

# **A Comparative Assessment of the PERT vs Monte Carlo simulation for Schedule Risk Assessment**

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## **Abstract**

The PERT and Monte Carlo analyses of schedule information are known to diverge under certain circumstances, however, the reasons behind such divergence has been unclear.

This study examines a project schedule using both the PERT and the Monte Carlo simulation. The results indicate that the Monte Carlo simulation and the PERT analysis converge only in the case of a dominant, insensitive critical path. The critical path may appear to be different when comparing the two methods due to the fact that the PERT uses weighted average task durations. When the schedule has parallel paths of nearly equal duration, such that the critical path is very sensitive to activity durations, the PERT method results begins to diverge from the Monte Carlo simulation results.

## **Introduction**

The Program Evaluation Review Technique (PERT) and Monte Carlo simulation are widely recognized as project management scheduling techniques. Both approaches create more accurate activity duration estimates by using mathematical calculations to account for uncertainty. The purpose of this paper is to illustrate the similarities and differences of both the PERT and the Monte Carlo simulation so project managers and organizations considering adopting a schedule risk assessment tool are aware of the limitations.

The authors begin with a brief literature review of the PERT and the Monte Carlo simulation including key concepts, techniques, and criticisms. This is followed by two examples which illustrate the results of both techniques, given a simple project network and a complex project network. The first example is a simple project network with a single critical path. The second example, a more realistic project scenario, is a more complex project with a sensitive network where parallel critical paths emerge. The results of the PERT and Monte Carlo simulations are compared and discussed.

## **Literature Review**

Project managers have used the PERT - Program Evaluation Review Technique - to analyze project schedules since the 1950s (Engwall, 2012). The Project Management Institute offers a contemporary definition as “A technique for estimating that applies a weighted average of optimistic, pessimistic, and most likely estimates when there is uncertainty with the individual activity estimates” (Project Management Institute, 2013, p. 553). As an extension of Critical Path Method analysis, the PERT allowed project managers to analyze projects with indeterminate task durations. Additionally, it provided

the means to assess the probability of completing the project at given target dates (Kamburowski, 1997). The technique has always found acceptance outside of the field of project management in the context of optimizing operations (Ajiboye, 2011).

In spite of the apparent benefits of the PERT, the technique has been critiqued by multiple researchers and practitioners since its introduction. For example, the PERT is said to make assumptions about task variance and task independence that are only rarely encountered in actual practice (Herrerí'as-Velasco, Herrerí'as-Pleguezuelo, & van Dorp, 2011). The potential correlation between interdependent project network paths has also been observed in practice (Banerjee & Paul, 2008). Further, the use of the beta distribution as well as the particular form in which it is used in the PERT has been questioned (Trietsch & Baker, 2012). Researchers have also pointed to the need to calibrate PERT in order to validate the resulting probabilities (Kamburowski, 1997). Over time, it has therefore been recognized that the PERT, as originally proposed, may introduce errors and bias (Banerjee & Paul, 2008).

As a result, improvements to the PERT have been suggested by researchers. The use of the log normal distribution with linear associations as well as historical data for PERT estimates has been recommended (Trietsch & Baker, 2012). Simplified methods of employing the PERT are cited to be just as effective as the original method, but more useful for practitioners (Lu & AbouRizk, 2000). It is also observed that the original claims of the PERT's effectiveness were more a result of improving stakeholder communication and management rather than providing significant predictive results (Engwall, 2012). In this respect, the PERT is also said to be useful primarily in the context of high-level schedule negotiation with executives (Marion & Richardson, 2014).

The limitations of the PERT analysis have been largely overcome by the application of readily available computing power and software applications. Although the Monte Carlo simulation was first introduced as a technique in the 1940's, it was only in the 1990's that supporting technology made it readily available to project managers (Kwak & Ingall, 2007). Aided by the power of computer programs, the Monte Carlo simulation is "A process which generates hundreds or thousands of probable performance outcomes based on probability distributions for cost and schedule on individual tasks. The outcomes are then used to generate a probability distribution for the project as a whole" (Project Management Institute, 2013, p. 547).

The Monte Carlo simulation is said to be more accurate than the PERT as it does not rely solely on simple weighted averages in order to predict schedule duration. Instead, it applies computing power to randomly assign time estimates to each task over thousands of simulation runs in order arrive at overall schedule completion priorities (Kerzner, 2010; Kerzner, 2013; Larson and Gray, 2014; Meredith and Mantel, 2001; PMI, 2013). Further, since the Monte Carlo simulation analysis uses time estimates for all tasks in the project rather than only the critical path task weighted averages, the technique is able to capture the effect of critical path sensitivities (Kwak & Ingall, 2007).

In spite of the benefits, Monte Carlo simulation is also said to have its own limitations. For example, this analysis method does not take into account management and project team countermeasures that will likely be used in order to overcome project delays (Williams, 2004). Further, the method has historically only been used when projects required it due to lack of familiarity with implementing the method and

interpreting the results. However, with the increasing availability of Monte Carlo software, the technique has experienced increased adoption by project managers. (Kwak & Ingall, 2007).

## Methods

The following exercise compares quantitative schedule risk assessment (SRA) results using the PERT approach and the Monte Carlo simulation. The SRA techniques will be applied first to a simple example with an insensitive critical path, then to a more complicated schedule with a sensitive critical path.

The term sensitivity is used to reflect the likelihood the original critical path(s) will change once the project is initiated. Sensitivity is a function of the number of critical or near-critical paths. A network schedule that has only one critical path and noncritical activities that enjoy significant slack would be labeled insensitive. Conversely, a sensitive network would be one with more than one critical path and/or noncritical activities with very little slack. Under these circumstances the original critical path is much more likely to change once work gets under way on the project. (Larson and Gray, 2014, p. 174-175)

The results illustrate the relative accuracy of the two techniques in the simple case, and then we evaluate the divergence of accuracy as the schedules become more complicated. The PERT calculations are made using the methods first documented by Malcolm, Roseboom, Clark, & Fazar in 1959. The Monte Carlo simulations are generated using the commercial software application *Full Monte*, published by Barbecana Software. While Barbecana allows for a range of distributions, for this paper the *Beta distribution* model is consistent with traditional three-point estimating PERT calculations (Gido and Clements, 2014; Larson and Gray, 2014; Meredith and Mantel, 2001; PMI, 2013). Both the PERT and the Monte Carlo simulation are widely accepted and the formulas are described in most project management bodies of knowledge (PMI,

2013; IPMA date APA date) and project management textbooks (Gido and Clements, 2014; Larson and Gray, 2014; Meredith and Mantel, 2001).

### Case 1: Schedule With an Insensitive Critical Path

The first case uses the hypothetical data shown in Table 1:

Activity	Optimistic Time (O)	Most Likely Time (M)	Pessimistic Time (P)	Predecessors
A	3	5	8	
B	5	10	20	A
C	8	10	15	B
D	12	15	18	B
E	4	11	30	C,D
F	1	3	5	E

Table 1: PERT Data Inputs for Case 1

This schedule has a critical path A-B-D-F with a duration of 62 days. The parallel path through C and E is 58 days in duration, making the critical path relatively insensitive to activity durations. The probability of finishing in 60 days and 67 days will be calculated.

### PERT Results for Case 1

“PERT uses three time estimates for each activity. Basically, this means each activity duration can range from an optimistic time to a pessimistic time, and a weighted average can be computed for each activity” (Larson and Gray, 2014, p. 239). The standard calculated values for PERT calculations are as follows (NOTE: the initial calculations apply to each project activity and then the calculations result in an analysis of the entire project):

The weighted average activity time,  $t$ :

$$t = \frac{O+4M+P}{6} \quad \text{Equation 1}$$

where:

O = optimistic activity time (1 chance in 100 of completing the activity earlier under normal conditions)

M = most likely activity time (without any learning curve effects)

P = pessimistic activity time (1 chance in 100 of completing the activity later under normal conditions)

The activity standard deviation for each activity,  $\sigma_a$ :

$$\sigma_a = \left( \frac{P-O}{6} \right) \quad \text{Equation 2}$$

where O = optimistic time estimates and P = pessimistic time estimates.

The standard deviation for the project,  $\sigma_p$ , more commonly called the variance:

$$\sigma_p = \sqrt{\sum \sigma_a^2} \quad \text{Equation 3}$$

where  $\sigma_a$  is the result from Equation 2. It is important to note that only critical path activities be included in Equation 3.

The critical path duration of the project,  $T_{cp}$ , is determined by adding up the durations of the activities on the critical path.

$$T_{cp} = \sum t \text{ (critical path values only)} \quad \text{Equation 4}$$

where  $t$  are the weighted average activity times calculated in Equation 1, not the most likely times identified in Table 1.

The critical result of the PERT method is the probability of finishing a project by a desired completion date,  $T_{des}$ . The probability,  $P$ , is determined by first calculating a  $Z$  value then using it to find  $P$  in a *Table of Standard Normal Probabilities*. For the purposes of this study the Table of Standard Normal Probabilities posted by the University of California at Santa Barbara (UCSB) was used. The  $Z$  Value is calculated as follows:



$$Z = \frac{T_{des} - T_{cp}}{\sigma_p} \quad \text{Equation 5}$$

where  $T_{des}$  is the desired project duration,  $T_{cp}$  is the critical path duration from Equation 4, and  $\sigma_p$  is the project standard deviation described in Equation 3. Note that the *Z Value* is calculated using only the values for the critical path activities.

Applying all these formulas results in the following data in Table 2:

Activity	Optimistic Time (O)	Most Likely Time (M)	Pessimistic Time (P)	Predecessors	Weighted Average Time (t)	Activity Standard Deviation $\sigma_a$	Activity Standard Deviation Squared $\sigma_a^2$	Critical Path and Durations (t)
A	17	29	47		30.0	5.00	25.00	30.0
B	6	12	24	A	13.0	3.00	9.00	13.0
C	16	19	28	A	20.0	2.00	4.00	
D	13	16	19	B	16.0	1.00	1.00	16.0
E	2	5	14	C	6.0	2.00	4.00	
F	2	5	8	D,E	5.0	1.00	1.00	5.0
							Critical Path Duration ( $T_{cp}$ ):	64.0
							Project Standard Deviation ( $\sigma_p$ ):	6.00

Table 2: Calculated PERT data

Using this information it is possible to determine the probability of finishing the project in desired times of 60 days and 67 days. These results are shown in Table 3, with the probabilities looked up for the Z Values in the Table of Standard Normal Probabilities (UCSB):

Desired Duration	Z Value = $(T_{des} - T_{cp})/\sigma_p$	Probability (P) of Finishing in Desired Duration
60 days	-0.67	25%
67 days	0.50	69%

Table 3: PERT calculations for probability of meeting desired schedule durations

Equations 6 and 7 summarize the probability of finishing in 60 days and 67 days, respectively, as calculated using the PERT technique.

$$P(60)_{PERT} = 25\% \quad \text{Equation 6}$$

$$P(67)_{PERT} = 69\% \quad \text{Equation 7}$$

### Monte Carlo Results for Case 1

The Monte Carlo simulation Method of probabilistic determinations was developed in 1946 by Stanislaw Ulem at the Los Alamos National Laboratory (Eckhardt, 1987). This method relies on the random calculation of values that fall within a specified probability distribution of described by using three estimates: minimum or optimistic, mean or most likely, and maximum or pessimistic. The overall outcome for the project is derived by the combination of the values (Gido and Clements, 2014; Larson and Gray, 2014; Meredith and Mantel, 2001; PMI, 2013). This approach is growing in acceptance as the computer and software applications are no longer a limitation.

The tool used for this study is the *Full Monte* software add-in for Microsoft Project 2013, provided by Barbecana Software. The probability distribution for each activity is selected as *Beta* to match the traditional assumptions in PERT. MS Project 2013 defaults to a traditional workweek of Monday – Friday. Building a MS Project schedule for Case 1 provides the Gantt Chart shown in Figure 1.

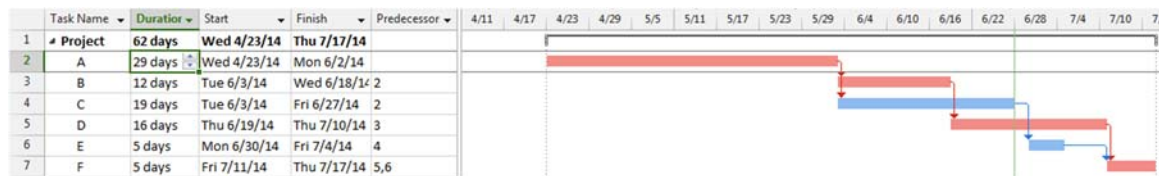


Figure 1: Gantt chart in MSProject 2013 derived from the data in Table 1.

Note that the Gantt chart in Figure 1 uses the most likely duration estimates from table 1, not the weighted average activity times,  $t$ , from Table 2. This results in the

Monte Carlo schedule having a critical path of 62 days rather than the 64-day critical path of the PERT schedule.

After populating the optimistic and pessimistic activity duration values, based on the values in Table 1, into the Monte Carlo simulation, the simulation was run based 10,000 iterations of the data and the resulting probability histogram is shown in Figure 2.

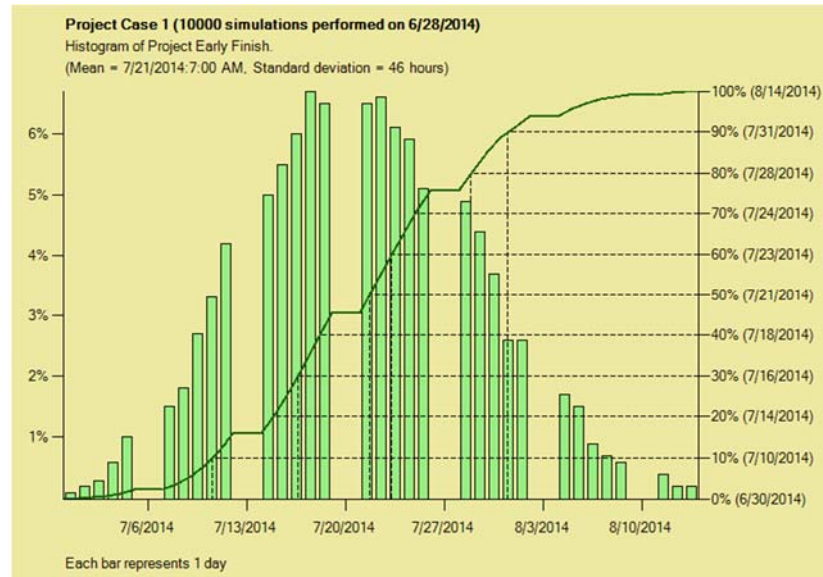


Figure 2: Probability histogram for finishing the project shown in Figure 1.

The difference in critical path duration can be ignored for this case example, however, since the goal is to determine the likelihood of finishing in 60 and 67 days, which equate to 7/15/14 and 7/24/14, respectively (weekends are not considered in scheduling). The histogram in Figure 2 shows the probability of finishing by 7/15/14 as approximately 25%, and the probability of finishing by 7/24/14 as 70%.

Equations 8 and 9 summarize the probability of finishing in 60 days and 67 days, respectively, as calculated using the Monte Carlo technique.

$$P(60)_{MC} = 25\% \quad \text{Equation 8}$$

$$P(67)_{MC} = 70\% \quad \text{Equation 9}$$

## Comparing the PERT/Monte Carlo simulation Results for Case 1

Comparison of the Monte Carlo simulation results with PERT results for Case 1, with an insensitive critical path, are in complete agreement. Equation 6 illustrates the PERT calculations for the probability of finishing the work in 60 days being 25%, as does the Monte Carlo result (Equation 8). Equation 7 shows the PERT result for the probability of finishing the work in 67 days being 69%, compared with approximately 70% for the Monte Carlo result in Equation 9; a statistically negligible difference.

### Case 2: Schedule with a Sensitive Critical Path

While case 1 illustrated a single critical path, case 2 is progressively more complex and the network sensitivity increases. A project with sensitive critical path better represents what a true project would exhibit. The PERT assumptions include an unchanging, single critical path during the analysis. If the project schedule has parallel paths with nearly identical durations, permitting the critical path to move between them during the Monte Carlo process, then PERT breaks down while Monte Carlo continues to provide accurate solutions. Using the processes outlined above, the following example illustrates this fact. This case is based on the Unmanned Aerial Vehicle project (UAV), “Case 2 UAV.mpp” schedule attached in Appendix 1. The PERT critical path data are extracted from that file and shown below in Table 4. A summary of the Gantt chart is illustrated in Figure 3. The probability of completion for the Case 2 schedule will be calculated for 240 days, 250 days, and 260 days.

Task No.	Task Name	Optimistic Duration (O)	Most Likely Duration (M)	Pessimistic Duration (P)	Predecessor
0	UAV		242		

1	Get requirements for UAV	1	1	2	
3	Configure PCs	10	10	16	1
4	configure printers	5	5	6	3
13	collect data for communications	2	3	4	4
14	research needed hardware	2	3	4	13
15	render tower model	8	9	14	14
16	get approval for rendering	1	1	2	15
17	adjust model as needed after approval	6	7	13	16
20	collect data for communications	3	3	4	17
21	research needed hardware	3	3	6	20
22	render pilot module	7	9	11	21
23	get approval for rendering	1	1	2	22
24	adjust model as needed after approval	3	5	6	23
25	create spec sheet for build team	3	4	6	24
27	Collect camera info requirements	2	3	4	25
28	research needed hardware	2	3	6	27
29	render camera module	7	7	11	28
30	get approval for rendering	1	1	2	29
31	adjust model as needed after approval	3	5	6	30
32	create spec sheet for build team	2	4	6	31
67	create mold of camera housing	9	10	12	32
68	cast camera housing	9	10	14	67
84	find site to lease	8	10	18	68
85	acquire production equipment	29	30	47	84
86	install production equipment	29	30	49	85
87	configure production equipment	18	20	32	86
89	train production team	31	9	56	87

Table 4: PERT Data Inputs for Case 2

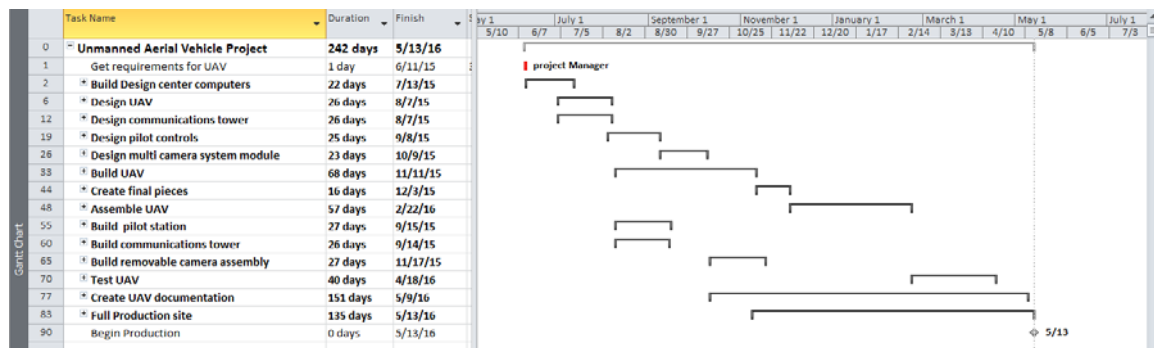


Figure 3: UAV Summary Gantt Chart

## PERT Results for Case 2

Applying the same formulas used for case 1 produces calculated PERT data as shown in Table 5.

Task No.	Task Name	Optimistic Duration (O)	Most Likely Duration (M)	Pessimistic Duration (P)	Predecessor	Critical Path Weighted Average durations (t)	Activity Standard Deviation $\sigma_a$	Activity Standard Deviation Squared $\sigma_a^2$
0	UAV		242					
1	Get requirements for UAV	1	1	2		1.2	0.17	0.03
3	Configure PCs	10	10	16	1	11.0	1.00	1.00
4	configure printers	5	5	6	3	5.2	0.17	0.03
13	collect data for communications	2	3	4	4	3.0	0.33	0.11
14	research needed hardware	2	3	4	13	3.0	0.33	0.11
15	render tower model	8	9	14	14	9.7	1.00	1.00
16	get approval for rendering	1	1	2	15	1.2	0.17	0.03
17	adjust model as needed after approval	6	7	13	16	7.8	1.17	1.36
20	collect data for communications	3	3	4	17	3.2	0.17	0.03
21	research needed hardware	3	3	6	20	3.5	0.50	0.25
22	render pilot module	7	9	11	21	9.0	0.67	0.44
23	get approval for rendering	1	1	2	22	1.2	0.17	0.03
24	adjust model as needed after approval	3	5	6	23	4.8	0.50	0.25
25	create spec sheet for build team	3	4	6	24	4.2	0.50	0.25
27	Collect camera info requirements	2	3	4	25	3.0	0.33	0.11
28	research needed hardware	2	3	6	27	3.3	0.67	0.44
29	render camera module	7	7	11	28	7.7	0.67	0.44
30	get approval for rendering	1	1	2	29	1.2	0.17	0.03
31	adjust model as needed after approval	3	5	6	30	4.8	0.50	0.25
32	create spec sheet for build team	2	4	6	31	4.0	0.67	0.44
67	create mold of camera housing	9	10	12	32	10.2	0.50	0.25
68	cast camera housing	9	10	14	67	10.5	0.83	0.69
84	find site to lease	8	10	18	68	11.0	1.67	2.78
85	acquire production equipment	29	30	47	84	32.7	3.00	9.00
86	install production equipment	29	30	49	85	33.0	3.33	11.11

87	configure production equipment	18	20	32	86	21.7	2.33	5.44
89	train production team	31	45	56	87	44.5	4.17	17.36
					Critical Path Duration ( $T_{cp}$ ):	255		
					Project Standard Deviation ( $\sigma_p$ ):	7.30		

Table 5: Calculated PERT data for Case 2

From these data it is possible to calculate via Standard Normal Lookup tables the probability of finishing the project in 240, 250 and 260 days. These probabilities are shown in Table 6.

Desired Duration	Z Value = $(T_{des} - T_{cp})/\sigma_p$	Probability (P) of Finishing in Desired Duration
240 days	-2.10	2%
250 days	-0.73	23%
260 days	0.64	74%

Table 6: PERT calculations for probability of meeting desired schedule durations

Equations 10, 11 and 12 summarize the probability of finishing in 240 days, 250 days, and 260 days, respectively, using the PERT technique.

$$P(240)_{PERT} = 2\% \quad \text{Equation 10}$$

$$P(250)_{PERT} = 23\% \quad \text{Equation 11}$$

$$P(260)_{PERT} = 74\% \quad \text{Equation 12}$$

### Monte Carlo Results for Case 2

The MSProject Gantt chart used for Case 2 is included as Appendix 1. The Monte Carlo analysis results for Case 2 are shown in Figure 4.

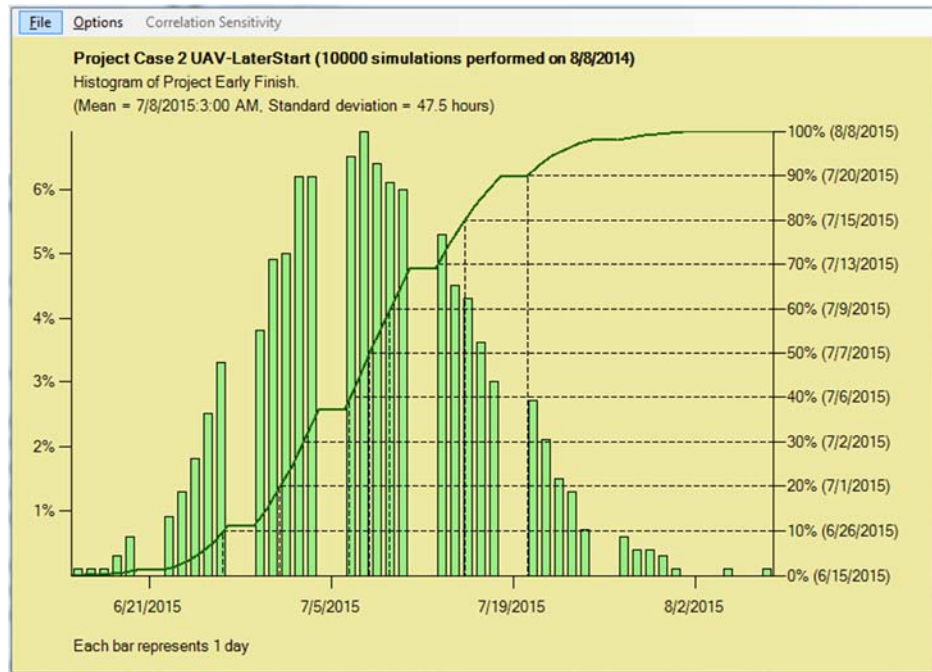


Figure 4: Probability histogram for finishing the Case 2 project.

For the purpose of comparing the Monte Carlo and PERT results, it should be noted that a duration of 240 days correlates to a project finish date of 6/19/15, 250 days correlates to 7/3/15 and 260 days correlates to 7/17/15. From the histogram in Figure 4 the probability of finishing in those durations is shown in Equations 13, 14 and 15, respectively.

$$P(240)_{MC} = 1\% \quad \text{Equation 13}$$

$$P(250)_{MC} = 35\% \quad \text{Equation 14}$$

$$P(260)_{MC} = 90\% \quad \text{Equation 15}$$

### Comparing the PERT/Monte Carlo simulation Results for Case 2

A comparison of the Monte Carlo simulation results with the PERT results for Case 2, with a sensitive critical path, shows poor agreement. For the 240 day duration the PERT prediction is 2% chance of completing on time, while the Monte Carlo simulation prediction is 1%. The probability of finishing in 250 days is predicted by the



PERT to be 23%, but predicted by Monte Carlo simulation to be 35%. The Monte Carlo simulation prediction is fully 50% higher than the PERT prediction. For the 260-day duration the PERT prediction is 74% and the Monte Carlo simulation duration is 90%.

Duration	PERT Probability	Monte Carlo Probability
240 Days	1%	2%
250 Days	23%	35%
260 Days	74%	90%

Table 7: Summary comparison of PERT vs. Monte Carlo predictions for Case 2.

### **Concluding remarks**

The objective of this paper was to present the findings of the PERT and the Monte Carlo simulations as schedule risk assessment techniques. We looked at current practice and used two cases to illustrate the results of each approach using the same data. The first case used a simple project with an insensitive critical path. The second case, which better represents a real-world project, is more complex with a sensitive critical path. The results indicate that the Monte Carlo simulation and the PERT analysis converge only in the case of a dominant, insensitive critical path. The critical path may appear to be different when comparing the two methods due to the fact that the PERT uses weighted average task durations. When the schedule has parallel paths of nearly equal duration, such that the critical path is very sensitive to activity durations, the PERT method results begin to diverge from the Monte Carlo simulation results.

We can, therefore, draw a set of conclusions:

1. Conventional PERT network calculations are insufficient, as they do not adequately account for network sensitivity.

2. Results calculated when using the conventional PERT will usually give a wide distribution, which reduces the credibility of the calculation.
3. When applying the Monte Carlo simulation, network sensitivity is accounted for through the numerous iterations of the schedule.

The purpose of this paper was to illustrate the similarities and differences of both the PERT and the Monte Carlo simulation so project managers and organizations considering adopting a schedule risk assessment tool are aware of the limitations. In light of these results, it makes sense that defense contracting reporting requirements were updated in January 2013 to require Monte Carlo-based Schedule Risk Assessments for all projects requiring Earned Value Management over \$20Million. (Department of Defense, 2013). As a funding authority, the U.S. Department of Defense considers the Monte Carlo simulation technique a proven risk reduction scheduling practice. It provides confidence levels for meeting schedule and budget targets and identifies the highest risk activities affecting the likelihood of meeting schedule and the budget targets.

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# Appendix 1

## “Case 2 UAV.mpp”

### Microsoft Project Data File for Case 2

