An Introduction to Schedule Risk Analysis for Cost Estimators

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Agenda

- What is Schedule Risk Analysis
  - Definitions; analogy to Cost Analysis
- Why should cost estimators/analysts care about Schedule Risk Analysis
  - What's our motivation?
- How to perform Schedule Risk Analysis
  - Overview, approaches, example
- How to use the results of Schedule Risk Analysis
  - Notional example
- Summary

Definitions

- **Schedule risk**: Inadequacy of planned project schedule to allow sufficient time for all required tasks to be completed so that project can meet its stated objectives
- **Schedule risk analysis**: A procedure
  - Represent activity attribute (i.e., duration, start date, work, etc.) as uncertain quantities (i.e., random variables) that have probability distributions
  - Combine activity attribute distributions statistically (e.g., By Monte Carlo sampling) to generate cumulative distribution of project's total duration
  - Read off 70th percentile duration, 90th percentile duration, etc., from cumulative distribution to estimate probable additional amounts of time needed to complete project at various confidence levels
  - Quantify confidence in "best" estimate (or any estimate, such as the congressionally-mandated schedule) of project duration

Reasons for Schedule Uncertainty

- Project complexity; TRL
- Poor project definition
- Design changes
- Contracting issues
- Production challenges

Cost Estimating

- Develop a WBS
- Estimate costs at the WBS element level
- Sum these costs to obtain the total system cost:

$$System\ Cost = X_1 + X_2 + \ldots + X_n$$

- Schedule estimating is more complicated

Schedule Estimating (Vice Cost)

- More complicated
  - More than a list of tasks; also includes network logic
    - Cannot simply add together the expected time for each task to obtain total duration
  - The unit is time (instead of money)
    - Money is more fungible than time – overruns and under runs can cancel each other out
    - Time cannot be moved from one activity to another, so "ahead-of-schedule" and "behind-schedule" conditions cannot cancel each other out
      - "behind-schedule" condition remains

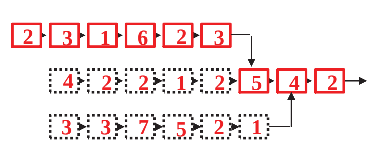
Cost and Schedule Comparison

- Cost
  - WBS based
  - Summation
  - Tools include:
    - Excel
    - ACE-IT
    - NAFCOM
- Schedule
  - Network based
  - More complicated than cost (Not just sums)
  - Tools include:
    - Project
    - RPT
    - Pertmaster
    - Primavera

Cost and Schedule Comparison (2)

- WBS for cost analysis is "linear," so total project cost is calculated by adding together costs of all items on that list
- Schedule network (unless entirely serial) is not linear – total project duration cannot be calculated by adding together durations of all activities in network

0.0	TOTAL BRILLIANT EYES PROGRAM
1.0	SPACE BRILLIANT EYES SYSTEM
1.1	System-Level Costs
1.2	Space Vehicle (SV) Segment
1.2.1	SV Program Level
1.2.2	Space Vehicle Prime Mission Equipment
1.2.2.1	Space Software
1.2.2.2	Space Vehicle
1.2.2.2.1	Space Vehicle IA&T
1.2.2.2.2	Sensor Payload
1.2.2.2.3	Insertion Vehicle
1.2.2.2.4	Survivability
1.2.3	Prototype Lot
1.2.4	Spare Parts
1.2.5	Technology and Producibility
1.2.6	Aerospace Ground Equipment
1.2.7	Launch Support
1.3	Engineering Change Orders (ECOs)
1.4	Other Government Costs
1.5	Risk



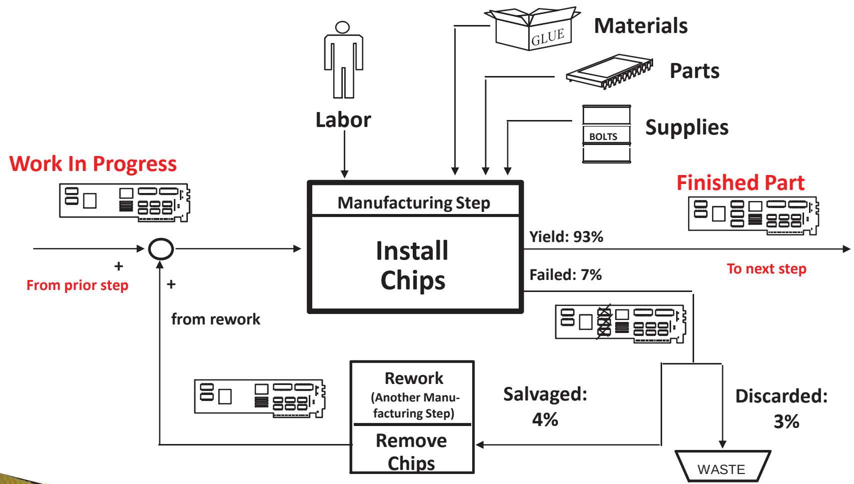
Schedule Networks - Analogy

- Schedule network is the schedule-analysis version of an Activity-Based Cost (ABC) model
- ABC model
  - Also called "bottom-up" model or engineering estimate
  - Generic shell for modeling costs of project development and production processes
  - Analyst assigns appropriate cost estimates to each activity involved in development and production
- Schedule network
  - Generic shell for modeling durations of project development and production processes
  - Analyst assigns appropriate duration estimates to each activity involved in development and production (activity durations typically serve as basis for contractor cost estimates)

Schedule Networks

- Break process flow into small steps of clearly defined activities, modeling predecessor and successor relationships among steps
- Develop estimates for time duration of each step based on probable work time for each type of labor involved
- Define rework loops if it is possible to rework bad parts
- Combine step durations to obtain an estimate of total time required to meet specific milestones
- Identify the "critical path" through the network, namely the list of individual activities that, if delayed, will delay the entire project

Example: Schedule and Manufacturing Logic



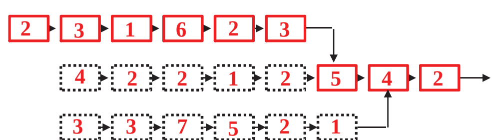
Schedule Network Basic Terms

- Serial Arrangement: two activities are “in serial” if each is a predecessor or a successor of the other
- Parallel Arrangement: two activities are “in parallel” if neither is a predecessor or a successor of the other
- Tree Structure: a mixture of serial and parallel activities
- Feedback Loop: a sequence of activities that contains at least two activities that are both predecessors and successors of each other

Serial Network in Detail

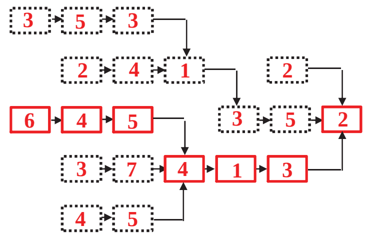
- Number in each box indicates number of days allocated to task represented by box
- Serial network's critical path passes through all boxes, and its duration is the sum of the durations of the individual activities in the serial network
- Critical path, consisting of boxes outlined in solid (red) lines, has total duration = 46 days

Parallel Network in Detail



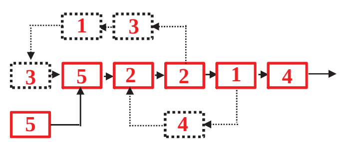
- Numbers in boxes indicate number of days allocated to task represented by box
- Parallel network's critical path passes through those boxes whose combined duration is the longest possible through the network
- Critical path, consisting of boxes outlined in solid (red) lines, has total duration = 28 days
- Sequences of boxes outlined in dotted black lines have "slack time", 6 days and 1 day, respectively

Tree-Structured Network in Detail



- Numbers in boxes indicate number of days allocated to task represented by box
- Critical path passes through those boxes whose combined duration is longest possible through network
- Critical path, consisting of boxes outlined in solid (red) lines, has total duration = 25 days
- Sequences of boxes outlined in dotted black lines have "slack time", 3 days, 5 days, 21 days, 5 days and 6 days, respectively

Feedback Loop in Detail

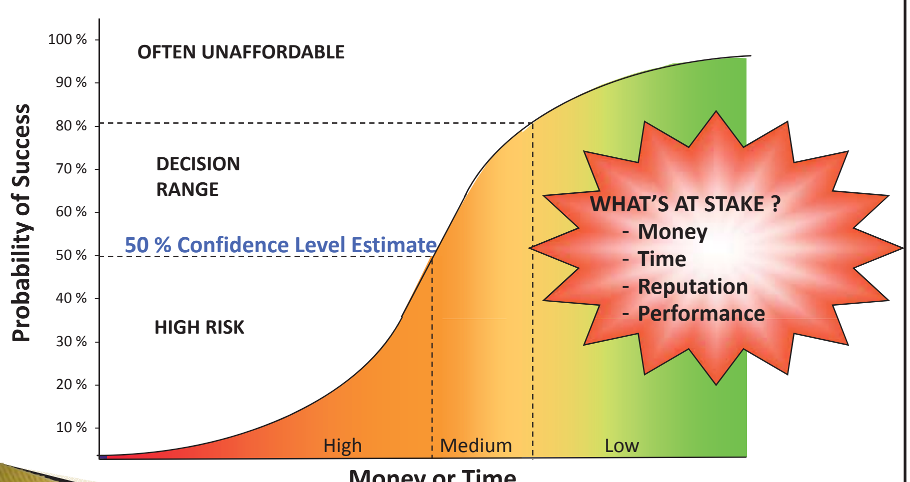


- Numbers in boxes indicate number of days allocated to task represented by box
- The critical path passes through those boxes whose combined duration is longest possible through network
- If "feedback" is not exercised, the critical path, consisting of boxes outlined in solid red lines, has total duration = 19 days
- If "feedback" is exercised once, all boxes lie on the critical path, which then has total duration = 44 days

Schedule Risk Motivation

- Schedules are highly uncertain and inherently risky, just like with cost
  - Cost and schedule have many of the same drivers, and at or near the beginning of a project, there is significant uncertainty in these factors
    - Average weight growth for satellites is on the order of 30%, for example (Tim Anderson, "Remaining Weight Growth of Satellite Systems," presentation to AFCAA, 2003)
  - Schedules are also subject to technical and external factors, such as budget constraints, which can cause schedules to grow
- Hofstadter's Law: "It always takes longer than you expect, even taking Hofstadter's Law into account." (Douglas Hofstadter, *Godel, Escher, Bach: the Eternal Golden Braid*, 1979)

How Much Risk Can We Afford ?



Objectives of Schedule Risk Analysis

- Improve accuracy of schedule dates
- Validate contract dates
- Establish schedule contingency
- Identify risk-driving events
- Communicate about and understand the project
- Continuously monitor changing schedule risk

Output of Quantitative Schedule Risk Analysis

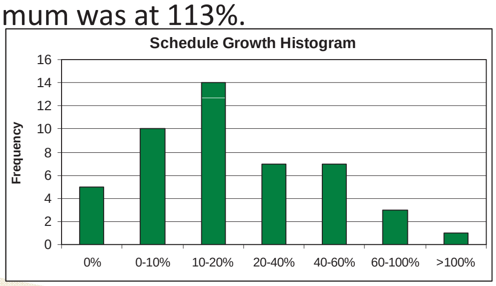
- How likely is the project to finish on or before the project completion date?
- By how much might the project overrun based on the organization's level of risk aversion?
  - How much time contingency is needed?
- Where is the major risk in the project?
  - Where should risk mitigation efforts be focused?
  - Why is that not always the critical path?

Schedule Drivers

- Same factors that drive cost also drive schedule:
  - Weights of components and subsystems
  - Power, cooling, attitude-control requirements
  - Integration and testing
  - Thrust requirements
  - Data memory requirements
  - Number of source lines of code to be written
  - Software testing complexity
  - Special mission equipment
  - Subcontractor interrelationships
  - Etc.

Schedule Growth

- In a recent schedule growth study for NASA missions, Smart (2009) found that:
  - 90% of schedules overrun, on par with the 87.5% of missions that experience cost growth.
  - The average schedule growth is equal to 25.6%.
  - The maximum was at 113%.



Network Schedule Analysis Process

- Establish logical flow of how activities lead to completion of project
  - Define how activities are linked
  - Determine order in which activities must be done
  - Identify milestone activities and "choke points"
- Estimate activity duration times
- Evaluate project completion time
  - Construct critical path
  - Sum estimated duration times of activities that are on the critical path to estimate total project duration
  - Compare the total-duration estimate with project's required completion time

How To Perform Schedule Risk Analysis

- Replace deterministic schedule estimates with probabilistic estimates
  - Project start date, activity durations, probabilistic branching for risk events
- Collect distribution data
  - Project risk register is good source
- Execute Monte Carlo simulation of schedule network
- Determine distribution of completion dates and cumulative likelihoods

Simulation

- Computer simulation of system performance using Monte Carlo analysis is a standard analysis technique in engineering work, where key technical characteristics are modeled as random variables, e.g.,
  - Weight, power, thrust, other physical characteristics
  - Pointing accuracy
  - Location accuracy
  - Aiming precision
- Schedule risk analysis, where activity attributes are modeled as random variables, enables analysts to develop a computer simulation of projects to model schedule progress

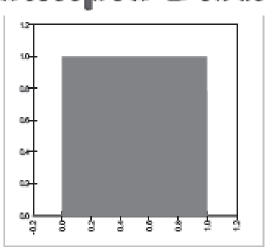
Schedule Simulation Mechanics

- Monte Carlo sampling process
  - Random sampling models activity attributes on basis of their probability distributions
  - No unique "the critical path", because each iteration pass through network potentially produces a different critical path
  - Project duration for each Monte Carlo pass equals sum of durations of activities that are on that pass' critical path
  - Probability distribution of project duration is established by compiling project durations of all iterations of schedule logic
- Commercial software can be applied to implement the process
  - Commercially available third-party add-ons to Microsoft® Project
  - Software outputs percentiles of project's total duration, project total duration probability density, cumulative distribution graphics, each activity's probability of being on critical path
- Alternative is to build your own using Excel/VBA
  - Realistically only possible for "simple" schedule network logic

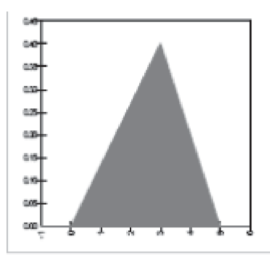
Simple Distributions

- Simple distribution functions can be very powerful in describing uncertainty with only a few values or arguments
- For example:
  - Uniform uses only 2 values (minimum, maximum) to describe the full range of the distribution and assign probabilities for all the values in the range
  - Triangular uses 3 easily identifiable values (minimum, most likely, maximum) to describe a complete distribution
  - Normal uses only 2 values (mean, standard deviation) to describe a complete distribution

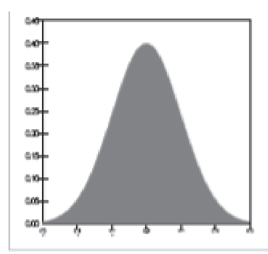
Simple Distributions



- Requires minimum and maximum values
- Every value across range has equal likelihood of occurrence
- Min < Max
- U(25,35) specifies a range anywhere between, and including, min of 25 to max of 35



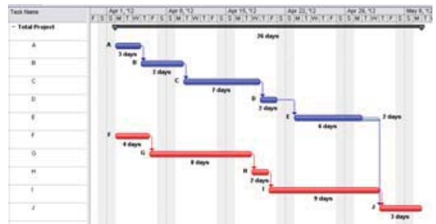
- Distribution with 3 points
  - Minimum
  - Most likely
  - Maximum
- Min<=Most likely
- Max >= Most likely
- T(100,200,300) specifies distribution with min value of 100, most likely 200, and max 300

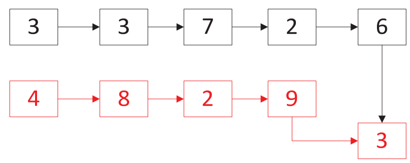


- "Bell curve" distribution
- Enter mean and standard deviation as parameters
- N(10,2) specifies a normal distribution with a mean of 10 and a standard deviation of 2

Example—No Uncertainty

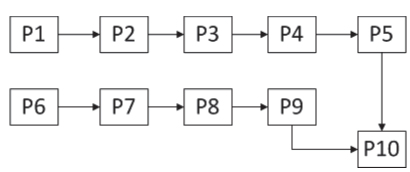
- Gantt representation shown
- Network diagram representation shown
- Numbers in network diagram boxes indicate task durations
- Critical path passes through those tasks whose combined duration is the longest
- Critical path (outlined in solid red lines) has total duration = 26 days



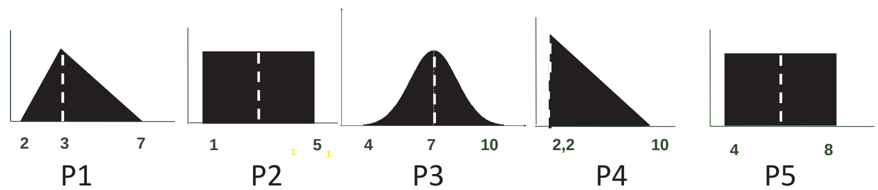


Example—With Uncertainty

- Random variable (P1, P2, …, P10) in boxes represents task duration
- Through Monte Carlo, a probability associated with each possible value of the schedule duration can be estimated



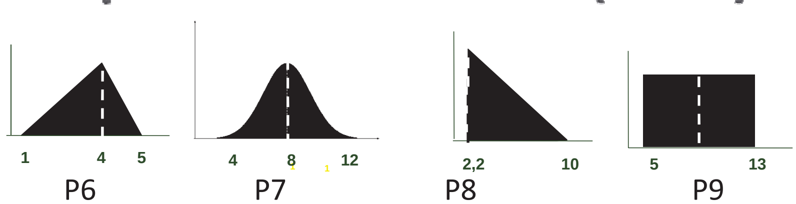
Example—Notional Values (1 of 2)



Monte Carlo samples for P1- P5 (duration):

Iteration	P1 Value	P2 Value	P3 Value	P4 Value	P5 Value	Total Duration
1	4.6	1.1	9.4	4.2	7.4	27
2	3.3	4.7	6.5	3.1	5.1	23
3	4.6	2.5	6.5	2.5	5.7	22
4	2.6	3.4	4.7	5.7	7.2	24
5	4.1	1.2	8.1	2.9	6.6	23

Example—Notional Values (2 of 2)

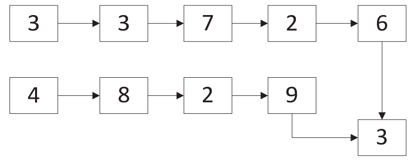


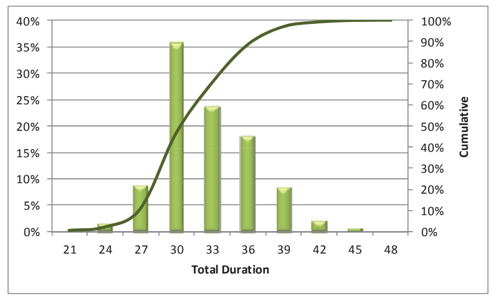
Monte Carlo samples for P6- P9 (duration):

Iteration	P6 Value	P7 Value	P8 Value	P9 Value	Total Duration
1	3.7	10.1	4.3	5.5	24
2	4.3	3.5	7.2	5.1	20
3	3.0	10.9	8.0	9.8	32
4	2.4	3.6	2.6	9.7	18
5	2.6	7.2	2.8	7.3	20

Example—Statistics

Duration Statistical Summary	
Mean	31
Mode (Most Likely)	29
Minimum	21
Maximum	47
Standard Deviation	5.3
20th Percentile	29
40th Percentile	31
60th Percentile	33
80th Percentile	35

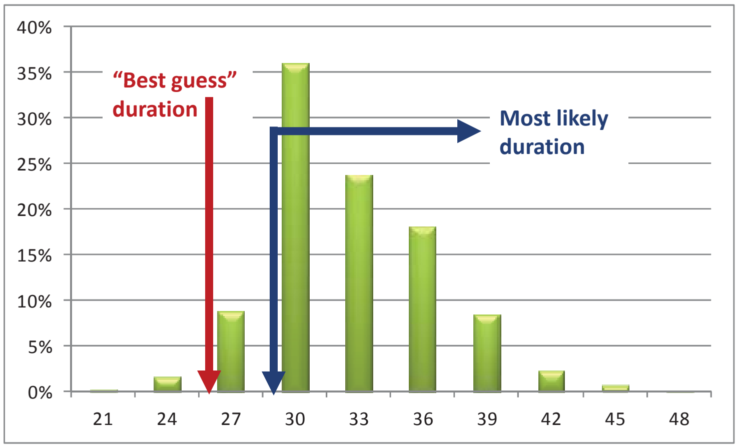




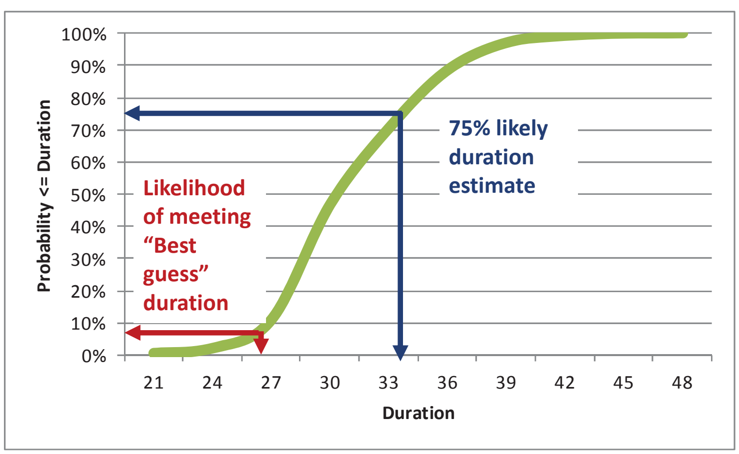
Example—Notional Results

- Risk-impacted duration estimates range from low of 21 days to high of 47 days, with most likely value of 29 days
- Recall (from earlier chart) “best” estimate of project duration based on roll-up of critical-path-activity best estimates, total duration = 26 days
- Risk analysis illustrates that so-called “best” estimate is NOT the most likely project duration, but instead is underestimate of same

Example—Notional Results

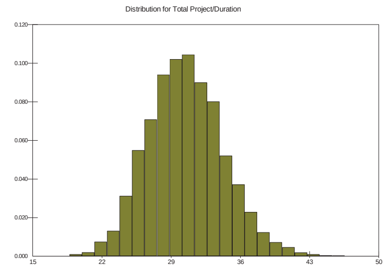


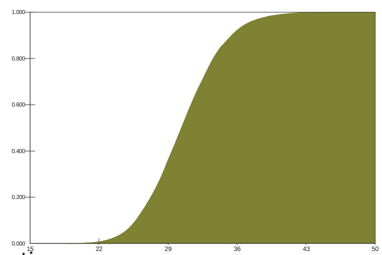
Example—Notional Results



Notional Commercial Tool Results

Name	Total Project/Duration
Description	Output
Output	Task 1
Minimum	18.73
Maximum	46.57
Mean	30.48315
Std Deviation	3.809935
Variance	14.5156
Skewness	0.2634933
Kurtosis	3.159205
Errors Calculated	0
Mode	31.84
5% Perc	24.52
10% Perc	25.7
15% Perc	26.52
20% Perc	27.23
25% Perc	27.86
30% Perc	28.4
35% Perc	28.88
40% Perc	29.38
45% Perc	29.87
50% Perc	30.33
55% Perc	30.83
60% Perc	31.3
65% Perc	31.81
70% Perc	32.4
75% Perc	32.95
80% Perc	33.56
85% Perc	34.35
90% Perc	35.44
95% Perc	36.93





Based on 10,000 iterations

Advanced Topics

- Probabilistic Branching
  - Can represent activities in a project plan that may occur or may not occur
  - Example: Testing pass or fail. If a test is failed, then additional activities are included in the schedule to repair and repeat the test; those additional activities aren't required if the test is passed
- Correlation
  - When some risk driver affects the duration of two activities together, making the activities "move" together (e.g., if one activity takes longer than planned, then the other also does)
  - Example: Sample value for product development duration is high; product documentation preparation duration should also be high since the development duration could indicate high complexity or low resource availability
- Both increase the complexity of Schedule Risk Analysis

Benefits of the Schedule Risk Analysis

- Known level of confidence in the estimate
  - Schedule and cost estimates are improved and a rationale basis for the estimates is demonstrated
- Standardization of the confidence level among various projects becomes feasible
- Ability to quantify an estimate that has a greater than 50% probability of being accurate
- Use of higher probability level estimates means:
  - Less performance surprises
  - Less re-baselining
  - Less trips back to the money coffer
  - Better coordination among stakeholders
  - Improved image

Wrap-up

- Questions???
- Contact information

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Emerging Practice:
Joint Cost & Schedule Risk Analysis

2012 SCEA National Conference
Orlando, Florida
Eric Druker

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Outline

- Introduction
- What is Joint Cost & Schedule Risk Analysis?
- What Goes Into Joint Cost & Schedule Risk Analysis?
- Joint Cost & Schedule Risk Analysis Process
- Results: Traditional Risk Analysis vs. JCL Analysis
- Additional Benefits of Joint Cost & Schedule Risk Analysis
- Challenges of Joint Cost & Schedule Risk Analysis
- Conclusion//The Path Forward

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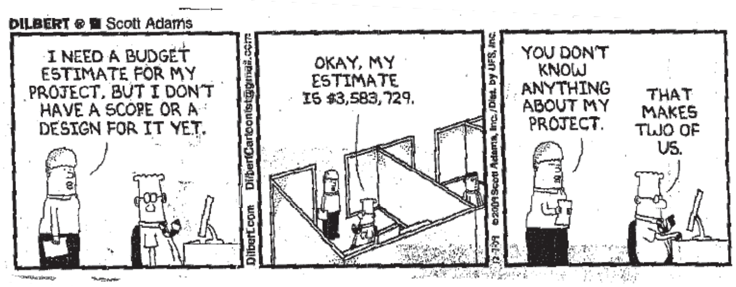
Attempt at Humor



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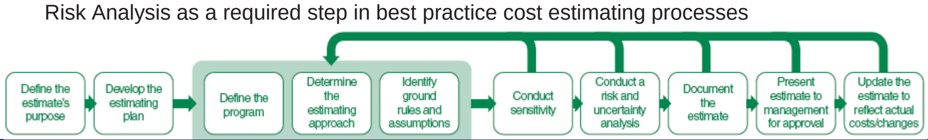
Introduction

- Whether assessing/analyzing NASA, DoD or Intelligence Community owned projects, the story is the same each time: **Programs are increasingly experiencing growth above and beyond their initial cost and schedule estimates**
- This is not just a cosmetic problem: **Cost and schedule growth delays capabilities and constraints the budgets of other programs causing a waterfall of instability**
- Studies have examined the reasons behind this growth reaching similar conclusions
  1. Early program optimism leading to optimistic estimates
  2. Insufficient cost and schedule reserves available to cover risk
  3. Weak independent validation of cost and schedule
- Recognizing this, many guides, including the GAO's Cost Estimating Handbook, have included Risk Analysis as a required step in best practice cost estimating processes



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Introduction

- Unfortunately, there is often little to no relation between typical cost risk analysis results and the program’s schedule
  - This can lead to risk adjusted cost estimates that, if come to pass, will almost always imply associated schedule growth
- From the other side, traditional schedule risk analysis typically leads to risk adjusted schedules that, if come to pass, will result in cost growth
- Even when both of these analysis are performed on a program, they are typically done by disjoint groups under different sets of assumptions
- Joint Cost & Schedule Risk Analysis is an attempt to integrate cost and schedule risk analysis in a way that produces meaningful, compatible results
- This presentation will examine the differences between traditional risk analysis and joint cost & schedule risk analysis
  - It will focus on the benefits of integrating the two analysis and the process by which this can be accomplished

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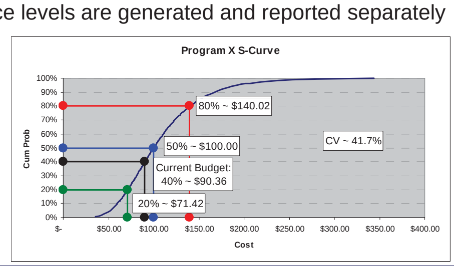
What is Joint Cost & Schedule Risk Analysis?

- **Definition:** Joint Cost and Schedule Risk Assessment (sometimes referred to as JCL analysis) generates a joint bivariate probability distribution relating cost and schedule in a way that allows the analyst to determine the confidence level for meeting both target budgets and schedules simultaneously
  - But what does this mean?
- Traditional cost *or* schedule risk analysis generates a distribution of potential final costs and durations from which confidence levels for budgets and schedules can be derived
  - These confidence levels are generated and reported separately



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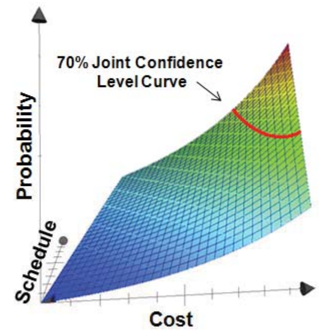
What is Joint Cost & Schedule Risk Analysis?

- Joint Cost & Schedule Risk Analysis creates a bivariate distribution of final cost and schedule pairs
  - Thus, the confidence level of any cost and schedule pair represents the probability of the program finishing ***both under cost and ahead of schedule***
  - These are known as Joint Confidence Levels
- There are several methods for performing joint cost & schedule risk analysis
- At early program phases, parametric cost and schedule estimates/risk analysis can be combined to produce joint confidence levels
- When the program matures, and artifacts such as an integrated master schedule are developed, the build-up method can be used
  - This presentation will focus primarily on the build-up method due to the additional insights it provides

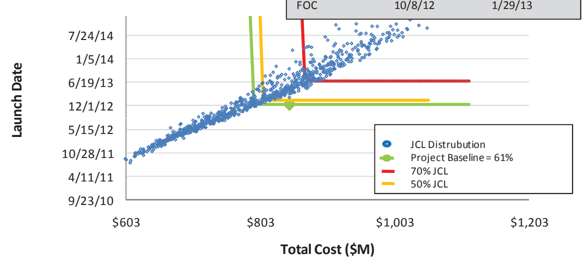


What is Joint Cost & Schedule Risk Analysis?

- Another way to display Joint Cost & Schedule Risk Analysis results is through a scatter plot
  - Each point on the scatter plot represents 1 iteration of a Monte Carlo simulation performed on the JCL model
  - From this any % JCL can be uncovered

Joint Confidence Level
Final Results

	Knee in the Curve Values	
	50%	70%
Cost	$787.7M	$831.5M
FOC	10/8/12	1/29/13



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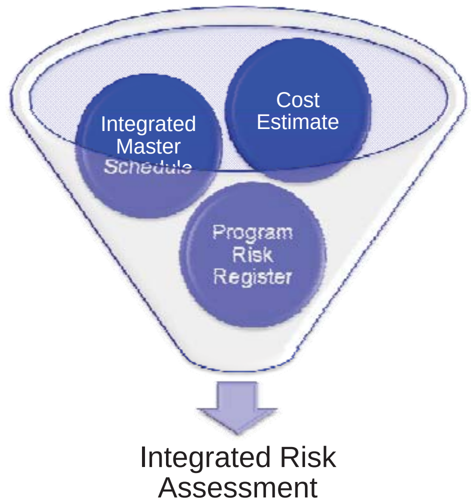
What Goes In To Joint Cost & Schedule Risk Analysis?

- **The Integrated Master Schedule (IMS)**
  - A schedule health check is performed on the IMS
  - Uncertainty around schedule tasks (at a level where there is sufficient insight) is quantified
- **The Cost Estimate**
  - The cost estimate is loaded into the IMS at a pre-determined level
  - Uncertainty around the point estimate is quantified
- **Program Risk Register**
  - Risks being managed as a part of the program's risk management plan are quantified in terms of cost and schedule impacts and mapped to tasks in the IMS



Joint Cost & Schedule Risk Analysis Process

- Typically, JCL analysis is performed using the risk management, cost estimating and scheduling personnel already on the program
  - One person is flagged as the focal point for the analysis, responsible for collecting all artifacts and conflating them into the JCL risk model
- The creation of artifacts used in the JCL process takes approximately two weeks, although this depends on the initial maturity of these artifacts:
  - The integrated master schedule with uncertainty bounds at the pre-determined summary level
    - Typically subsystem or above
  - A quantified risk register (probabilities, cost & schedule impacts) where each risk is mapped to a task in the IMS
  - A cost estimate with uncertainty bounds that maps to the IMS at a the pre-determined summary level
    - Costs are broken into time-dependent (increase as schedule grows) and time-independent costs (are unaffected by schedule growth)
- Running the JCL model and analyzing the results typically takes an additional week

Joint Cost & Schedule Risk Analysis Process

Artifact Generation

- Integrated Master Schedule (Health Checks Performed)
- Quantified Risk Register
- Cost Estimate

JCL Model Development

- Risks entered as tasks into IMS
- Cost estimate applied to summary level tasks in the IMS
- Cost and schedule uncertainty applied to the baseline cost an duration estimates

Monte Carlo Simulation

- Risks an uncertainties are added into the cost-loaded IMS
- A Monte Carlo simulation is run to determine their combined effects
- For each run, desired metrics (costs and milestone dates) are captured an recorded

Analysis of Results

- Joint Confidence Levels
- Probabilistic Critical Paths
- Risk Rankings (both cost & schedule)

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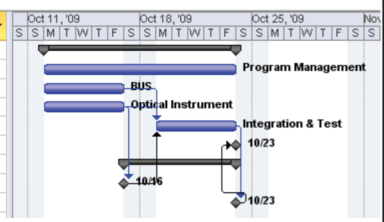
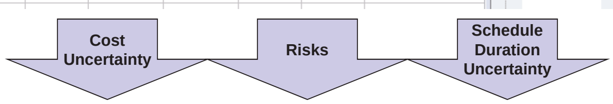
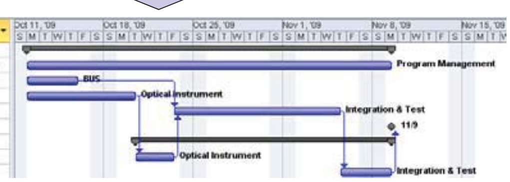
Example JCL Model

	Task Name	Duration	Start	Finish	Cost	Fixed Cost	Resource Names
1	**Firesat Program**	**10 days**	**Mon 10/12/09**	**Fri 10/23/09**	**$23,400.00**	**$0.00**	
2	Program Management	10 days	Mon 10/12/09	Fri 10/23/09	$8,000.00	$0.00	Program Management
3	BUS	5 days	Mon 10/12/09	Fri 10/16/09	$4,600.00	$1,000.00	BUS
4	Optical Instrument	5 days	Mon 10/12/09	Fri 10/16/09	$5,000.00	$1,000.00	Optical Instrument
5	Integration & Test	5 days	Mon 10/19/09	Fri 10/23/09	$5,800.00	$1,000.00	Integration & Test
6	Launch	0 days	Fri 10/23/09	Fri 10/23/09	$0.00	$0.00	
7	**Risks**	**5 days**	**Fri 10/16/09**	**Fri 10/23/09**	**$0.00**	**$0.00**	
8	Late Delivery of FPA	0 days	Fri 10/16/09	Fri 10/16/09	$0.00	$0.00	Optical Instrument
9	Additional Therm Testing	0 days	Fri 10/23/09	Fri 10/23/09	$0.00	$0.00	Integration & Test





	Task Name	Duration	Start	Finish	Cost	Fixed Cost	Resource Names
1	**Firesat Program**	**20.5 days**	**Mon 10/12/09**	**Mon 11/9/09**	**$35,720.00**	**$0.00**	
2	Program Management	20.5 days	Mon 10/12/09	Mon 11/9/09	$16,400.00	$0.00	Program Management
3	BUS	4 days	Mon 10/12/09	Thu 10/15/09	$3,580.00	$700.00	BUS
4	Optical Instrument	[illegible]	Mon 10/12/09	Tue 10/20/09	$6,000.00	$800.00	Optical Instrument
5	Integration & Test	[illegible]	Fri 10/23/09	Thu 11/5/09	$9,740.00	[illegible]	Integration & Test
6	Launch	0 days	Mon 11/9/09	Mon 11/9/09	$0.00	$0.00	
7	**Risks**	**14 days**	**Tue 10/20/09**	**Mon 11/9/09**	**$6,320.00**	**$0.00**	
8	Late Delivery of FPA	[illegible]	Tue 10/20/09	Fri 10/23/09	$4,400.00	[illegible]	Optical Instrument
9	Additional Therm Testing	[illegible]	Thu 11/5/09	Mon 11/9/09	$1,920.00	$0.00	Integration & Test



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Demonstration

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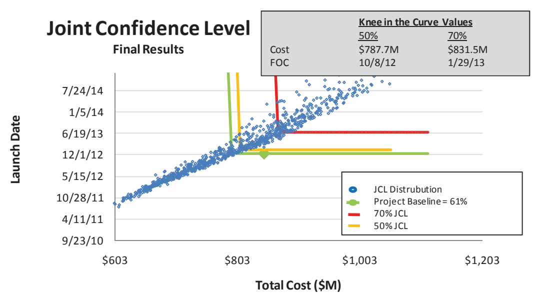
Results: Traditional Risk Analysis vs. JCL Analysis

- **Confidence Levels**
  - **Traditional Risk Analysis**: Disjoint cost and schedule confidence levels are generated. The confidence of meeting both is unknown and it is generally unclear that the two analysis use similar assumptions
  - **JCL Analysis**: The results provide a probability of meeting *both* cost *and* schedule
    - The relationship between cost and schedule is shown
    - Answers questions such as: "How much cost growth can I expect per day of schedule growth?
    - Results can be parsed to lower levels for the development of cost and schedule reserves



JCL analysis provides confidence levels that include both cost and schedule and allows decision makers to develop compatible risk adjusted budgets and schedules

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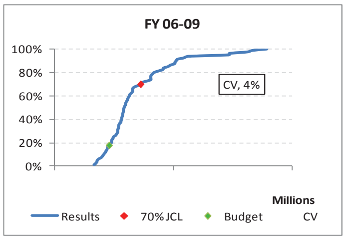
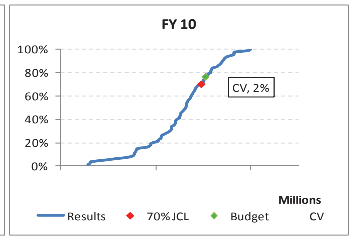
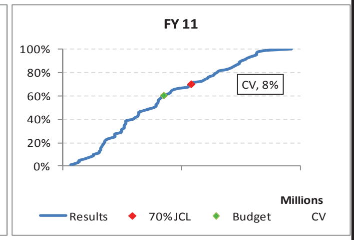
Time-phased JCL Example







FY 06-09

•JCL model uses August '09 schedule and includes risks to FY 09
•$10M delta between budget and 70% JCL represents risks occurring in FY 09

FY 10

•FY 10 represents peak burn rate
•Impacts of time-dependent risks occurring in FY 10 will prolong this burn rate but will not greatly impact FY 10 outside of time-independent impacts
•Excess budget (vs. 70% JCL cost) in FY 10

FY 11

- In FY 11 the burn rate begins to decrease
- As risks occur in FY 09 and FY 10, they push out the end dates for tasks ending in FY 11
- **Delta between budget and 70% JCL represents a delay in tasks ramping down**

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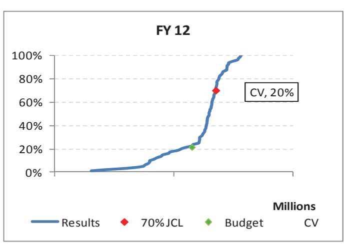
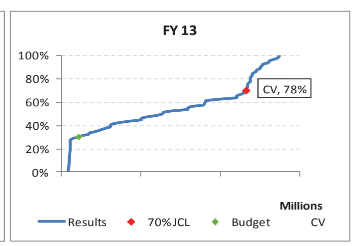
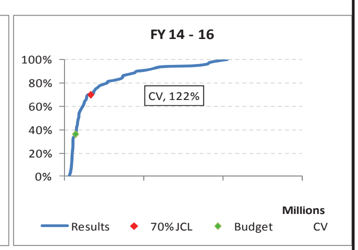
Time-phased JCL Example







FY 12

- Results for FY 12 are analogous to results for FY 11
- Wider CV because many more tasks are ramping down in FY 12
- **Delta between budget and 70% JCL represents a delay in tasks ramping down**

FY 13

•Probability of an on time launch according to the JCL is ~25% - reflected in 25% confidence level of current budget
•Wider CV because of more tasks ramping down
•Large delta between budget and 70% JCL represents a delay to launch

FY 14-16

•Steep right tail on this curve represents small (~20%) probability that launch slips to FY 14
•Wider CV because costs in these FYs represent "worst-case scenarios"
•Large delta between budget and 70% JCL represents a delay to launch

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Budget vs. 70% Time-Phased JCL Cost

Budget vs. 70% JCL ($M)

	Total	FY 06-09	FY 10	FY 11	FY 12	FY 13	FY 14-16
Budget							
70% JCL							
Delta							
Delta (%)	-22.4%	-3.5%	0.3%	-4.0%	-17.5%	-949.8%	-132.1%

- Above chart shows Project X's budget vs. it's 70% JCL for each year
- Lessons learned
  1. FY S-Curves trace directly back to the schedule – It was easy to determine why each FY's S-Curve looked the way it did when examining the activities occurring each year
  2. FY S-Curves will increase in CV the further out one goes in time – Time-dependent cost impacts will occur as activities ramp down; generally in the later years

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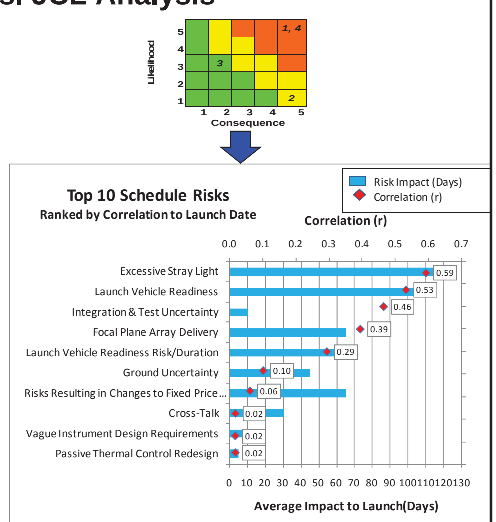
Results: Traditional Risk Analysis vs. JCL Analysis

- **Risk Rankings**
  - **Traditional Risk Analysis**: Risks are ranked in terms of their expected value, typically nothing more than a likelihood multiplied by a consequence factor
  - **JCL Analysis**: Risks are ranked based on their *impacts on the project*. Downstream effects of risks occurring are captured due to their incorporation into the IMS.
    - Example: One risk may have a low cost and schedule impact on its own, but if the task it affects has little or no slack, the downstream schedule impacts and associated standing army cost impacts will cause it to have a large impact on the program



JCL analysis provides insights into the true impacts of risks and allows the development of optimal mitigation plans

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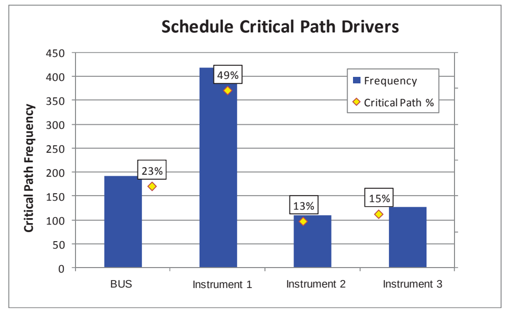
Results: Traditional Risk Analysis vs. JCL Analysis

- **Probabilistic Critical Path**
  - **Traditional Risk Analysis:** Analysis is performed on summary level schedules that may or may not mimic the lowest level schedule logic
  - **JCL Analysis**: Analysis is performed on the program's existing IMS resulting in no loss of accuracy
  - The probability that any set of tasks will be on the critical path is uncovered
  - This allows program managers to focus their attention on the tasks that are most likely to cause their schedule to slip and their costs to grow



JCL analysis uses the lowest level schedule logic to determine which tasks are most likely to cause schedule slips

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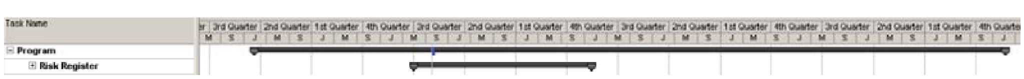
Additional Benefits of Joint Cost & Schedule Risk Analysis

- **Communication**
  - **Traditional Risk Analysis**: Cost estimators, schedule estimators and risk managers may or may not interface
  - **JCL Analysis**: These three groups must collaborate as they are no longer producing independent products
- **Quality of Deliverables**
  - **Traditional Risk Analysis**: The quality of deliverables (estimates, IMS, risk registers) is often unclear with very few ways to check quality
  - **JCL Analysis**: Errors or omissions in the deliverables are immediately apparent in the results due to the integrated nature of the model
    - Integrating risks into the IMS clearly shows the range over which risks are forecasted; often reveals that risk registers are short-sighted
    - "This thing reveals logic problems in the schedule better than any schedule health tool"



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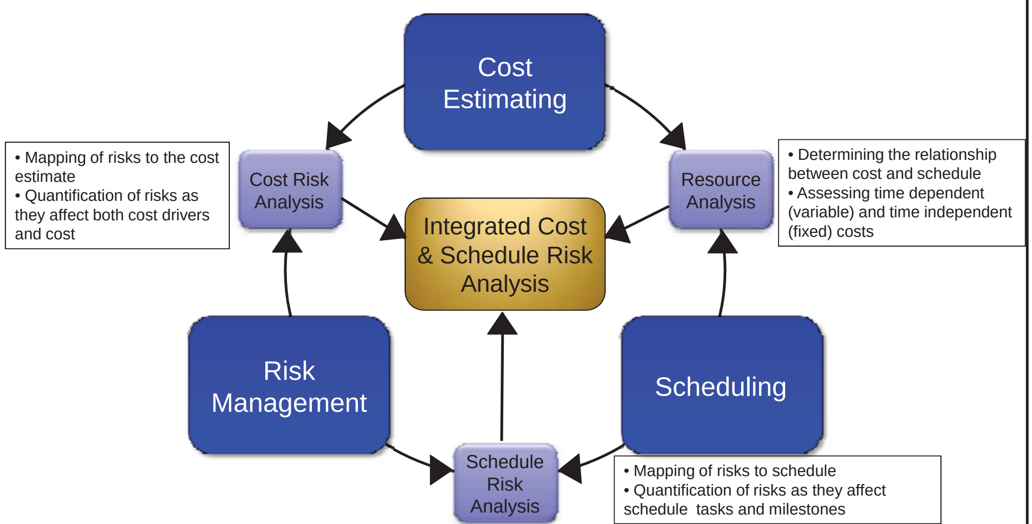
Additional Benefits of Joint Cost & Schedule Risk Analysis: Communication



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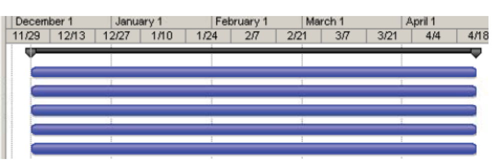
Challenges of Joint Cost & Schedule Risk Analysis

- **Understanding**
  - **Traditional Risk Analysis**: Understanding how cost distributions are summed to achieve a program level cost estimate is fairly simple to grasp
  - **JCL Analysis**: Understanding how schedule distributions combine to achieve a program level finish date is complicated
- The example below illustrates a project consisting of 5 schedule elements, each with an estimated duration of 100 days and an estimated cost of $100
- To assess risk, a *symmetric* 20% uncertainty factor was applied to each cost and schedule element

	Task Name	Duration	Start	Finish
1	**Project**	**100 days**	**12/7/09**	**4/23/10**
2	Element 1	100 days	12/7/09	4/23/10
3	Element 2	100 days	12/7/09	4/23/10
4	Element 3	100 days	12/7/09	4/23/10
5	Element 4	100 days	12/7/09	4/23/10
6	Element 5	100 days	12/7/09	4/23/10



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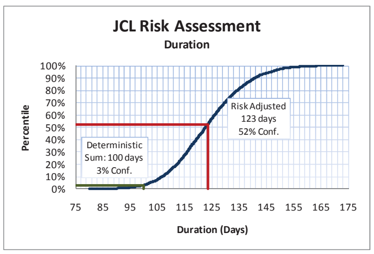
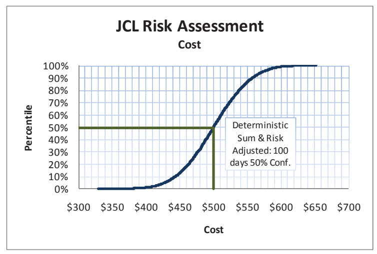
Challenges of Joint Cost & Schedule Risk Analysis

- One's first guess would be that, given symmetric uncertainties, the most probable outcome would be 100 days and $500
  - This however, is not the case
- In order to finish the project, all 5 parallel tasks must be completed
  - The probability of all tasks finishing at or under 100 days (project finishing on time) is ~3%
- While the most likely cost is $500, the most likely duration is ~123 days





	Duration	Cost
20%	112 days	$ 464
50%	123 days	$ 500
80%	134 days	$ 538

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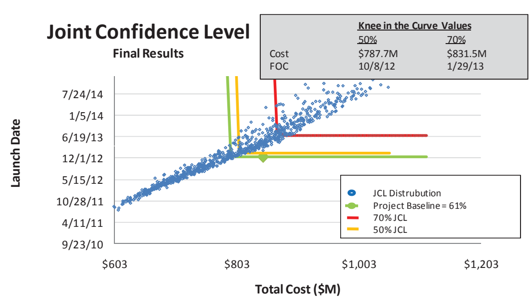
Challenges of Joint Cost & Schedule Risk Analysis

- **Understanding (cont.)**
  - **Traditional Risk Analysis**: A single cost or schedule s-curve can be explained to, and understood by, decision makers
  - **JCL Analysis**: Understanding a joint-bivariate distribution and its implications is difficult
    - Implications include JCL iso-curves and budgeting to higher cost/schedule confidence levels to achieve desired JCL



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Challenges of Joint Cost & Schedule Risk Analysis

- **Correlation**
  - **Traditional Risk Analysis**: Correlation only affects the spread of the cost estimate; no impact on most likely cost
  - **JCL Analysis**: Correlation has a direct impact on the most likely completion date
    - As of publish date, there are no firm guidelines on correlation between schedule tasks
- **Simulation Run Time**
  - **Traditional Risk Analysis**: Even the most complicated cost risk analysis models can generally be run through a Monte Carlo Simulation fairly quickly
  - **JCL Analysis**: Simulation run time increases with the number of tasks in the IMS
    - Experience on NASA projects has yielded simulation run times of up to 20 seconds *per iteration*
    - Schedule shortening axioms currently in development to combat this problem

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Challenges of Joint Cost & Schedule Risk Analysis

- **"Arbitrary Inputs"**
  - **Traditional Risk Analysis**: The level at which the analysis is performed has no effect on the outcome so long as the same inputs are used
  - **JCL Analysis**: The level at which the analysis is performed has a direct effect on the results
    - Example, the decision to apply uncertainty on 5 parallel schedule elements vs. at their summary level
    - Applying at the parallel level will lead to a higher most likely duration
    - Rolling up the schedule means when risks affect tasks, schedule slack/reserves may not be fully accounted for; leads to overestimation of risk
- **Model Shortcomings**
  - **JCL Analysis**: Simulations using the Integrated Master Schedule cannot account for a manager's ability to reschedule their program in order to minimize the impact of risks
    - Example: rescheduling I&T to mitigate impact of late GFE delivery
    - An argument could be made that this is captured in the uncertainty

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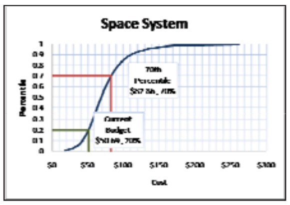
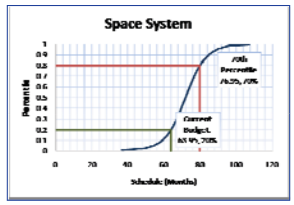
Examples of Joint Cost & Schedule Risk Analysis: Parametric

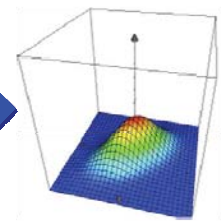
- Typically used early in a program's lifecycle (Phase A & prior)
- Generally performed using either the inputs or outputs based risk methodology
- Involves conflating independent cost & schedule risk analysis into JCL
  - This is done by injecting correlation between the cost and schedule distributions and running them through a Monte Carlo simulation



Probabilistic Cost Estimate



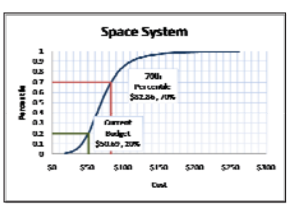
Probabilistic Schedule Estimate



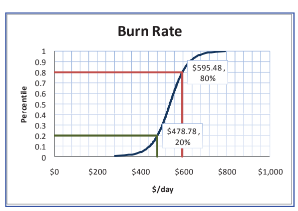
Joint Cost and Schedule Estimate

Examples of Joint Cost & Schedule Risk Analysis: EAC Projection

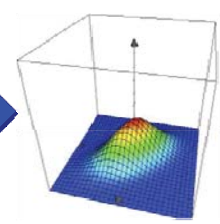
- Typically used in production phase
- Probabilistic burn rate is applied to the probabilistic cost estimate to develop a risk adjusted schedule and joint confidence level curve
- Works best on production programs with stable burn rates
  - E.g.: Ship production programs



Probabilistic Cost Estimate



Probabilistic Burn Rate



Joint Cost and Schedule Estimate

Conclusion/The Path Forward

- As of late, Joint Cost & Schedule Risk Analysis has been moving towards the mainstream
  - NASA Policy Directive 1000.5 specifically calls out the creation of "Joint Confidence Levels"
  - Formal guidelines are currently under development by the Space Systems Cost Analysis Group (SSCAG)
  - Research is also being done to combine JCL analysis with EVM metrics
- Joint Cost & Schedule Risk Analysis is invaluable in that it aids programs in:
  - Developing and defending cost and schedule management reserves based on desired confidence levels of program success
  - Ranking risks based on their effect on the program, not just their localized impacts
  - Developing optimal mitigation strategies
- It also presents several challenges which still need to be addressed by industry
- For more information contact: Eric Druker
  - Druker_Eric@bah.com
  - (314) 368-5850

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