An Overview of CPM/PERT/MCS in Project Planning

This article will discuss how to model risk in project planning. The two critical aspects of running a successful project include project costs and project schedule. Since projects contain many sources of variation, all two aspects are prone to not meeting targets. Project managers need to use appropriate tools to manage the variability (or risk) in the project.

We'll focus on time because it is slightly more complicated; a similar analysis can be applied to cost planning. The risk in planning for project completion time is, naturally, that your projections are incorrect. Underestimating project time can result in additional costs and potential penalties. Overestimating project time can result in wasted resources

PMI's Pulse of the Profession research (The High Cost of Low Performance -2016), which is consistent with other studies, shows that "fewer than two-thirds of projects meet their goals and business intent, and about 16 percent fail outright. Failed projects waste an organization's money: for every £1 billion spent on a failed project, £122 million is lost forever…unrecoverable."

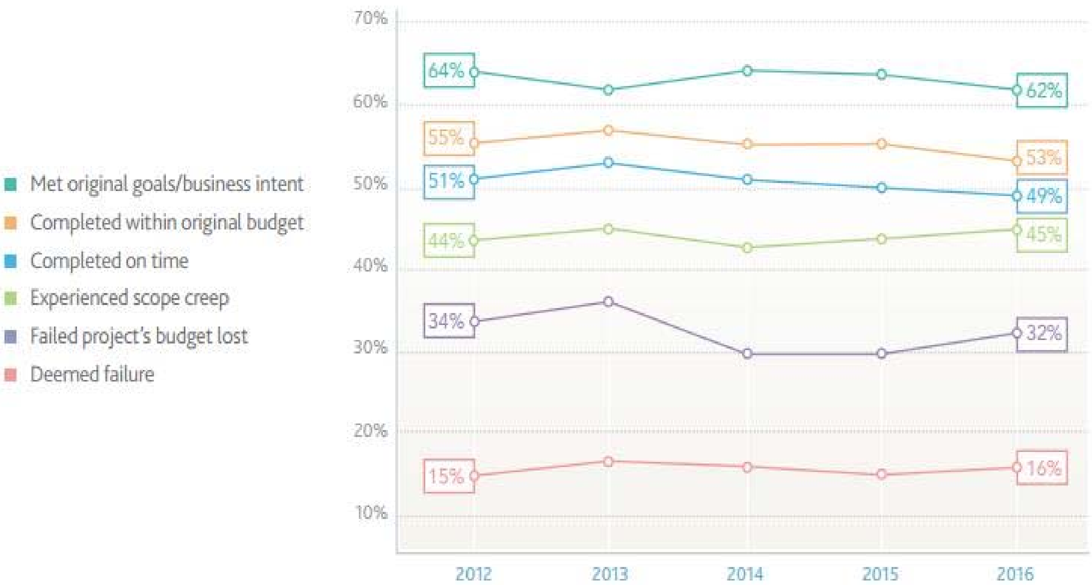

Figure 1: Current State of Project Outcomes / Source: PMI's Pulse of the Profession- The High Cost of Low Performance -2016

A project schedule is, in effect, a projection or forecast of how and when the project will be performed, and as Niels Bohr, Yogi Berra, or Samuel Goldwyn (depending on who you ask) once may have pronounced, "Prediction is very difficult, especially about the future." Everything we think we know about the future is subject to uncertainty, and duration estimates are no exception. The amount of uncertainty varies, depending upon how much the current project resembles previous ones, how much relevant historical data we have, and so on. But we can be certain that there is some uncertainty. Recognition of this fact is essential to creating realistic project plans.

With practice, and good analytical techniques, you can generally construct a reasonable projection for project completion time. But in the real world, it's not possible to anticipate every contingency, and even the best project planning will include some over- or underestimates.

Critical Path Method (CPM)

The Critical Path Method or CPM is a network analysis technique concerned with planning and controlling of complex, but routine projects. Simply, Critical path method is generally used for the projects whose time duration is known with certainty and also the amount of resources required for the completion of the project is assumed to be known.

The technique for using this method is to construct a model of the project schedule using a list of all the project activities, the duration of each activity and the dependencies of each activity. The critical path method uses these values to calculate the longest path of planned activities that are required to complete the project. It also calculates the earliest and latest that each activity can start and finish without delaying the project. This method determines which activities are on the "critical path" – the sequence of activities that add up to the longest overall project duration. This determines the shortest time possible to complete the project; any variability on the critical path directly affects the planned project schedule. A project can have several paths that can become critical depending on the actual duration of the project activities.

The Critical Path method is deterministic in nature, this means that you get the same results (in this case, project duration) for a given set of initial conditions (project activity duration). But, in reality, all project activities will display variation due to factors such as poor estimating, unexpected events or undefined customer expectations. This variation creates risk because of its potential to affect the project schedule. Although some project schedules have only a few uncertainties that can be easily managed with good project planning, when the number of uncertainties becomes greater, such as in a large capital project, it becomes more difficult to make the correct decisions.

Program Evaluation and Review Technique (PERT)

Developed by the US Navy in the 1950's to manage the Polaris missile program, PERT (Program Evaluation and Review Technique) was an early attempt to incorporate uncertainty into the project schedule. It was based upon the assumption that task durations had a beta-PERT distribution represented by three parameters — the optimistic value A, the most likely value B, and the pessimistic value C — and that this resulted in a mean of (A+4B+C)/6 and a standard deviation of (C-A)/6, though both of these are approximations.

PERT is a network planning technique used to plan, schedule, and control projects. Unlike the CPM (Critical Path Method) which assumes actual project activity times are deterministic, PERT views the actual performance time for an activity as a random variable. The conventional PERT procedure ignores all sub-critical paths which leads to an optimistically biased estimate of the expected earliest occurrence time for the network events. The most promising approach to solving this problem (called the merge event bias problem) appears to be simulation.

Merge bias is probably the single most important reason why PERT is incorrect and why Monte Carlo simulation is the only way to properly process uncertainty in project networks.

Merge bias occurs whenever two or more paths converge in a network and the uncertainty about their durations is such that any of them might turn out to be critical.

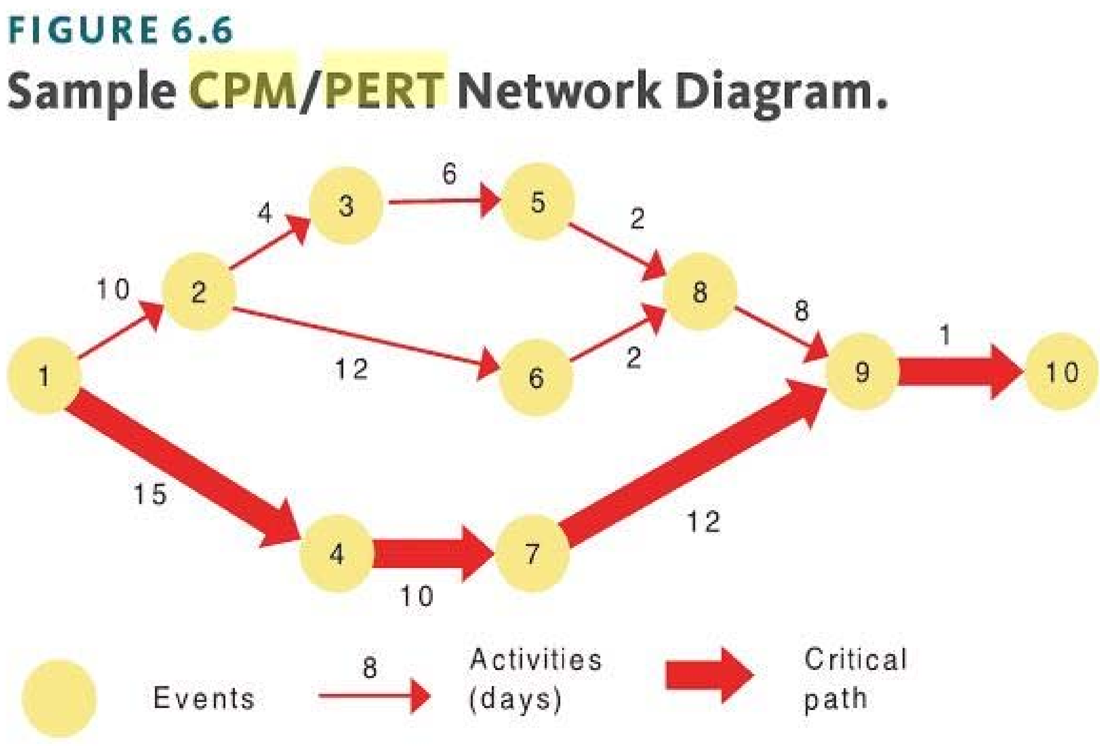

Figure 2: Current Sample CPM/PERT Network Diagram

Monte Carlo Simulation (MCS)

An alternative method for managing the risk in a project schedule is to create a probabilistic model of the project schedule, where activity durations are not described by unique values, but rather by probability distributions. Monte Carlo simulation is a process that generates random values for inputs that are processed through a mathematical model in order to generate multiple scenarios. The distribution type (normal, exponential, uniform, etc.) is specified by the user and is based on the situation that is being modeled.

Let's try to understand this with the help of an example. Suppose you are managing a project involving several sub-projects and activities/tasks. Based on prior experience or other expert knowledge, you determine the best case, expected and worst-case estimates for each of these activities. Let's further assume that we define a project start date (e.g. 1st-Jan-2017) and that some of the tasks must be completed in certain sequence, meaning each task may be dependent on a prior task, as given below:

Start Date	1/1/2017			Duration			Best Case			Expected			Worst Case		
SubProject ID	Task ID	Name	Dependencies	Best	Expected	Worst	Start	End		Start	End		Start	End	
A		Planning													
	A.100	Construction Plan		15	30	45	1/1/2017	1/16/2017	15	1/1/2017	1/31/2017	30	1/1/2017	2/15/2017	45
	A.200	Hiring Plan		15	30	45	1/1/2017	1/16/2017	15	1/1/2017	1/31/2017	30	1/1/2017	2/15/2017	45
	A.300	Plan Review	A.100, A.200	10	15	30	1/17/2017	1/27/2017	10	2/1/2017	2/16/2017	15	2/16/2017	3/18/2017	30
B		Construction													
	B.100	Construction: Task 1	A.300	60	90	120	1/28/2017	3/29/2017	60	2/17/2017	5/18/2017	90	3/19/2017	7/17/2017	120
	B.200	Construction: Task 2	A.300	60	90	120	1/28/2017	3/29/2017	60	2/17/2017	5/18/2017	90	3/19/2017	7/17/2017	120
	B.300	Construction: Task 3	A.300	30	45	100	1/28/2017	2/27/2017	30	2/17/2017	4/3/2017	45	3/19/2017	6/27/2017	100
C		Review													
	C.100	Construction Review	B.100,B.200,B.300	15	30	60	3/30/2017	4/14/2017	15	5/19/2017	6/18/2017	30	7/18/2017	9/16/2017	60
	C.200	Internal Review	A.300	15	30	60	1/28/2017	2/12/2017	15	2/17/2017	3/19/2017	30	3/19/2017	5/18/2017	60
	C.300	Compliance Review	C.100, A.300	15	30	60	4/15/2017	4/30/2017	15	6/19/2017	7/19/2017	30	9/17/2017	11/16/2017	60
	C.400	Compliance / Completion	C.200, C.300	15	30	60	5/1/2017	5/16/2017	15	7/20/2017	8/19/2017	30	11/17/2017	1/16/2018	60
	C.500	Project Review	C.200, C.400	10	15	20	5/17/2017	5/27/2017	10	8/20/2017	9/4/2017	15	1/17/2018	2/6/2018	20
Completion Date								5/27/2017	146		9/4/2017	246		2/6/2018	401

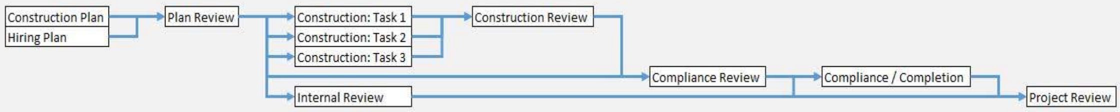

Figure 3: Project minimum, expected and maximum duration for each of the project activities and the Dependency Map

You can look at the projections for each task and based on the start and completion dates of the project you will get the best-case (146 days), expected (246 days), and worst-case scenario (401 days) for the entire project.

This is useful, but still unrealistic; because it's unlikely that each task will take the best-case time, or the worst-case time. More likely, one task will take a little longer, and another will be completed ahead of schedule.

This is where Monte Carlo analysis can be helpful. Starting with the estimates for the project, we can run an analysis based on random estimates for each task. This will produce a model that takes into account variability, and also considers that each task is independent. The Monte Carlo simulation randomly selects the input values for the different tasks to generate the possible outcomes. Let us assume that the simulation is run 1,000 times. When the simulation is complete, we can look at statistics and projections from the simulation' to understand the risk in the model.

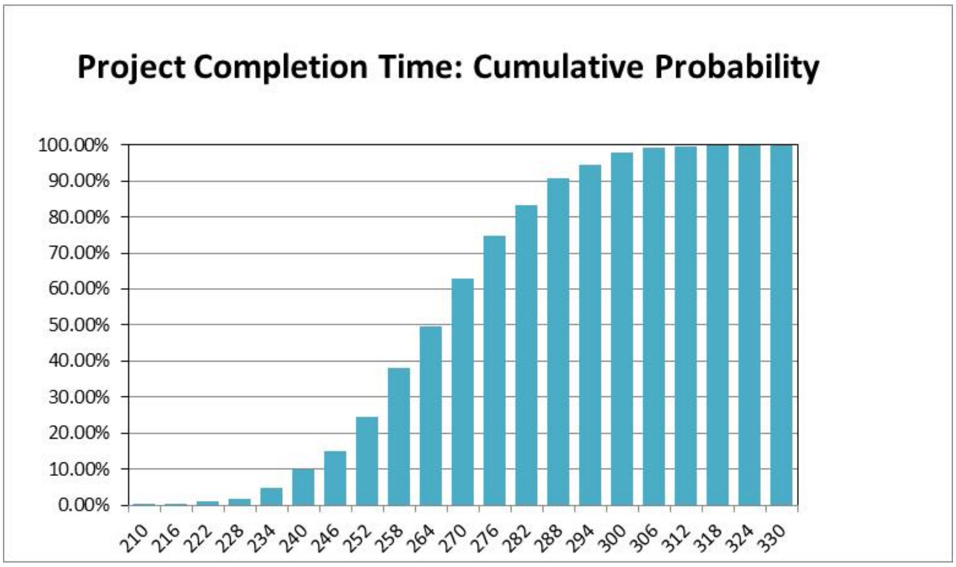

Figure 4: Project Completion Time: Cumulative Probability

This chart plots the time, in days (at the bottom), against the probability (on the left) of completion within that time. It shows there is only a 10% chance that the project will be completed within 241 days; but there is a 90% chance the project will be completed within 288 days.

What does that mean? When we ran the Monte Carlo simulation, we used random values for each task (based on the estimates), and found the total time for the project. We did that 1,000 times, and each time different random values were selected, resulting in a new random total.

When the simulation was complete, we look at every trial and count the number of times that the total was 240 days or less. We find that in only10% of the trials (100 out of 1,000) the total project time was 241 days or less. We can therefore say that, during the simulation, there was a 10% probability that the project was completed within 241 days.

Similarly, during the simulation there was a 90% chance that the project was completed within 288 days.

We can also reverse the question, and ask what the completion time was — based on probability from the simulation — at various probability levels. If we want to be 80% sure that the project will be complete, for example, we need to budget 281 days for the project; because in 80% of the cases the project took at least 281 days to complete.

Based on this analysis, we can find some of key points from the model and the analysis:

Original Model	Days	Date	
Expected Completion	246	9/4/2017	
Best-Case	146	5/27/2017	
Worst-Case	401	2/6/2018	
Probability Analysis	**Days**	**Date**	**Probability**
Completion within "Expected"	246	9/4/2017	16.8%
- within 10% overrun	271	9/29/2017	63.9%
- within 20% overrun	296	10/24/2017	96.0%
Minimum	213	8/2/2017	
Maximum	326	11/23/2017	
Average	265	9/22/2017	
Confidence Ranges	**Days**	**Date**	
75% Confidence	278	10/6/2017	
80% Confidence	281	10/9/2017	
90% Confidence	288	10/16/2017	

Figure 5: Probability Analysis Key Points

Additionally, sensitivity charts can be used to show the influence of each activity on the total project cycle time. The sensitivity chart displays these rankings as a bar chart, indicating which activities are the most important or least important in the model. You can look at single-factor sensitivity using the R-squared (R2) value from a linear regression; this is also called the *coefficient of determination*.

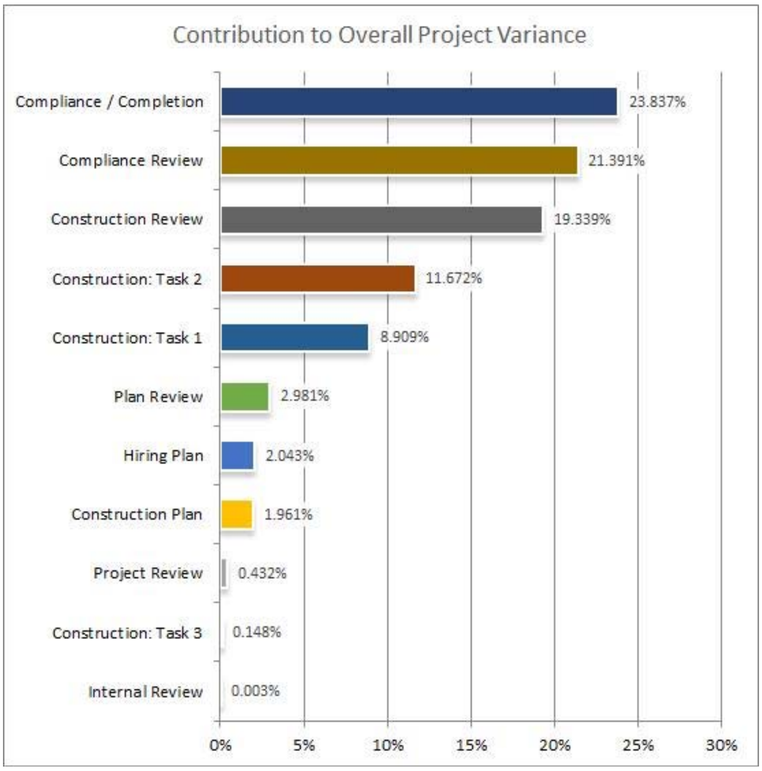

Figure 6: Single-Factor Sensitivity Analysis (R2)

The benefits of this analysis are to: 1) discover which activities most influence the project duration, reducing the amount of time needed to refine estimates, 2) find out which activities least influence the cycle time, so that they can be ignored and 3) develop realistic schedule models that increase the accuracy of your results.

Summary

Monte Carlo simulation is a valuable technique for analyzing risks, specifically those related to cost and schedule. The fact that it is based on numeric data gathered by running multiple simulations adds even greater value to this technique. It also helps in removing any kind of project bias regarding the selection of alternatives while planning for risks. While running the Monte Carlo simulation, it is advisable to seek active participation of the key project decision-makers and stakeholders, specifically while agreeing on the range values of the project risk variables and the probability distribution patterns to be used. This will go a long way in building stakeholder confidence in your overall risk-handling capability for the project. Moreover, this serves as a good opportunity to make them aware of the entire risk management planning being done for the project.

Though there are numerous benefits of the Monte Carlo simulation, the reliability of the outputs depends on the accuracy of the range values and the correlation patterns, if any, that you have specified during the simulation. Therefore, you should practice extreme caution while identifying the correlations and specifying the range values. Else, the entire effort will go waste and you will not get accurate results.