Portfolio Management

Program Management

Project Management

Portfolio-Engineering, Inc.

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Project Scheduling Revisited

Deterministic, Probabilistic and Stochastic Analysis

Version 1.00

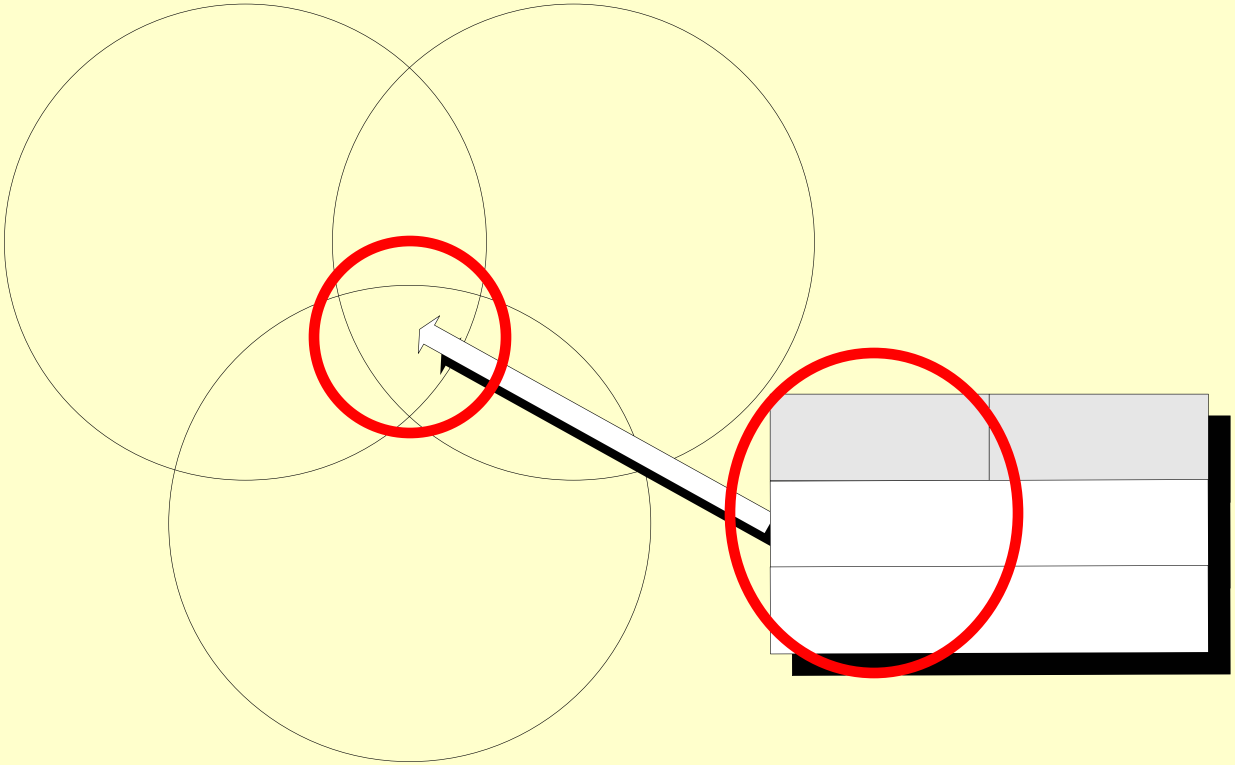
Feb. 20, 2004

Prerequisites

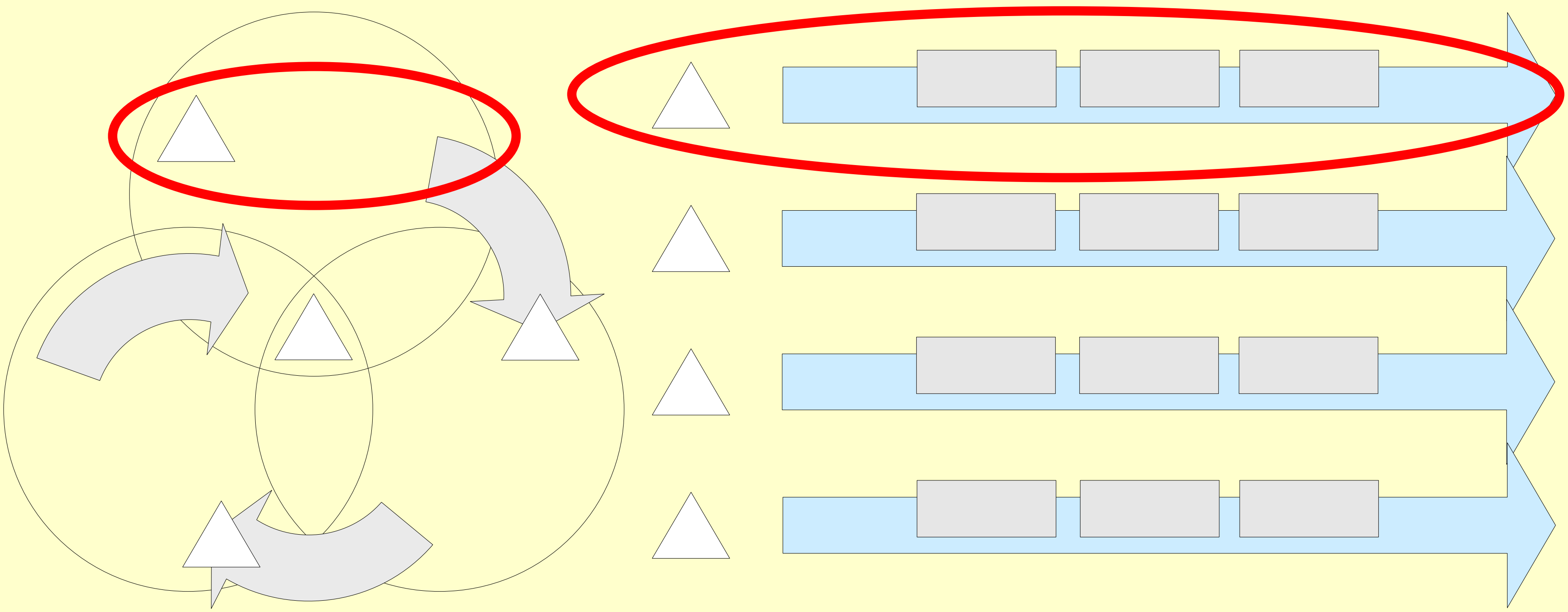
Portfolio-Engineering recommends reviewing the following materials before considering Project Sponsor / Project Charter:

- Introduction to Schedule Development

Context and Boundaries of the Discussion



Context and Boundaries of the Discussion



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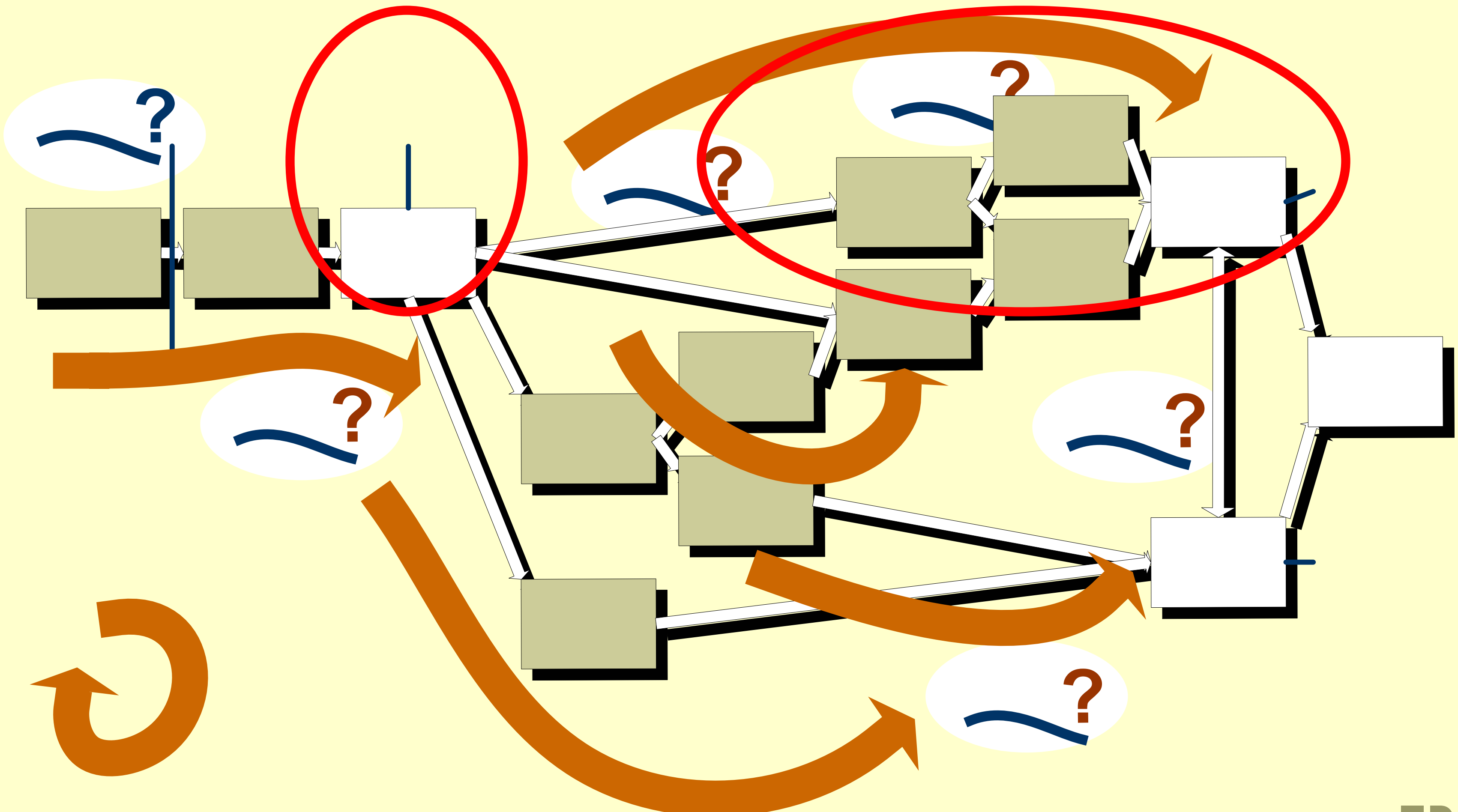
Core PMI Planning Outputs Flow



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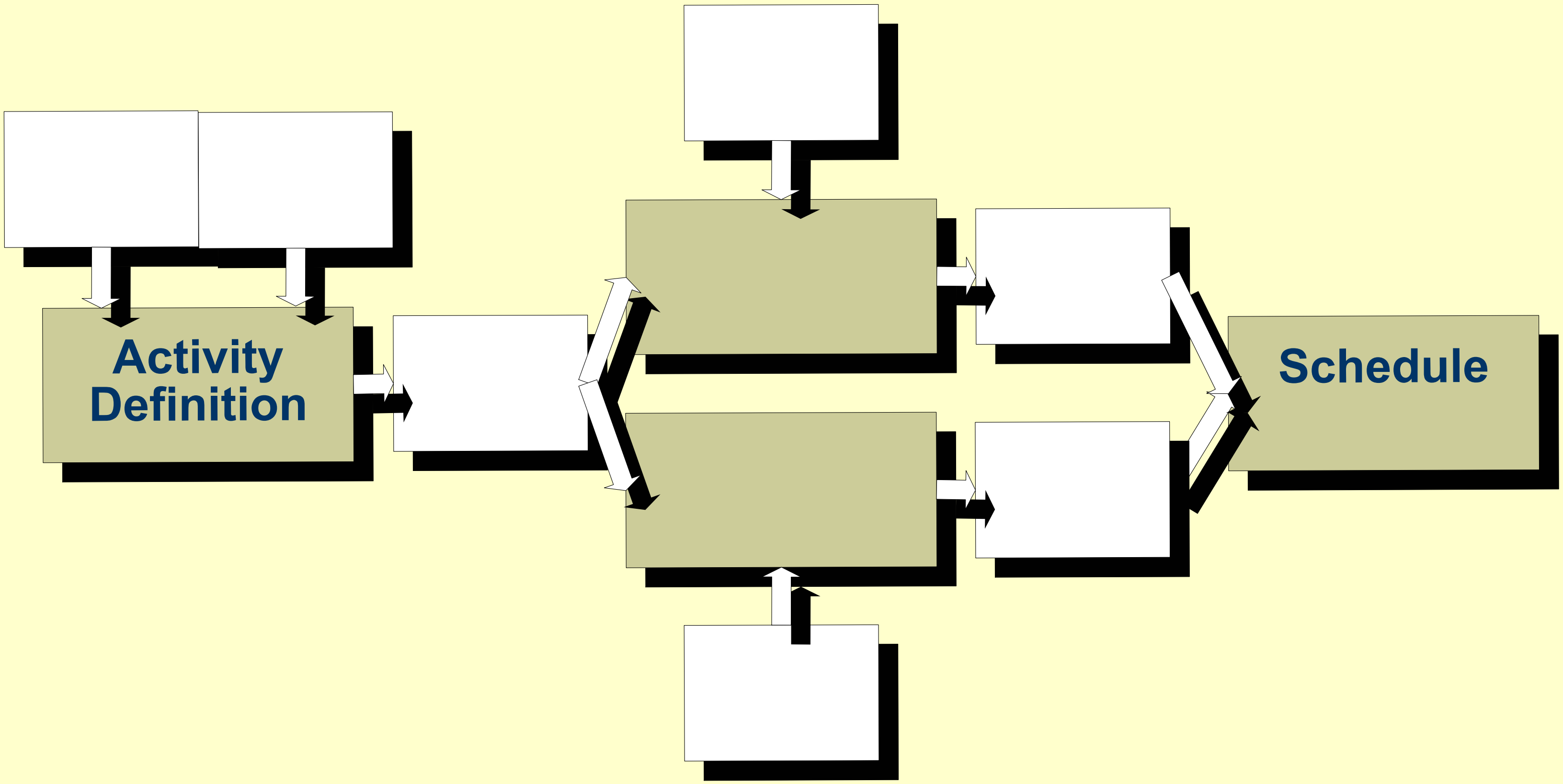
Simplified PMI Schedule Development Processes Flow



Project Scheduling Revisited

Deterministic Analysis

	CPM Critical Path Method *Deterministic*	*Probabilistic*	*Stochastic*
	Mathematical analysis technique used to calculate theoretical early and late start and finish dates for the project and each of its activities and to determine the amount of scheduling flexibility each activity has, identifying the series of activities that have the least amount of flexibility.		
Duration Estimate Requirements	1 · Duration Estimate (probability unknown although typically a low risk estimate)		
Other Requirements	· PDM or ADM Project Network Diagram (Activities, Networked by Finish-to-Start Relationships) · Project Management Software		
Features	· Determines early and late start and finish date for each activity · Calculates best-case project duration · Identifies critical path · Calculates total slack and free slack for each activity		
Basis for Project Duration Calculatation	· Single point duration estimate of unknown probability		

CPM (Critical Path Method)

Example of PDM Network Diagram created using Post-it® Notes on poster paper with applied CPM calculations

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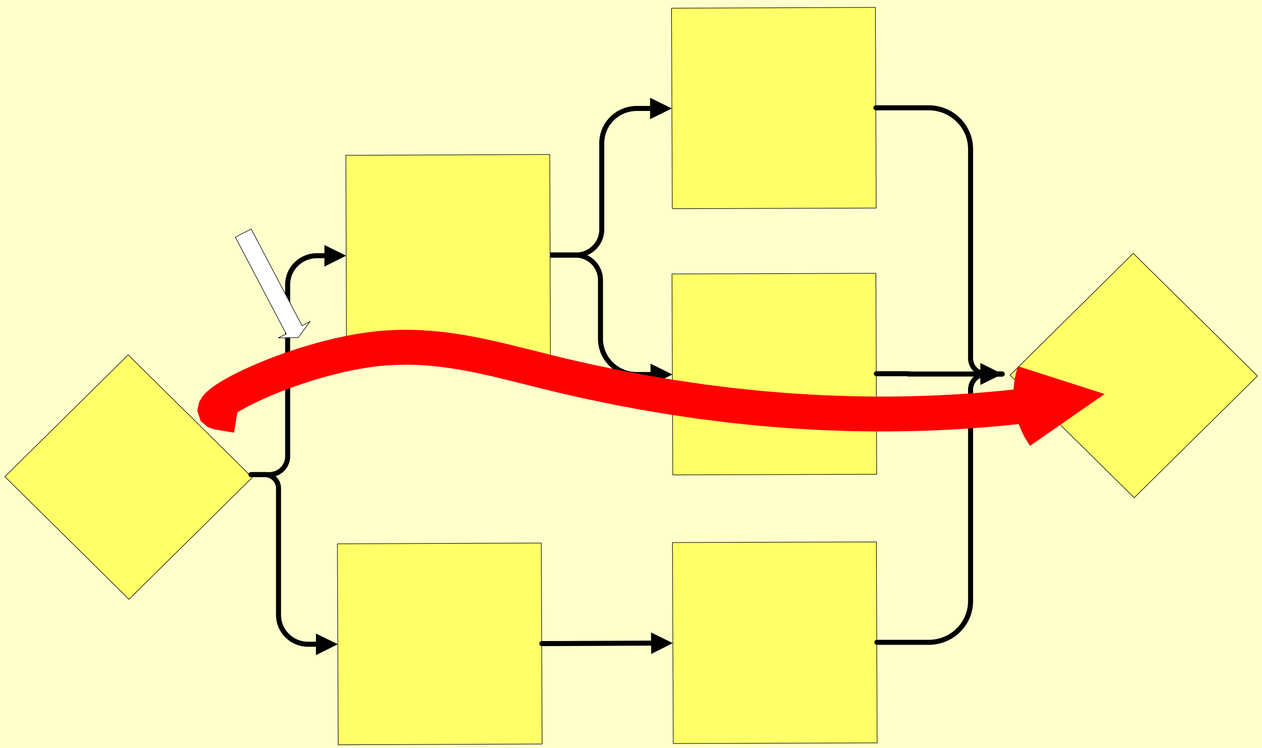

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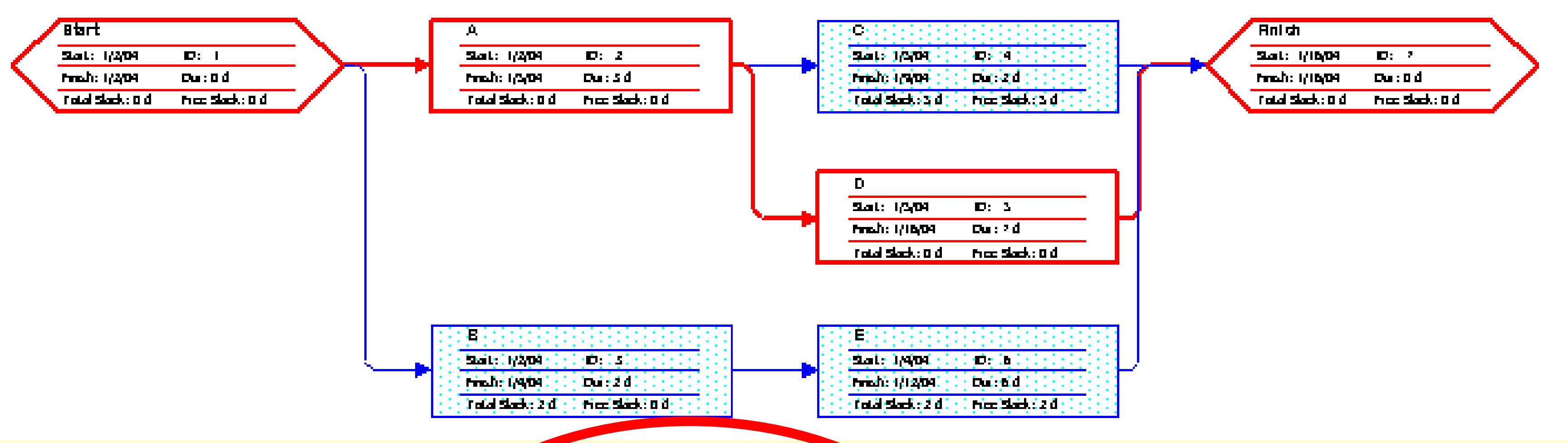
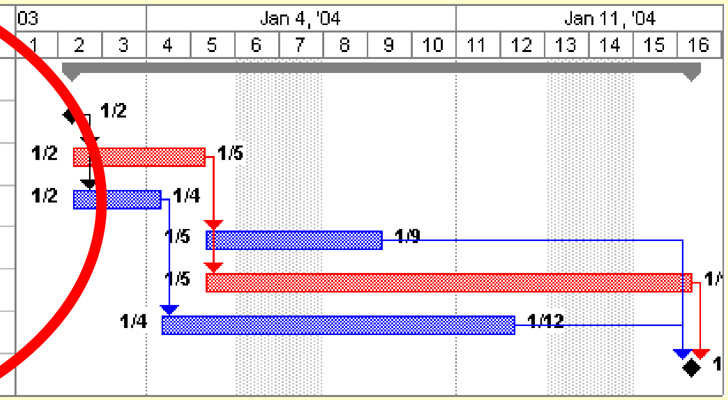
CPM in MS Project



Activity	Duration	Predecessors	Critical	Total Slack	Free Slack
Sample	**10 d**		**Yes**	**0 d**	**0 d**
Start	0 d		Yes	0 d	0 d
A	3 d	1	Yes	0 d	0 d
B	2 d	1	No	2 d	0 d
C	2 d	2	No	5 d	5 d
D	7 d	2	Yes	0 d	0 d
E	6 d	3	No	2 d	2 d
Finish	0 d	4,5,6	Yes	0 d	0 d



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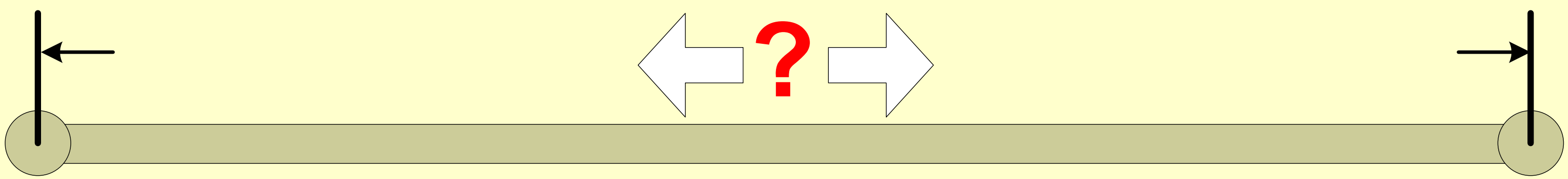
Certainty Continuum

While estimating, you must have a feel for where you are on the “Certainty Continuum”. There is always a real duration. The continuum illustrates how likely it is that you are able to estimate *that* duration at the current time.

- “Certain” activities will have a very limited range of possible results
- Uncertain activities have a very wide range of possible results, making estimating significantly more complex

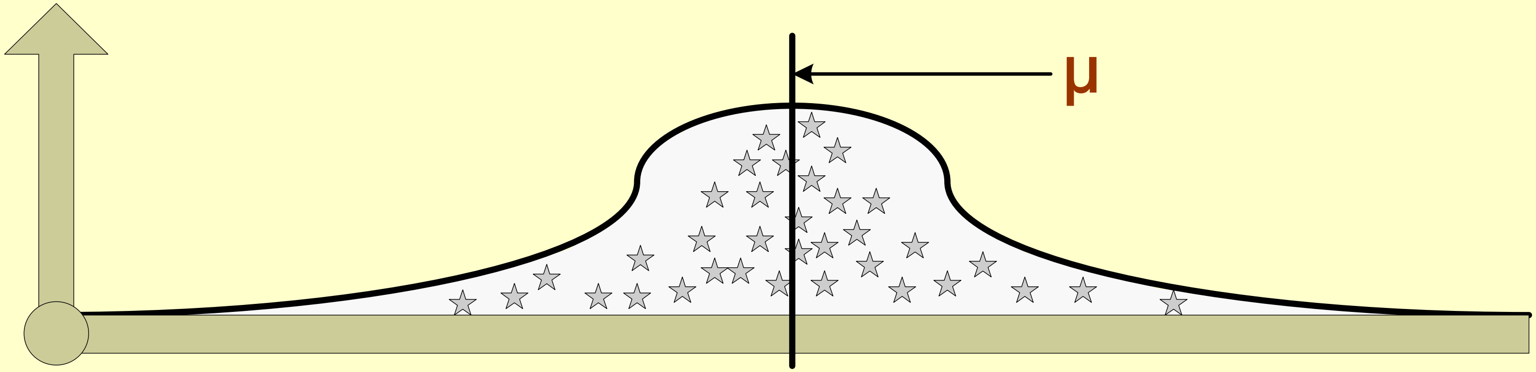


Project Scheduling Revisited

"Certain" Activities

For activities that are high on the Certainty Continuum, we can determine a fairly accurate estimate with a 50% probability of accuracy (μ or mean of a normal distribution)

- While 50% is a very low probability, it may be appropriate as:
  - Half of our "certain" activities will come in early and half late (with 0 net impact on the project duration)
  - By nature, "certain" activities have a normal variation of a minor duration
- With "certain" activities, single point estimating (CPM) can be used successfully!



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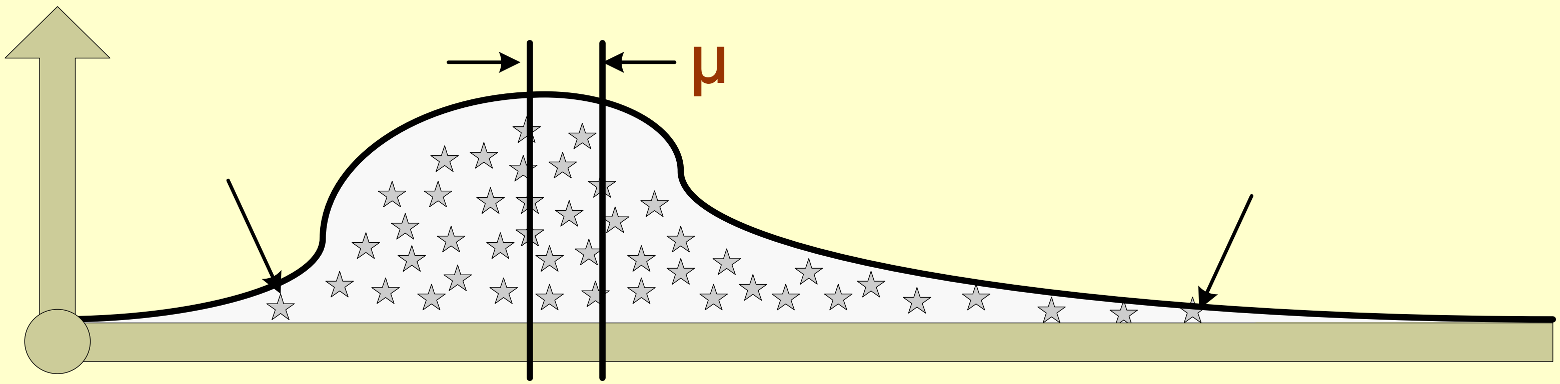
Uncertain Activities

For activities with a great deal of uncertainty, the range of estimates cannot be plotted as a bell curve. A beta distribution can be used (sometimes referred to as "the dragon's tail").

- The best-case scenarios (lowest duration) have a minimum that is driven by the laws of physics
- The worst-case scenarios (highest duration) are often relatively unbounded and can be *very* high driven by the laws of Murphy



*** Example of a beta distribution.**

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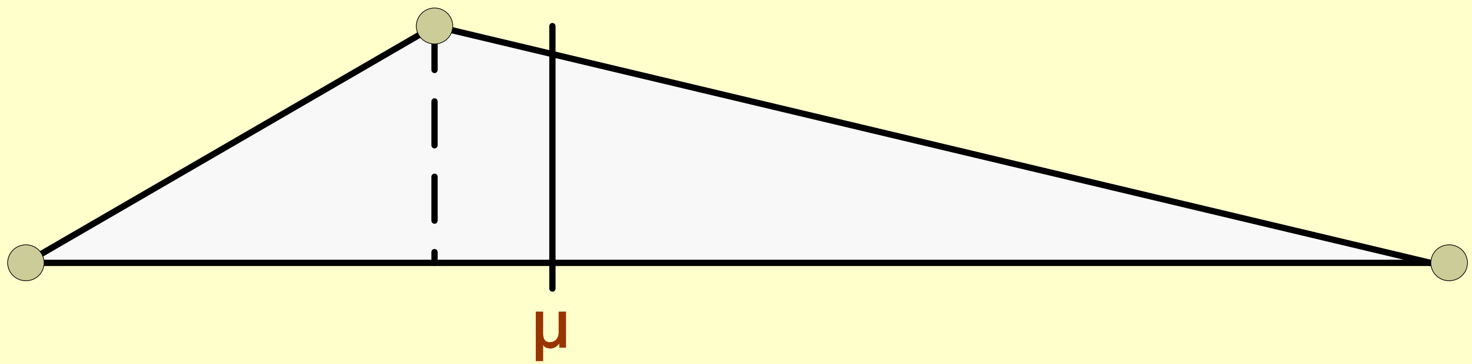
Uncertain Activities

A triangular distribution can also be used to illustrate the distribution of possible results for uncertain activities.

With a triangular distribution, possible results are not as clustered around the most likely result causing the mean to be closer to the worst case result. Triangular distributions are more conservative or risk oriented.



*** Example of a triangular distribution.**

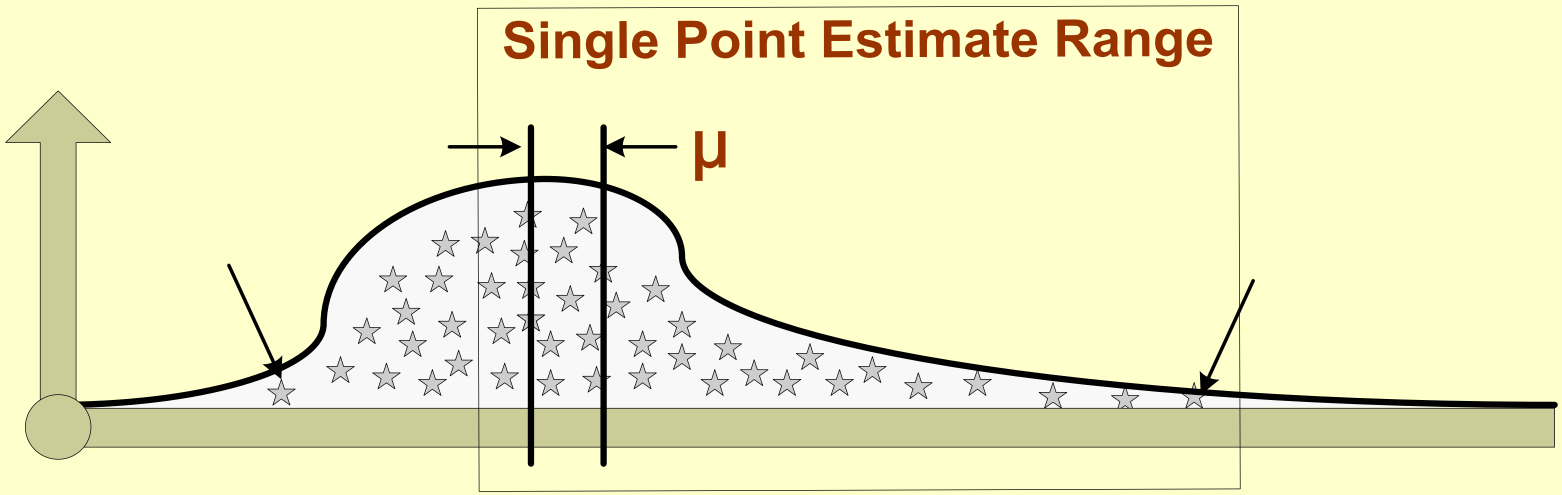
Uncertain Activity Exercise

- QUICKLY, how long does it take to drive to Las Vegas from Los Angeles?
- What would be the absolute best case?
- What would be a reasonable but possible worst case? (BE CREATIVE!)
- So, how much time should you plan for the drive?

* Example of a triangular distribution.

Unknown Estimate Probability

- For activities with a great deal of uncertainty, single point estimating (CPM) will produce highly subjective estimates with an unknown and wide range of probability (i.e. 40 - 90%)
- Probability of estimates will vary based on the nature of the individual, their current state of mind and understanding of the task, and even expectations surrounding the project being planned



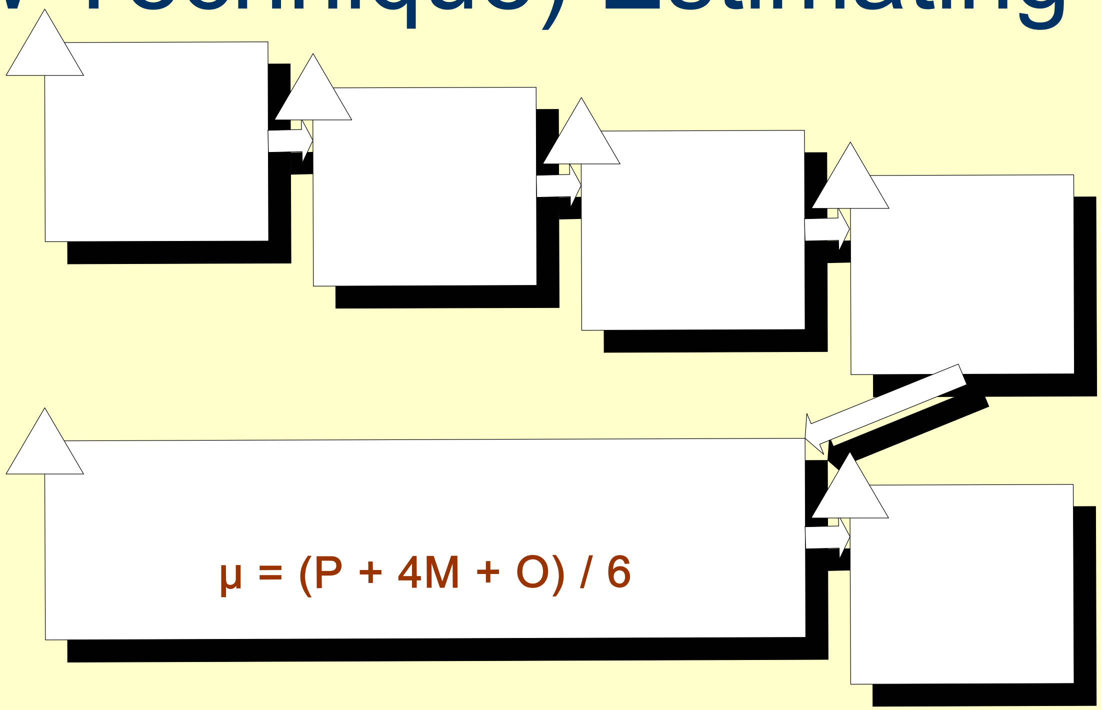
Project Scheduling Revisited

Probabilistic Analysis

	CPM *Deterministic*		PERT Program Evaluation and Review Technique *Probabilistic*		*Stochastic*	
			Mathematical estimating technique used to calculate activity durations as the mean of a three point estimate to factor in uncertainty, to create a schedule with an improved likelihood of being met, and to support probability analysis.			
Duration Estimate Requirements			3 (PMO)	· Pessimistic Estimate P · Most Likely Estimate M · Optimistic Estimate O		
Other Requirements			· CPM Technique			
Features			· Introduces concept that an estimate is a range not a single point · Determines μ (mean) activity duration estimate (50% probability) · Determines task and project variance · Employs beta distribution theory to calculate standard deviation and project probability			
Basis for Project Duration Calculatation			· μ (mean) of a three point estimate (approx. 50% probability)			

Project Scheduling Revisited

PERT (Program Evaluation and Review Technique) Estimating Process



Note: The terms “optimistic” and “pessimistic” are used to be consistent with PMI. The attributing of emotions to estimates is inappropriate and better terms are “best case” and “worst case”.

Consideration

Use Single Point Estimating on "Certain" Activities

- Consider adding "Uncertain?" as an attribute to the activities in your automated schedule (as a simple yes/no toggle)
- For activities flagged as certain, use a single point estimate as it is simple and relatively accurate
- Strive for an estimate with a 50% probability. That is, do not pad the estimate and do not add contingency. This will produce single point estimates with some consistency with regard to their probability. If you feel that contingency is necessary, mark the activity as uncertain and do not use a single point estimate

Consideration

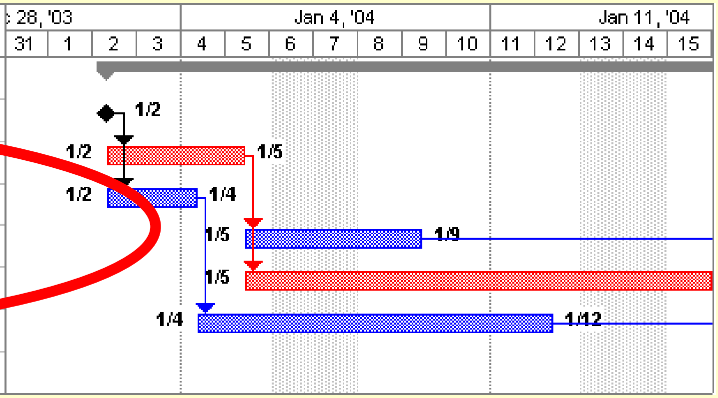
Use PERT to Estimate Uncertain Activities

- For activities flagged as uncertain, use PERT (three point estimating) to calculate a weighted estimated duration (the μ, mean, or expected time) using **$\mu = (P + 4M + O) / 6$**. The mean should be used as the duration for CPM purposes. The mean has a probability of approximately 50%.
- For high risk projects (or risk averse organizations), consider a different weighting for the PERT calculation such as **$\mu = (2P + 3M + O) / 6$**

Project Scheduling Revisited

PERT Estimating in MS Project

Activity	Duration	Uncertain?	Optimistic	Most Likely	Pessimistic
Sample	**10.83 d**	No	**7 d**	10 d	**18 d**
Start	0 d	No	0 d	0 d	0 d
A	3.33 d	Yes	2 d	3 d	6 d
B	2.17 d	Yes	1 d	2 d	4 d
C	2 d	No	0 d	0 d	0 d
D	7.5 d	Yes	5 d	7 d	12 d
E	6 d	No	0 d	0 d	0 d
Finish	0 d	No	0 d	0 d	0 d

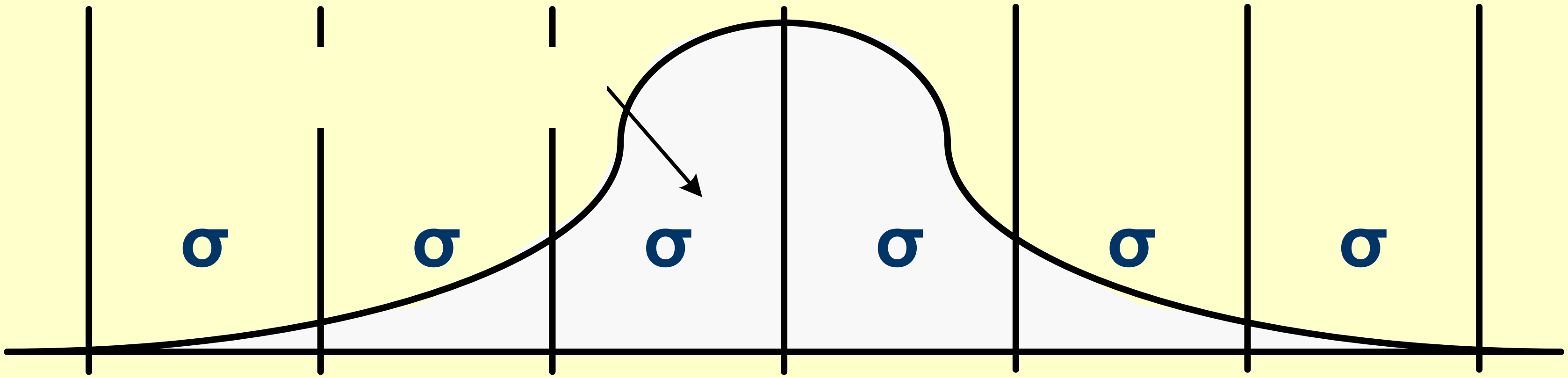


Note: MS Project has full PERT support which can be accessed by turning on the PERT Analysis toolbar.

Project Scheduling Revisited

Standard Deviation Theory

Standard deviation theory assumes that in a normal distribution (i.e. bell curve) there are 6 standard deviations (6σ or six sigma) of equal measure between the low and the high points



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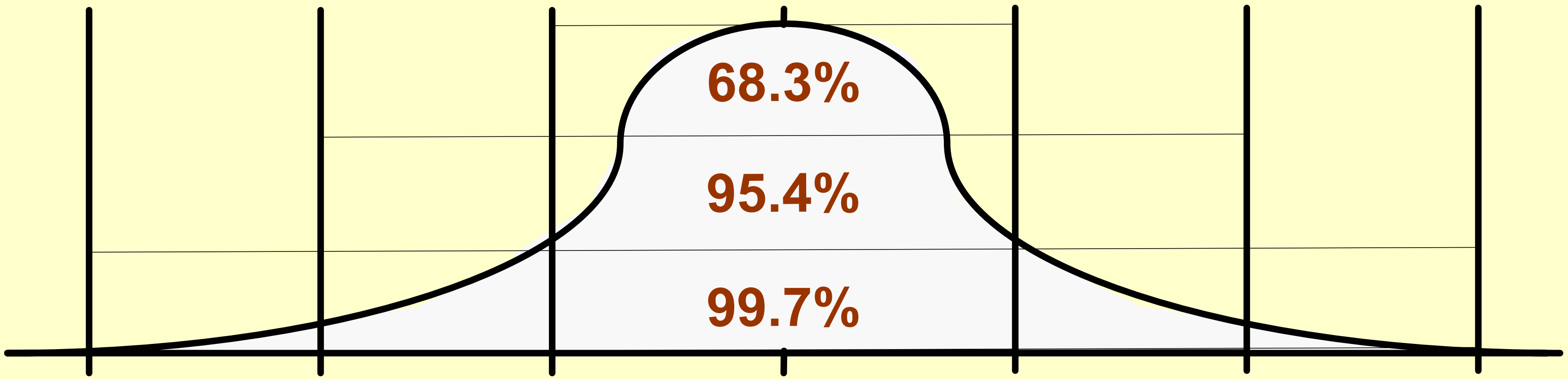
Standard Deviation Theory

Standard deviation theory asserts that the normal distribution follows a pattern.

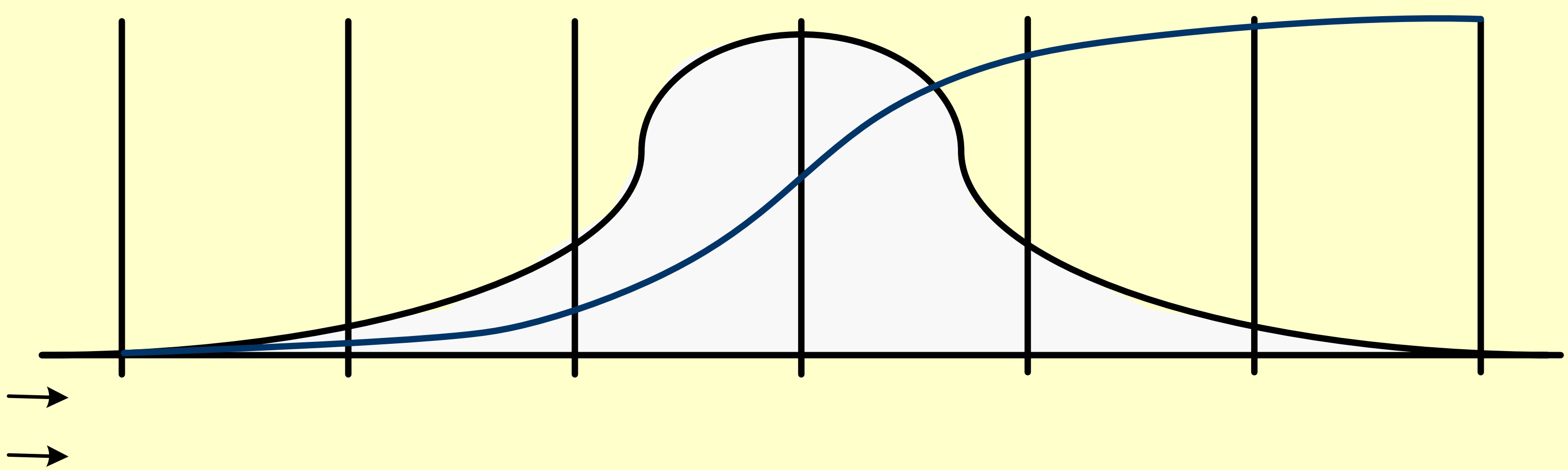
σ	%
± 1 σ	68.3%
± 2 σ	95.4%
± 3 σ	99.7%



Project Scheduling Revisited

Standard Deviation Theory

Standard deviation theory allows us to calculate a cumulative probability for any point at zσ.



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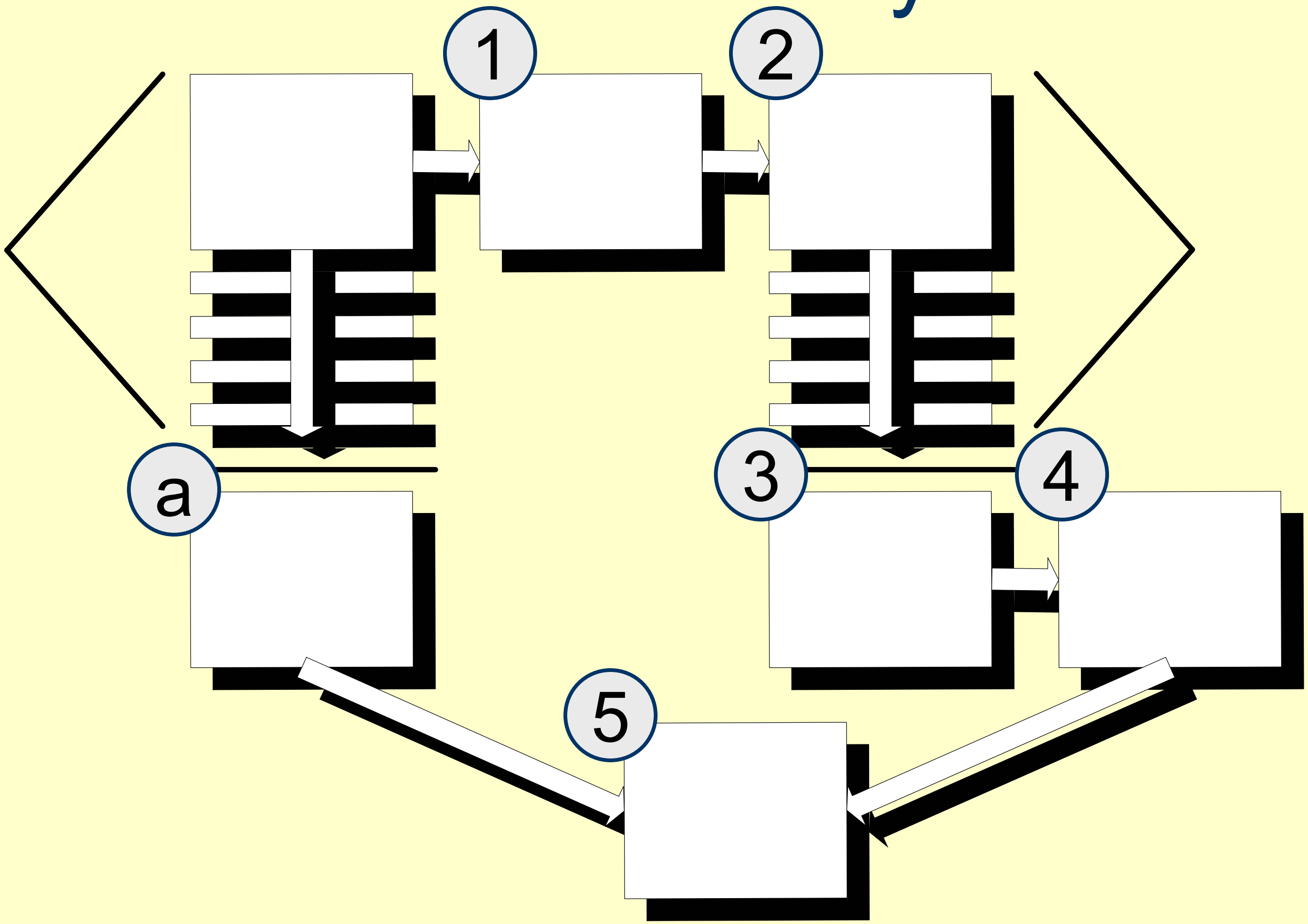
Standard Deviation Theory

z	Probability	z	Probability	z	Probability
-3.0	0.1%	-1.0	15.9%	1.0	84.1%
-2.9	0.2%	-0.9	18.4%	1.1	86.4%
-2.8	0.3%	-0.8	21.2%	1.2	88.5%
-2.7	0.3%	-0.7	24.2%	1.3	90.3%
-2.6	0.5%	-0.6	27.4%	1.4	91.9%
-2.5	0.6%	-0.5	30.9%	1.5	93.3%
-2.4	0.8%	-0.4	34.5%	1.6	94.5%
-2.3	1.1%	-0.3	38.2%	1.7	95.5%
-2.2	1.4%	-0.2	42.1%	1.8	96.4%
-2.1	1.8%	-0.1	46.0%	1.9	97.1%
-2.0	2.3%	0.0	50.0%	2.0	97.7%
-1.9	2.9%	0.1	54.0%	2.1	98.2%
-1.8	3.6%	0.2	57.9%	2.2	98.6%
-1.7	4.5%	0.3	61.8%	2.3	98.9%
-1.6	5.5%	0.4	65.5%	2.4	99.2%
-1.5	6.7%	0.5	69.1%	2.5	99.4%
-1.4	8.1%	0.6	72.6%	2.6	99.5%
-1.3	9.7%	0.7	75.8%	2.7	99.7%
-1.2	11.5%	0.8	78.8%	2.8	99.7%
-1.1	13.6%	0.9	81.6%	2.9	99.8%
-1.0	15.9%	1.0	84.1%	3.0	99.9%

PERT Probabilistic Analysis Process



Task Standard Deviation

1

σ (standard deviation) for a task, given the low and high points of the three point estimate:

$$\sigma = (P - O) / 6$$

Task Variance

2

A measurement of the uncertainty of a task estimate:

$$TV = \sigma^2 \text{ or } TV = [\,(P - O) / 6\,]^2$$

A task can be said to have an expected duration ± TV

Project Variance

3

A measurement of the uncertainty of a project duration estimate:

$$PV = \Sigma\ TV$$ (i.e. sum of the task variances)

Note: Only include the tasks that are on the critical path in this calculation

A project can be said to have an expected duration ± PV

Project Standard Deviation

4

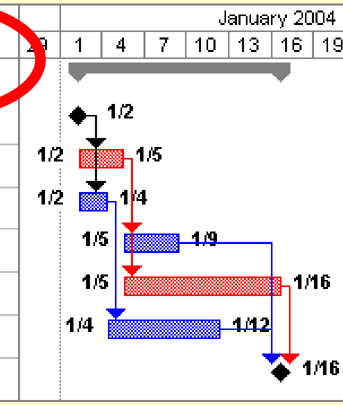
Pσ, project standard deviation :

$$P\sigma = \sqrt{PV}$$

Project Scheduling Revisited

Probabilistic Analysis in MS Project

Activity	Duration (a)	Pessimistic	Optimistic	SD (P-O)/6 (1)	TV (SD) Sqrd (2)	PV Sum Critcl T[illegible]s (3)	PSD Sqrt PV (4)
Sample	**10.83 d**	**18 d**	**7 d**			**1.81**	**1.34**
Start	0 d	0 d	0 d	0	0	0	
A	3.33 d	6 d	2 d	0.67	0.44	0.44	
B	2.17 d	4 d	1 d	0.5	0.25	0	
C	2 d	0 d	0 d	0	0	0	
D	7.5 d	12 d	5 d	1.17	1.36	1.36	
E	6 d	0 d	0 d	0	0	0	
Finish	0 d	0 d	0 d	0	0	0	



Note: Utilizing MS Project customizable fields, the software can be modified to calculate each of the probability values.

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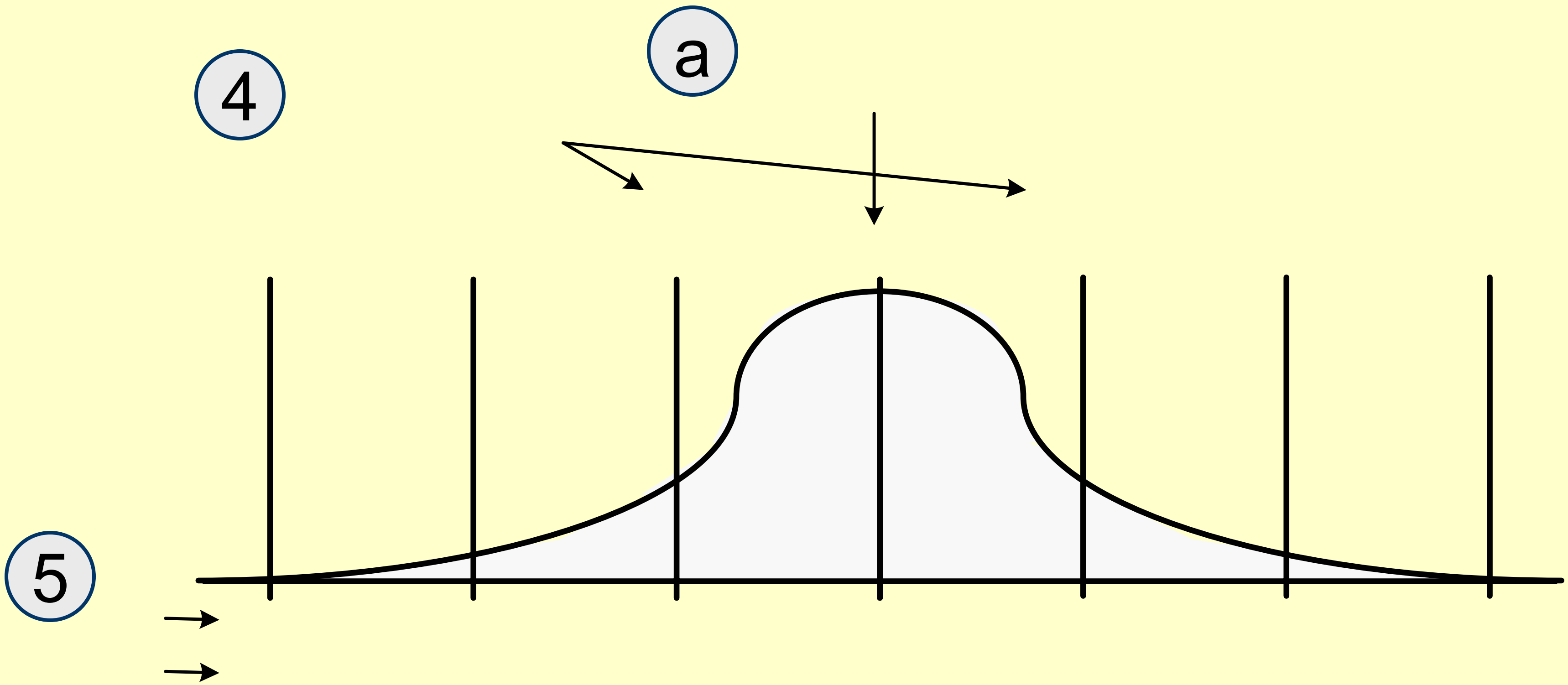
Probable Project Duration

5



Proposed Duration Probability

5

Calculates the number of standard deviations a proposed project delivery date is from the mean:

z = (Proposed Duration – Expected Duration) / Pσ

MS Excel's NORMSDIST(z) function can be used to provide an exact probability given z

Exercise: What is the probability of completing the sample project in 9 days?

Consideration

Utilize Probabilistic Analysis

Consider utilizing probabilistic analysis while scheduling and planning to determine appropriate project time frames and set reasonable expectations

Consider utilizing an automated project scheduling tool such as MS Project to crunch the numbers for you

Consideration

Triangular Distribution Alternative

As an alternative to PERT (based on beta distribution), you may wish to use the Triangular Distribution calculation alternatives. They are more conservative (the factor in additional contingency) and the calculations are more exact.

- Replace the mean or expected time calculation of (P + 4M + O) / 6, with:

$$(P + M + O) / 3$$

- Replace TV (task variance) calculation of [(P – O) / 6] ², with:

$$[(P - O)^2 + (M - O)(M - P)] / 18$$

Project Scheduling Revisited

Stochastic Analysis

	CPM Critical Path Method *Deterministic*	PERT Program Evaluation and *Probabilistic*	Monte Carlos Analysis *Stochastic*
			Technique that "solves" (or iterates) the project hundreds or thousands of times by choosing random activity durations within the estimated ranges that is used to determine overall project schedule risk.
Duration Estimate Requirements			3 (PMO) · Pessimistic Estimate P · Most Likely Estimate M · Optimistic Estimate O
Other Requirements			· CPM Technique · Monte Carlos Analysis simulation software · Resource Leveling Technique
Features			· Determines the optimal number of project simulations required for thorough analysis · Determines the range of possible dates, the relative frequency and probability for the dates, and the likely date for the project completion and for the significant project milestones · Determines the required contingency to complete the project with a reasonable probability · Determines all possible critical paths and their relative frequency and probability
Basis for Project Duration Calculatation			· random duration within the three point estimate distribution for each task during each of hundreds or thousands of simulations

Monte Carlos Analysis Tools

- @RISK by Palisade Corporation (MS Project Add-on)
- Risk Master by Sphygmic Software Ltd. (imports data from popular scheduling software)
- Risk+ by C/S Solutions Inc. (MS Project Add-on)

Consideration

Utilize Monte Carlos Analysis

Consider utilizing Monte Carlo Analysis if your project:

- Has a large budget (Monte Carlos Analysis tools can be expensive) and is high risk
- Is being Fast Tracked (serial tasks are being done in parallel through the addition of additional resources at extra cost)
- Has many parallel paths, merging paths, multiple critical paths or an uncertain critical path

Schedule Contingency Planning

Applying the considerations presented so far will result in a performance baseline:

- With a duration with an over-all probability of 50% (no project contingency)
- Comprised of activities with 50% probability (no activity contingency)

Clearly contingency time must be added to create a project schedule with an acceptable probability

Do Not Add Contingency to Activities

Practice mean-based scheduling to avoid padding activity duration estimates. Contingency within activities is wasted by the "schedule busters":

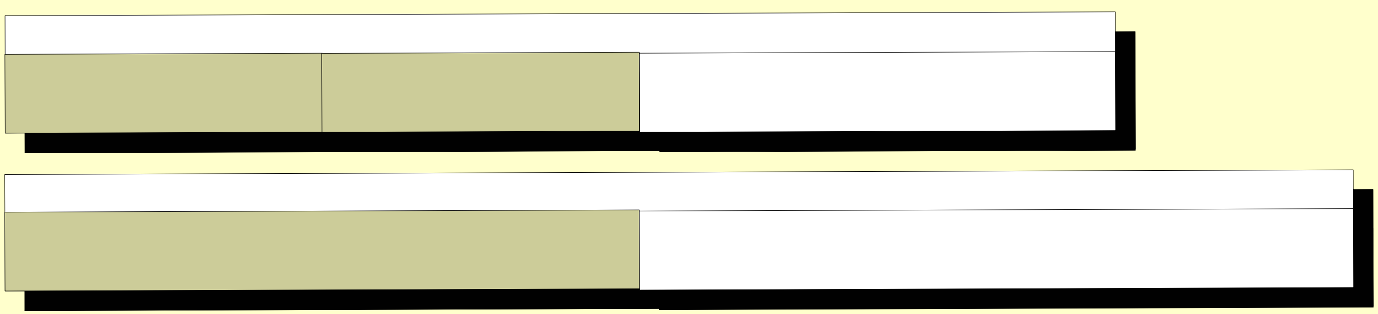
1. Delayed Engagement Syndrome
2. Parkinson's Syndrome
3. "As-Planned" Phenomenon

Delayed Engagement Syndrome

1

Also known as “Student Syndrome” or simply procrastination, delayed engagement syndrome is the wide-spread practice of starting activities at the latest possible moment.

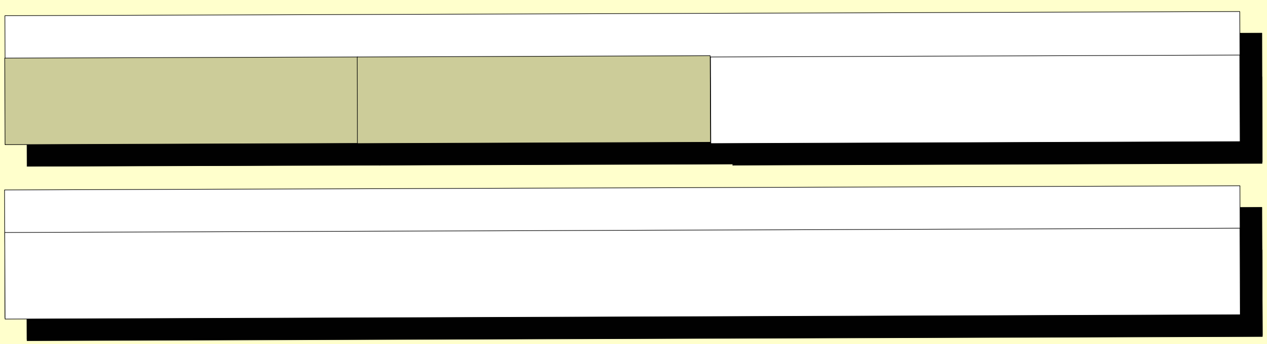
Given the syndrome, the contingency created by estimating uncertain activities with a 90% probability is often used to do other work and is never applied to the uncertain activity at all.



Parkinson's Syndrome

"Work expands so as to fill the time available for it".

Parkinson's syndrome reminds us that activity duration estimates often become a self-fulfilling prophecy. Rather than the scope and quality solely determining the activity duration, the actual duration estimate may itself become a determinant.



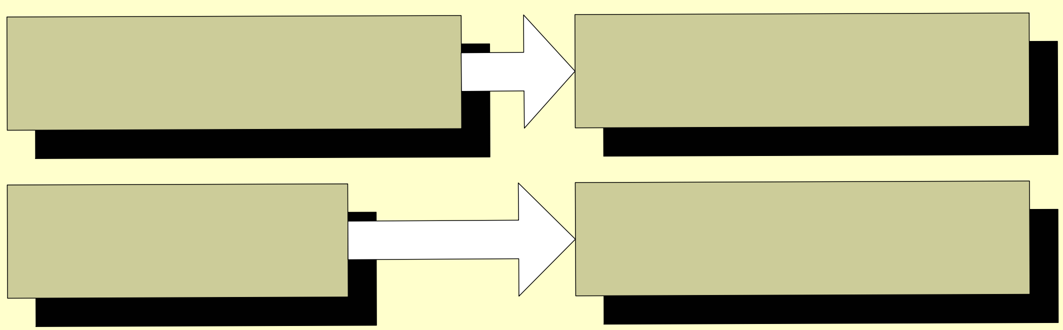
"As-Planned" Phenomenon

3

While project schedules are dynamic, resources are rarely as dynamic.

When a task is completed early (and is reported as such), other tasks may keep their planned start dates for a number of significant organizational reasons. Time saved is usually lost.

Again, the estimated duration of activity A ended up becoming a determinant of the start of activity B.



Reserve Time (Contingency) Buffers

Reserve time (schedule contingency) must be planned for and added to the schedule. It is often added in the form of buffers that are managed by the project manager.

The principal buffer is the Project Buffer (PB) which is an amount of reserve time that is added to the end of the critical path and included in the project duration calculation.

Other buffers such as the Critical Chain Scheduling Feeding Buffer (FB), Resource Buffer (RB) and Drum Buffer (DB) are designed to ensure that the schedule is met and do not contribute to the actual project duration estimate.

Consideration

Calculating the Project Buffer (PB)

Possible approaches include:

- Using Project Standard Deviation
- Percent of Critical Path Duration

It may be that you wish to use the maximum result of both methods to establish your PB.

Consideration

PB: Using Project Standard Deviation

Standard deviation (PERT) tells us that:

Baseline +1σ = ~84% Probability
Baseline +2σ = ~98% Probability
Baseline +3σ = ~100% Probability

Thus the project σ already calculated can be used as the basis for calculating the PB. Using 2σ or 3σ is the standard for this approach.

This approach to calculating the σ is called SSQ (square root of the sum of the squares). The major draw-back of the approach is that the statistical method of pooling variances deployed creates a PB that gets significantly smaller (as a percent of the project duration) as the total number of project activities increases. This "opportunity" for pooling variances is not in line with the experience of many long, complex projects executed in the past 2 decades. Experience shows that the PB

Consideration

PB: Percent of Critical Path

The default rule (from Critical Chain scheduling technique) is to calculate a PB as 50% of the duration of the critical path (or critical chain). This is identical to 50% of the performance baseline.

On some projects this calculation may prove to create a PB that is too large and that results in a lose of competitiveness. For some projects that are given to only minimal uncertainty and common cause variation, a PB that is as little as 25% of the duration (and 10% of the cost) of the critical path has proven successful.

Consideration

Additional PB Requirements

Analysis of recent project trends suggests that the following factors may also be required to appropriately size the PB:

- **Omissions**

  Essential project activities overlooked during planning and not caught by practices such as use of checklists, review of historic plans, use of planning templates and lessons learned

  5 – 15% of overall project cost estimate (and perhaps schedule)

From "Schedule and Cost Buffer Sizing" – Project Management Journal June 2003

Consideration

Additional PB Requirements

- **Merging Paths**

  Project plans with parallel activity paths that merge experience schedule delays (due to coordination requirements) that grow exponentially with the number of paths merging.

  It is not possible to precisely quantify the impact but it can be managed and minimized through the use of Critical Chain management feeding buffers (FB).

  This negative schedule bias should be factored into the PB. Projects that are fast-tracked require significant PB allowance for the resultant complexity of project management.

From "Schedule and Cost Buffer Sizing" – Project Management Journal June 2003

Consideration

Additional PB Requirements

- **Errors (Cost of Poor Quality COPQ)**

According to Deming, the COPQ in most companies is 20 – 40%. In high quality organizations (i.e. Six Sigma) the COPQ may be as low as 5%.

Schedule impact of errors depends on the ultimate impact to the critical path (or critical chain). Assuming a 5% minimum impact may be best practice.

From "Schedule and Cost Buffer Sizing" – Project Management Journal June 2003

Consideration

Additional PB Requirements

- **Overconfidence (Bad Estimating)**

Studies show that even (sometimes *especially*) subject matter experts consistently under-estimate as much as 50% of the time and by as much as 10%. This is equally true when using PERT three point estimating.

To compensate for this, some have revisited the PERT Task Standard Deviation formula (TV=(P-O)/6) that assumes the two extreme points of the estimate will fall within ±3σ. Instead they use TV=(P-O)/4, assuming that the estimates cover only ±2σ (or ~84%) of the actual distribution. This will provide for a larger PB if σ is used.

From "Schedule and Cost Buffer Sizing" – Project Management Journal June 2003

Consideration

Additional PB Requirements

- **Queuing**

If project plans are not fully resource-loaded and resource-leveled or resource and drum buffers (Critical Chain management) are not used, the project schedule will be delayed as work gets queued up for key resources.

In organizations that use 80% or higher resource utilization for capacity planning, the impact will be significantly greater.

The PB must account for expected schedule delays due to queuing issues.

From "Schedule and Cost Buffer Sizing" – Project Management Journal June 2003

Managing the Project Buffer (PB)

Buffers are controversial because they are misunderstood and sometimes viewed as padding. Some project managers choose to represent the PB with names that suggest they are quality or integration tasks.

The project team must buy into the concept. They must understand why activity duration estimates are relatively short (mean-based). They must understand (and not abuse) the PB.

Adding a PB will not bring a project in early. They are designed to bring the project in on time.

Consideration

Managing the Project Buffer (PB)

The PB can be divided into 3 parts:

- OK (Green)
- Watch & Plan (Yellow)
- Act (Red)

As the buffer is depleted, the style of management must change.

OK (Green)	**Watch & Plan (Yellow)**	**Act (Red)**

Project Scheduling Revisited

CCS / BM Highlights

CCS / BM Critical Chain Scheduling / Buffer Management
An emerging technique for scheduling and buffer management based on the Theory of Constraints that recognizes paths created not only through precedence and duration but also through resource conflicts. The technique which constructs and protects a mean activity duration-based precedence and resource-feasible deterministic baseline is very focused on delivering projects on-time.
50% probability activity duration estimates
No activity due dates, no project milestones
No multitasking (buffer management enables focused work on single project task)
Schedule objectives = minimize makespan; minimize work in progress
Determine a precedence and resource-feasible baseline schedule
Identify the critical chain
Aggregate uncertainty allowances into buffers
Keep the baseline schedule and the critical chain fixed during project execution
Determine an early start-based unbuffered project schedule and report early completions (apply the roadrunner mentality, start when activity is available and continue at 100% until it is complete)
Use the buffers as a proactive warning mechanism during schedule execution
Use feeding buffers at the end of chains of activities that merge into the critical chain
Across project resource leveling through project priority setting and staggering of project starts to the capacity of the constraining resource with a capacity buffer

From "Critical Chain Project Scheduling: Do Not Oversimplify" – Project Management Journal December 2002

Consideration

Remove Bottle-necks and Inefficiencies

Identify current resource bottle-necks and increase their through-put. This will decrease delays due to work "stack" and backlog. (Also called "tampering" as the cost often outweighs the benefits.)

Keep organizational administration and overhead to a minimum. This will increase productivity at the cost of some loss of management control.

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Consideration

Stop Multi-tasking!

- It is inefficient and expensive
- You cannot do 2 knowledge-based tasks simultaneously
- The overhead of multi-tasking (“switch-back time) is extensive
- Turn off email and the phone when doing knowledge-based work
- Single-tasking is “hard to slow down”. Multi-tasking is “hard to speed up”.

Consideration

Get Project Team Focused

- Have resources dedicated to your project
- Set-up a “skunk-works” to remove your project team from organizational administration and overhead
- Co-locate your project team to make communication efficient
- Secure a high project prioritization within the organization so that your activities will be placed at the top of all work “stacks” and by-pass backlogs

Consideration

Hyper Manage Critical Path / Chain

- Identify your critical path (and critical chain)
  - Never allow resources on a critical activity to multi-task
  - Have a physical symbol (i.e. "the baton") that is held by the resource currently on the critical activity
  - Exploit the resource dedicated to the critical activity
  - Subordinate other resources to the critical resource
- If you need to press performance to its maximum, measure it. People work their most efficient when being measured.

Next Steps

For additional information, **Portfolio-Engineering** recommends reviewing the following related materials:

- Project Plan Development

References

- CPM (Critical Path Method) developed approx. 1957 by du Pont to assist in various chemical plant construction and maintenance projects.
- PERT (Program Evaluation and Review Technique) developed in 1958 by the Special Projects Office of the US Navy and Booz, Allen & Hamilton to plan and control the Polaris missile program.

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