally, KSC has sought to form partnerships with private companies and other organizations to share resources, knowledge, and expertise.

Overall, the changes that have come with the addition of commercial space providers have

been significant and challenging for KSC. However, the center has been proactive in addressing these challenges and remains committed to exploring new technologies and processes to maintain its position as a leader in space exploration and technology. By trying embracing a more cost-effective and efficient business model and developing new spacecraft and launch vehicles, KSC is working to ensure its continued success in an increasingly competitive marketplace but may prove to be too little too late.

11_EVM Year in Review

Authors: Jon Fleming, Kristen Kehrer

Presenters: Jon Fleming, Kristen Kehrer

Abstract: The *EVM Year in Review* highlights some of the great accomplishments and progress by the Agency Team and EVM practitioners across NASA's diverse portfolio of programs and projects. An overview of the support and products provided by OCFO-SID, the stewards of the EVM Discipline, will be discussed along with several efforts such as: EVMS Surveillance, NASA-led EVMS Compliance Review, Integrated Baseline Review Improvement Initiative, Agency's EVM Software, Integrated Program Management Data Analysis and Report (IPMDAR) Rollout, and more! Please visit nasa.gov/evm for more information.

12_ CADRe: Year in Review

Authors: Eric Plumer

Presenters: Eric Plumer

Abstract: The Cost Analysis Data Requirement (CADRe) is a formal project document that describes the programmatic, technical, and life-cycle cost, schedule, and risk information of a project. CADRe is NASA's unique response to improve cost and schedule estimates during the formulation process, providing a common description of a project at a given point in time. By capturing key technical and programmatic information, the CADRe tracks and explains changes that occur from one milestone to the next. Completed CADRes are available on the One NASA Cost Engineering Database (ONCE) database, a secure, web-based application which allows for easy retrieval and fast analysis of CADRe data across multiple projects and milestone events. Utilization of CADRe data supports analysis of important project attributes and enables project managers to develop improved cost and schedule estimates. Additionally, CADRe documents provide a wealth of project data that enables countless types of analysis to support data driven decision processes. This presentation will provide an overview of CADRe and describe recent CADRe accomplishments and planned future enhancements.

15_ Minding your P's and Q's: Escalation in the NNSA

Authors: Mike Metcalf, Alan Karickhoff, Brian Flynn, Omar Akbik, Ray Vera

Presenters: Mike Metcalf, Alan Karickhoff, Brian Flynn, Omar Akbik, Ray Vera

Abstract: Inflation ran at its highest levels in decades through 2021 and 2022 in the U.S. and abroad. The U.S. dollar in 2022 was worth about 73 cents compared to ten years earlier, or 73

cents of buying power in the marketplace. The same situation of diminished value holds for a government budget, a salary, a pension, a dividend, or a company's cash balances. Many firms and government organizations are attempting to develop custom escalation indices for labor, material, and construction in the face of high inflation. But questions remain as to the consistency of any such indices with local labor-market conditions, their technical quality and accuracy, the scope of their coverage, and the degree to which self-fulfilling prophecies are at play.

The authors ventured to understand the National Nuclear Security Administration's (NNSA's) unique labor and material environment and its relationship to the broader inflationary market. We established a view of escalation history for the labor and materials markets in which the NNSA participates, focusing on nuclear construction, non-nuclear construction, and weapons programs. We then used the broader financial market to build probability distributions of inflation rate forecasts, using financial instruments actively traded on Wall Street, such as Treasurys and inflation derivatives. As economists note, focus sharpens and credibility rises when prices are set by market agents that bear financial risk, such as pension, insurance, and hedge-fund managers. By combining market projections with NNSA's recent history, we built unique composite escalation indices and probability distributions for each NNSA Site and each category of program, suitable for use in cost estimates, AoAs, budget estimates and other estimates where contractual rates have not been established.

16_ How Effective are NASA's Collaborations with the Industry?

Authors: Moon Kim

Presenters: Moon Kim

Abstract: In line with the national policies for fostering a robust commercial space industry, NASA's modern day acquisition strategy involves more collaborations with the industry. In forms of public-private partnerships and commercial developments, industry collaborations have gained both internal and external support and will continue to be a major part of the Agency's strategy. As an effort to assess the effectiveness of NASA's collaborations, this study developed a set of measures of effectiveness (MOEs) that encompass cost-savings, access to capability, and market development. Using the MOEs, the study analyzed 16 space flight programs of various collaboration types using a mixed-methods approach. Based on the MOEs, the study found a varied collection of effective, partially effective, and ineffective outcomes. Furthermore, in the assessment process, the study found several topics of importance the Agency could consider for future collaborations. The study initiates a critical discussion of performance metrics in the absence of a formal Agency process to assess the effectiveness of the emerging procurement arrangement types.

17_ What's a metric got to do to be useful 'round here?: A SCaN Schedule Case Study

Authors: Kailey Melton, David Payne

Presenters: Kailey Melton, David Payne

Abstract: To be worth their salt, metrics need to provide actionable insights to decision-makers. Metrics also are like lunch; they are never free - they impose burdens, and the benefit needs to be worth the cost. And for better and worse, Heisenberg's lessons on observers applies to schedules as the choice of measurements alters the thing measured. Over the past year, the loosely-coupled SCaN Program has revamped its schedule metrics approach with lessons learned and a smorgasbord of analogies and metaphors to share.

18_ The Schedule Deep Dive – An IBR Head Start?

Authors: Christopher Sadler, Melissa Lee

Presenters: Christopher Sadler, Melissa Lee

Abstract: Miriam-Websters dictionary defines the Deep Dive as “an exhaustive investigation, study, or analysis of a question or topic.” Industry defines the Schedule Deep Dive (SDD) as “a schedule analysis that identifies anomalies, facts and issues that can happen throughout the process of the project due to both intentional or unintentional actions. This is used to verify compliance with the client's contract specification, overall schedule coherence and logical sequence between activities.” SDDs are used across the NASA agency at various times; however, many projects across the agency are not using this process as a pre-cursor to the Integrated Baseline Review (IBR).

The IBR is a risk-based review conducted to ensure a mutual understanding between the customer and supplier of the inherent risks in the supplier’s Performance Measurement Baseline (PMB). A secondary, but equally important purpose, is to ensure the PMB is realistic for accomplishing all the authorized work within the authorized schedule and budget across the five risk areas of technical, cost, schedule, resources, and management processes. The SDD process can give projects a head start on the IBR by revealing valuable points of focus to assist in gaining the mutual understanding between customer and supplier.

This session will provide background information on SDDs, the process of conducting of an SDD, and uncover the benefits of conducting a deep dive before the IBR. Our goal is to introduce Schedule Deep Dives as a best practice prior to IBRs.

19_ PCEC Robotic Missions – Challenges Getting Data and Statistics to Cooperate

Authors: Shawn Hayes, Mark Jacobs, Brian Alford

Presenters: Shawn Hayes, Mark Jacobs

Abstract: Since the release of PCEC v2.3, many new projects have been added to the PCEC Robotic Mission Database. During the application of the PCEC normalization process to the new project data, several challenges arose, such as; capturing of COVID impacts, appropriate splitting of the different flight elements of Mars landed missions, and limitations associated with Firm Fixed Price (FFP) contracts. While deriving updated CERs, it was observed that CER performance is not as good for flagship missions and some of the high-end outliers which had complex payloads that were

not well-represented by CER input candidates. Multiple alternative approaches have been explored including Classification and Regression Tree (CART) analysis, payload accommodations Figures of Merit (FoM), and category specific CERs.

New missions added to the database include; SMAP/JPSS-1/GOES-T (Earth Sciences), Solar Probe (Helio-Physics), TESS/IXPE/JWST (Astrophysics), and Mars 2020/DART/Lucy (Planetary). Collectively, these new missions cover a broad range of mission types. All missions in development after March 2020 experienced some impact from COVID. Normalization efforts are wrestling with the question - Is this the new normal?

The Mars landed missions (MER/MSL/Mars 2020) have multiple flight elements (Cruise Stage, Entry/Descent/Landing, and Lander/Rover) that were not clearly separated during development. Methods to allocate costs to each element have been over-simplistic (mass-based). Analysis of the data indicates a mass-based approach over-estimates the Cruise Stage and EDL and under-estimates the Lander/Rover.

Multiple alternative methods are being explored. These include CART analysis, FoMs for Payload Accommodations, and Category Specific CERs. CART analysis may make it possible to include larger directed missions, which were outliers in the PCEC v2.3 CERs, providing more inclusive CERs. The lower-cost end of the mission spectrum may also see improvements.

PCEC inputs characterizing the payload are limited. Payload mass and power are input candidates for System I&T, but mass and power do not seem to accurately affect payload complexities that affect System I&T. Other options to characterize the payload complexity are being explored. Metrics under consideration for a Payload accommodation FoM include mass, power, physical volume, thermal requirements, data rates, and pointing requirements. FoMs can be included as input candidates for the PCEC CER process to test their merit.

Multiple category specific CERs are being explored. Categories include Directed or AO Mission, Flagship-specific, or by SMD directorate (Planetary/Helio-Physics/Earth Sciences/Astrophysics).

As the normalized data is studied while developing PCEC CERs, weaknesses from data limitations can arise. PCEC data collection and normalization efforts have been continually refined to incorporate lessons-learned from CER development. These challenges that have been encountered as work progresses towards the next release of PCEC will be discussed.

20_ HLS Joint Confidence Level Analysis Approach

Authors: Brian Alford

Presenters: Brian Alford

Abstract: The Human Landing System Program acquisition approach uses Firm Fixed Price (FFP) contracts for the development and demonstration of an initial HLS system for the first Artemis crewed flight demonstration to the lunar surface. A Joint Confidence Level (JCL) analysis is typically one of the key inputs to the Key Decision Point -C (KDP-C) Agency Baseline Commitment (ABC) decision, however, traditional JCL analyses at NASA have not involved commercial programs with Firm Fixed

Price contracts. This presentation will look at the HLS FFP services approach and how the major differences from a traditional JCL are factored into modeling cost and schedule growth. Future work to improve modeling will also be discussed.

23_ Preventing Increased Cost with Sound IGCEs

Authors: John Moore, Erin Roberts

Presenters: John Moore, Erin Roberts

Abstract: To inform the Cost Estimating Community on current policy as to when IGCEs are formally required. This session will identify and discuss the background areas of Federal Acquisition Regulations (FAR) driving the need for development and use of sound IGCEs as well as lessons learned from weak IGCE development and/or documentation. Sound IGCEs serve the procurement process from planning to award. Best practices for determining and developing adequate level of detail, documentation style, as well as when and how interactions between cost estimator and procurement personnel is best timed will be discussed. There can be significant, complex differences in estimating techniques between Program hardware buys and Institutional services. But if the different estimating techniques are applied and documented effectively, either method can result in the development of sound IGCEs. Benefits of a clearly stated and documented IGCE result in successful procurement reviews, timelines, and ultimately set the program up for effective performance.

25_ You Get What You Pay For: The New Frontiers Operations Cost Cap

Authors: Ben Clare, Kathy Kha, Rachel Sholder

Presenters: Ben Clare, Kathy Kha

Abstract: As budgets get tighter, NASA is increasingly looking at different ways to control costs. In the latest draft Announcement of Opportunity for New Frontiers 5, a cost cap is being implemented for Phase E and F. Capped at $300M FY22$, this seemingly limits both the destination and type of mission that will be possible. But exactly how limiting is it? In this presentation, we will go back and examine the Phase E costs of previous Discovery and New Frontiers missions and how well they would have fared with a $300M FY22$ cost cap to see what seems feasible for $300M FY22$.

26_ NICM 10: The 2023 Release of the NASA Instrument Cost Mode

Authors: Joe Mrozinski, Luther Beegle, Kyle Brown, Robert Cesarone, Michael DiNicola, Samuel Fleischer, Michael Fong, Melissa Hooke, Alfred Nash, Sherry Stukes, Marc Walch

Presenters: Joe Mrozinski

Abstract: The newly released NASA Instrument Cost Model (NICM 10) will be introduced and demonstrated. NICM 10 includes 36 instrument cost and schedule estimating relationships, including 6 new models. The demonstration will focus on many of the upgraded capabilities including: 1) the new repeatable, analytic cost estimating solutions in both the System and

Subsystem Tools, 2) the new isoquants displays in the JCL plots, 3) the improved Bayesian imputation method with boundary conditions, 4) K Nearest Neighbors weighted average estimating capability added to the NICM Search Engine Outputs along with new summary data 5) Expanded Search Engine capabilities, and more!

28_ Assessing Program Level Objectives of Human Mars Missions Using Portfolio Optimization Methods

Authors: Bill O'Neill

Presenters: Bill O'Neill

Abstract: The large number and significant variety of systems available for space exploration missions produce countless potential architecture combinations. Compounding this are the scheduling intricacies of system lifecycle phases, time dependent operational dependencies, as well as the uncertainty associated with each technology in terms of cost, schedule, and performance. Traditional space mission architecting emphasizes the individual design of component systems over the wide-ranging and robust assessment of architecture options early in mission design. A top-down method that can assess the capabilities, requirements, and risks associated with the diversity of available space systems and select optimal portfolios of interdependent systems based on stakeholder objectives is necessary. Our work describes and demonstrates a portfolio optimization technique that can design and assess Mars exploration architectures by optimizing on programmatic objectives such as cost, performance, schedule, and robustness while simultaneously accounting for system operational interdependencies and schedule dependencies of the selected systems. This adaptation of portfolio optimization is further differentiated by including system sizing relationships within the architecture as well as accounting for technological dependencies of undeveloped systems.

The horizon goal of NASA's human space exploration initiative is a landed crew mission to the Martian surface. Further, private companies are developing their own vehicles and mission objectives for cis-lunar activities. While a bespoke architecture could be designed to accomplish mission objectives, it would be advantageous to integrate a portfolio of existing and future systems that satisfies overarching objectives, minimizes both development cost and schedule, reduces risk through flight tested hardware, and encourages commercial and international involvement. An abundance of potential systems exist or are in near term developmental stages that could compose an optimal architecture. Capitalizing on these systems and technologies while balancing the complexity of integration will be challenging but could be rewarding to stakeholders.

The questions that remain are which systems to select, when to develop, produce and operate them, and how they interact. Given the large number of potential choices for various systems and the differences in capabilities, cost, schedule and robustness of each, the resulting combinatorial problem becomes difficult to evaluate in terms of overall architecture cost, performance, schedule and robustness. Compounding this is the scheduling dependencies that exist between systems, the cost of Design Development Test and Evaluation (DDT&E) of new technologies, and the impact of an annual budget on system selection. The

enhanced version of Robust Portfolio Optimization demonstrated in this presentation and paper offers a potential solution to these problems. This optimization forms a framework of combining various tools in the form of a modified version of NASA's Advanced Missions Cost Model (Cost and Schedule), various domain specific estimators, technology sizing tools, and existing published data.

29_ Test Facility Request System (TFRS) Augmentations: Integration and Automation of Facilities Scheduling and Workforce Planning for All of Glenn Research Center's Aero and Space Testing Capabilities

Authors: Dennis Bowers, Alan Sikon, Joseph Panek, Michael Zernic

Presenters: Dennis Bowers, Alan Sikon, Joseph Panek, Michael Zernic

Abstract: The Test Facility Request System was originally developed to provide annual test services forecasting for the utilization of all of GRC's aero and space test capabilities which are grouped into 10 different Capability Asset Groups. Each Capability Asset Group covers a distinct test area. (e.g. Aero Acoustics, In Space Propulsion and Power, Fuel Cells, Aero Sciences, etc.). Currently, test requestors provide basic parameters to allow facility managers, in conjunction with engineering and technical staff managers, to develop high-level schedules and estimates of staffing levels. Once all parties approve the labor levels and schedule for hundreds of tests per year, the data remains static for the remainder of the fiscal year.

Since the current system is static in nature, it limits the managers' capability to keep up with changing testing requirements. Integrating monthly labor estimates into the schedule would provide a higher level of fidelity to manage staff. This would allow managers to forecast future labor utilization across the testing facilities and provide data for staff leveling. If the staff could be tracked by skill, the proper discipline could be assigned when required. These capabilities would deliver higher efficiency.

Managers had previously created Excel planning tools that were designed for their own unique purposes. Leveraging on the concepts of those tools, we are creating a standardized yet tailorable solution that will automate and streamline the process of integrating staffing and schedule. Tailoring will allow each manager to enter the appropriate amount of information based on the complexity of the test. Automation will reduce labor, improve schedule consistency, and eliminate errors in transferring data. A labor and schedule dashboard provides a simple way to monitor labor and schedule trends. The captured data can be utilized to enhance future test planning for all of Glenn Research Center's aero and space testing capabilities, grouped into 10 different Capability Asset Groups (CAGs).

Using standard tools, MS Project, and Excel with their capability to run macros, standard templates are being created to implement the solution. Initial estimates for labor and schedules are created in Excel. Macros create a standard MS Project file with estimated labor, per project subtask. MS Project schedules will be updated monthly by the respective facility managers, while labor will be updated monthly

by the engineering and technical managers in Excel. Macros will be run to update the labor data in MS Project. This information will then be collected within an online database. The database will source information to the labor and schedule dashboard.

This presentation will discuss the current state of the project and snapshots of the various tools.

30_ Wait, What? How Competed Missions Might Be Experiencing More Cost Growth than Directed Missions

Authors: Rachel Sholder

Presenters: Rachel Sholder

Abstract: In a follow-up to last year's runaway hit presentation *Math is Hard,* in this analysis, we dive deeper into one of the most surprising findings from that analysis. At face value, a competitive selection process is supposed to translate into lower cost missions. However, *Math is Hard* showed that is actually not the case. In fact, from *Math is Hard*, we learned that the opposite is true and that, when missions are selected via a competitive AO process, they experience on average 13% more cost growth than directed missions. In *Wait, What?*, we examine competed mission cost growth by program class (i.e., SMEX, MIDEX, Discovery), evaluate potential reasons for cost growth variability, and discuss ideas on how to control mission level cost growth when a mission is selected via a competitive AO process.

31_Math is EZIE (aka Math is Hard 2.0): How Contracts Help Control Cost

Authors: Rachel Sholder

Presenters: Rachel Sholder

Abstract: The NASA cost estimating community relies on risk analyses to estimate confidence in a project's budget. At a NASA mission's preliminary design review (PDR), convention requires that baseline cost confidence plus project-held reserves should be around the 50th percentile and cost plus project-held reserves and unallocated future expenses (UFE) should be around the 70th percentile of the joint distribution of total cost and schedule. But how can we test whether our approach to determining 50th and 70th percentiles for missions going into PDR is reliable? An analysis of historical costs from past NASA missions shows that there is an 84% chance that a mission will experience cost growth from PDR to Launch. At the empirical 50th and 70th percentiles, NASA missions are spending their full budgets plus 16% and 27%, respectively. But does this change when we compare in-house spacecraft builds to contracted builds? As more commercial hardware options become available, NASA missions have relied on various cost contracts, particularly cost-plus (CP) contracts and firm-fixed-price contracts (FFP). In May 2022, the Electrojet Zeeman Imaging Explorer (EZIE), passed its PDR. EZIE is just one of many recent examples of NASA using commercially available hardware and FFP contract vehicles to control costs. With carefully designed science techniques that take advantage of commercial off the shelf (COTS) hardware from Blue Canyon

Technologies, EZIE will be able to collect groundbreaking science for a lifecycle cost of $57.5M (FY22). To ensure the success of the EZIE mission, NASA must allocate and budget adequate funding. In this analysis, actual costs of NASA missions with contracted spacecraft are compared with actual costs of NASA missions with in-house builds. This paper will allow us to examine the NASA cost community's approach to reserve postures, particularly when contracts are employed. Using the empirical dataset as our guide, how can projects approaching PDR provide cost and schedule analysis that supports the goal of achieving 70% confidence in the budget at the portfolio level?

32_ Aerospace Viewer of NASA Project Staffing Data (aView): A Practical Tool for Analyzing Staffing Levels and Cost Across Missions

Authors: Sarah Lang, Justin McNeill Jr, Tommy Tran, Alexander Zarate Garcia, C Jason Zhang

Presenters: Sarah Lang, Justin McNeill Jr, Tommy Tran, Alexander Zarate Garcia, C Jason Zhang

Abstract: A team from The Aerospace Corporation will discuss the capabilities and recent updates that have been released in aView 2022, the Aerospace Viewer of NASA science missions staffing profiles. aView is currently in the final test and compliance review phases with the One NASA Cost Engineering (ONCE) team and will soon be available via the ONCE portal to the NASA cost/schedule analyst community. Built upon the FTE Tool first released in 2011, aView is a database and browser-based charting tool for historical programmatic data of NASA science missions, specifically of Full-time Equivalents (FTE), Work Year Equivalents (WYE), and cost. It can be used for comparative analysis of staffing profiles of science missions. aView provides high-level views of the historical data of primarily planetary missions for development Phases C and D as well as the operations Phase E. When reviewing and evaluating the basis of estimate for future science mission phases, aView can be used to better understand how the labor basis of estimate compares with past NASA missions. The Aerospace Corporation produces and delivers the aView tool for the benefit of its NASA customer, the NASA Planetary Missions Program Office at Marshall Space Flight Center

34_ Shaping Workforce with Business Intelligence

Authors: Jeff Fajardo

Presenters: Jeff Fajardo

Abstract: NASA is a trailblazer of space technologies and has been for decades. Evidence of this claim is clear in the evolution of the Agency programs, such as Hubble to Webb, Apollo to Artemis, Curiosity to Perseverance, and so forth. NASA's Project and Business management must also stay on the cutting-edge by advancing Business Intelligence Technologies and developing its workforce. In Information Systems, a common business major in academia, Moore's Law is a familiar reference. Moore's Law was an observation by Gordon Moore, the co-founder of Intel. Moore observed that the number of transistors in a dense integrated circuit doubles about every two years. The law is often applied to general computational progress

suggesting that tech will become exponentially faster, smaller, and more efficient over time. Are NASA's business technologies growing at an acceptable rate? At a rate that stays on pace with Moore's Law? It is within our power to identify the steps needed to position the Agency on the leading-edge of business practices for our missions. Agency leadership has made decisions that propel the "Future of Work" such as making investments in software and tools, empowering the workforce to prioritize data-driven decision making. On November 18, 2022, the Office of the Chief Information Officer (OCIO) sent an agency-wide email stating, "As of Friday, November 18, Power BI Pro is now available to all NASA end users at no cost!" This was a giant leap towards stimulating business innovation. Pockets of dashboard builders are scattered across the NASA centers. They are recognizing the power of the PowerBI software. Like artists with canvases, paint, and brushes, these originators are creating their own masterpieces. We are seeing automation in business processes and the creation of advanced analytics that are giving new insights to key decision makers. The Orion Program's PP&C office is embracing the maturation of the PowerBI technology. Ambitious team members are rethinking the ways analysts and managers interact with data in the Program. Monthly and quarterly cost performance reporting is shifting to dashboards. The level of insights is expanding, the time spent producing reports is shrinking, and the skills of the team are blossoming. The presentation for this abstract showcases recent Orion business innovations and lays out a path for the future of work at NASA. This presentation was perfected in JSC's Toastmasters club. It has been given to audiences in Orion, SLS, and EGS at the Cross Program Integrated PP&C Integration Team Face-to-Face meeting in January 2023. The response has been extremely positive. It turns on light bulb ideas for audience members.

36_ Thresher and TIDBIT: Tools on Automating Schedule Risk Assessments

Authors: Jessica Clarke, Patrick Schneider, Kimberly Smith

Presenters: Jessica Clarke

Abstract: Schedule Risk Assessments can be a tedious and time-consuming effort without the right tools and context. Developing methods to automate the tedious efforts of Analysis schedule building and backing into triangular distributions will save time and reduce frequency of errors. The following tools are addressing needs that have been identified for use in NASA Artemis-related Schedule Risk Assessments.

Thresher: A tool for simplifying a schedule to only critical or near-critical tasks

Project schedules are often quite complex, running to many thousands of tasks owned by dozens of organizations and embodying huge amounts of data. This volume of information, though valuable for project management, makes it difficult and time consuming to easily perform analysis of critical and near critical path tasks.

Thresher is a new tool designed to reduce the amount of data and thus the complexity and time needed to analyze the critical and near critical path tasks of a schedule. Thresher creates a new MS Project file containing only selected tasks in it and preserves all data such as

unique IDs, start/finish and baseline dates, logic, etc. for those selected tasks. This new file, containing a small subset of tasks from the original file, is simpler to navigate, easier to analyze and dramatically cuts down time needed to analyze the critical/near critical path of a schedule.

TIDBIT: Triangular Inverse Distribution Back In Tool

Uncertainty or risk distributions provided by organizations are often delivered in one of two formats: either a duration uncertainty or an array of best case, most likely, and worst-case dates. Encountering the latter is nearly guaranteed while conducting any schedule risk assessment. One current tactic is to back into the duration uncertainty using a triangular distribution formula, which could take weeks compared to receiving a duration uncertainty that is ready to be modeled historically with Microsoft Excel VBA macro. Once the best case, most likely, and worst-case dates are entered in, the triangular distribution formula guides checks and inputs through a trial-and-error process by the user. Checks are desired to resolve to 0 or within a ± 5-day range to ensure that an accurate distribution has been calculated. Achieving a distribution within the acceptable range of checks can take weeks depending on the number of iterations required for the model.

TIDBIT is a tool that runs both the triangular distribution formula and error checks significantly faster as compared to historical methods. This reduces the time required to develop an uncertainty distribution from weeks to a day. The tool comes in two formats: python Jupyter notebook and HTML/JavaScript, both of which use the same formula to calculate resulting distributions. The HTML/Javascript version was created so that TIDBIT can be run without requiring the user to configure a local environment or install software dependencies.

This brief will cover uses for both Thresher and TIDBIT in NASA Artemis-related Schedule Risk Assessments.

37_ Breaking Down Data Silos

Authors: Kailey Melton

Presenters: Kailey Melton

Abstract: Siloed schedule data creates barriers to information sharing and collaboration. In short, siloed data is not healthy data. If schedule data isn't easy to find and use in a timely fashion (or can't be trusted when it is found) it isn’t adding value. Many programs, projects, and initiatives are accustomed to working in their own worlds with their own lingo, processes, and challenges. This culture of separation carries over to schedules. This presentation will showcase SCaN’s efforts to break down the silo mentality.

38_ Successful EVM Implementation Depends on Surveillance

Authors: Nick Frazier, Briannah Smith

Presenters: Nick Frazier, Briannah Smith

Abstract: Routinely testing any system ensures it is working properly. That system can be manufacturing line producing parts for engines, a fire alarm at the Vehicle Assembly Building or an EVM system (EVMS). Checking

the EVMS is necessary to provide performance data that is valid, accurate and timely. The key word in an earned value management system is system. It is not just the data produced but is comprised of the tools, people and process that work together to produce EVM data.
NASA began performing EVMS surveillance on our Suppliers in October 2019. In August 2021, the *Agency Surveillance Plan for In-House Projects* was updated to include surveillance starting in early formulation. We have been gathering findings from quarterly surveillance events, captured in 50+ reports, and watching trends emerge in the data.
This presentation will cover EVMS surveillance and how it's conducted from early formulation through Phase D. It will describe project planning and control functions that NASA performs well and areas where we struggle to implement sound project planning and control practices. The impacts of poor project management practices on the performance data will be conveyed. A list of the improvements that have been made based on surveillance findings will be briefed. The goal is for participants to come out with an appreciation of what an EVMS is, and how the success of the EVMS is predicated upon sound cost estimating, budgeting, scheduling practices.

39_ The Smart Projects and Reviews with Transformative Analytics (SPARTA) Project

Authors: James Price, Sharon Straka, Matthew Dosberg, Amanda Cutright, Dan Friedrich, Tara Dulaney

Presenters: James Price

Abstract: The Smart Projects and Reviews with Transformative Analytics (SPARTA) project will transform NASA's work by developing an automated, customizable system that makes programmatic data available on-demand to multiple levels of stakeholders. It is developed to improve communication of project progress and status by providing rolled up data while enabling drill-down of key programmatic and engineering information in a configurable dashboard format. This will allow project and program managers, review board members, directorate, center, and headquarters leaders, as well as other stakeholders across the Agency to monitor programmatic metrics, track project progress and challenges, assess mission risk, enable informed decision making, and review data throughout the project lifecycle in one location. SPARTA uses Microsoft Power BI to increase efficiency, transparency, and communication targeted at each level of management, with easier access to key information across the NASA portfolio to better facilitate those informed decisions. SPARTA captures data over time to enable trending and other time series analysis.

The timely transfer of project data through multiple management levels has traditionally been a challenge. Projects prepare their status review packages monthly in PowerPoint with inputs from their supporting team. The resulting package is then presented or reviewed at several levels of management at the center before reaching headquarters, where it can undergo additional levels of reviews. By the time the data gets to all levels of NASA management, it can be more than one to two months out of date. SPARTA will streamline the time needed to prepare for these status reviews, make the data readily accessible in a customizable format, and reduce the review cycle time allowing information to be more current. Searchable functions, slicers, and filters allow project analytics to be compared to data from similar projects at the same development phase. Meeting projects where they are to have minimal impact to the project's progress is a key aspect to SPARTA. Therefore, the SPARTA team has developed methods to extract information from existing diverse project sources including PowerPoint, Excel, Project, and other applications, tools, and database sources.

40_ Mission Operations Cost Estimation Tool (MOCET)

Authors: Marc Hayhurst, Brian Wood, Cindy Daniels, Lissa Jordin, Washito Sasamoto, Waldo Rodriguez

Presenters: Marc Hayhurst

Abstract: The Mission Operations Cost Estimation Tool (MOCET) team will present an overview of recent model updates and other research topics. Model updates include changes to cost estimating relationships for earth science, planetary, and International Space Station (ISS) hosted missions. Research topics focused on modeling of extended mission costs and Level 2 work breakdown structure cost. An overview of the state of the user community will be presented including statistics from the One NASA Cost Engineering (ONCE) model portal and *software.nasa.gov*. MOCET is a model developed by the Aerospace Corporation in partnership with NASA's Science Office for Mission Assessments (SOMA), which provides the capability to generate cost estimates for the operational, or Phase E, portion of NASA science missions. MOCET is comprised of CERs that have been derived from historical data for Planetary, Earth Science, and Explorer missions. The resulting CERs and accompanying documentation have been implemented as a standalone Excel based tool which is now available via the One NASA Cost Engineering (ONCE) model portal and *software.nasa.gov*.

41_ The Mystery of the Metrics: Contractor Schedule Management

Authors: Erin Wood

Presenters: Erin Wood

Abstract: Many of us can recall the classic family game in which someone excitedly screams out "Colonel Mustard did it in the Conservatory with a revolver!". The suspense and intrigue, the required logic, and the thrill of figuring out who the perpetrator of a mysterious murder is. Supporting the NASA side of the contractor project controls for Space Flight projects is not unlike that. I'm not intimately involved with the SpaceDoc teams as I would be when embedded into an in-house project, so I must use the schedule and information from the 533, resource analysts, and project managers from both NASA and the contractor teams to fully understand not only what happened in the preceding month, but also what concerns or pitfalls may lay ahead.

Travel with me through the 9 rooms of metrics management, each room representing a crucial piece of information that must be gathered to evaluate progress and the go forward plan. As we go, we'll discover six weapons (tools & software) to get the answers you need from limited data provided and meet the characters that represent some patterns that you may discover hidden in the numbers in our ultimate effort to remove the barriers that may be in the way of mission success.

We will put all of the clues the metrics provide us together to be able to solve the mystery and support project management, program management, and our CORs

- where (what information is important)
- with what weapon (what tool did we use to get that information)
- and who (telling patterns)

42_ Agile Methodology Applied to Systems Engineering in the Domain of Cost Analysis of a 6U CUBESAT

Authors: Ana Carolina Di Iorio Jeronymo, Lidia Hissae Shibuya Sato, Luís Eduardo Vergueiro Loures da Costa, Jonas Bianchini Fulindi, Victoria de Souza Rodrigues

Presenters: Victoria de Souza Rodrigues

Abstract: This paper presents the use of agile approach applied to system engineering in a cost analysis during the development of a 6U CubeSat called Scintillation Prediction Research Observations Task - SPORT.
A CubeSat project has characteristics that could facilitate its development, due to the existing standardization and available commercial of the shelf products, but this does not imply that less effort needs to be done on the system engineering process. Usually, it is the other way around in scientific missions, for instance: the effort can be as hard as in a large satellite to find a suitable trade-off among what is available, what can be developed and what the stakeholder needs. Agile methodologies are well known and largely used in software projects and its efficiency can be seen in the literature. Because of that, there is an increasing interest in using this approach in projects other than software-related ones, especially in complex projects.
Agile methodologies in general implies in developing a project in small portions known as sprints, and in each sprint a value is added to the product delivered at that time, and it is seen if it attends the expectations of the stakeholders. The same concept is used in this work, where the agile approach guides the cost analysis in the activities of planning, developing and supporting a CubeSat-based small satellite mission.
The system engineering processes are applied in sprints being a valued product presented to the stakeholders at the end of each sprint.
This work demonstrates how the agile approach makes use of the sprints and how it is derived to the cost analysis of a space project. Focusing on the cost management and procurement guidance, our approach is demonstrated in a practical application of the SPORT project, a bi-national CubeSat-based scientific nanosatellite, which platform development is being made by ITA.

45_ Through the Looking Glass- Why EVM Is An Essential Risk Mitigation Measure for Decision Makers and Program Managers at NASA

Authors: Symantha Loflin

Presenters: Symantha Loflin

Abstract: The author is providing research that defends and strengthens the contractual addition of Earned Value Management (EVM) as a risk mitigation measure. As a key NASA acquisition priority, EVM system compliance and surveillance are functions of the EVM discipline that provides program managers with the capabilities required to execute the program/project as effective stewards of the taxpayers' money.

It takes a whole-of-government approach to defend and protect the world's dependance on the sea, air, and space through conformality with legal and regulatory processes of the federal procurement of Made in America products and the growth of small businesses to achieve economic opportunities and national security strategy.

Each year, the federal government increases the funding of developmental contracts as a measure to "Protect Sea, Air, and Space" (National Security Strategy, October 2022). These efforts aim to protect U.S. interests in developing technologies, creating economic opportunities, and enabling climate surveillance, and to responsibly oversee the space environment.

As a risk mitigation measure, the implementation and use of EVM through the roles of the contracting officer, management, and functional specialist is essential to the fundamental assessment of the program/project performance. It is imperative that program managers and decision makers rely on current, accurate, and defensible data obtained from EVM compliance through surveillance to make informed performance decisions. These measures enhance risk mitigation by controlling cost, schedule visibility, and technical readiness. In addition, value is added to the taxpayer, federal government, and the national security strategy.

47_ A Significant Other: Hypothesis Testing on Qualitative Predictor Coefficients in CER Regression

Authors: Cassandra Chang

Presenters: Cassandra Chang

Abstract: Cost estimating relationships (CERs) are used to predict costs for new space missions based on historical data from past missions. Many of these CERs are developed using regression techniques. Variable selection for CER models tends to come from hypothesis testing on individual parameter coefficients. However, there are many nuances to consider when determining if a predictor is significant or not, especially with qualitative variables, also known as binary, dummy, or logical variables, in nonlinear regression. It is important to ensure that the null and alternative hypotheses being tested reflect the realistic effect that a predictor may have on the response variable. This can range from testing the fitted coefficient against a specified nonzero value to choosing between one sided and two sided hypothesis tests. Selecting variables that are statistically significant in the right contexts can help create more realistic CERs and better cost estimates.

48_ Aleatoric and Epistemic Uncertainty Quantification in Bayesian Dirichlet Cost Rules of Thumb

Authors: Melissa Hooke

Presenters: Melissa Hooke

Abstract: The total cost of any project is the sum of the costs of its components. At NASA, these components are called the Work Breakdown Structure (WBS). There are eleven numbered elements at the top level of the NASA WBS, including 1: Project Management, 2: Systems Engineering, 4: Science/Technology, 5: Payload(s), and 6: Spacecraft. During the earliest phases of the project lifecycle, the costs of only one or a few of these components are well constrained, and the cost of the other elements must be estimated in order to submit a proposal with a reasonable chance of success. In the absence of time, money, or the level of detail to produce grassroots estimates, cost estimators look to past missions to gain insight; they have traditionally averaged the percentage

allocations for each WBS breakdown from previously flown missions and used them to predict allocations for the new project that they are trying to cost. At NCSS 2022, we presented a novel costing method to project costs for future MIDEX class missions; rather than relying on average percentages, we proposed a Dirichlet-distributed model, which aptly describes the uncertainty of resource allocation by capturing the correlation between components. Here, we expand on our work from last year by (a) applying similar methodologies to more mission classes other than MIDEX (Flagship, New Frontiers, Discovery, SMEX, etc.), (b) imputing missing data records using expert knowledge of how costs are bookkept, (c) expanding our communication to align with up-to-date Uncertainty Quantification standards (categorizing uncertainty as aleatoric or epistemic), and (d) generating an interactive web tool easily accessible and usable by systems engineers. This presentation will review the Dirichlet ROT model and demonstrate the capabilities of the online tool.

49_ ASCoT 3: Nonlinear Principal Components Analysis and Uncertainty Quantification in Early Concept Spacecraft Flight Software Cost Estimation

Authors: Melissa Hooke

Presenters: Melissa Hooke

Abstract: For mission planners and evaluators alike, value in cost models comes from a mean or median prediction, an understanding of the uncertainty on that prediction, and an understanding of model performance. Here we apply advanced statistical and machine learning methods to spacecraft flight software cost, effort, and SLOC estimation, and present the results in the latest version of the Analogy Software Cost Tool (ASCoT). We present in- and out-of-sample performance metrics for our models, each of which incorporate some amount of epistemic uncertainty. ASCoT, hosted on the One NASA Cost Engineering (ONCE) database via the Online NASA Space Estimation Tool (ONSET), was first showcased in 2016 as a number of analogy-based models and methods (kNN and Clustering) to support early project formulation. This ASCoT update improves upon the previous analogic methods by incorporating uncertainty in the data transformations. In particular, we use a Nonlinear Principal Components Analysis (NLPCA) to deal with ordinal data.

50_ Analogy Cost Estimation for CubeSats using COMPACT

Authors: Melissa Hooke

Presenters: Melissa Hooke

Abstract: The CubeSat Or Microsat Probabilistic and Analogies Cost Tool, or COMPACT, is a NASA Headquarters funded effort to fill the gap in cost estimating capabilities for CubeSats during early formulation. The COMPACT team has collected technical, programmatic and cost data on dozens of flown CubeSats missions led by NASA, research labs, and universities. The purpose of COMPACT's online cost tool (available through ONCE) is to provide transparent access to historical data and a framework for analogy-based cost estimation for future CubeSat missions using verified cost data from historical CubeSat missions.

One of the challenges of analogy cost estimation is the identification of analogue missions to use for the cost estimate. COMPACT's k-Nearest

Neighbors (KNN) algorithm provides a ranked order list of possible analogy missions. COMPACT now also provides mission data sheets which can be used to read up on historical missions and view additional data directly within the tool in order to determine whether the past mission qualifies as an appropriate mission analogue. This presentation will walk through how to navigate the new mission data sheets and show an example of how the data sheets may be used for analogy comparisons relevant to early formulation costing.

52_ Joint Confidence Level Analysis for Projects with Multiple Objectives

Authors: Michael Trumper, Lev Virine

Presenters: Michael Trumper, Lev Virine

Abstract: Traditional Joint Confidence Level (JCL) is an integrated project cost and schedule risk analysis. The result of a JCL shows the probability that both a project's cost will be equal to or less than the targeted cost that the schedule will be equal to or less than the targeted finish time. To perform JCL analysis, the summary cost-loaded project schedule is developed, risk and uncertainties are assigned to schedule activities, Monte Carlo simulations are performed, and results are shown on a scatter plot. The traditional methodology has a major limitation: JCL is performed only for project cost and schedule. In reality most projects have multiple objectives, including achieving technical performance, as well as quality, safety, security, environmental protection, public relations, and many other objectives. The impacts of risks and uncertainties are not limited to just schedule and cost, but can affect other such objectives. The paper proposes a process of integrating multiple objectives to JCL analysis and presenting results on different plots. The results of analysis will be the probability that cost, schedule, technical performance, and others will meet certain targets.

The same project risks can affect multiple objectives, but with different impacts. For example, poor performance of subcontractor may increase project duration and cost but can also affect technical performance and safety. Duration and cost are schedule-related objectives because schedule needs to be recalculated to determine impacts of a risk on the project, while others are non-schedule. Different risks will have different impacts on the same objective, risks may or may not be correlated with each other. Risks impacting non-schedule objectives are assigned to the tasks and total impact of such risks is calculated using Monte Carlo simulations together with cost and schedule uncertainties.

JCL analysis with multiple objectives includes the following steps:

1. All non-schedule related objectives should be defined and quantified by establishing reference points. For example, for technical performance objective, minor issues may have 0-20% impact, moderate issues – 20-40%, etc. Organizations often have scales for different risks associated with such objectives in their risk management systems.

2. All objectives including schedule related (cost and schedule) and non-schedule (e.g., technical performance) must be prioritized. This prioritization can be

achieved using a methodology derived from the Analytical Hierarchy Process. The process includes pairwise comparison of multiple objectives based on their quantitative scales. For example, risk impact on technical performance will be 5 times more critical than impact on cost. Essentially this is a judgement elicitation process from the experts involved in the project.

3. Risks are assigned to different tasks and resources of project schedule. The risk impact on schedule-related and non-schedule objectives are defined. Monte Carlo simulation of the project schedule is performed. Total impact of risks for each non-schedule objective is calculated as a sum of impact of individual risks.

4. Total probabilities and impacts will be normalized for all iterations on Monte Carlo simulations. The result analysis is scores for each objective. They are the indicators for each objective that can used to compare with predefined targets. For example, 0% score for technical performance would mean that all risks affecting technical performance will be avoided. All risks can be ranked based on score of individual objective or for all objective together based on priority of each objective.

5. Results can be presented on the scatter plot. The scatter plots can be 2D, such as finish time vs. technical performance or 3D, such as cost, duration, and technical performance. The plot also includes frontier lines or lines where the combination of objectives meets certain predefined targets. In case of 3D chart frontier lines would become 3D surface where all three objectives (cost, duration, and technical performance) meet predefined targets.

6. If probability of cost, duration (finish time), technical performance and other objectives don't meet predefined targets, certain risk mitigation measures should be implemented. In order to measure their efficiency new JCL analysis should be performed.

The proposed methodology has several advantages:

- JCL analysis with multiple objectives allows to estimate probability that targets related to project duration, cost, technical performance and other objectives will be met.

- Project risk analysis with multiple objectives allows to rank project risk based on integrated score for all objectives.

- JCL analysis can be used to assess efficiency of risk mitigation measures and how they would affect multiple objectives.

- The results of JCL analysis with multiple objectives can be presented on 2D and 3D with frontier lines or frontier surfaces, which can be used to depict probabilities that objectives will meet predefined targets.

53_ Quantified Benefits of Earned Value…and Their Benefits

Authors: Matt Jones

Presenters: Matt Jones

Abstract: Historically, NASA has lagged behind the Department of Defense (DoD) in adopting Earned Value Management (EVM). It is widely agreed that organizational buy-in is a key driver of adoption and quality of any given Earned Value Management System (EVMS). EVM buy-in is hindered by the lack of compelling studies with quantified data confirming the consistent. Some recent quantitative studies have even claimed that EV benefits have decreased since 1996.

This presentation delves into data from eight recent NASA projects compiled by the EVMS of the Johns Hopkins University Applied Physics Laboratory (JHU/APL) as well as data from a previous DoD study that attempted to quantify the benefits of EVM. Quantified EVM benefits are confirmed across industries. Differences between industries, that are likely driven by varying levels of scope risk, are investigated. Statistical trends, especially the relationship between scope risk and EVM's predictive power, are presented.

Potential future applications of these findings are also explored. These include techniques for using the findings to gain EVM buy-in and a novel methodology for using the quantified EVM benefits metrics as a low cost alternative to labor intensive EVM surveillance processes.

54_ Programmatic Cost Tool

Authors: Joe Mrozinski

Presenters: Joe Mrozinski

Abstract: At the 2018 Symposium, we introduced the Programmatic Cost Tool (PCT), including inputs and outputs as one would expect, but also gave a deep dive into the historical lineage of the tool and how it grew out of previous efforts at NASA, industry and DoD. A few general results from previous studies were also reviewed.

At the 2022 Symposium, we took the audience along on a test drive as we ran the tool live during our talk to show the latest capabilities that had been added to the tool suite while analyzing a fictious architecture.

At the 2023 Symposium, we will talk about how PCT was used to help develop the "Concept for 2033 Crewed Mars Orbital Mission with Venus Flyby," which was published in 2022 in the *Journal of Spacecraft and Rockets.* This complex architecture would require 17 launches of various systems over the course of 5 years. The key question attendees at this Symposium would be asking themselves: could all of the needed systems be developed and produced under a reasonable budget in the relatively compact schedule needed in order to take advantage of the rare orbital alignment needed by this architecture? We will show PCT's success answering this question for this fascinating and surprisingly affordable concept for the first human flyby of Venus and the first human orbit of Mars.

56_ Yes, NASA, a project can be cancelled

Authors: Justin Hornback

Presenters: Justin Hornback

Abstract: NASA projects and programs in development have faced continued challenges from COVID, higher inflation, and supply chain disruptions over the past three years. Outside of these unique challenges, traditional challenges of developing a solid baseline and

executing to the baseline for robotic space flight projects remain.

This presentation will share an anonymous case study of a project that was cancelled in late Phase C (implementation/integration) after breaching the KDP-C cost and schedule commitment and going through one rebaseline prior to cancellation. The cancelled project was selected through a competed Announcement of Opportunity (Ao). Proposal analysis estimated a likely inability to delivery to technical requirements within schedule or cost. Assessment of the project as it matured through its life cycle continued to show the likelihood of the project not meeting cost/schedule estimates and the inconsistency of these estimates with Agency requirements. Assessments were considered at Key Decision Points (KDPs) but ultimately did not drive significant changes with the project until cancellation.

The presentation will also examine how project reporting was disconnected with program office and independent assessments. Many metrics, including Earned Value Management (EVM), reporting did not reveal issues without detailed examination of project management products like the Integrated Master Schedule (IMS) and 533 reports.

This presentation will also consider impacts of external factors like loss of proposed project partners, COVID, and the project being named in appropriations with its own operating plan as additional factors for why the project continued given the significant risks identified at every stage of a project's development life.

57_ EVM Analysis Tool for Complex Projects with Varied Data Sources

Authors: Donald P. Rice, Jr.

Presenters: Donald P. Rice, Jr.

Abstract: The Planetary Missions Program Office at NASA's Marshall Space Flight Center is responsible for oversight of Science Mission Directorate/Planetary Science Division robotic exploration missions. Some of these missions are large & complex with work spread over multiple contracts. The purpose of this briefing is to demonstrate how a simple spreadsheet tool can pull together the available data to provide meaningful analysis of large & complex projects, using Europa Clipper as an example of the initial setup, the monthly process, and how to produce a final monthly analysis briefing.

To analyze the whole Europa Clipper project, data is collected on eight different contracts. The data availability varies depending on the contract. Complete IPMRs are only available for two contracts. IPMR Format 1 data is available for six contracts. However, Empower data are only available for three of the contracts. Additionally, there are a few other pieces of information delivered monthly, including management reserves log for one of the contracts, a liens and threats list, and a Control Account Manager Notebook. Initially, analysis was only performed on the largest contract, covering about 70% of the total project value. This left 30% of the project not being analyzed, and a lot of the significant issues on the Europa Clipper Project were found in the smaller value contracts.

With that in mind, a tool was developed to tie all the available data together and provide as much analysis as possible for the whole project and for the individual contracts. The analysis tool uses a set of automated calculations to develop a range of traditional EVM metrics (e.g., SPI(t), SPI, CPI, and TCPI for a variety of different targets), Earned Schedule, EAC estimates, and data trends. It also generates a consistent set of analysis charts that allows tracking at all Project levels. Examples of these charts will be demonstrated during the briefing.

Additionally, the monthly updating process will be described. Once monthly updates are completed, the analyst is ready to start working on the monthly EVM Analysis slides using the summary level charts and any of the contract level charts as needed for detailed analysis. The generated charts point the analyst towards the

specific areas that need to be investigated further to support completion of monthly reporting to Program Office Management.
It is anticipated that this analysis tool could be used by others in the NASA EVM community for their complex projects.

58_ Examining the Effects of Implementing Data-Driven Uncertainty in Cost Estimating Models

Authors: Vicky Nilsen

Presenters: Vicky Nilsen

Abstract: When conducting probabilistic cost analysis, correlation assumptions are key assumptions and often a driver for the total output or point estimate of a cost model. Although the National Aeronautics and Space Administration (NASA) has an entire community dedicated to the development of statistical cost estimating tools and techniques to manage program and project performance, the application of accurate and data-driven correlation coefficients within these models is often overlooked. Due to the uncertain nature of correlation between random variables, NASA has had difficulty quantifying the relationships between spacecraft subsystems with specific, data-driven correlation matrices. Previously, the NASA cost analysis community has addressed this challenge by either selecting a blanket correlation value to address uncertainty within the model or opting out of using any correlation value altogether. One hypothesized method of improving NASA cost estimates involves deriving subsystem correlation coefficients from the residuals of the regression equations for the cost estimating relationships (CERs) of various spacecraft subsystems and support functions. This paper investigates the feasibility of this methodology using the CERs from NASA's Project Cost Estimating Capability (PCEC) model. The correlation coefficients for each subsystem of the NASA Work Breakdown Structure were determined by correlating the residuals of PCEC's subsystem CERs. These correlation coefficients were then compiled into a 20x20 correlation matrix and were implemented into PCEC as an uncertainty factor influencing the model's pre-existing cost distributions. Once this correlation matrix was implemented into the cost distributions of PCEC, the Latin Hypercube Sampling function of the Microsoft Excel add-in Argo was used to simulate PCEC results for 40 missions within the PCEC database. These steps were repeated three additional times using the following correlation matrices: (1) a correlation matrix assuming the correlation between each subsystem is zero, (2) a correlation matrix assuming the correlation between each subsystem is 1, and (3) a correlation matrix using a blanket value of 0.3. The results of these simulations showed that the correlation matrix derived from the residuals of the subsystem CERs significantly reduced bias and error within PCEC's estimating capability. The results also indicated that the probability density function and cumulative distribution function of each mission in the PCEC database were altered significantly by the correlation matrices that were implemented into the model.
This research produced (1) a standard subsystem correlation matrix that has been proven to improve estimating accuracy within PCEC and (2) a replicable methodology for creating this correlation matrix that can be used in future cost estimating models. This information can help the NASA cost analysis community understand the effects of applying uncertainty within cost models and perform sensitivity analyses on project cost estimates. This is significant because NASA has been frequently critiqued for underestimating project costs and this methodology has shown promise in improving NASA's future cost estimates and painting a more realistic picture of the total possible range of spacecraft development costs.

59_ Bayesian Quantitative Risk Analysis

Authors: Christian Smart, Murray Cantor

Presenters: Christian Smart, Murray Cantor

Abstract: This presentation proposes extending the traditional practice of using three-point estimates and Monte Carlo simulations in quantitative risk analysis by incorporating Bayesian updates using actual observations. This approach enables tracking schedule and cost risk throughout the life cycle and can raise red flags if the uncertainty does not decrease. These reports are particularly useful for innovative projects with a high degree of uncertainty.

The presentation includes a case study demonstrating how incorporating actuals can reduce uncertainty. It concludes by discussing this approach's potential benefits and limitations and its implications for project management practice**.**

60_ Distribution Free Uncertainty for CERs

Authors: William King, Shaun Irvin

Presenters: William King, Shaun Irvin

Abstract: For this presentation we intend to introduce and demonstrate the application of conformal prediction as a tool to specify prediction intervals (PI) for any machine learning algorithm. Unlike the more commonly used methods for developing prediction intervals (e.g., which assume error normality and utilize a first order Taylor series approximation to estimate the variance of the functional form), conformal prediction intervals offer rigorous statistical coverage guarantees without stringent distributional assumptions (required by classical inference), and only assumes the exchangeability of data, a weaker assumption than independence (which is also required by classical inference). This means that conformal prediction can be applied to a wider range of problems. Generating these prediction intervals is simple and can be done as part of the k-fold cross-validation process. Specifically, we intend to demonstrate a conformal prediction technique known as CV+ (Cross-Validation Plus), and its locally weighted variant, introduced in the paper *Predictive Inference with the Jackknife+* by Barber, Candes, Ramdas, Tibshirani (2021).

61_ONCE Database

Authors: James Johnson, Eric Plumer, Julie McAfee, and Mike Blandford

Presenters: James Johnson

Abstract: The One NASA Cost Engineering database (ONCE) provides vital data on NASA projects to a community of close to 700 users that includes NASA Civil Servants, Contractors, FFRDCs/UARCs, and others. The data contained in the ONCE database comes from the official NASA Cost Analysis Data Requirements (CADRe) which includes a variety of important technical and programmatic information on projects and programs. CADRes were initially manually entered into the ONCE database and then were moved to an automated process several years ago that imported the Excel files into the SQL database via SQL Server Integration Services (SSIS). The ONCE team has matured the CADRe import process yet again with an online entry capability for the CADRe developers. This allows

for identification and elimination of any data anomalies before the data is entered into the ONCE database. Another exciting development is the capability for ONCE to host containers on Amazon Web Services (AWS).
Containers provide a standard way to package application's code, configurations, and dependencies into a single object. The containers hosted within ONCE share an operating system installed on the NASA HQ Managed Cloud Environment (MCE) and run as resource-isolated processes, ensuring quick, reliable, and consistent deployments, regardless of environment. This new capability allows the NASA PP&C Community to develop their own web applications quickly and easily with open-source software. ONCE currently hosts Aerospace's aView model in a container and is working with several other developers to host their models and tools. This presentation will provide an overview of the new capabilities and information on the future updates to the ONCE database.

62_ Diving Deep in the Domains, Running with AzTech

Authors: Crystal Bonds

Presenters: Crystal Bonds

Abstract: This presentation will brief the Symposium on the newly identified eight (8) project performance domains listed from the recently published 7th Edition of Project Management PMBOK and will exhibit the use of a NASA provided schedule management tool, RunAzTech (RAZ) and its ability to address activities and identify coordination of project deliverables recommended in the Planning Performance Domain.

1. Guidance and update of 7th edition PMBOK
   a. Project Performance Domains

This presentation will also cover the impression of the RAZ tool and its capacity to maintain, monitor, and articulate schedule expectation for program management teams, enabling effective tracing of the critical path, identifying out-of-sequence status, and navigating through large schedules on both Microsoft Project Desktop and Project Online/Server.

2. NASA management Tool enabling support of the PMBOK Planning Performance Domain
   a. The GASP (Generally Accepted Scheduling Principles) of RAZ!
      - 8 Doctrines
      - 5 Qualities describing valid schedules
      - 3 Qualities describing effective schedules
- Presentation to include a RAZ demo on utilizing the GASP's as a governance mechanism for Planning and Scheduling.

64_Risk Management

Authors: Damaris Gonzalez

Presenters: Damaris Gonzalez

Abstract: The main emphasis of this presentation will be on methods to establish effective processes at the outset of a project that contribute to effective risk analysis. The danger in formalized processes is that they can become bureaucratic and burdened with procedures, so that the project manager and his/her team lose sight of the benefits that come from managing their risks. This presentation will explain how to do manage risks through the definition of risk management and demonstrate how these processes can be mapped onto the

stages of the project life cycle, as they relate specifically to Project Planning & Control (PP&C) competencies, such as cost and schedule.

This presentation will provide the audience with a fundamental understanding of risk management and how a consistent and tailored, but not overly prescriptive, process can contribute to an informed project management approach and project success. Balancing risk and expectation is one of the most challenging aspects of any effort, but it can also offer great satisfaction, provided the team is able to operate in a climate of understanding and openness about their risk posture.

65_ Using Excel to Facilitate JSC Analyses

Authors: Barney Roberts

Presenters: Barney Roberts

Abstract: Have you ever been in an SRB meeting trying to field questions such as:

- What does our baseline case look like when compared with a case where the estimates for risk X are twice (or half) the estimate by the project?
- What does Case A look like when compared to Case B?
- What does our worst case look like when compared to our best case?
- What does it look like when all of the uncertainties are changed to “x” and compared to the baseline case? To case A? to Case B?
- What would be required to mitigate risk A, B or C, or all together to get the launch date back into a reasonable likelihood of achieving?

While the JCL tools in the NASA inventory have acceptable graphical output capabilities, they are quite ponderous for quick response to most questions requiring comparisons of cases. Responding to such questions over the years has led to the development of a Microsoft Excel tool and associated input process that allows quick response to such questions. In addition, Excel is very capable and flexible in producing graphical JCL outputs that are much easier to manipulate to show comparisons and relevant data.
Any of the Monte Carlo JCL analysis tools provide the data for each individual random draw. That data is loaded into the Excel tool which produces the cost and schedule scatterplot, the Cumulative Distribution Function (CDF or S-Curve) for both cost and schedule for that case. But, so what, the NASA JCL tools also produce these plots. The advantage comes when each case is recorded on the first tab for tracking, then each case is relegated to its own tab. A few of the first tabs are set aside for summaries and comparisons. This is where the real advantage comes into play. Having quick access to all cases allows for quick response to questions. Then when the request for a new case arises, any of the JCL tool can run a case very quickly, the data file can be copied and loaded into a new tab in Excel, then all cases are available for comparison. Furthermore, the Excel plots can be hyperlinked into a Microsoft PowerPoint file for presentation capability. Having such an Excel-based tool greatly facilitates the SRB’s assessments and reporting capabilities.