TECOLOTE RESEARCH, INC.
Bridging Engineering and Economics
Since 1973

Probabilistic Schedule Reserve Allocation

NASA 2013 Cost Symposium

August 29, 2013
Param Nair – NASA GSFC Code 400
Charles Hunt – NASA HQ OoE/CAD
Matt Blocker –Tecolote Research, Inc.
Darren Elliott – Tecolote Research Inc

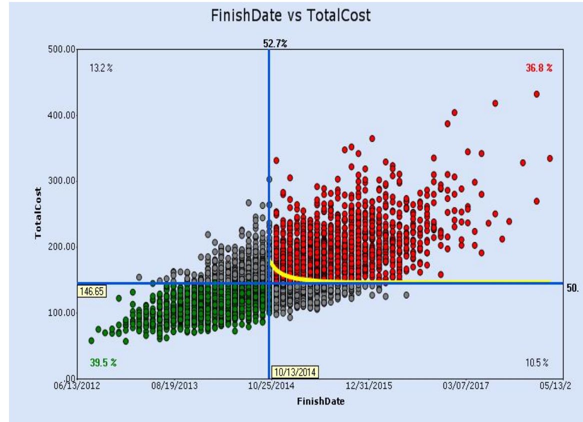
Background

- **In 2012, NASA CAD Conducted a Study to Identify Schedule Allocation Algorithms**
  - Multiple disciplines were researched and current and potential techniques were identified
    - Place margin throughout schedule based on best judgment or heuristics
    - Use individual task percentile values (e.g., P50, P80) to come up with allocated schedule.
    - Iterative search to determine an equi-percentile value for all task durations
  - An algorithm developed by Los Alamos National Laboratory[1] (LANL) was identified as having potential for systematic use to allocate schedule reserves
    - Requires a detailed schedule risk assessment and schedule network
    - Initial assessment identified the algorithm to be a viable reserve decomposition approach
- **(This) Current study commissioned in 2013 to determine if a repeatable data-driven methodology could be developed that enables temporal allocation of reserves that address a project's unique risk profile and schedule complexity**
- **The 2013 study focused on implementation of the LANL algorithm for real-world NASA JCL models**
  - Ensure the algorithm properly addresses complex networks sequencing
  - Investigate alternate methods of allocating the reserve to schedule activities
  - Identify if the algorithm is tool agnostic and if current models can provide required data
  - Evaluate objective measures to determine a recommended approach

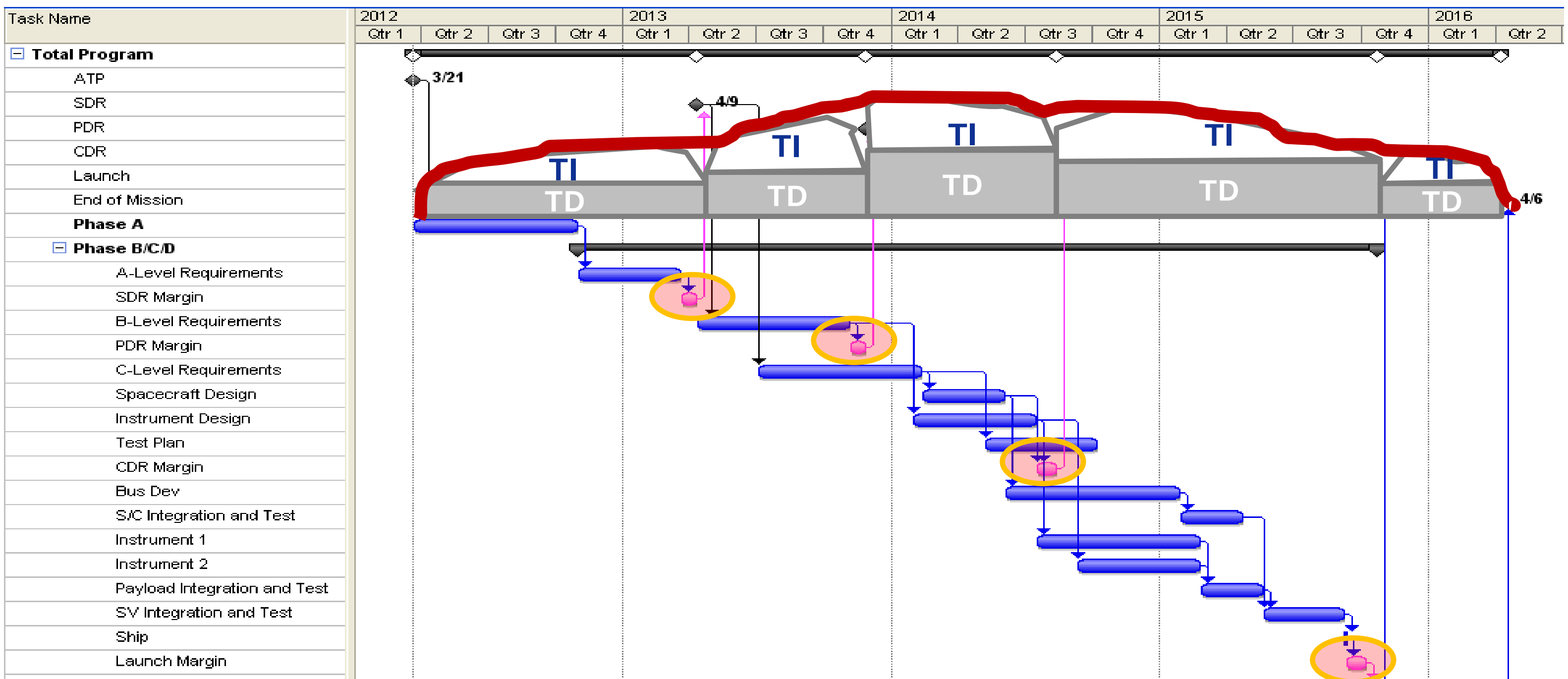
[1]John Kindinger, Los Alamos National Laboratory, *"Development of Schedule Contingency Based on Probabilistic Risk Results"*

Joint Study by OoE/CAD, GSFC Code 400, and Tecolote to Develop a Data-Informed JCL Phasing Method

- **Joint Confidence Level (JCL) scatter plot only identifies a finish date and total cost**
  - Identifies probability that a given project or program's cost will be equal or less then the targeted cost AND the schedule will be equal or less then the targeted schedule date
  - Does not provide a phased JCL result, many paths available for users to "create" a phased view



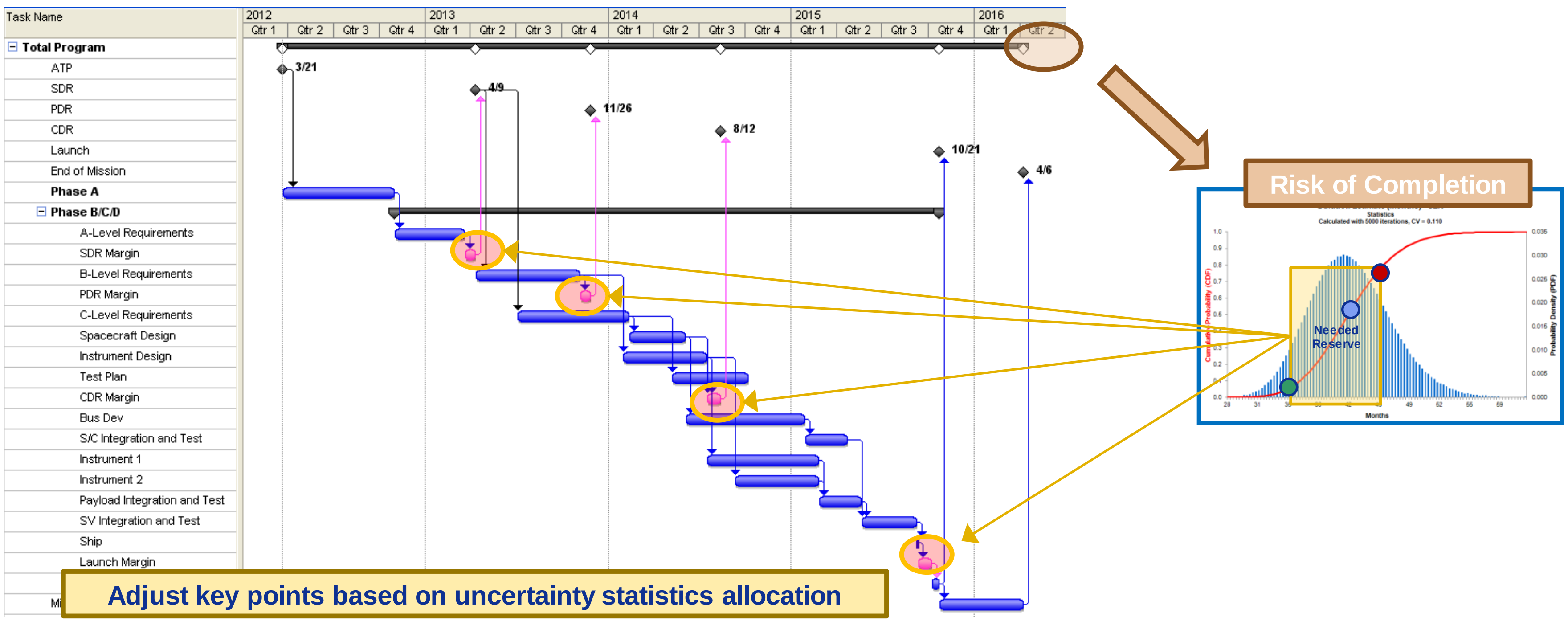
- **This study seeks to define a Data Driven (Risk-Informed) Phasing Method to align cost with project's schedule risk posture to provide enriched phasing insight**



Align costs with risk-adjusted dates

Foundational Basis for Aligning Costs is to Identify the Temporal Schedule Risk

- **Schedule models are based on logic networks, meaning that downstream finish dates are affected by earlier up-stream activities.**
- **A methodology for schedule allocation is an enabling step to identifying target phasing profiles for a JCL target and an indication of when reserves (dollars and time) are needed.**
- **Schedule allocation uses the results of the SRA and/or JCL to appropriately place the needed reserves within the logic**
  - SRA and JCL results provide risk statistics for all activities in the schedule, however management tends to target an end deliverable to have an identified level of confidence (e.g., 70%).
  - No current methodology exists within our industry on how to use SRA results to allocate schedule reserve
  - Cost allocation techniques do not directly apply for Schedule allocation because of network logic



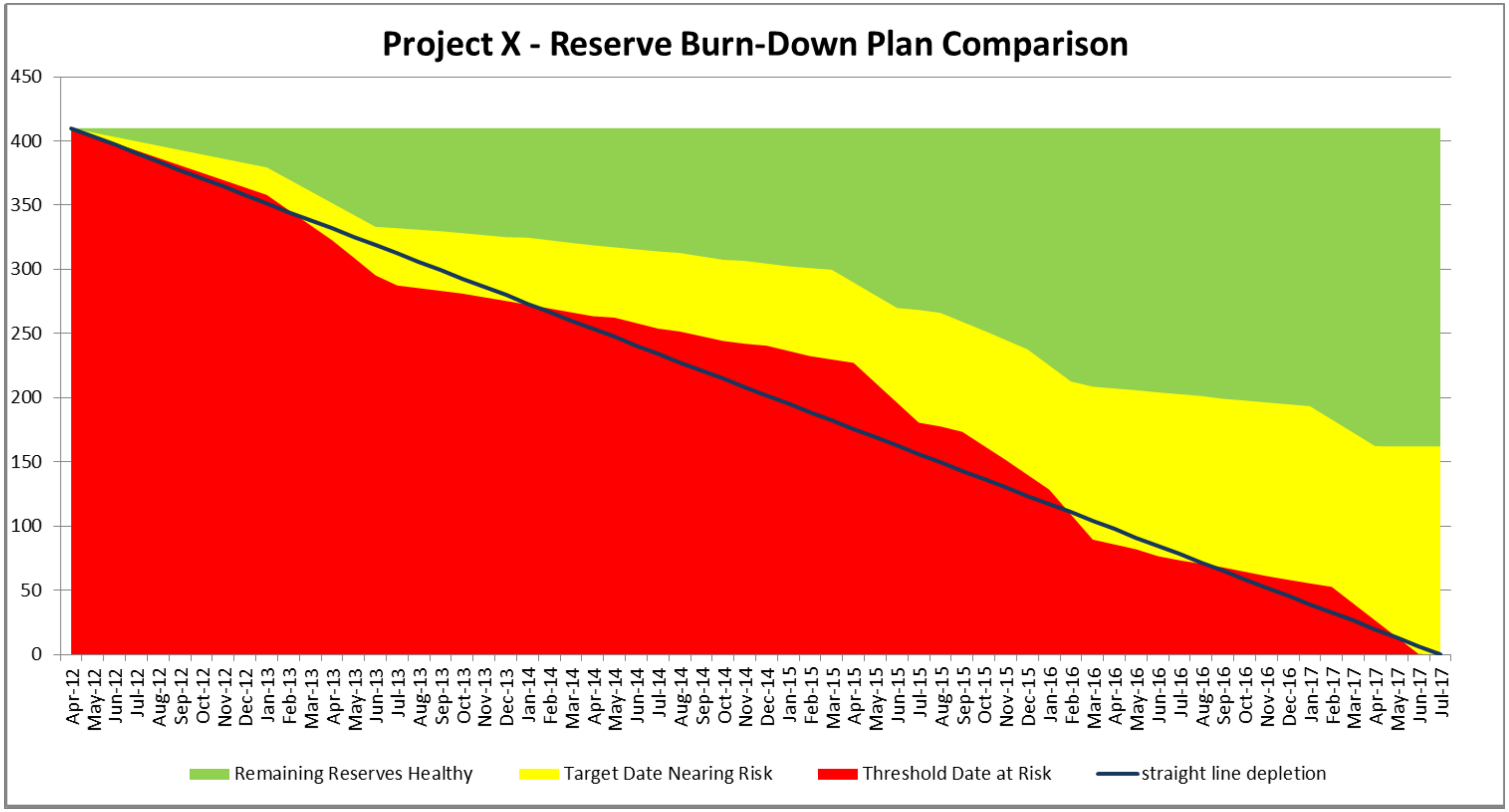
Schedule Reserve Allocation Algorithm Provides Multiple Benefits

- **Establishes a foundation for alignment of budgetary reserves**
  - An allocated schedule aligns the activities in time for where the effort will extend, thereby enabling (alignment) allocation of costs to the schedule
  - Provides the ability to layer in cost reserves over the baseline execution plan to determine overall funding (needs) requirements
- **Provides a basis for budgeting schedule margin over time**
  - Allows project manager to determine realistic target dates for major project milestones and contract deliverables
- **Identifies a roadmap for reserve consumption**
  - Project manager can compare finish dates of recently completed activities against plan-with-reserve and determine if a given branch of the schedule is (on-par) on-track
- **Allows for evaluation of a project or contractors identified schedule margins**
- **Enables insight into (delegating) allotment of reserves to subordinate organizations**
  - Project manager can set contractual deliverable dates and incentive fee profiles (for contractors) based on an informed understanding of the amount of risk inherent in those dates

Leverages KDP-B and KDP-C Products To Provide Increased Value for Project Management in Operational Execution Phases of a Project

Data-Driven Reserves Enhances Insight

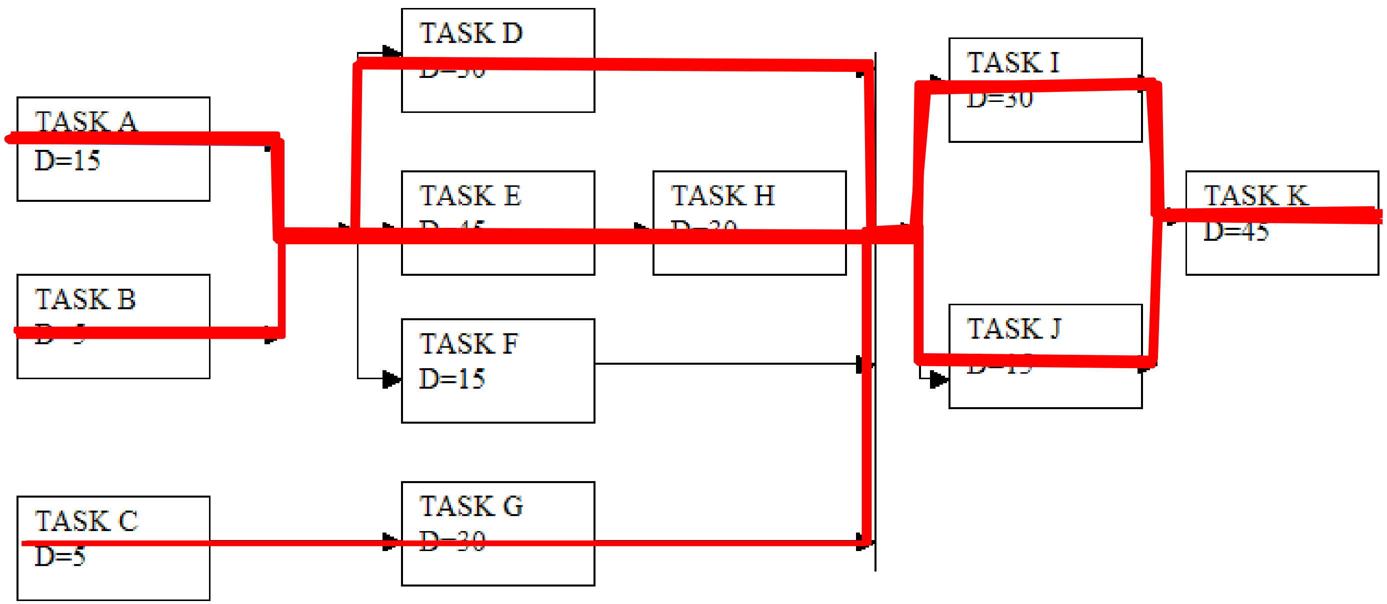
- Margin Burn-downs are normally based on either high-level heuristics (e.g., 1 month of margin for every year during dev, etc) or on expert judgment
- Schedule allocation enables <u>data-driven</u> derivation of the margin burn-down requirements and provides effective communication to management if they are expending margin faster than assessed for their target completion date



Data-Driven Burn-Down Captures Project Unique Risk Profile

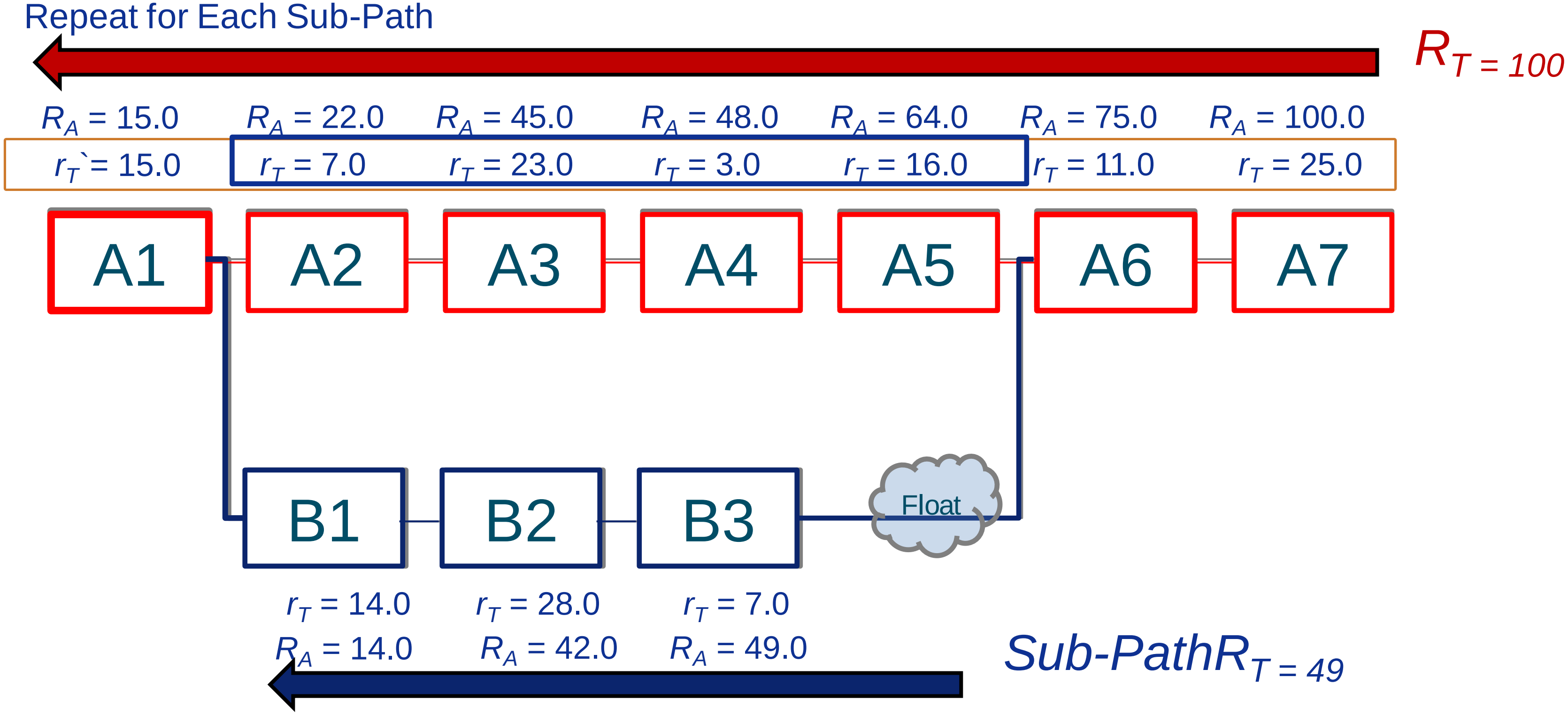
Importance of the Critical Path

- **All schedules have *static* (deterministic) critical path(s)**
- **Project duration can be calculated by *relatively* simple summation along the critical path**
  - Project Duration = Sum of $\text{TaskDurations}_{CP}$ + Sum of TaskLeadLags_{CP}
- **During risk simulation, interesting behavior occurs**
  - In risk models, all constraints are removed so that the overall finish date is free to move
  - The critical path is found to be the end-to-end path with no float
  - On each iteration the critical path can change
  - The criticality index is the percent of time (during simulation) a task is on the critical path
- **The Most Frequent Critical Path (MFCP) is the overall path with the highest frequency of occurrence during simulation**



The LANL Approach

1. **Identify Total Reserve to Allocate (Delta from Confidence Level Target and Deterministic Point Estimate)**
2. **Primary Allocation - Allocate Total Reserve End-to-End Across the Schedule**
   1. Find Most? Critical Path
   2. Calculate Total Reserve Pool
   3. Allocate Reserve to the Duration Point Estimate along this path based on Risk Statistics
3. **Sub-path Allocation(s)**
   1. Calculate Reserve Pools for Each Sub-path based on Primary Allocation
   2. Allocate Reserve Along Sub-Path based on Risk Results
   3. Repeat for Each Sub-Path



Study Identified Enhancements to LANL Algorithm

Enhancement 1: Use Probabilistic Data to Determine the MFCP

- LANL did not provide methodology for determining the Most Critical Path
- Using the Deterministic critical path creates situations where reserves may be inappropriately placed in time
- **Solution:** From the Finish Task, select the preceding task with the highest Criticality Index all the way through the logic to the Start to find the MFCP

Enhancement 2: Use Two-Step Method (Protection and Discretionary) for Allocating Reserves

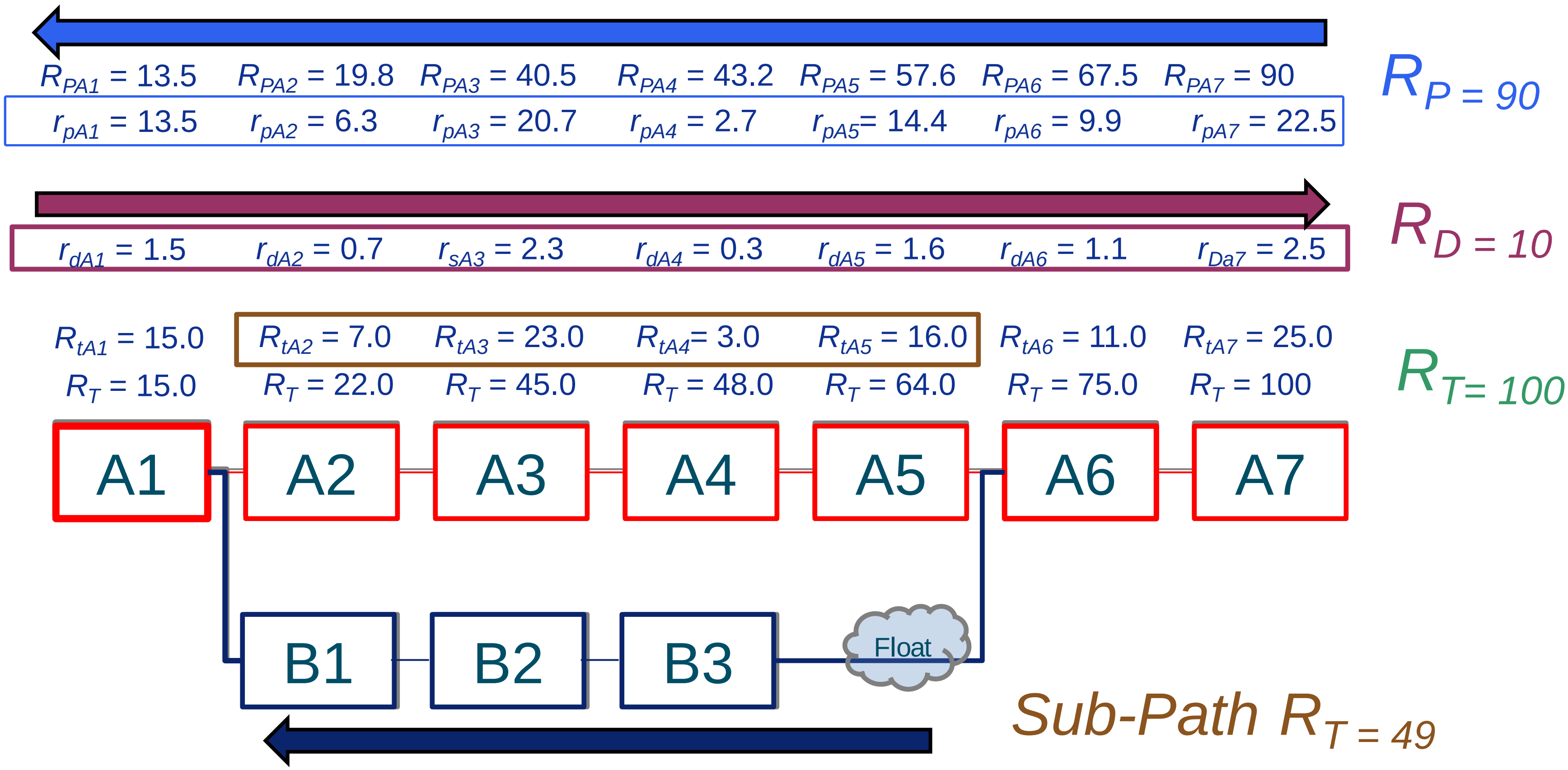
- LANL method applies only a one-step process to the original duration, this creates issues as tasks are at different levels of confidence and position within their distributions
- Using the one-step method creates potential of over and under allocating reserves within the network
- **Solution:** Implement Two-Step method for reserve allocation
  - Step one (Protection) is to adjust all durations to a statistically similar position (e.g., mean, median, CL%) and determine the amount of reserve used and the remaining pool
  - Step two (Discretionary) use statistical metric (e.g., SD, PSD, SV) to allocate remaining pool

Enhancement 3: Use Statistics Conditioned on Criticality for MFCP Allocation

- LANL method uses general statistics, using conditional statistics ensures that the distribution range are valid for when tasks on the MFCP are critical
- **Solution:** Analyze statistics for only the iterations when the task is on the critical path and use as basis for allocation

Schedule Reserve Allocation Algorithm

1. **Allocate Total Available Reserve End-to-End Across the Schedule**
    1. Find Most Frequent Critical Path (MFCP)
    2. Calculate Total Reserve Pool (R_T) by the delta between the Target and the Baseline Duration
    3. Adjust each task in MFCP to a designated metric (e.g., $mean_{CoC}$ and calculate the Protection reserves (R_P) applied
    4. Determine the remaining reserves ($R_T – R_P$) which are available for discretionary use (R_D)
    5. Allocate Discretionary Reserve (R_D) along MFCP based on proration of a Statistical metric (i.e., $+\sigma_{CoC}$)
2. **Calculate Reserve Pools for each Sub-Path and Repeat Allocation Process**



Data Required to Implement Methodology Available from JCL and SRA Models

- **Must know which task in schedule is "final"**
  - Not necessarily last item in schedule, and doesn't have to be final item in logic
  - Schedule needs to be set up so that critical path is measured to that item (e.g., adding a long duration dummy task)
- **Simulation iteration results**
  - Criticality result (on or off critical path) for each task, for each iteration
    - Use for mean criticality
    - Use for statistics conditioned on criticality
  - Duration results for each task, for each iteration
- **Schedule data**
  - Logic – predecessors/successors, relationships (FS, SS, etc.), lags and leads
  - Constraints – ASAP, SNET, etc.
  - Durations and slack

Methodology is Tool Independent

Schedule Reserve Allocation Algorithm Provides Multiple Benefits

- **Establishes a foundation for alignment of budgetary reserves**
  - An allocated schedule aligns the activities in time for where the effort will extend, thereby enabling alignment of costs to the schedule
  - Provides the ability to layer in cost reserves over the baseline execution plan to determine overall funding needs
- **Provides a basis for budgeting schedule margin over time**
  - Allows project manager to determine realistic target dates for major project milestones and contract deliverables
- **Identifies a roadmap for reserve consumption**
  - Project manager can compare finish dates of recently completed activities against plan-with-reserve and determine if a given branch of the schedule is on-track
- **Allows for evaluation of a project or contractor's identified schedule margins**
- **Enables insight into allocating reserves to subordinate organizations**
  - Project manager can set contractual deliverable dates and incentive fee profiles (for contractors) based on an informed understanding of the amount of risk inherent in those dates

Leverages KDP-B and KDP-C Products To Provide Increased Value for Project Management in Operational Execution Phases of a Project

Summary

- **Key Outcomes**
  - Allocation technique has been defined and testing is complete
  - Allocation technique is feasible using data generated during a JCL analysis with current tools
  - Allocation technique has intuitive basis, allowing resonance and communication with decision makers
    - Primary allocation along Most Frequent Critical Path
    - Uses Statistics Conditioned on Criticality for MFCP Allocation
    - Two-step Process of Protection and Discretionary Reserves
  - Provides a flexible framework to allow for continued evolution
  - Establishes a foundation for alignment of cost phasing/reserve identification and use within the operational program management environment

- **Next steps**
  - Develop joint cost/schedule phased allocation alignment algorithm
  - Develop prototype

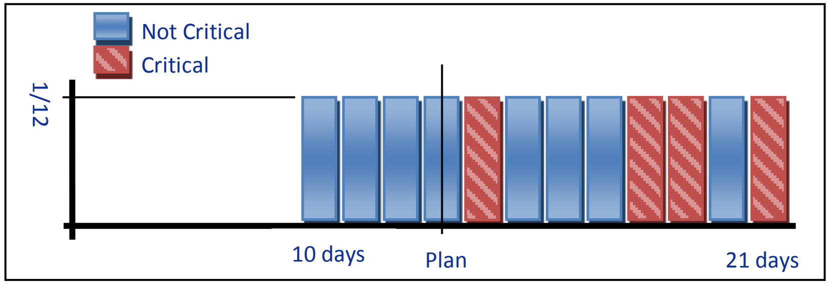
Acknowledgements

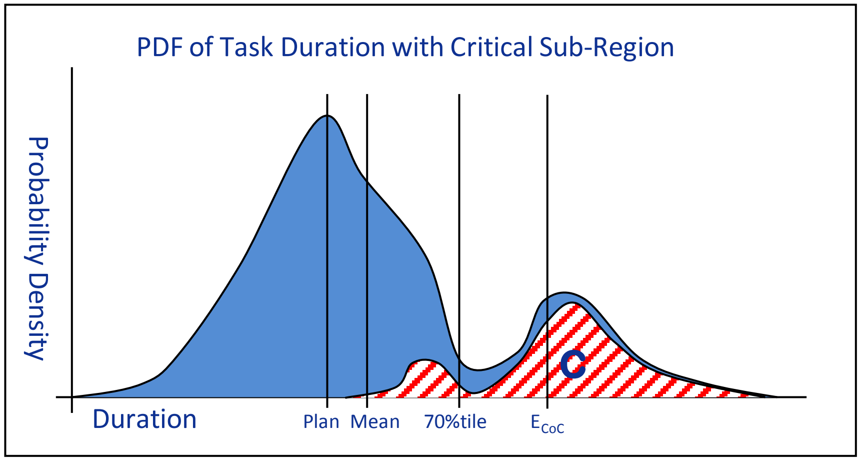
- **We'd like to acknowledge the many individuals who have helped us in this study**
  - GSFC Project Offices
    - GEMS
    - SGSS
    - OSIRIS-REx
  - ARMD ERA Program Office
  - Los Alamos National Laboratory
    - John Kindinger
    - F.K. Houghton
  - Tecolote Research, Inc
    - Shu-Ping Hu
    - Peter Frederic
    - John Sandberg
  - Ray Covert
  - NASA HQ OoE/CAD (James Johnson)

THANK YOU

Conditional Statistics - Conditioning on Criticality for Reserve Allocation

- **Two types of statistics – general and conditional**
- **It is rare for an interim task to appear on the critical path 100% of the time**
  - To the right is a simple example of 12 samples from a uniform distribution. Only 4 elements are critical—meaning that during simulation, they were on the critical path on their respective iterations,
  - Criticality index is 4/12 = 33 1/3%
- **When a task appears on the critical path, it means that if the task has any variation (Growth, Reduction) it will have a direct impact on the overall Finish Date**
- **Statistics (e.g., mean, standard deviation, median, variance, etc) generated from general case differ from those conditioned on criticality (only iterations when critical)**
- **To account for using the tasks on the most critical path, the statistics used should be based on conditional statistics**





When Not On Critical Path, Duration Has no Effect on Finish Date – General Statistics Include These Situations and Should NOT be used as Primary Basis for Reserves

Study Findings on Test Cases

- **MFCP Allocation**
  - Choice of Protection metric sets the general behavior of the allocation scheme
  - Discretionary reserve based on statistical metrics accounts for minor differences within a group
  - Differences within the groups can be subtle, differences between the groups are significant
  - Recommendation is to use $Mean_{COC}$ for Protection and PSD_{COC} for Discretionary
    - Results suggest protection metric hierarch of $Mean_{CoC}$, $Median_{CoC}$, Mean, Median, $TargetCL_{CoC}$, and TargetCL
    - All discretionary metrics within a protection scheme appear to yield similar results
- **Sub-Path Allocation**
  - Conditioned on Criticality statistics not recommended for use
  - Results similar to MFCP allocation, where Protection scheme is driver
  - Recommendation is to use Mean for Protection and SD for Discretionary
    - Easy to calculate, all tools provide the data
    - Conditioned on Non-Criticality results provide a minor improvement, but require user post -processing