Probabilistic Delay Analysis

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Abstract

Schedule duration risk analysis is a large and thriving subset of Critical Path Method (CPM) scheduling. Based on the sales literature from the various project risk software developers, it can be inferred that most major owners are using some sort of CPM risk analysis to better plan their project. Further, the use of schedule risk analysis is becoming a standard part of proper due diligence prior to investment approval. When accuracy is important, Project Managers use CPM risk analysis to sharpen the focus.

No where is accuracy more important than with schedule delay analysis. Schedule delay analysis (or more commonly labeled, "Forensic Analysis") is the central issue of many construction disputes that is based on investigation and proving the exact extent of the effects of delay. With this consideration in mind, it is foreseeable that the Forensic industry will need to embrace probabilistic scheduling analysis when it measures delay. Hopefully, this paper will begin such a dialogue toward that end.

Introduction to Schedule Risk Analysis

It is a common occurrence on projects that either the completion date is not achieved or that the work has to be accelerated to achieve the completion date. Project managers complain that they had a CPM schedule but had zero chance of achieving the end date. Some projects completion dates are simply unreachable. David T. Hulett, Ph.D., College of Scheduling Risk Expert, writes [1]

> "Project managers need to understand some key reservations about the standard CPM, and how to use a schedule risk analysis to provide information crucial to a project's success, before they embark on their project:

- The project duration calculated by CPM is accurate only if everything goes according to plan. This is rare in real projects.
- In many cases the completion dates CPM produces are unrealistically optimistic and highly likely to be overrun, even if the schedule logic and duration estimates are accurately implemented.
- The CPM completion date is not even the most likely project completion date, in almost all cases.
- The path identified as the "critical path" using traditional CPM techniques may not be the one that will be most likely to delay the project and which may need management attention."

CPM Schedules are impacted by a variety of outside factors that can affect activity durations and the work sequence to achieve the completion date. Risk managers allege that estimated durations for schedule activities are at best "order of magnitude" estimates and at worst "wild guesses". Prior to examining the methods used to calculate probable project completion dates based on duration variations, we should first review the elements of risk in a CPM schedule.

The primary variable elements of a schedule are network logic and activity duration. The activity duration may vary as a result of multiple causes such as manpower availability, labor productivity, and actual production rates. Changes in network logic may be caused by weather, product availability or manpower however, it is usually a management decision that triggers the logic change. A finish-to-start relationship could end up being a start-to-start relationship, or the construction sequence may be altered. Since there are, two variables to consider there are actually four types of schedules**[4]**:

- **Deterministic logic with deterministic durations**
  In the deterministic logic and duration network, the durations of the activities are fixed and the logic of the schedule is fixed. A typical construction CPM schedule has deterministic logic with deterministic durations.

- **Deterministic logic with probabilistic durations**
  In this model, the network logic is fixed and the durations vary. This is a CPM schedule with a Monte Carlo type duration analysis. The schedule risk is calculated for variations in activity duration. The schedule logic is based on both

constructive and preferential relationships based on the contractor's means and methods. The duration of the activities is estimated based on the contractor's experience and understanding of the work involved.

- **Probabilistic logic with deterministic durations**
  The design phase considers probabilistic logic as the actual elements to be inserted into the project have yet to be completely determined. For example, a simple roof-mounted air handler may suffice and require 5 weeks to manufacture. If the weight limitations preclude this, then an alternate, specially designed unit will need to be designed and fabricated, requiring 10 weeks to fabricate. This type of model does not usually apply to the construction phase as the design is complete by this time. If probabilistic logic is to be considered, then probabilistic durations will also need the same consideration.

- **Probabilistic logic with probabilistic duration**
  In this type of schedule, both the logic and the duration are subject to variations. In reality, the dual variation is rarely considered in construction schedules. The ability to evaluate the multiple variations results in a very complex model, which is not easily reproduced by any commercially available schedule risk software. As a result, this truly complex situation will not be discussed in this presentation. Calculating the true risk of a construction project schedule, recognizing that there are both probabilistic logic and probabilistic duration, is beyond the reach of this paper but worthy of further study.

Current risk management programs perform probability scheduling using the deterministic logic/probabilistic logic duration network model. The risk management software currently available allows an analysis of the uncertainty of the durations and quantification of the probability of finishing the project on time or by a specified date. The duration of the activity is changed from a fixed time frame to a probabilistic distribution time frame. A triangular probability distribution is most often used to decide the minimum duration of the activity, the most likely duration of the activity and the maximum duration of the activity. As a result, the scheduler inputs the triangular distribution for each activity in the schedule such as shown below in Figure 1.

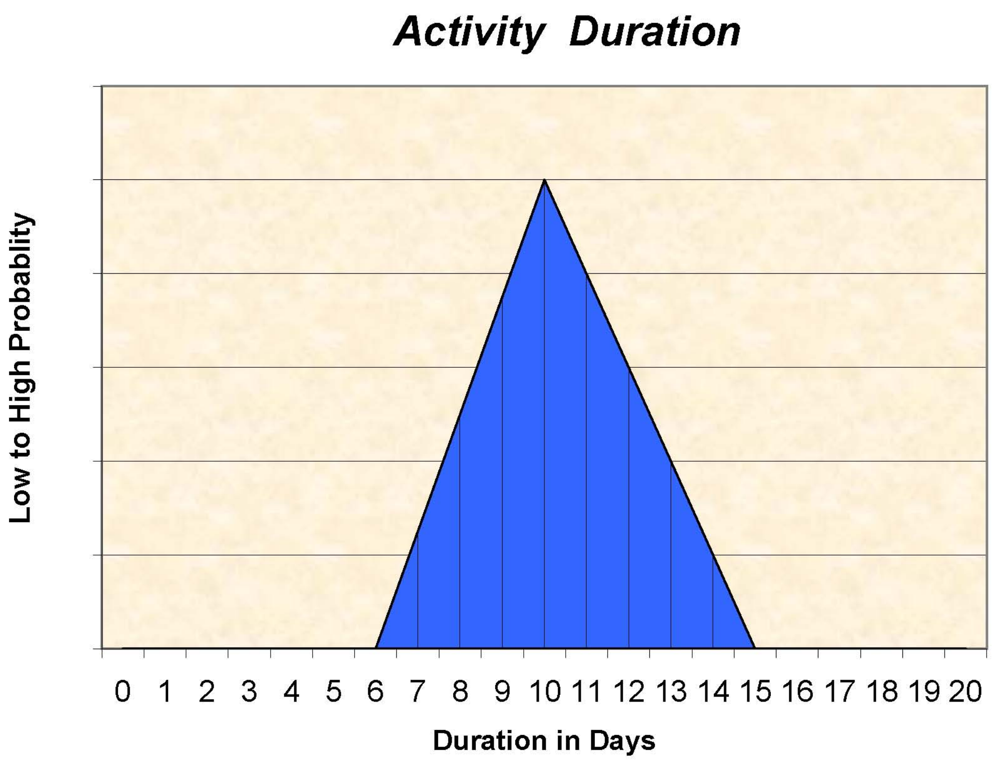

FIGURE 1: Triangular Distribution

The risk analysis program then runs probability distributions of each of the activity durations and develops an overall distribution of the project providing an analysis of the frequency of the summation of durations, or the completion of the project. A distribution graph is normally provided. Figure 2 below shows a sample distribution graph from the PertMaster [2] Project Analytics software. The Distribution shows there is an 85% chance of finishing the entire project before 13th November.

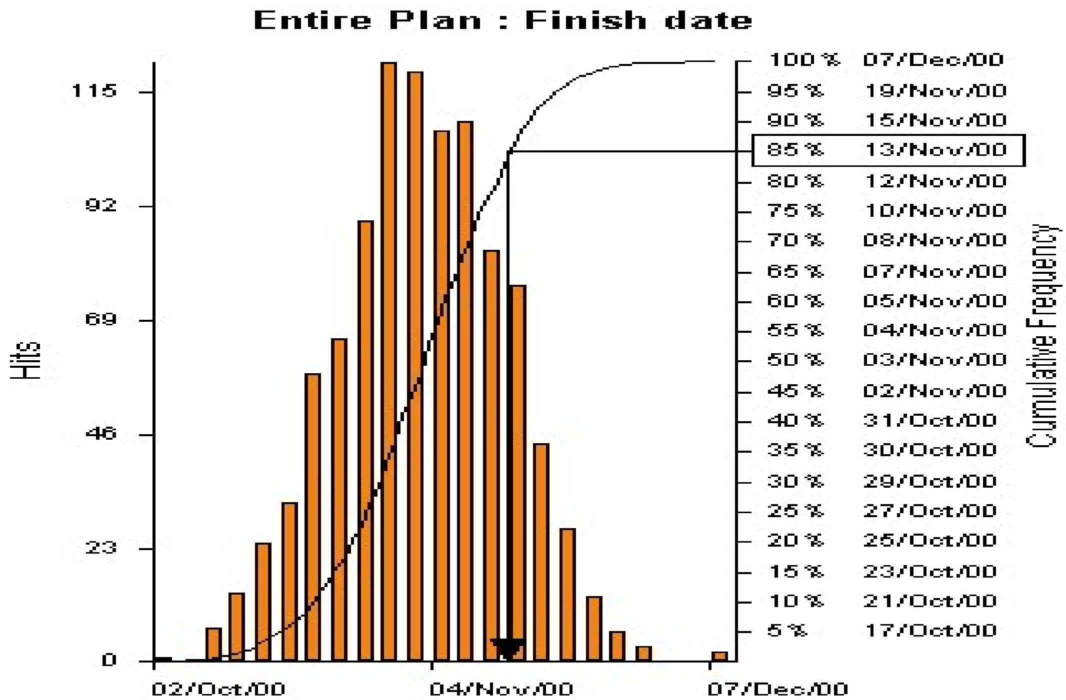

FIGURE 2: Example finish date distribution

In addition to providing a graph of the overall probability of project duration, the PertMaster software also provides a distribution of float for each activity in the schedule. Figure 3 below is an example of the PertMaster float distribution when the distribution shows there is a 90% chance of the selected task having 32 days float or less.

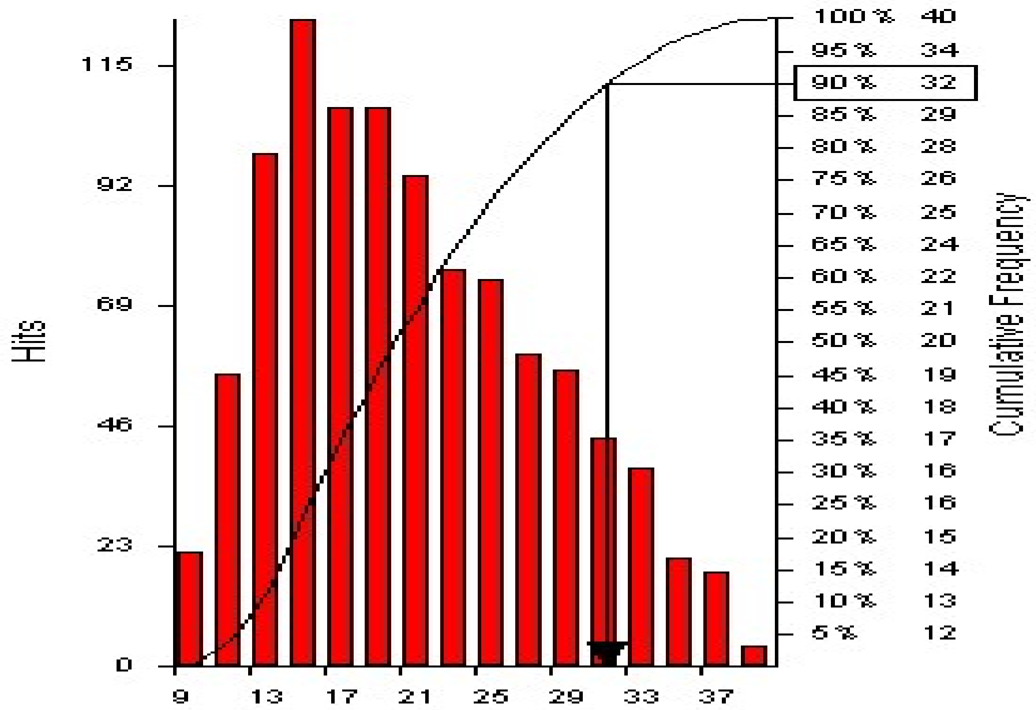

FIGURE 3: Example float distribution

In addition to providing a distribution of float on individual activities, the program also provides a critical path report. The critical index is defined by PertMaster[2] as follows:

> "During risk analysis tasks can join or leave the critical path. The criticality index expresses as a percentage, how often a particular task was on the critical path during the analysis. Tasks with a high criticality index are more likely to cause delay to the project as they are more likely to be on the critical path."

Figure 4 below is a sample print out. Please note that some activities are 100% critical, some are 55% critical, and some have a zero percent chance of being critical.

Pertmaster Criticality Path Report

Task Status: *Completed* +Underway+

Criticality Path				Preceding Tasks				
Name	Description	Rem Dur	Criticality	Link	Name	Description	Rem Dur	Criticality
80	BRICKWORK	7	74.90%	FS	*0070*	CONCRETE FOUNDATION	0	0%
100	ROOF TRUSSES	6	100%	FS	+0080+	BRICKWORK	7	74.90%
				FS	90	INSTALL WINDOWS	6	45.70%
120	ROOF FINISH	7	100%	FS	100	ROOF TRUSSES	6	100%
140	PLASTER WALLS	12	100%	FS	120	ROOF FINISH	7	100%
				FS	110	ROUGH PLUMBING & ELECTRIC	4	0%
190	FINISH PLUMBING	4	70.10%	FS	140	PLASTER WALLS	12	100%
200	DECORATE	4	100%	FS	190	FINISH PLUMBING	4	70.10%
				FS	180	FINISH ELECTRICS	4	55%
210	CLEAN DOWN	1	100%	FS	200	DECORATE	4	100%
220	SNAGGING	1	100%	FS	210	CLEAN DOWN	1	100%
				FS	130	LANDSCAPING	4	0%
230	END	Mlstn	100%	FS	220	SNAGGING	1	100%

FIGURE 4, PertMaster Criticality Path Report

Probabilistic Delay Analysis

The question arises of why we need probabilistic delay analysis (especially in retrospective delay analysis where the durations are known?) The quick answer is that current retrospective delay analysis assumes that the original duration estimates were absolutely correct. We assume that any change in observed actual duration during a delay must be the sole cause of the delaying event.

We have just shown how an entire body of knowledge involving probabilistic CPM analysis has sprung-up to address the concerns and error of using average duration estimates to determine project duration. These same concerns are valid when considering the effects of a delay on that same project duration.

Using single, fixed deterministic activity duration estimates in Forensic Analysis could be as misleading in delay analysis as it is in CPM schedule analysis. Consideration must be made for the differences between average and most likely durations. Ranges of duration possibilities must also be considered. The assumption of precise and accurate duration estimates are often questioned during an analysis when the result determines the amount of a legal settlement involving thousands or millions of dollars.

It is probably safe to forecast that our industry is headed in the direction of probabilistic scheduling. Probabilistic scheduling will not eliminate the need to perform delay analysis. As an example, if a project is delayed by a change in conditions, the project completion date will still need to be properly adjusted.

The Critical Path

The first question that must be determined in any delay analysis is "what is the critical path of a project?" Is there a critical path in a probabilistic schedule analysis?

The PertMaster Critical Path report identifies multiple critical paths. The program identifies the probability of activities on the critical path with the risk analysis. The probability of an activity being critical is identified in the risk analysis. Some activities have 100% probability of being critical; others have less and some have zero.

So, if a delay occurs on the project, the effect it will have on the completion date of the project is affected by its critical probability. However, an analysis of the critical probability is not the sole variable in performing the delay analysis.

Schedule Delay Analysis

Schedule delay analysis can be divided into two methods: prospective or retrospective.[3] Using a prospective (or 'forward looking') view, choosing a method from the existing list of useable techniques such as Impacted As–Planned or the Windows Method is difficult to determine because the schedule is no longer static. Recognizing that there is not an approved method of probabilistic delay analysis, the following examples are offered to stimulate discussion on the matter.

Let's analyze one activity such as excavation that has a triangular distribution of six days being the minimum duration, ten days being the most likely duration and 20 days being the maximum duration. Also, this activity has a 100% chance of being critical. Using "The Triangle Distribution: Mathematica Link for Excel,"[6] we produce an example like shown in Figure 5 below.

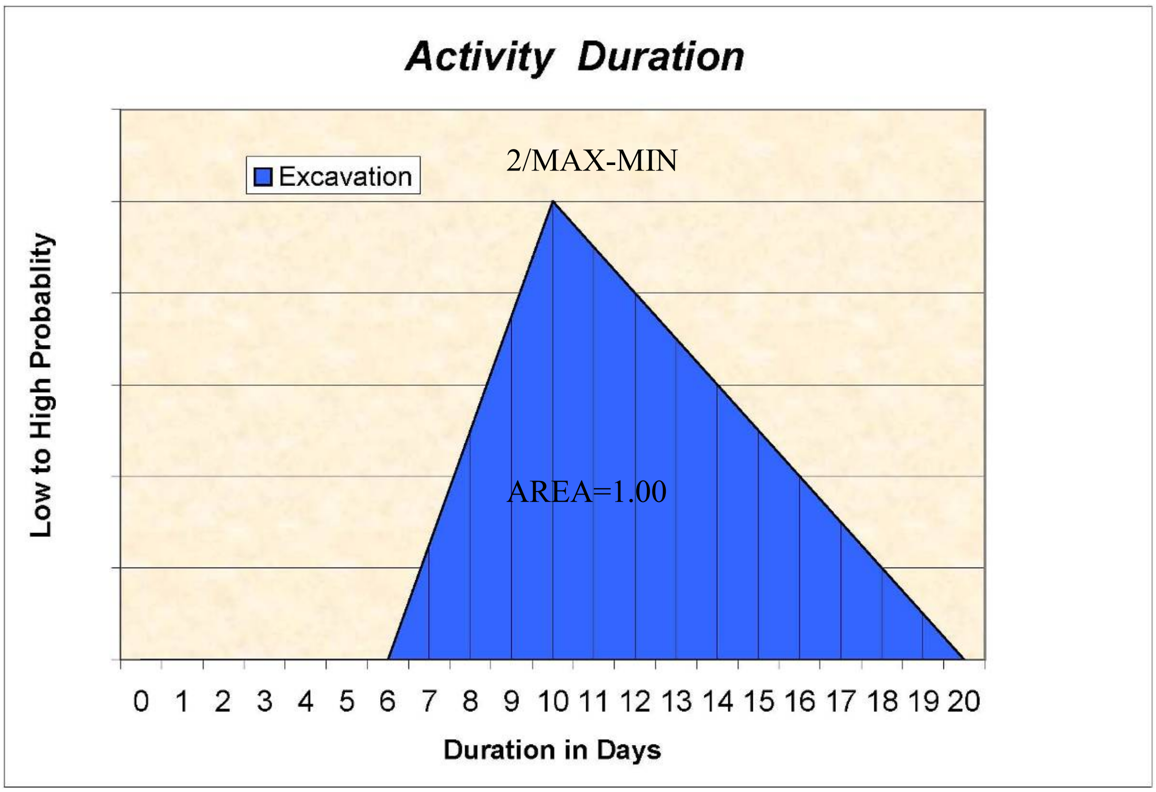

FIGURE 5: Triangle Distribution Example

After three days into the excavation, a change of condition occurs that suspends the completion of the excavation for seven days. After the change in condition has been resolved, it takes four days to complete the excavation. The overall duration of the excavation ended up being 14 days as shown in Figure 6 below.

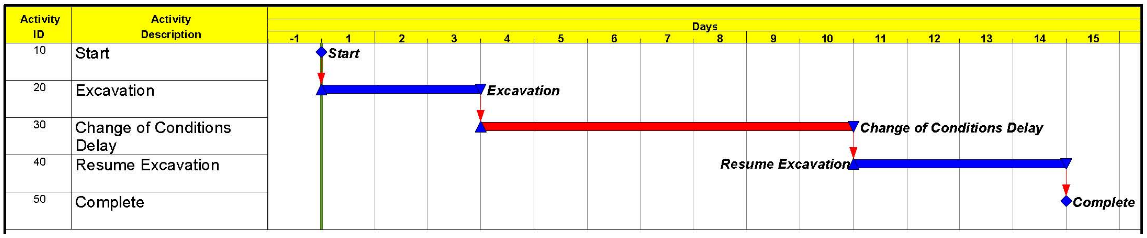

FIGURE 6: Schedule Delay Example

First Method

There appears to be two approaches that could be used. The first approach is to remove the probability of duration activity change from the activity that was delayed. The schedule risk analysis would be rerun with excavation duration equal to the minimum, probabilistic and maximum amounts.

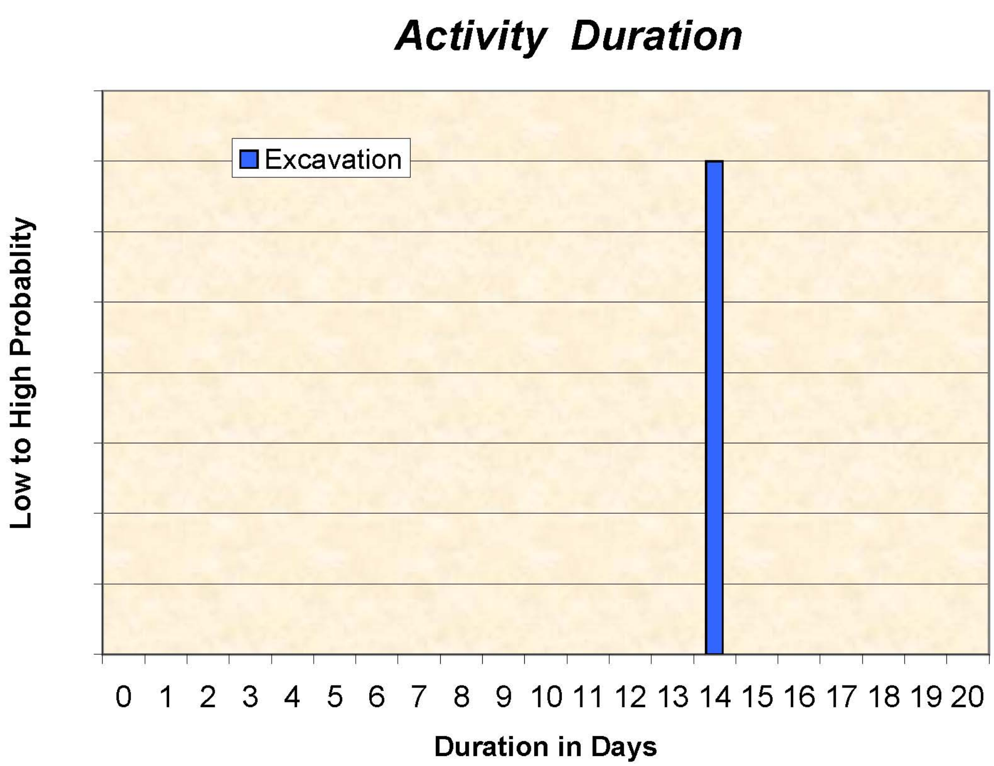

FIGURE 6: Triangle Distribution becomes a Column

The revised finish date distribution would be calculated and the 85% project completion date would be determined. The difference between the 85% calculation prior to the change in the excavation duration compared to the impacted duration would determine the probabilistic delay on the project.

This first method would appear to be realistic; however, it should be observed that the change in excavation duration from a probable duration of ten days to an actual duration of seven days is not recognized in the calculation. The Contractor's good performance is actually subtracted from the Change in Conditions delay.

Second Method

The second proposed method to calculate project extension would be to index the original minimum duration, most likely duration, and maximum duration by the seven days for the changed condition and again recalculate the 85% project completion date.

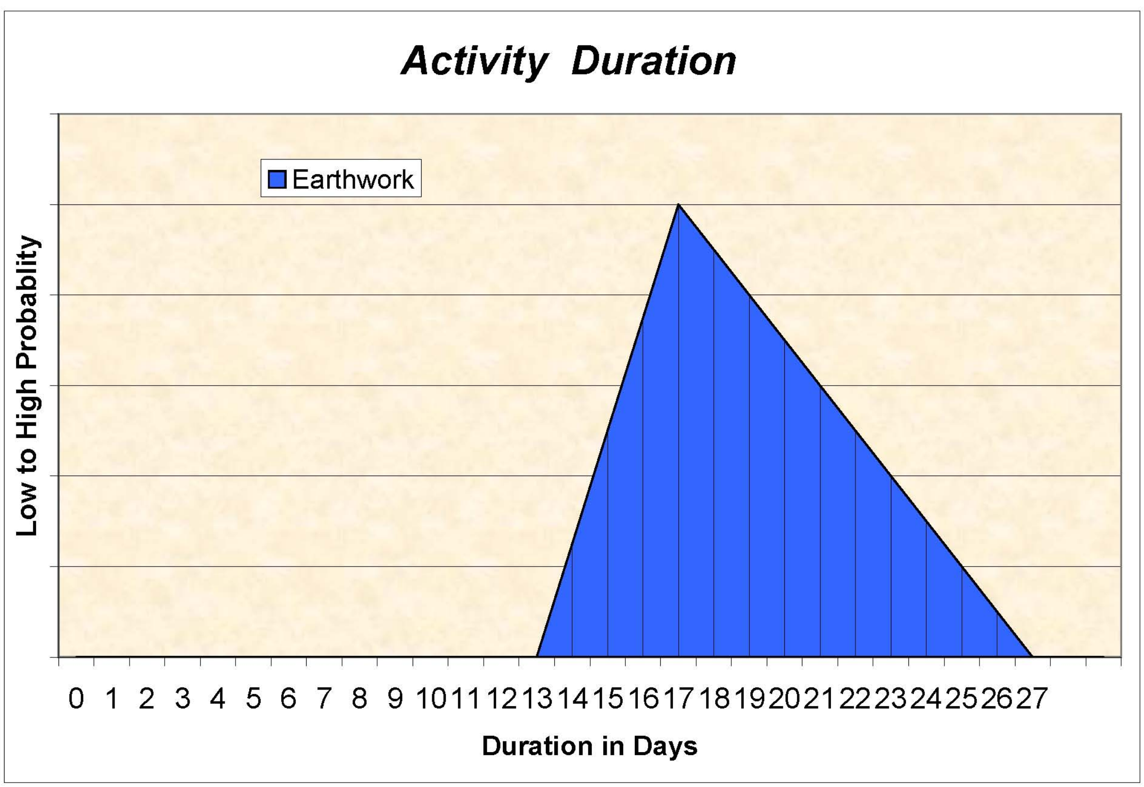

FIGURE 7: Triangle Distribution with 7 day Shift

This method assumes that none of the changed condition durations was anticipated in the maximum probabilistic duration. When the scheduler determined a maximum of 20 days, he was most likely not anticipating the soil condition change.

A New Scenario

The more intriguing problem is assuming the same scenario of a change in conditions suspending work for seven days. However, in this example the excavation activity only has a 64% chance of being critical.

Does one rerun the risk program with the impacted duration and measure the end date, or what does it mean if the activities criticality is increased to 95% by the change in conditions? In order to discuss the impact of percentage critically, a review of a float profile assists our understanding. Below is a float profile of an excavation activity on a project.

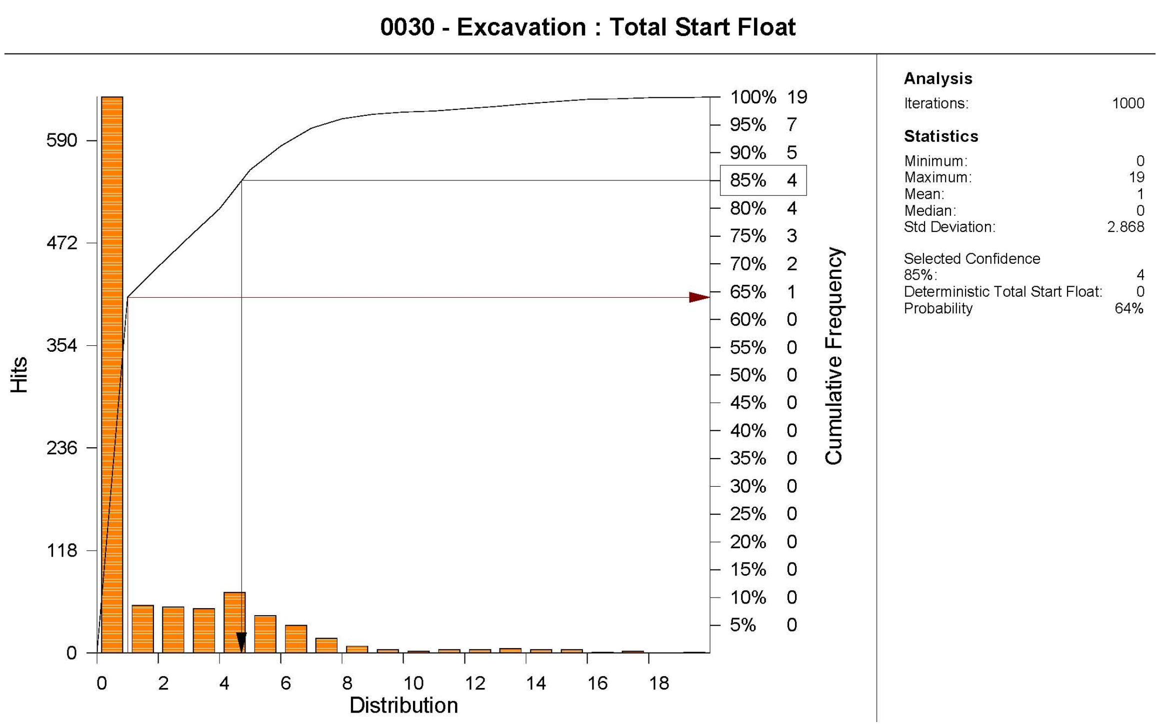

FIGURE 8: Excavation Float Profile

Is the answer that the 7-day Change in Conditions will result in:

a) Extending the project completion 7 days 64% of the time
b) Increasing the probability that the excavation to 95%
c) In addition to (a) extend the project completion 2 day , 5% of the time
d) In addition to (a) extend the project completion 3 day , 10% of the time
e) In addition to (a) extend the project completion 4 days, 5% of the time
f) In addition to (a) extend the project completion 5 days, 5% of the time
g) In addition to (a) extend the project completion 6 days, 6% of the time
h) All of the Above
i) None of the above

The various scenarios all have advantages and disadvantages. However as in normal forensic delay analysis, when all else fails, look at the As-Built schedule.

A retrospective view of a probabilistic schedule is an analysis of a schedule with fixed duration, which we are all comfortable with. The analysis would be performed on actual as-built durations and the impact of a delay could be determined by an Adjusted As-Built Method or the But-For Method [3].

Conclusion

As much as we would like to be able to proscribe an exact procedure for implementing probabilistic delay analysis in this paper, this process is only being introduced here. The concept is valid and in an industry that prizes accuracy and accountability so highly, the implementation of this model is inevitable.

References:

[1] "Schedule Risk Analysis Simplified," David Hulett, Hulett & Associates

[2] PertMaster 2006 Project Risk Software

[3] “Construction Scheduling: Preparation, Liability, and Claims,” Wickwire, Driscoll, Hurlbut, and Hillman, © 2003 Aspen Publishers

[4] “Construction Planning and Scheduling,” Second Edition, Thomas E. Glavinich, D.E. PE, the University of Kansas, 2004

[5] “How the Implementation of Pertmaster Network Software Will Enhance the Project Schedule Credibility,” John G. Zhao, Major Projects, Suncor Energy, Inc. 2006

[6} “The Triangle Distribution: Mathematica Link for Excel”, Rick Hesse, Decision Line, May 2000