Applying Schedule Uncertainty in JCLs – Problems and Solutions

NASA Annual Cost and Schedule Symposium

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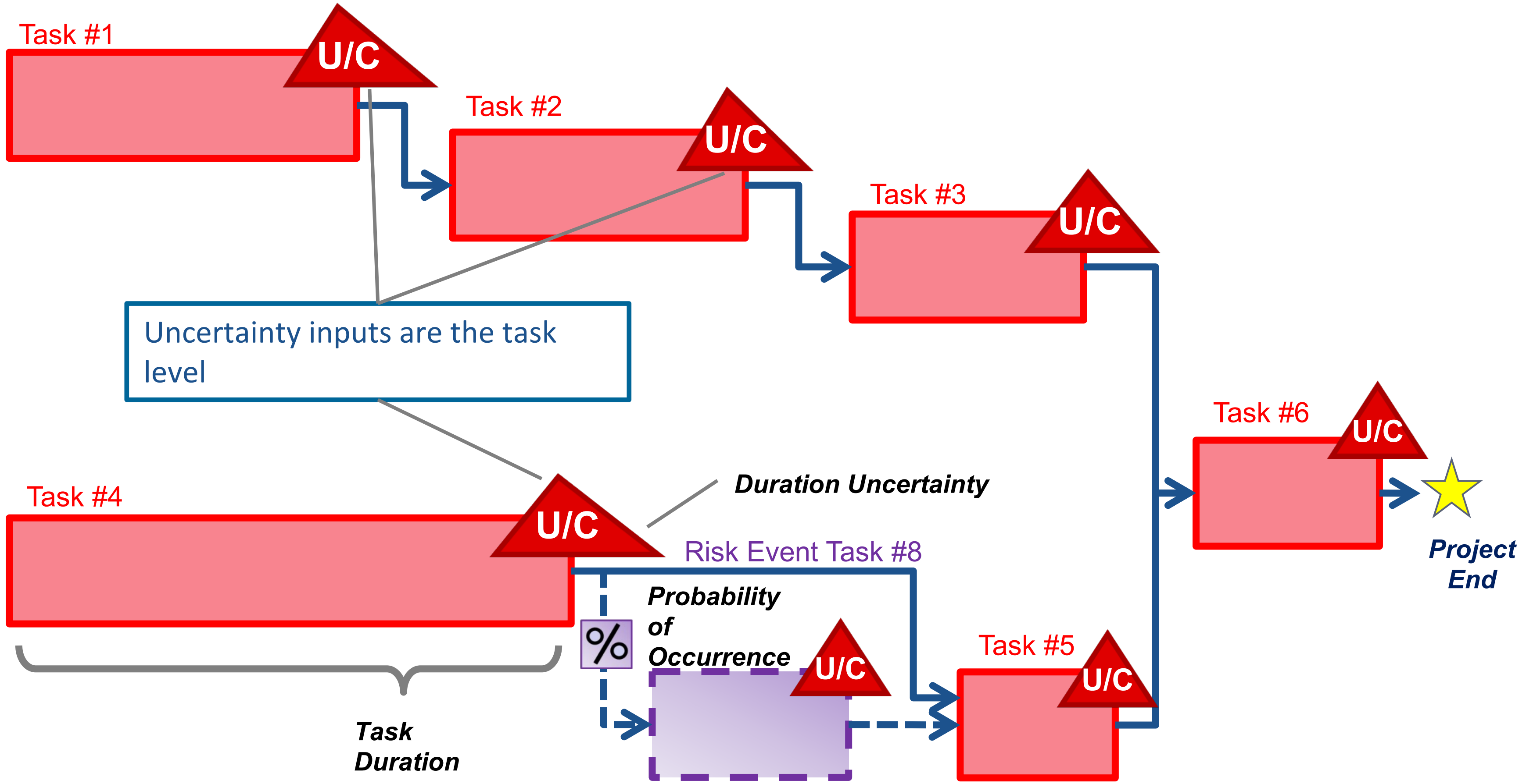
TECOLOTE RESEARCH

Background

- Schedule Risk Analyses (SRA), performed alone or as a part of a JCL, have several unique challenges:
  - The application of uncertainty because of the mismatch between data and input
  - SRA results tend to have lower variability, a particular difficulty when applying NASA's JCL policy
- These issues are related and this presentation provides an approach that hopefully alleviates them for future modelers
- Benefits include:
  - Simpler, more defensible method of using data to generate uncertainty inputs
  - Higher variability in results in a way that is logically connected to inputs
  - More predictable relationship between input and output

The key is accepting the limitations of our inputs in spite of highly-detailed schedules

The Schedule Risk Analysis - Concept



- Activities have a planned duration with uncertainty on those durations
  - The model simulates possible combinations of these uncertainties and finds a distribution of outcomes
- Different tools have different ways of entering groups of input and handling correlation
- The simulation models individual tasks

Available Schedule Data

- No historical data at the task level
  - ONCE has a database of schedule files, but need to parse and map tasks to each other
  - There are issues with assigning uncertainty based on task-level inputs (Whitley, 2014)
- Good modeling practice: Don't model below the level of your data

What schedule data is usually available?

	ATP	SRR - MDR/SDR	PDR	CDR	SIR	TRR	I&T END Date	PSR	LRD	Actual Launch Date
Mission Level										
SPACECRAFT ELEMENT										
Spacecraft Bus										
Attitude Control Subsystem										
Command and Data Handling										
Communications Subsystem										
Propulsion Subsystem										
Structure Subsystem										
Thermal Control Subsystem										
Wire harness										
Software Development										
PAYLOAD ELEMENT										
Instrument 1										
Instrument 2										
Instrument 3										

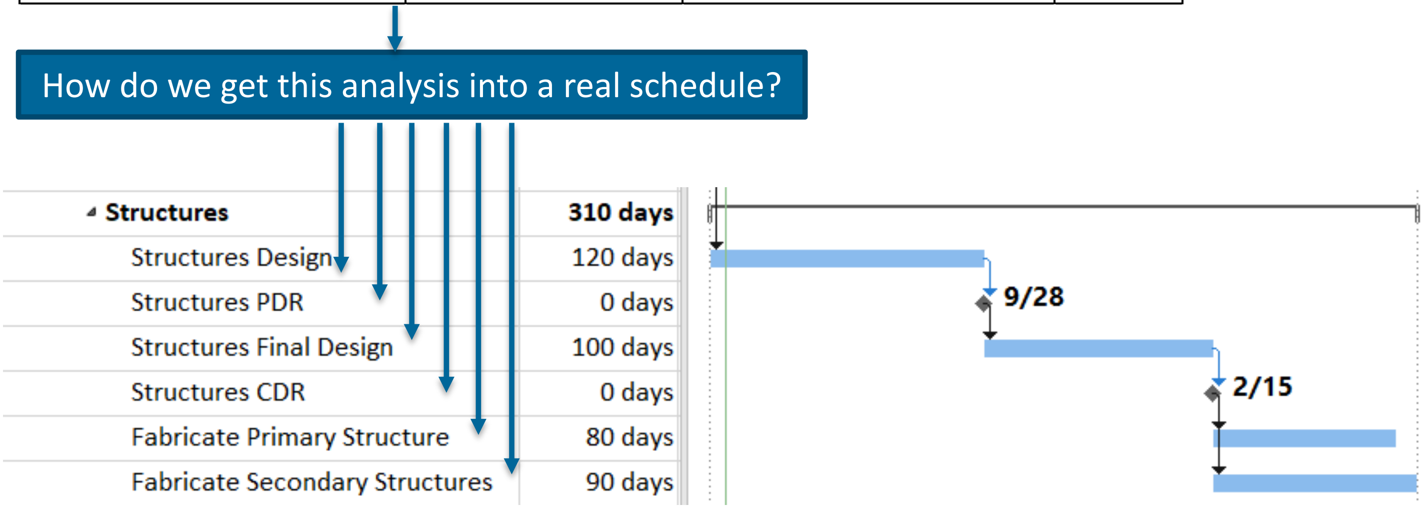
CADRe Part C template gives us one example: Mission, SC and subsystems, and instruments by milestone

Schedule data will be at a higher level than our inputs

Disconnect from Analysis to Input

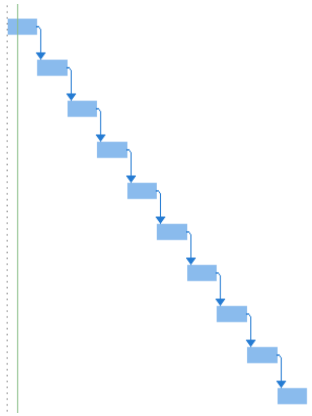
- Analysis may look at historical data (e.g., CADRe), elicit SME input, group activities by some metric (e.g., complexity), etc.
- The problem is that the analysis does not reach down to the individual activity level

	Confidence of Success	Mean Duration (% of Planned)	CV
Structures Subsystem Analysis:	33%	120%	0.32



Quick Discussion on Schedule Math Issues

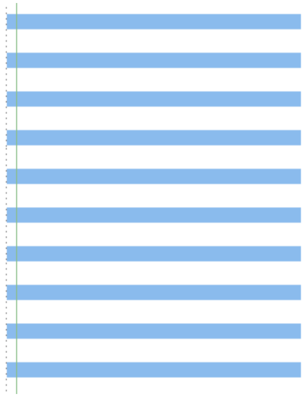
- Our example structures subsystem analysis on the prior slide can be decently modeled with a triangular distribution*:
  - Low=80%, Mode=100%, High=165%
  - Low/high percentiles are 15%/85%



Name	Planned Duration	Mean Duration	CV
Serial Task Summary	200	242	0.1
Task 1	20	24.2	0.32
Task 2	20	24.2	0.32
Task 3	20	24.2	0.32
Task 4	20	24.2	0.32
Task 5	20	24.2	0.32
Task 6	20	24.2	0.32
Task 7	20	24.2	0.32
Task 8	20	24.2	0.32
Task 9	20	24.2	0.32
Task 10	20	24.2	0.32

Mean makes sense!*

Yikes!



Name	Planned Duration	Mean Duration	CV
Parallel Task Example	200	366.3	0.11
Task 1	200	241.6	0.32
Task 2	200	241.6	0.32
Task 3	200	241.6	0.32
Task 4	200	241.6	0.32
Task 5	200	241.6	0.32
Task 6	200	241.6	0.32
Task 7	200	241.6	0.32
Task 8	200	241.6	0.32
Task 9	200	241.6	0.32
Task 10	200	241.6	0.32

Mean Demonstrates Merge Bias!

Yikes!

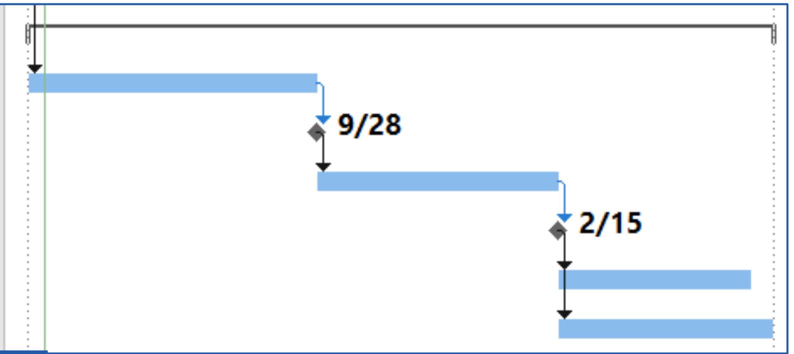
* The mean of this distribution is ~121% instead of 120% - I wouldn't mention it except it's obvious in the example!

Impact on Example Analysis

Input

	Confidence of Success	Mean Duration (% of Planned)	CV
Structures Subsystem Analysis:	33%	120%	0.32

Structures	**310 days**
Structures Design	120 days
Structures PDR	0 days
Structures Final Design	100 days
Structures CDR	0 days
Fabricate Primary Structure	80 days
Fabricate Secondary Structures	90 days

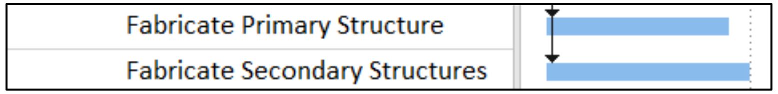


Output

	Confidence of Success	Mean Duration (% of Planned)	CV
Structures Subsystem Output:	13%	125%	0.17

Our schedule model mangles our high-level data:
Input and output don't match

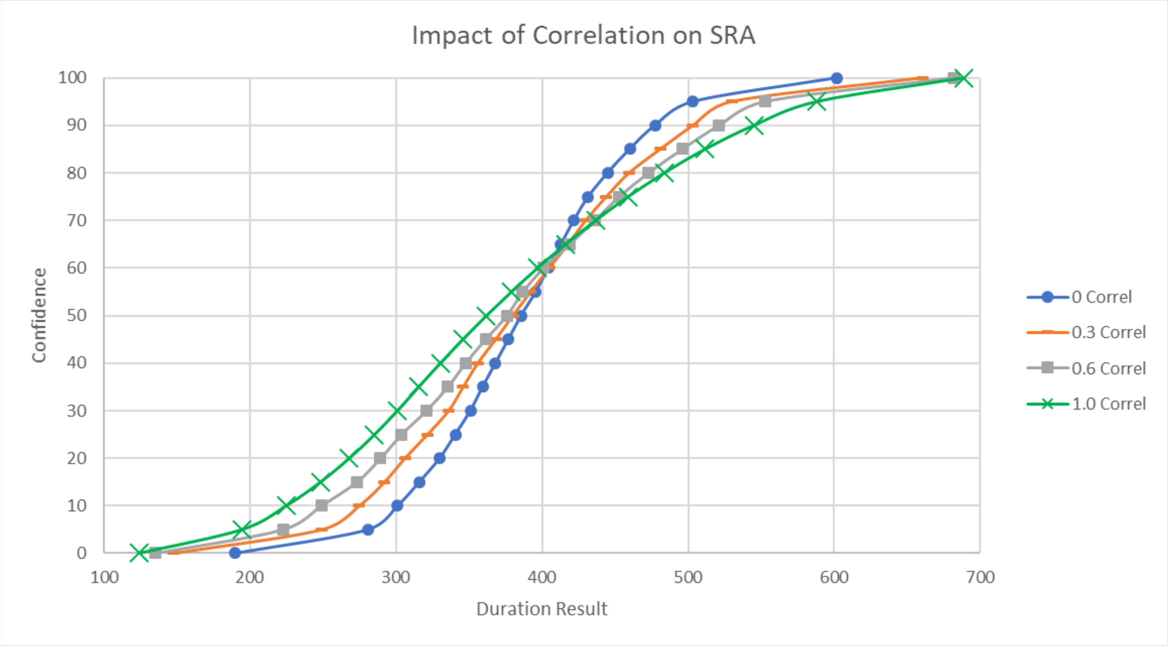
Impact on Critical Path

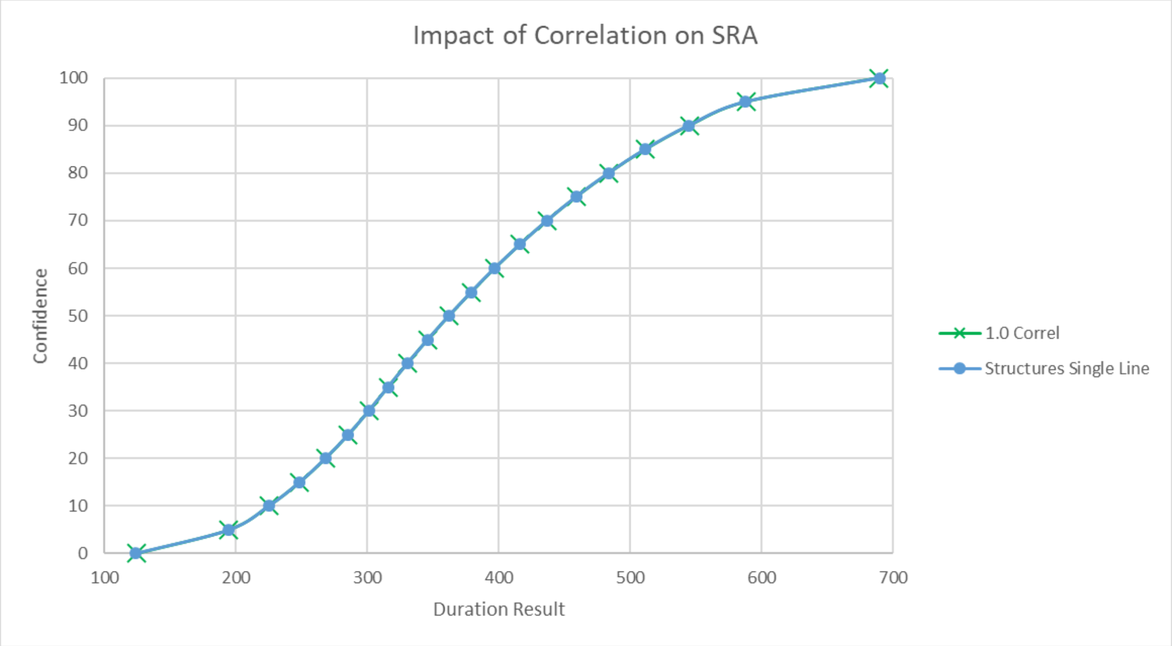
- An often-stated benefit of schedule risk analysis is being able to analyze probabilistic critical paths
- Our example file had two: 

  - ‘Fabricate primary structure’ has 10 days of total slack
- It so happens in our example risk analysis that ‘Fabricate primary structure’ eats up that slack and becomes critical 40% of the time

Should our system-level input data be able to alter these paths?
-There was no data on primary or secondary structure durations-
-The changing critical paths contribute to the lower CV that does not reflect the input-
Are we modeling below the level of our data?

Does Correlation Help?





1.0 Correlation perfectly matches single-line result

- 1.0 correlation can be thought of as replacing individual uncertainty inputs with a *single factor*
- We know correlation helps spread out results, but 1.0 correlation goes so far as to say:

Distributions correlated at 1.0 like in this example reduces the *effective* number of inputs to 1
Is that good?

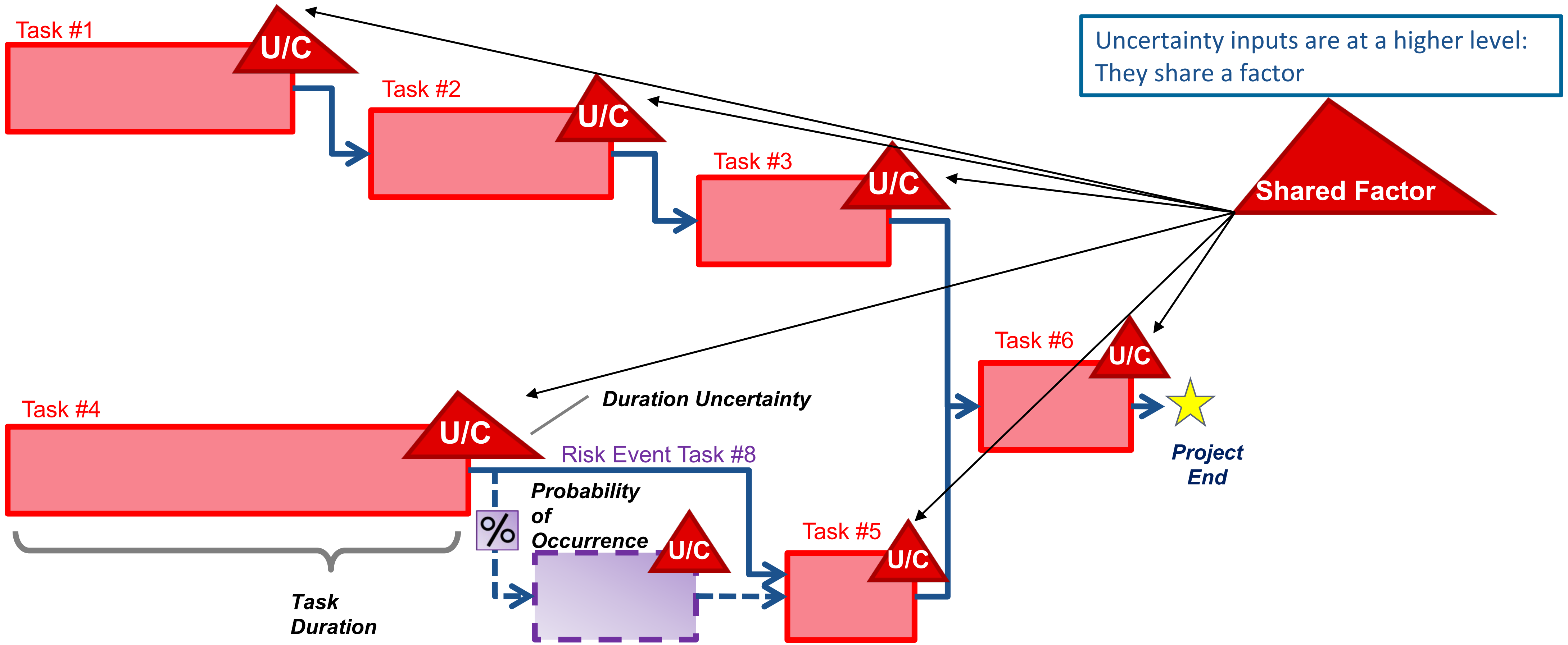
Side Effects of Single Factor (i.e., 1.0 correlation)

- Using a single factor *locks* the relative layout of the schedule in place
- In our earlier example the critical path went through primary structure 40% of the time
- With the single factor approach the critical path goes through secondary structure (the deterministic) 100% of the time

The schedule will not do anything unless we tell it: In our example our input is at the "Structures" level and in the model "Structures" expands and contracts as *one unit*

- To get a lower level of schedule permutation you need a lower level of schedule input
  - In our example you could try to seek *specific* data on primary structures and decouple those inputs

The Schedule Risk Analysis - Revisited

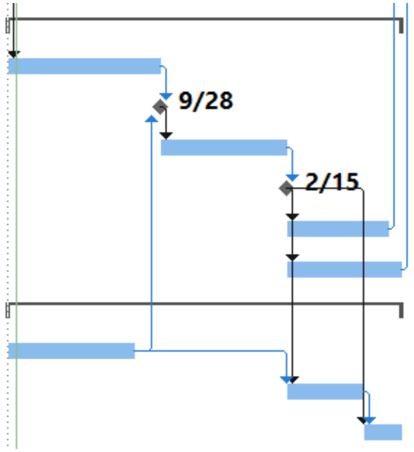


- Note in this simple cartoon that the risk event uncertainty does not inherit the factor
- Risk events can still change the higher-level result, which may or may not be desirable
  - Depends on how your analysis was done, how unique you believe the risks are, etc.

External Schedule Impacts to Factors

- Have we effectively reduced the schedule to a few lines? No!
  - Logic leading into and out of a given schedule section is still maintained, and those connections stay in the same relative place
- Our previous examples looked at a structures subsystem in a vacuum
  - Now the example will add a mechanisms section that is intertwined with structures

Structures	**310 days**
Structures Design	120 days
Structures PDR	0 days
Structures Final Design	100 days
Structures CDR	0 days
Fabricate Primary Structure	80 days
Fabricate Secondary Structures	90 days
Mechanisms	**310 days**
Mechanisms Design	100 days
Mechanisms Final Design	60 days
Fabricate Mechanisms	30 days



Intertwined Schedule Example

- The Mechanisms factor input is triangular:
  - Low=90%, Mode=105%, High=150%
- With both structures and mechanisms active:

	Confidence of Success	Mean Duration (% of Planned)	CV
Mechanism Subsystem Analysis	28%	124%	0.23

	Confidence of Success	Mean Duration (% of Planned)	CV
Mechanism Subsystem Output:	20%	124%	0.21

	Confidence of Success	Mean Duration (% of Planned)	CV
Structures Subsystem Analysis:	33%	120%	0.32

	Confidence of Success	Mean Duration (% of Planned)	CV
Structures Subsystem Output:	28%	124%	0.28

- Once again, our output is disconnected from our input
- It's clear these differences are from structure and mechanisms impacting each other
  - These inter-system impacts are probably baked into our data, so this isn't ideal either

Factor-Based Uncertainty Conclusions

- Applying higher-level uncertainty to lower-level tasks produces results that vary from the higher-level inputs based on:
  - Number and duration of activities
  - Logic within group of tasks (merge biases and shrinking CVs)
  - Logic between groups of tasks (“external” links)
- The factors based input produces a result that:
  - Matches the input *if* external tasks move in the same relative way
  - Removes the impact of the *internal* merge biases and other logic issues
  - Varies from input because of external linkages

This approach is easy to apply and discuss, the outputs and inputs relate in a predictable way, and the final result’s variance is not pushed down by merge bias

Intersection of SRA and JCL Policy

- Example 4-year schedule (Table 5-30 from NASA Schedule Management Handbook)
  - 2 years of development @ 1.5 months per year = 3 months FSM
  - 1 year of I&T @ 2 months per year = 2.5 months FSM
  - 2 months delivery to launch = 0.5 months FSM
  - 6 months FSM total
- For a "healthy" program reasonable expectations are that:
  - Schedule with no FSM is low confidence (<=%15)
  - Schedule with FSM is good confidence (~60% for 50% JCL)
- These two points limit the range of possibilities for a schedule s-curve

Schedule S-Curve Expectations

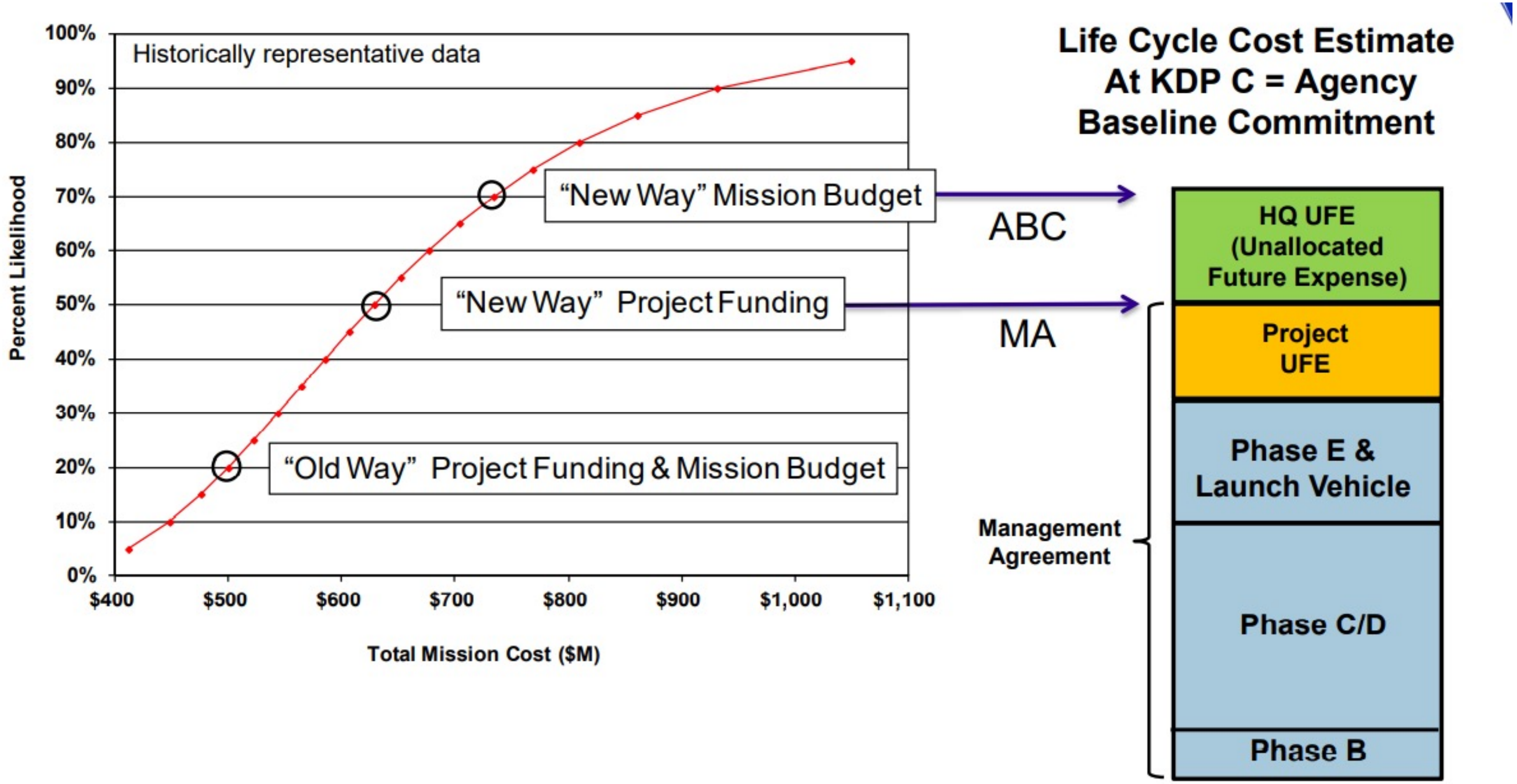
- A 4 year program with 6 months of FSM assuming
  - 15% confidence with no FSM
  - 60% confidence with all FSM
- If the resulting S-curve behaves like a lognormal distribution (With a right skew) the CV is approximately 0.10
  - 80% schedule confidence (for an example 70% JCL) is ~3 months past MA
  - Typical for any continuous distribution you try to fit to those points
- SRA results don't necessarily behave like a continuous distribution, but this seems to reflect the overarching problem
  - JCLs try to rely on low likelihood, high impact risk events to selectively inject variance into the higher confidences
  - This does not work out in practice

JCL Policy Conclusions

- There are techniques to overcome merge bias and decreasing variance in schedule models
- Even with these techniques, assumptions underpinning the JCL policy make it difficult for “healthy” programs at PDR to plan UFE using 70% JCL
    - Programs need either higher confidence in no FSM result, lower confidence in planned result, or significant injections of uncertainty from risk events
    - In practice risk events in JCL models have not been sufficient to spread out the 50% and 70% JCL results

BACKUP

JCL Policy



Projects fund to Management Agreement (MA) but NASA budgets to Agency Baseline Commitment (ABC)

- The Effect of Policy Changes on NASA Science Mission Cost & Schedule Growth
  - Bitten, et al, presented at 2018 NASA Cost & Schedule Symposium

Funded Schedule Margin (FSM)

- JCL policy assumes a “reasonable” delta between 50 and 70% JCL to calculate UFE
- For reference, this table shows a standard used for allocating funded schedule margin
  - Table 5-30 from NASA Schedule Management Handbook

From (Point in Life Cycle)	To (Point in Life Cycle)	Amount of Planned Margin
Confirmation Review	Beginning of Integration & Test	Varies: 1-2 month of schedule margin per year
Start of Integration & Test	Shipment to Launch Site	Varies: 2-2.5 months of schedule margin per year
Delivery to Launch Site	Launch	Varies: 1 day per week, 1 week per month, 1 month per year

Figure 5-30. Established standards for margin allocation.