(RISK-2196) Removing the Early-Dates Bias in CPM Risk Analysis

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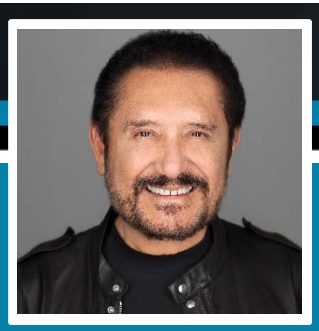
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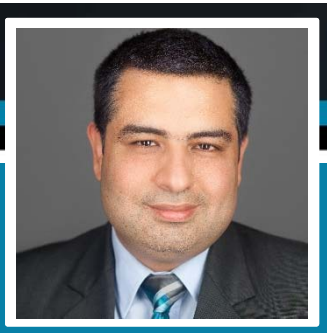
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BIO of Dr. Gui Ponce de Leon

Founder/CEO of PMA Consultants, LLC, a pure project management firm with a 45-year track record

- Professional experience includes executive and senior roles as program manager, project manager, project controls engineer, planner/scheduler, and forensic scheduler
- A project management inventor, who holds 4 US patents on his groundbreaking graphical path method aka GPM
- Awarded in 1972 the first PhD from the construction management program at the University of Michigan
- In 1969, with Prof. Tom Schriber as co-author, presented *Determination of Criticality Indices in the PERT Problem* at the Third Conference on the Application of Simulation



BIO of Dr. Vivek Puri

Senior Associate/Lead Developer
PMA Consultants, LLC

- Experience in construction management research, simulation and risk management, and construction planning and execution
- PhD in Civil Engineering (2012) from Purdue University and M. Tech in Construction Technology and Management (2005) from Indian Institute of Technology Madras, India
- PhD thesis focused on combined continuous and discrete event simulation of project operations and its use in project planning

AGENDA

- Introduction
  - **Conventional Scheduling**
  - **Scheduling Under Uncertainty**
  - **Float Use Impact on Project Completion**
- Graphical Path Method
- Case Study
- Bounding Completion Risk Envelope
- Safe float
- Conclusions

INTRODUCTION

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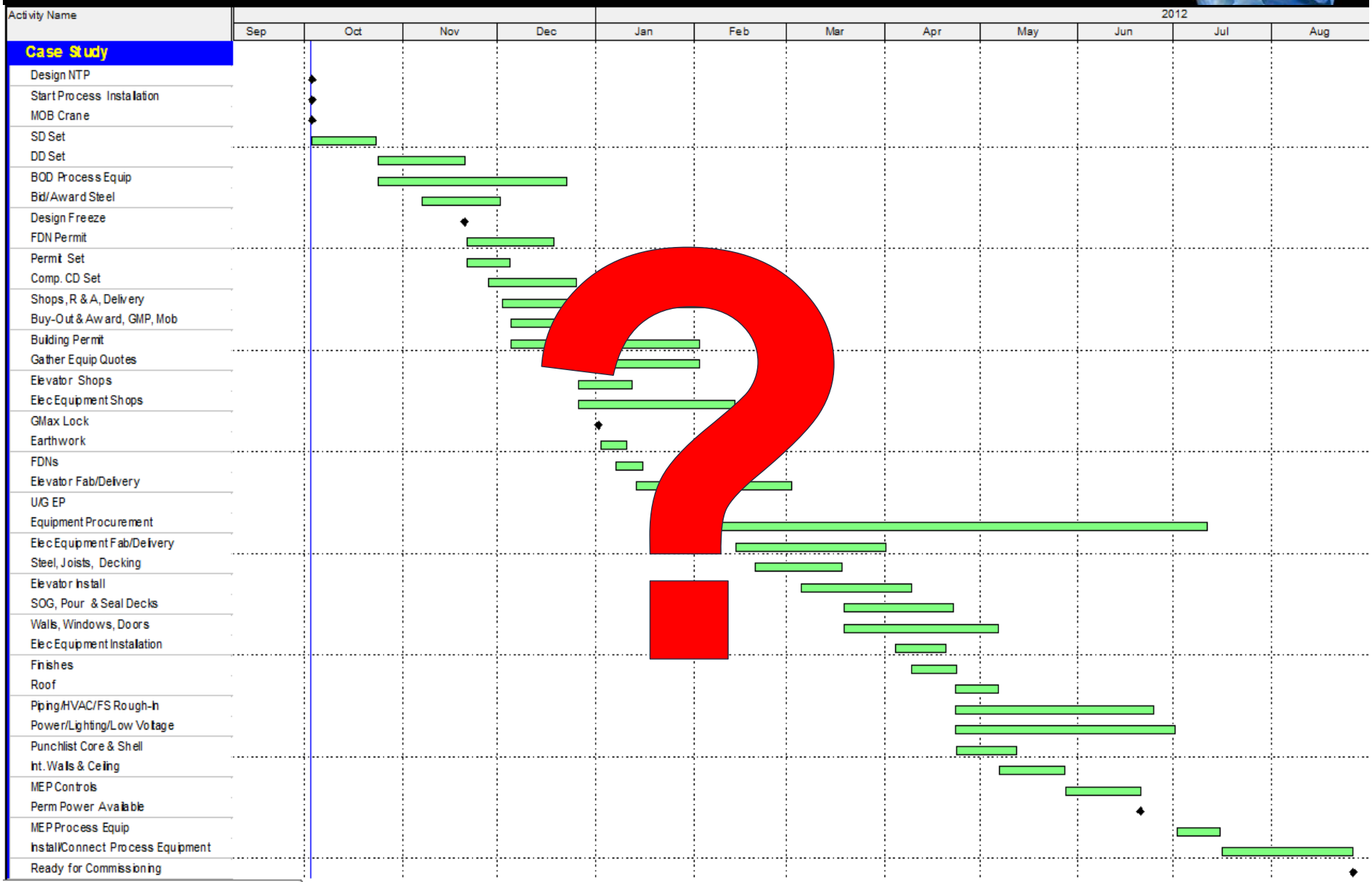


Conventional Scheduling

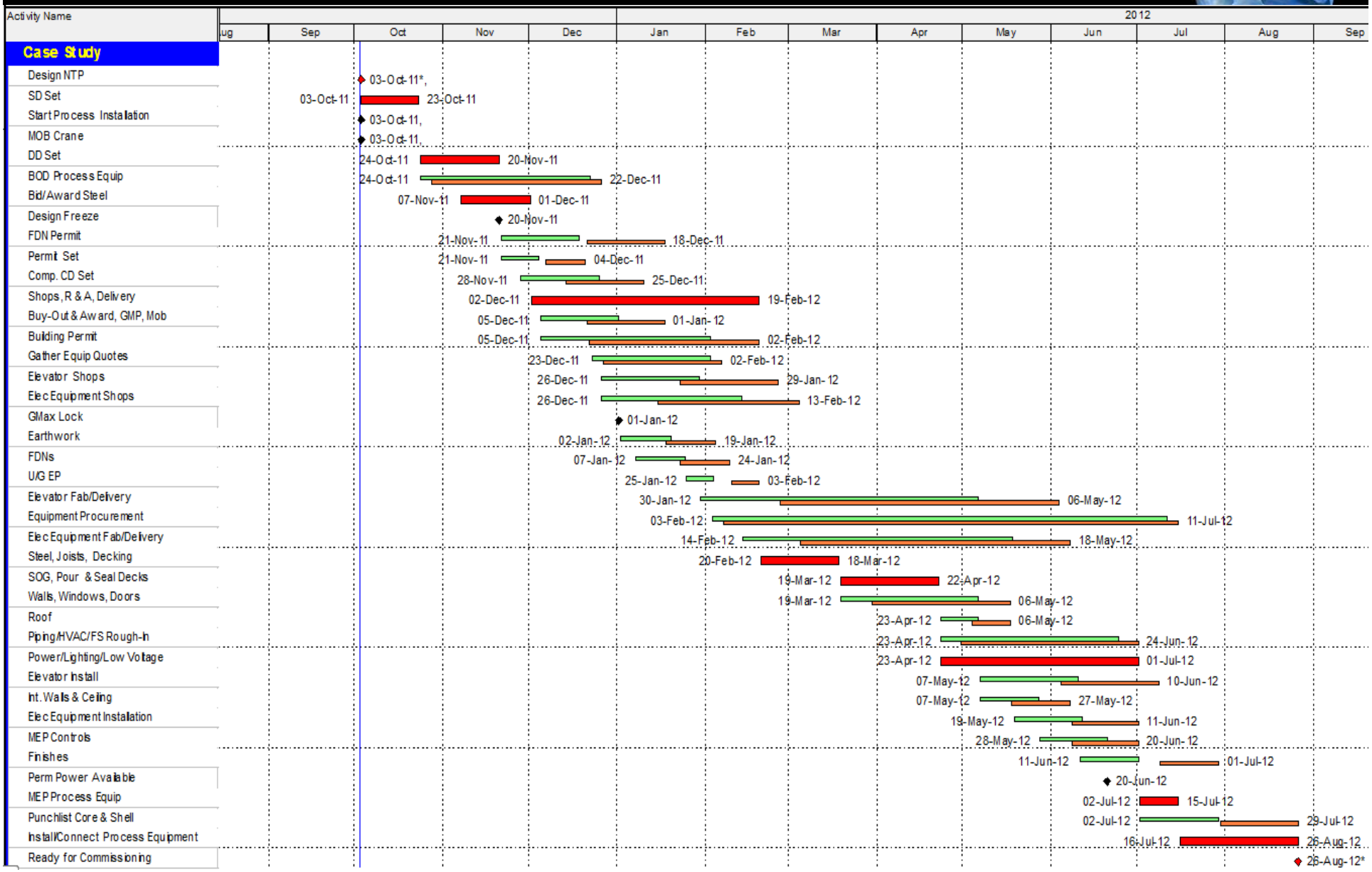


- In critical path method (CPM) scheduling, activity durations are assumed to be known with certainty
  - **Single-point duration estimates**
  - **Schedule uncertainty is dealt with through contingency, e.g., AACE RP 70, Principles of Schedule Contingency Management**
- CPM algorithms functionality
  - **Using a forward pass, activities are scheduled to start on the earliest possible dates largely based on network logic**
  - **Using a backward pass, late dates and total floats are determined by fixing the project completion date**
- CPM is not used where activity durations are uncertain

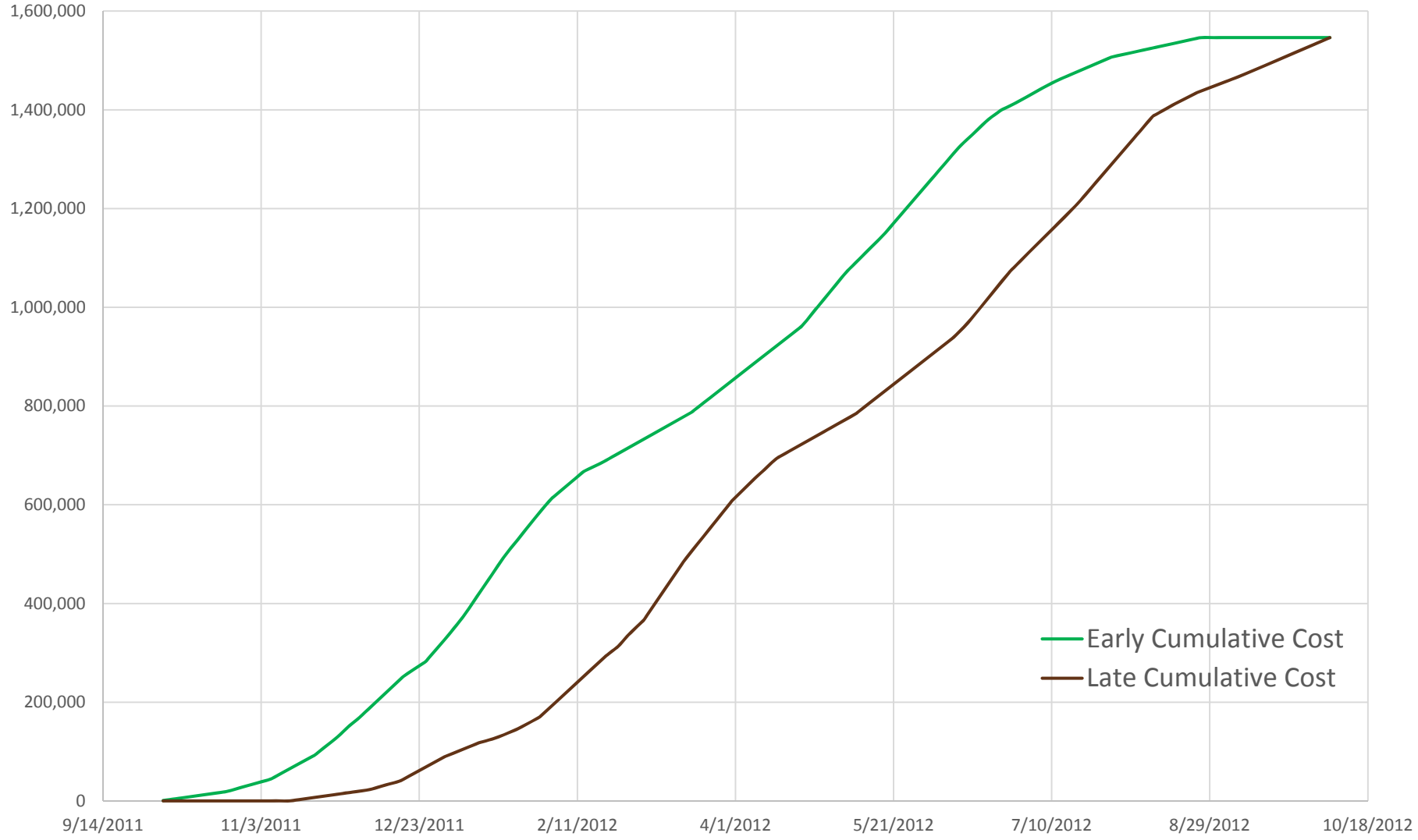
Before CPM, Activities Had One Start Date



With CPM, Activities Have Early & Late Dates



CPM Early & Late Bounding Distribution Curves



Scheduling Under Uncertainty



- Common sources of uncertainty
  - **Production rates, weather, estimating tolerance**
  - **Internal and external risks impacting durations**
- PERT introduced in 1957 for estimation of uncertainty
  - **Activities have three-point duration estimates**
  - **Duration variability follows Beta-PERT distribution**
  - **Using a forward pass much as CPM does, PERT calculates the PERT project duration mean and variance**
  - **Appealing to the central limit theorem, project duration is assumed to follow a normal distribution**

The PERT Merge Bias

- The PERT solution is essentially a longest path algorithm that uses activity mean durations (as approximated by PERT) rather than single-point durations as CPM does
- The PERT approach introduces a merge bias
  - **By calculating mean start dates based on the maximum of the merging paths' mean durations, PERT underestimates mean start dates as the mean of the longest path is greater than or equal to the maximum of the merging paths' mean durations**

Schedule Simulation or Schedule Risk Analysis



- Van Slyke (1963) introduced a Monte Carlo simulation approach to correct for the underestimation from merge bias inherent in the PERT expected completion date
- Schedule simulation overcomes PERT limitations
  - **Uses any distribution to model activity duration uncertainty**
  - **Rather than using mean durations to develop one early-schedule occurrence of the project schedule, simulation uses sampled activity durations to develop multiple early-schedule occurrences of the project schedule**
  - **Each early-schedule occurrence is based on the sampled longest path thereby removing the PERT merge bias**
  - **Models risks & correlations**

Early-Dates Bias in CPM Schedule Risk Analysis



- By scheduling activities on early starts in every iteration, CPM risk analysis does not account for the impact of delayed or late starts (impact of float use) on project completion:
  - **The early-dates limitation is a deviation from the actual system modeled; on actual projects, activities off the critical are often *floated* and start later, making use of total float**
- By not modeling floating risk in any iteration, CPM risk analysis merely develops the early completion risk function because decisions to use float have a likelihood of causing critical path delay and affect the project completion date

Project Completion Distribution Curve



Float Use Impact on Project Completion



- On actual projects, it is common practice to delay non-critical work by using available total float
  - **Level resources**
  - **Pace progress**
  - **Other strategic reasons**
- Where activities have uncertain durations, floating activities in a simulation iteration–even within available float–alters the merge risk, which in turn risks a delay in completion
  - **High-total-float paths do not affect early-dates merge bias**
  - **When a high-total-float activity is floated by a sufficient amount of available float, the delay in start puts the activity closer to the merge event, and coupled with duration uncertainty has a likelihood of impacting completion**

GRAPHICAL PATH METHOD

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Graphical Path Method (GPM)

- Planning/scheduling method that allows planners to place activities on GPM *planned dates* between early and late dates while retaining the algorithmic early and late dates
- GPM planned dates generate drift
  - **Drift is unique to GPM as drift in CPM is always zero**
- GPM planned dates also generate float
  - **Float as a subdivision of total float is unique to GPM, as float in CPM is always equal to total float**

Graphical Path Method

- In GPM, regardless of planned start date established for an activity, drift + float always equals total float
  - **In GPM, planned dates generate drift without suppressing total float thereby preserving total float continuity**
- In CPM, date constraints that override logic do not generate drift, suppress total float, and cause total float discontinuity

Graphical Path Method *(cont'd)*

- Planned dates obviate the need for SNE date constraints, which makes GPM invaluable for assessing schedule risk as date constraints can adversely impact simulation results
- AACEI Recommended Practice No. 57R-09 recommends:
  - **The schedule should not rely on constraints to force activities to start or finish by certain dates**
  - **It should use logic for this purpose and not artificially reduce or restrict total float**

Core Tenets of GPM-Based Schedule Simulation



- Tenet #1–Each iteration begins with the base-case scenario and unfolds activity by activity according to network logic, as a simulated update of the base-case scenario
  - **Each iteration is a simulated progression of time rather than a batch replacement of activity duration**
- Tenet #2–In each iteration, activities may be scheduled on GPM planned dates, either because
  - **GPM planned dates are present in the base case, or**
  - **Positive-float activities, through sampling, are allowed to float by using a portion or all of then-available float**
- Tenet #3–In each iteration, the longest path has the least total float; late finish date of the last activity on the longest path equals its early finish date or the project finish date

CASE STUDY

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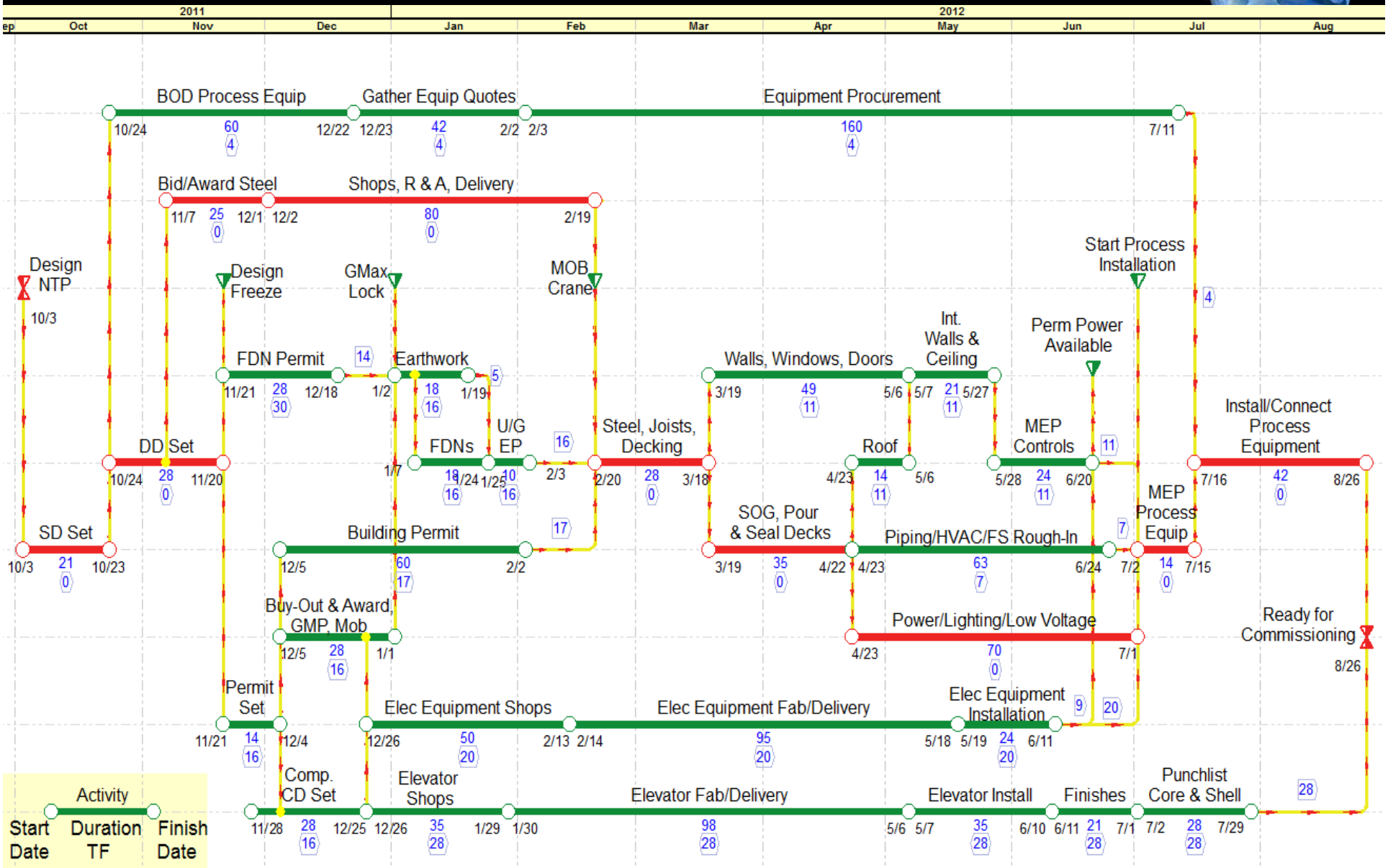


Case Study

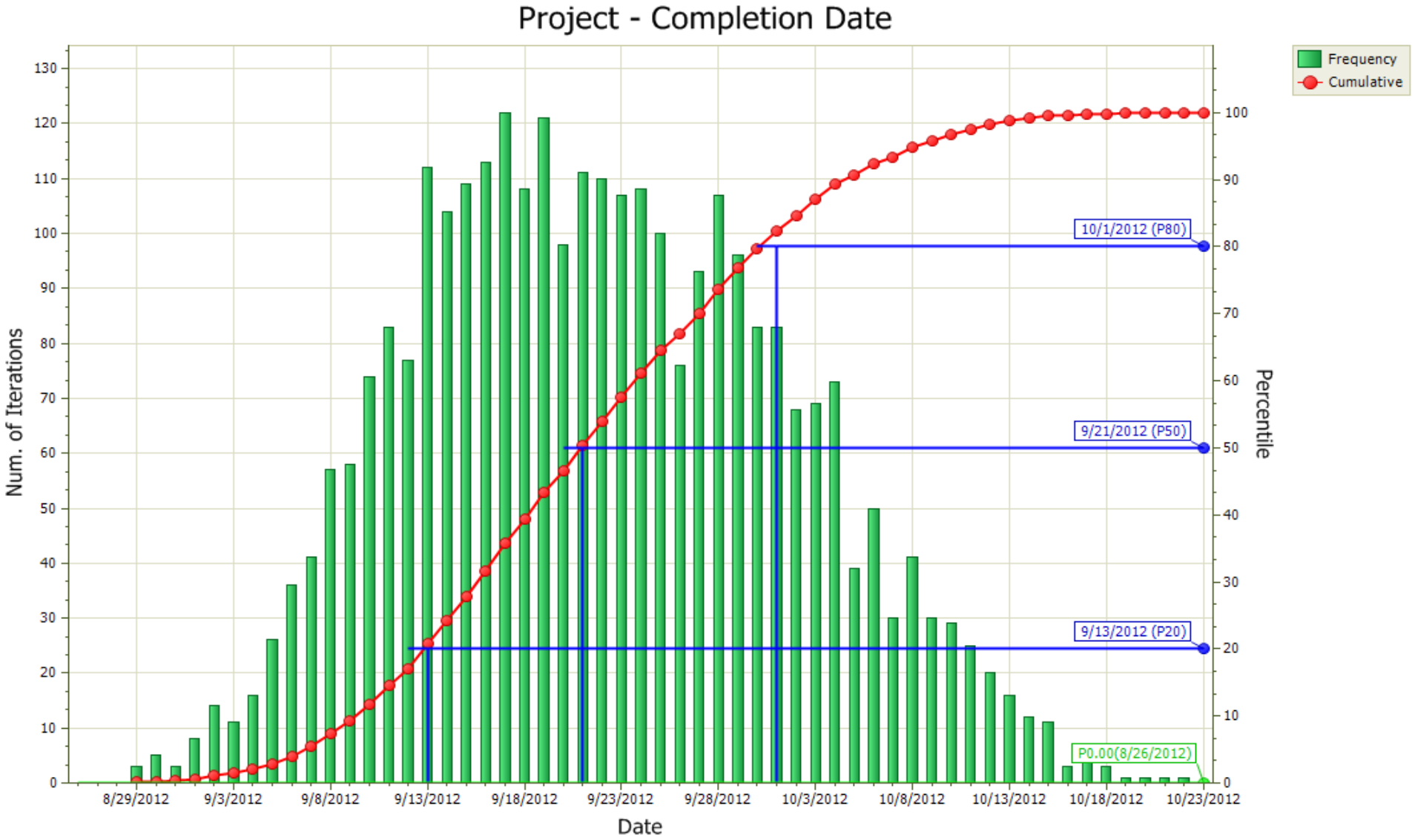


- Design-build contract to rebuild food processing facility
- Project Completion
  - **Required by 10/06/2012**
  - **Early planned completion by 08/26/2012**
  - **Total Duration: 328 calendar days**
  - **Early completion total float: 41 days (12.5%)**
- Modeled and simulated using NetPoint®/NetRisk™
- For simplicity,
  - **3-point duration estimates follow triangular distribution**
  - **All uncertainty in duration ranges, no other risks**

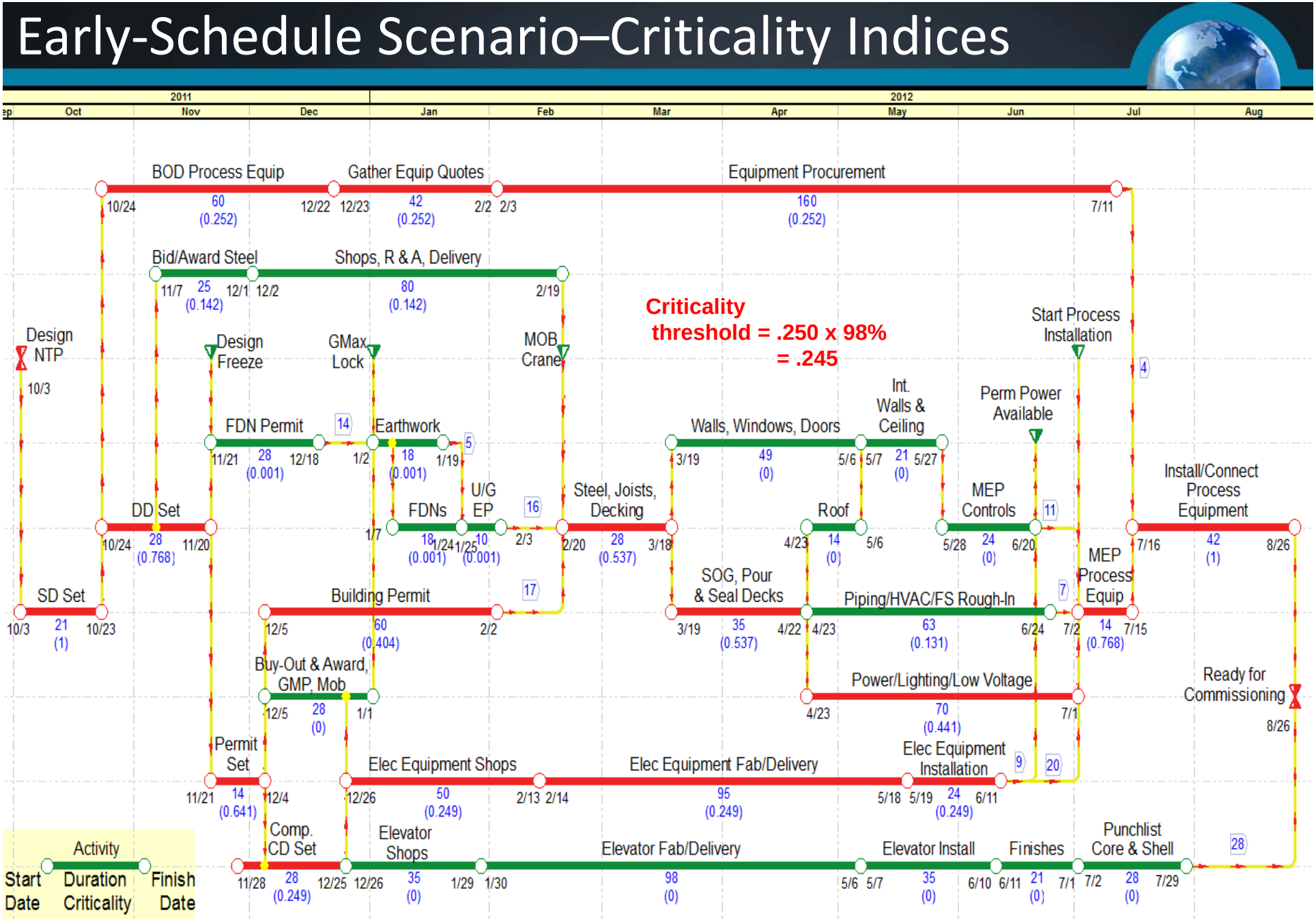
Project Schedule–Base-Case Scenario



Early-Schedule Scenario–Completion Distribution



Early-Schedule Scenario–Criticality Indices



BOUNDING COMPLETION RISK ENVELOPE

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Float Use by Modeling Floating and Pacing



- Floating
  - **Delayed start of activity to consume available float**
  - **Independent of actual progress**
  - **Random decision**
- Pacing
  - **Delayed start of activity to consume available float**
  - **Delay in another path increases available float**
  - **Decision based on threshold of current float to deterministic float**

Optimism Bias in CPM-Based Simulation



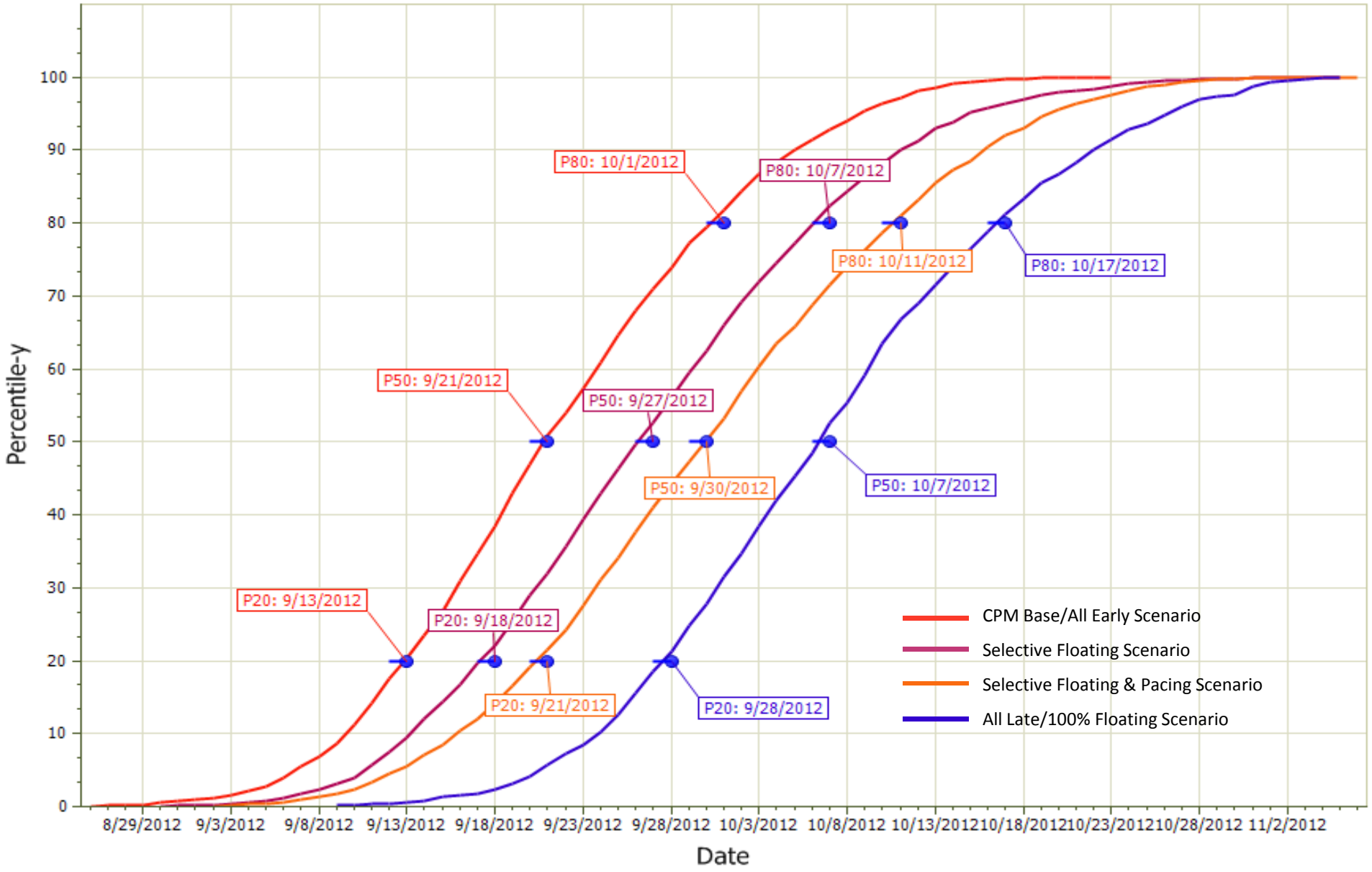
- CPM-based simulation is unable to model floating/pacing
  - **Activities are scheduled on early dates in each iteration**
  - **Impact of delayed start of any activity not considered**
  - **No decision-based rules to model floating/pacing**
- CPM-based simulation yields an optimistic completion distribution because it is predicated on the early-schedule
  - **For instance, a P80 date without considering floating may be the P60 date under a postulated floating scenario**

Modeling Bounding Completion Risk Envelope



- CPM-based simulation provides the envelope upper bound
  - **Activities always scheduled to start on early dates**
  - **The upper bound is the early-schedule completion risk curve**
- Although the maximum delay in project completion due to floating is theoretically unbounded, an envelope lower bound can be determined by assuming floating is limited by then-available float
  - **Modeled by floating activities off the critical path with 100% probability and using 100% of then-available float (meaning, float available at that point in an iteration)**
  - **Represents the late completion risk curve (different than starting activities on late dates)**

Bounding Completion Risk Envelope



SAFE FLOAT

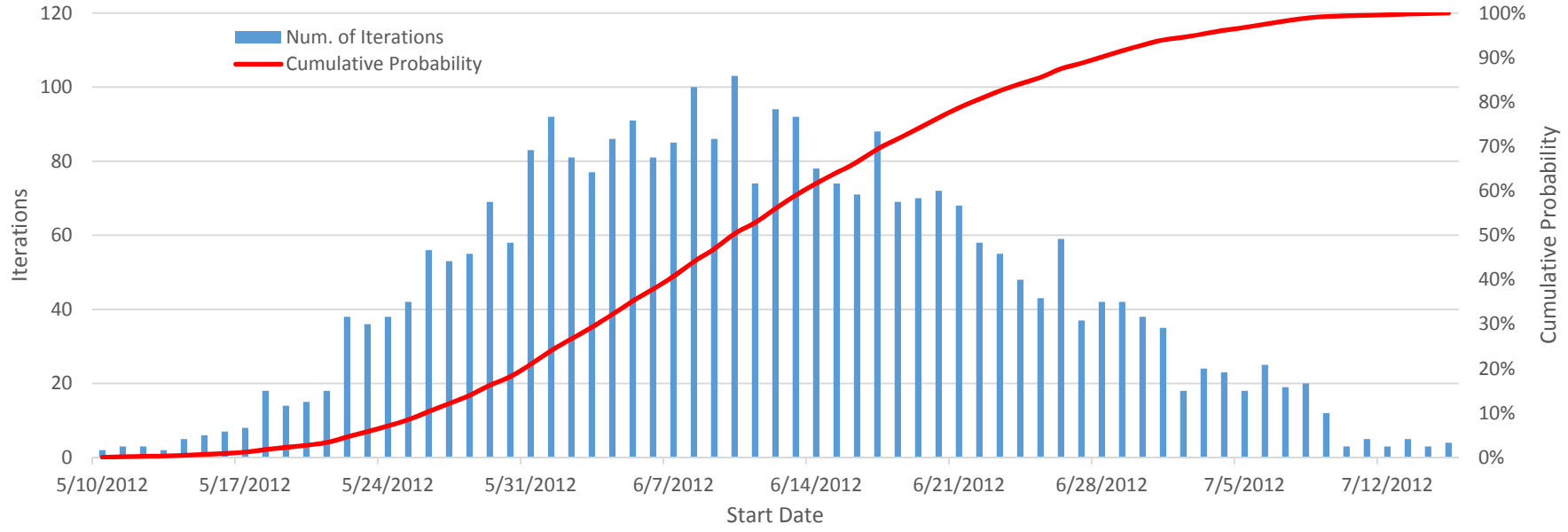


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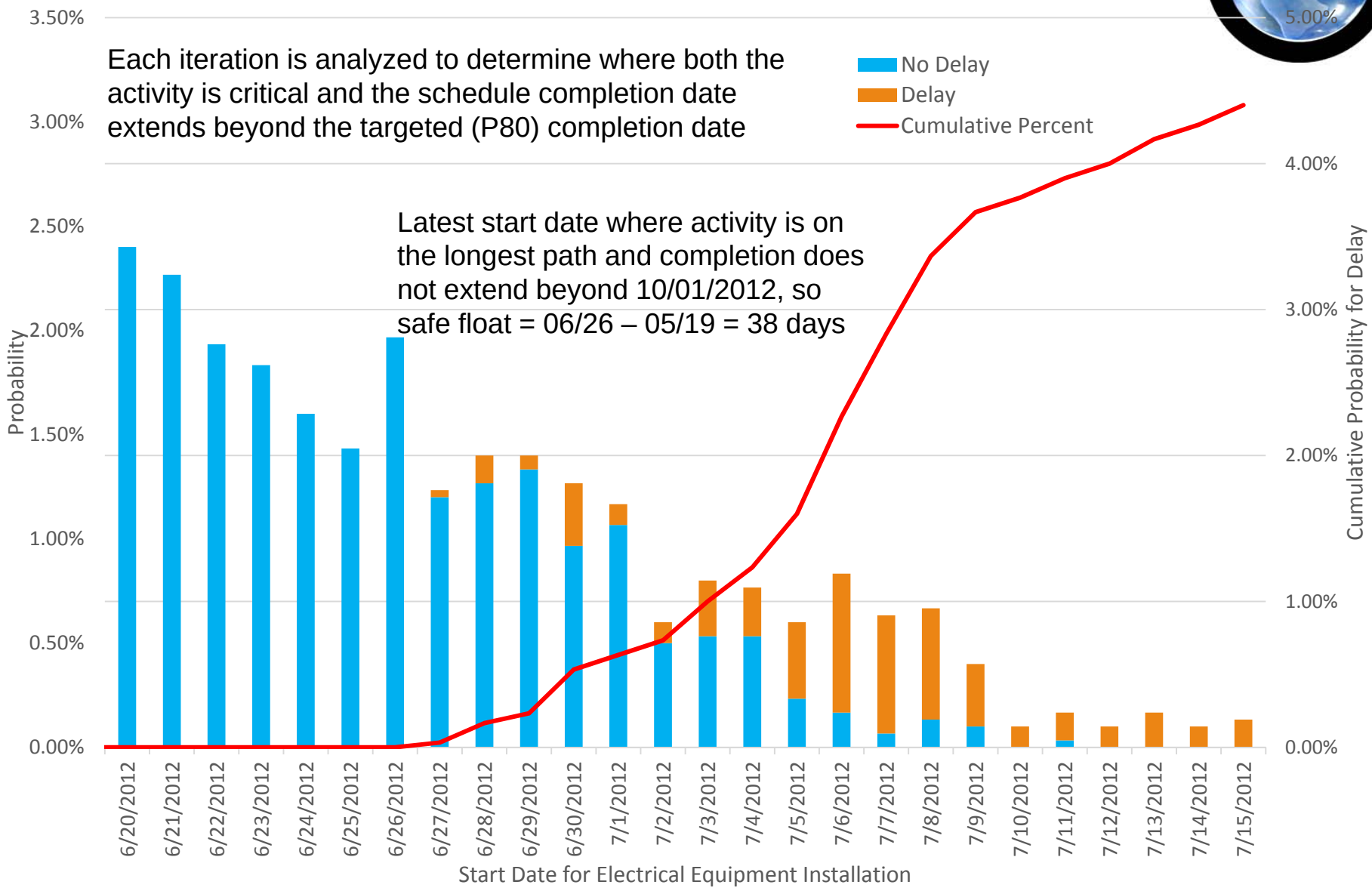
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Safe Float

- Safe float: within modeled uncertainty, extent an activity may be delayed from its base-case early start date without delaying the targeted (P value) project completion date
- Activity *Elec Equipment Installation* (early-dates simulation)
  - **Stochastic earliest Start: 05/10/2012**
  - **Stochastic latest Start: 07/15/2012**



Safe-Float Use–Stochastic Approach

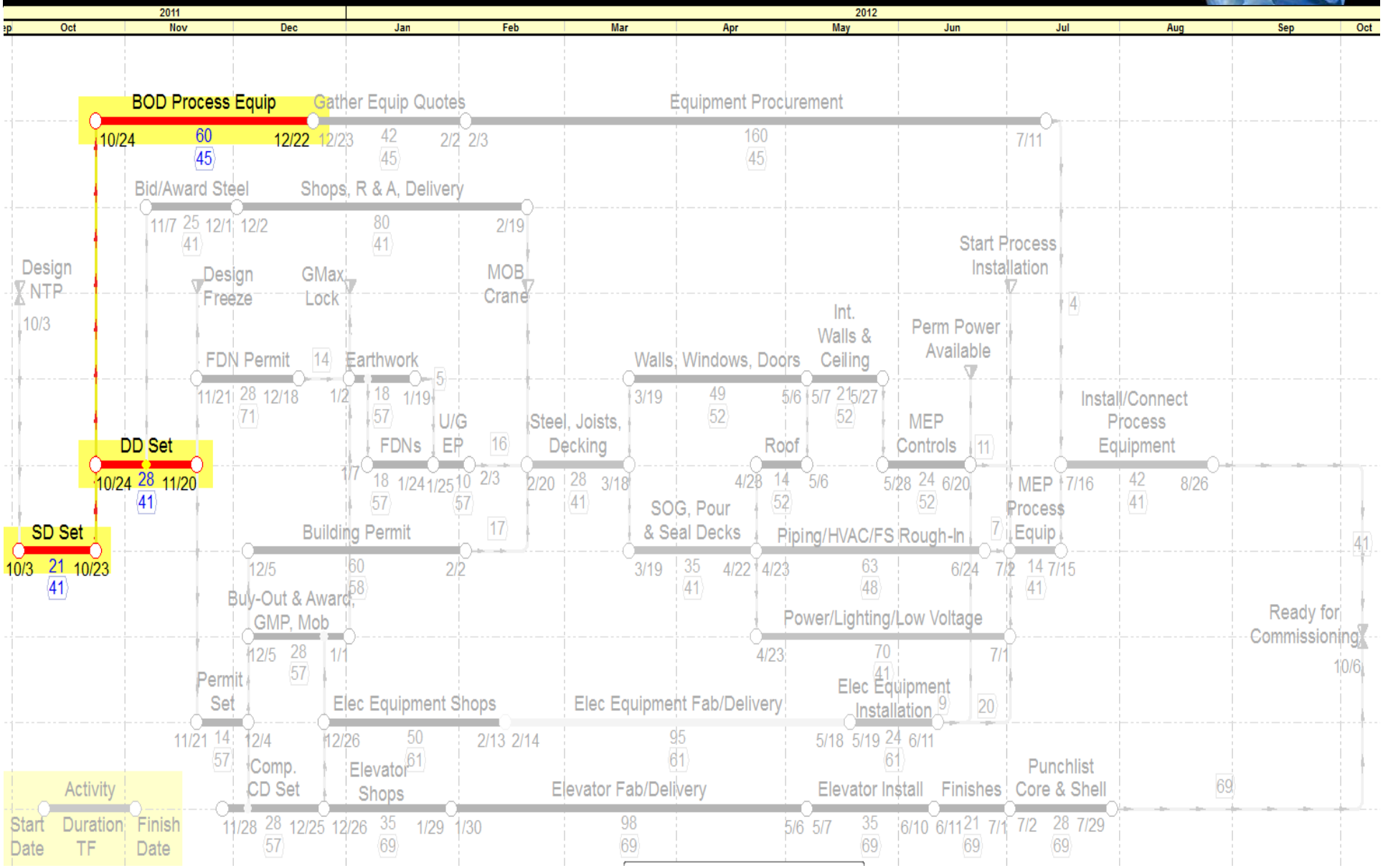


Safe-Float Use–Analyzing Results



- 3000 iterations
- Targeted (P80 date) project completion by 10/01/2012
  - **Latest start without delay 06/26/2012**
  - **98 days to targeted project completion**
- Remaining path length > 98 days
  - **Assuming the path to be always driving**
  - **Probability ≤ 0.012, practically insignificant**
- Safe float = safe float start date - base-case early start date

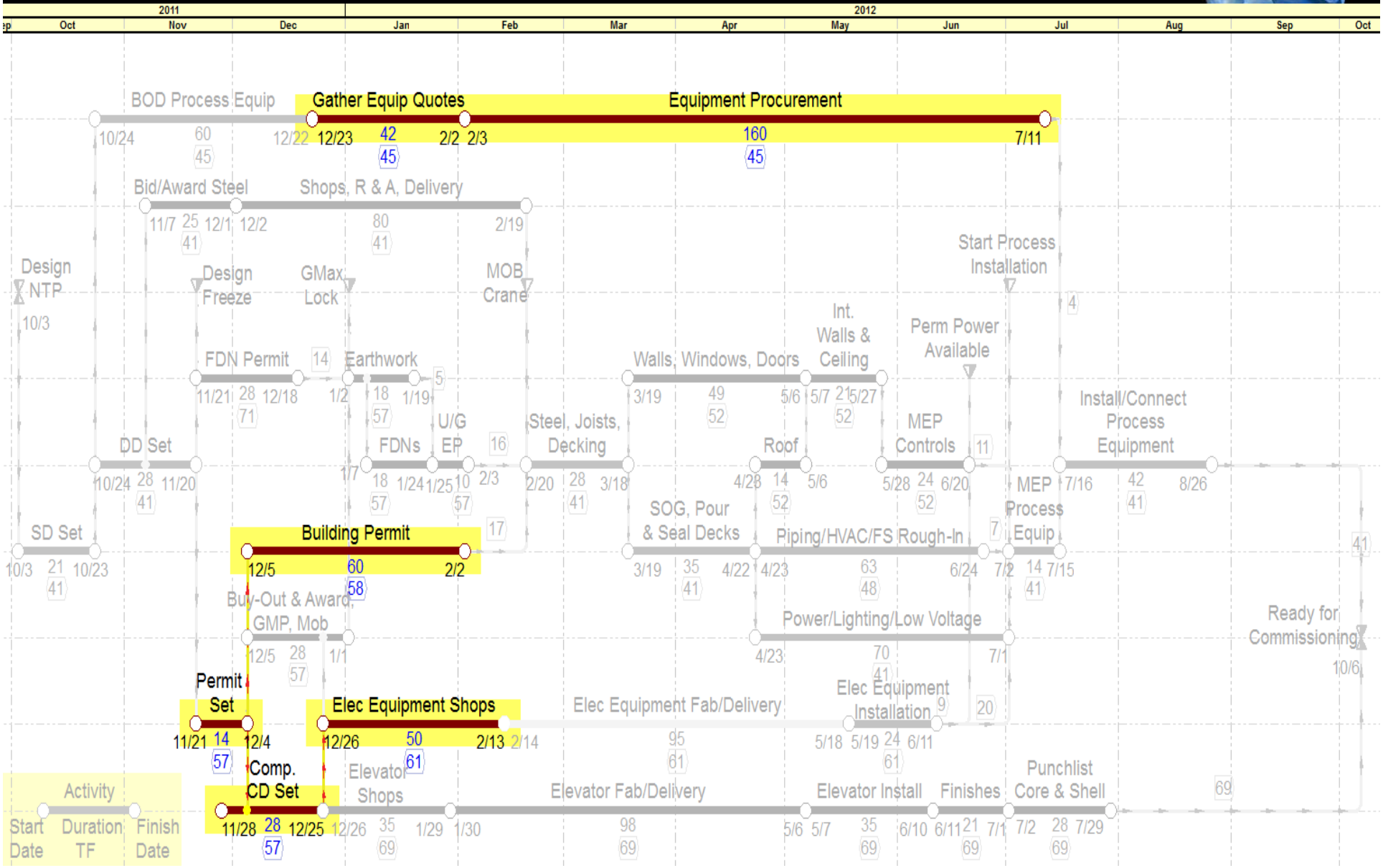
Unsafe-Float Activities: No Safe Float Start Dates



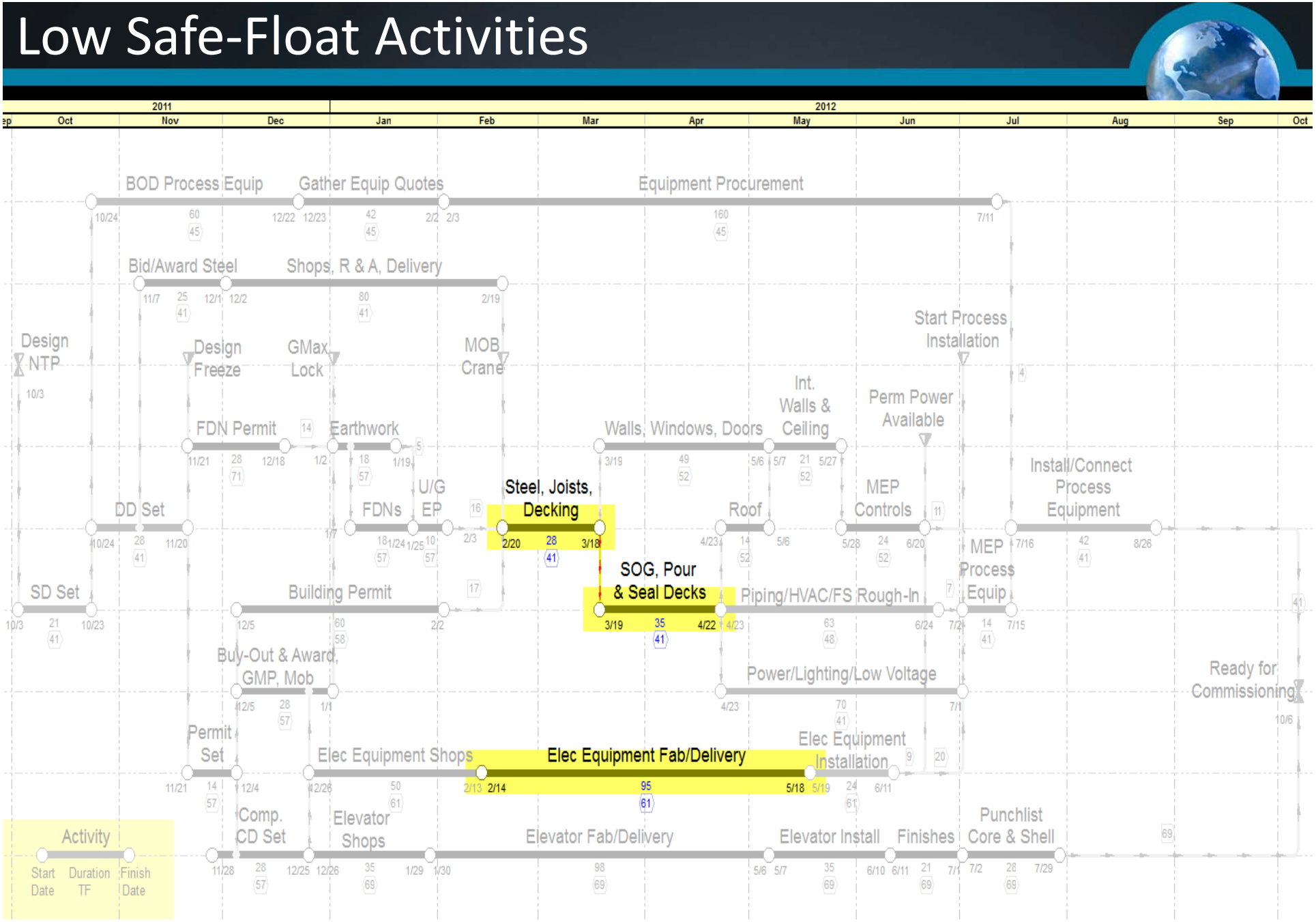
Categorizing Activities Using Safe Float Range

- **Unsafe-float activities**: under high duration variability, there may be two types of activities without safe float whatsoever
  - **Type 1: no possible start date later than the stochastic optimistic early start without delaying targeted completion**
  - **Type 2: no possible start date later than the base-case early start date without delaying targeted (P value)completion**
- **Low safe-float activities**: have safe float below a threshold, for example, safe float < 20 days
- **Mid safe-float activities**: Have safe float above a threshold, for example safe float ≥ 20 days
- **High safe-float activities**: have unbounded safe float within modeled uncertainty

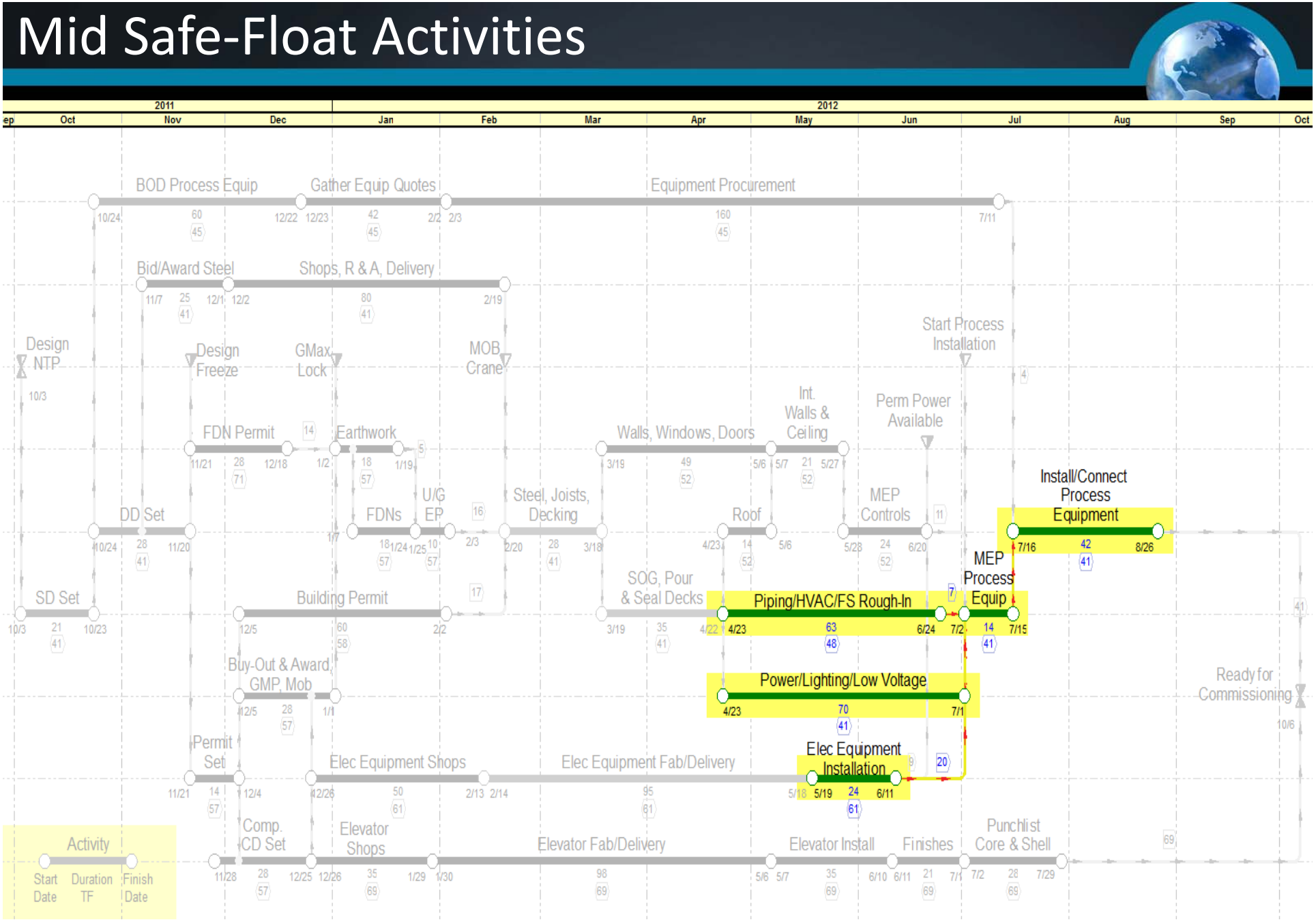
Type 2 *Unsafe*-Float Activities



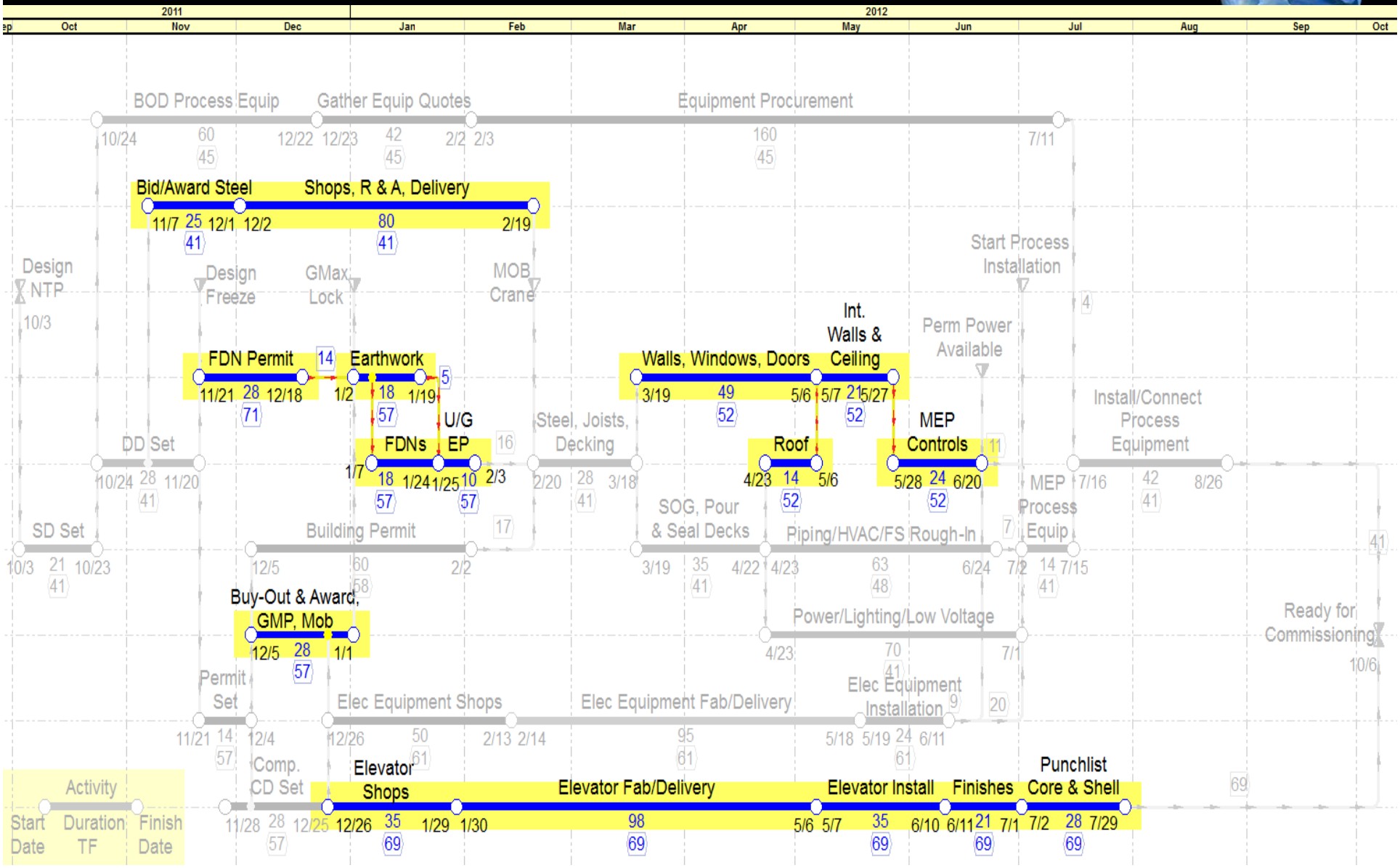
Low Safe-Float Activities



Mid Safe-Float Activities



High Safe-Float Activities

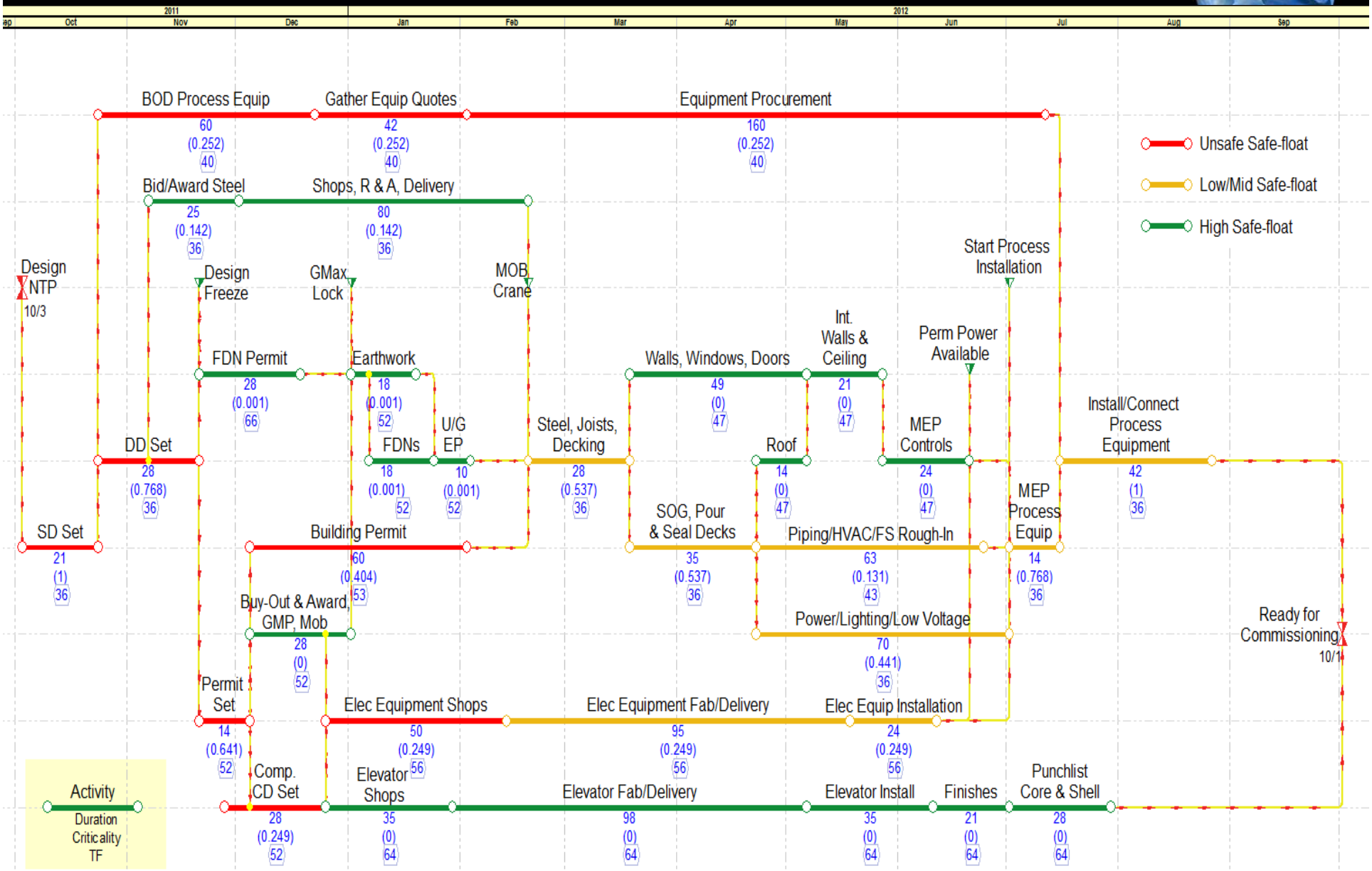


Safe-Float Values (Low & Mid)



Activity Description	Criticality	Base-Case Start Date	Safe-Float Start Date	Total Float	Safe-float
Elec Equipment Fab/Delivery	0.249	2/14/2012	2/16/2012	56	2
Steel, Joists, Decking	0.537	2/20/2012	3/9/2012	36	18
SOG, Pour & Seal Decks	0.537	3/19/2012	4/7/2012	36	19
Power/Lighting/Low Voltage	0.441	4/23/2012	5/14/2012	36	21
Piping/HVAC/FS Rough-In	0.131	4/23/2012	5/16/2012	43	23
MEP Process Equip	0.768	7/2/2012	7/27/2012	36	25
Install/Connect Process Equipment	1.000	7/16/2012	8/13/2012	36	28
Elec Equipment Installation	0.249	5/19/2012	6/26/2012	56	38

Safe-float & Criticality Overlay



CONCLUSIONS



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Conclusions

1. While correcting for the PERT merge bias, CPM risk analysis determines only the ***early-schedule*** completion risk curve
2. When merge bias from randomly selected delayed starts is considered, ***multiple*** completion risk curves are revealed
3. The ***100%-float-use scenario*** yields the stochastic equivalent of the late schedule impact on completion risk
4. With GPM, risk analysis catches up with the notion of bounding early/late distributions; targeted completion dates have a reliable P value that considers floating risk
5. A method is introduced to determine safe float, regardless of scenario, without impacting target completion (P date)
6. The method allows determination of unsafe-float activities
7. Activities are categorized as low and mid safe float based on selected safe-float thresholds and high safe float where safe float is *unbounded* by modeled uncertainty

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