Teaching PERT to MBAs—an Experiment in Pedagogy

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Abstract. With numerous projects suffering deadline or budget overruns, conducting PERT-type risk analysis has now become a formal part of project planning. However, for many students as well as practitioners PERT (Performance Evaluation and Review Technique) remains embroiled in the mystery of statistics and random variables. The assessment of *quantifiable* risks facilitates various risk response actions and at minimum sets up the associated risk monitoring procedure. A key tool to quantify uncertainty in project schedules is PERT. PERT inherently involves Monte Carlo simulation of the entire project—all tasks included—using information about the random character of each individual task in WBS. While many commercial SW packages deliver PERT analysis in a black box, this paper has probed teaching PERT effectively to second year MBA classes. This pedagogical evaluation experimented with various SW options that the students could use to conduct PERT. It has determined that Excel®, a ubiquitous desktop tool, would often be a good enough to help students to perform PERT—just as accurately and easily, for projects involving 20-30 key activities. Excel® is similarly found to be sufficient to teach estimation of the risk of cost overruns. Thus this experiment suggests that Excel®-based method could accomplish teaching management students the nitty-gritty of PERT—a part in teaching risk assessment in projects often merely brushed over.

Keywords: Project planning, CPM, PERT, Spreadsheets, Excel®

1. Introduction

Today almost all unique and significant undertakings of mankind that require mobilization of resources and the execution of a plan are cast in a managed framework. This professional framework commands its own body of knowledge and methodology. Not doing this, it has now been amply shown, costs dearly, leading to stakeholders' dissatisfaction and squandering of resources—material and human—in addition to wasted time. Recent project audits done in domains as diverse as IT (SW development), construction, space exploration, open heart surgery, pharma (new product development) and social projects done by NGOs all confirm the high value of *expertly conceiving*, *planning*, *executing* and *closing* a project. [1]

Teaching of the underlying techniques and methods must happen before the project planner plunges into mobilizing resources. Planned, executed and closed improperly, the consequences of a badly done project may lead to irreparable damage, loss of revenue, impaired market positioning and share, and perhaps most critically, a contractor's competitive edge. For IT projects, a study by the Standish Group [2] of 365 separate projects, as many as 53% were completed over budget and over schedule and did not meet original specs.

The timing, or the *scheduling* of the required tasks or work packages that emanate from the Work Breakdown Structure (WBS) of a project is not only critical but also an integral activity of the project manager before he draws up the contracts, earmarks or mobilizes resources and commits to various milestones and deadlines. While the WBS identifies the tasks and activities, it is *time estimates* that eventually determine the projected duration of completing all the activities. Time therefore becomes an essential input both in cost estimation and in the allotment of resources to execute those activities. The

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typical project planning steps to which MBAs are introduced are those of CPM, with a cursory mention of uncertainty and PERT [1].
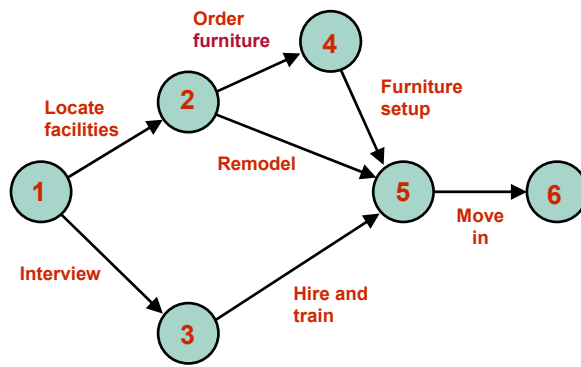

Fig. 1: A Typical Project Network showing Tasks and their Dependence

2. CPM and PERT

Giving students practice in developing the CPM network and identifying the critical path using only deterministic task times is fairly routine. The method closely related to CPM is called PERT (Program Evaluation and Review Technique) [1], also created in the '50s, to improve the scheduling and management of complex projects, rather specifically for projects in which activity durations involve *randomness*. PERT explicitly incorporates duration-related uncertainties that can impact an activity or a work package. Thus PERT takes perhaps a skeptical but *a more realistic view* of the time needed to complete each project stage.

In this pedagogical study, students were told that PERT accepts uncertainty as an "integral" (unavoidable) part of the unsure world of projects and it uses *probable* rather than single-point (deterministic) duration estimates for each task, or each work package, or each key project stage, whatever is available. PERT aims at quantifying or estimating the risk (probability) inherent in a project of overrunning some committed deadline—due to such uncertainty. To set up a PERT study, one first estimates the shortest possible (*optimistic*) time each activity will take, the *most likely* duration of completing the task, and the longest (*pessimistic*) time that a task might take if it goes longer than expected. Most contractors find specifying such range of estimates a great deal easier.   Except in the most trivial situations, the project planner then executes a process called *Monte Carlo simulation* of the whole project, to determine the *range of probabilities* for completing the project by certain times or deadlines (see Figure 5 below). In this study students were told that instead of generating a single estimate (equal to the total duration of completing all tasks on the critical path) for the project duration as done by CPM, PERT produces a *range of completion durations* and a corresponding *set of probabilities* or likelihood that the project would be delivered in time. This helps one to project the risk of not completing the project by a certain pre-specified deadline (Figure 2).
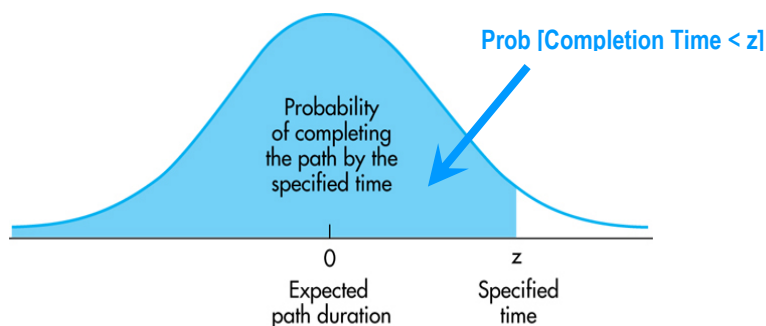

Fig. 2: The Probability of Completing a Project Before its Due Date

3. Monte Carlo on Excel®

Students were told that Monte Carlo [2] is a mathematical method used in assessing the risk or the probabilistic outcome of a complex process—a method routinely used in natural and physical sciences, engineering and business analysis to produce data that approximate the distribution of potential process results based on probabilistic inputs. The random pulling of a sample value for each input variable from its defined probability distribution (e.g. uniform, normal, lognormal, triangular, beta, etc.) generates the *simulated* input conditions. To illustrate this, students were asked to open an Excel® 2003 sheet and study the behavior and use of built-in Excel® functions such as RAND(), NORMINV, BETADIST, etc.

To simulate a random process, the students were shown how results of the random process are computed through a pre-specified relationship between the input and the results (the output variables). In PERT the input variables would be the various task durations whereas the result may be the project completion time. The randomly drawn (generated) input sample values would be used to calculate any results of interest, e.g. total project duration, or total project cost, as long as we are able to specify how the input variables and the output are mathematically related. In doing Monte Carlo, a repetitive procedure of sampling the input and computing the output is executed until the probability distributions are sufficiently well represented to achieve the desired level of statistical precision. Monte Carlo can thus be used to calculate the critical path, slack values, time overruns, cost overruns, etc. Monte Carlo simulations are now an established methodology used during the planning phase of a project that involves uncertainties in duration or cost estimates.

A simple illustration of Monte Carlo simulation was given as follows. Suppose a trivially simple project consists of three work packages or activities—*a*, *b* and *c*. Activities *a* and *b* each precede the one following it, thus making critical path *a* → *b* → *c* as no other activity is involved here. Let each activity's duration be *uncertain* or *random* integer values—in the range 5 to 10 for *a*, 9 to 15 for *b* and 6 to 11 for *c*. This would make the precise prediction of the length of time to complete this simple project *a-b-c* quite difficult, in fact impossible. What can be done here, instead, is to specify the *probability* of completing the project by say the shortest possible time (5 + 9 + 6 =) 20 time units, by 25 time units, etc. Of course, for the range of times provided, the project would for sure be over by (10 + 15 + 11 =) 36 time units, or with 1.0 probability. What about the durations in between? This answer may be easily derived, by Monte Carlo simulation, as follows.

First, for simplicity let's assume that each activity (for us it is now a random variable) follows a uniform distribution over earlier estimated integer values. Thus, *a* is distributed uniformly in the range 5 to 10, with each integer value having the likelihood of 1/6. Similarly, *b* is distributed uniformly in the range 9 to 15, each value having the likelihood of occurring of 1/7. Lastly, the distribution of *c* is uniform in the range 6 to 11, each having the chance of occurring of 1/6. One *random* draw of a value for *a, b* and *c* in the specified valid ranges provided, we find *a* = 7, *b* = 10 and *c* = 10, yield project duration to be 27. In the next random draw we find *a* = 9, *b* = 9 and *c* = 7, yielding project duration to be 25. If we repeat the sampling process over a 100 or more trials, we shall produce a range of values for the project duration, between the extremes 20 and 36, and the corresponding frequencies that can help us estimate the probabilities of interest—that of completing the *a-b-c* project before a certain deadline.

This sampling or simulation process can be easily be created in Excel®. In addition, Excel® provides us with several different built-in statistical functions from which certain pre-specified types of random numbers (integer or continuous) can be generated. The specific functions that can be useful here are as follows: RAND(), RAND()*(b − a) + a, and RANDOM NUMBER GENERATION. Excel® also has facilities quick data analysis, and for graphing or plotting of various graphs that can be used to produce cumulative or frequency plots to help determine time overruns or cost overruns, based on formulas that you insert in appropriate computational models or expressions linked, for instance, to randomly distributed task durations.

For our *a-b-c* project, Excel® produced the following numbers. For 100 samples randomly drawn, the values of *a* ranged between 5 and 10 with the observed frequency distribution shown below. Similarly, for *b* and *c*, Excel® produced values with distributions as shown.

a Bin	Frequency	*b* Bin	Frequency	*c* Bin	Frequency
5	14	9	18	6	21
6	27	10	14	7	20
7	15	11	7	8	19
8	18	12	6	9	15

9	13	13	18	10	14
10	13	14	18	11	11
		15	19		

Clearly, such samples produced were not "strictly uniform" because of our small sample size. This "quality" would improve with the number of samples drawn (see Chapter 1 of [2]). Now, if the randomly drawn values of *a*, *b* and *c* are 8, 7 and 10 respectively, Monte Carlo simulation asserts that the corresponding project would have a critical path length 25. In the next draw of random task times if *a* = 6, *b* = 9 and *c* = 7, the project would last 22 time units. And so on. Tried on Excel® with 100 replications, the histogram of project *a-b-c*'s completion times emerged as shown in Figure 3. Note that the histogram appears to approach the bell curve, or the normal distribution. The reason for this is that project completion time is the sum of three random variables, *a*, *b* and *c*. By Central Limit Theorem, the distribution of the sum of several random variable approaches the normal distribution [3].
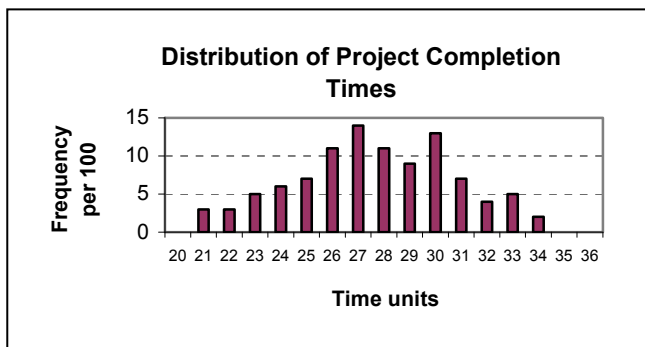

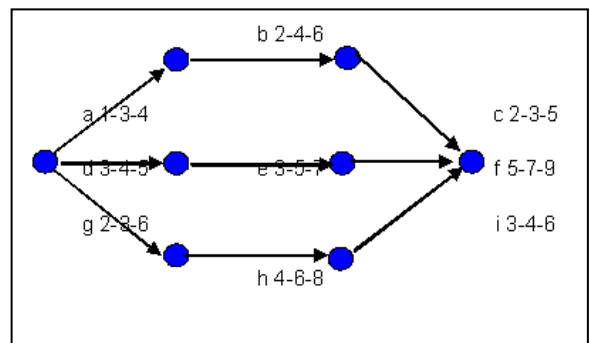Fig. 3: Distribution of Simulated Project
Completion Times

Fig. 4: The Activity Network for the PERT
Project

4. Risk Evaluation from distribution

It would not be difficult now to estimate the risk of project overrun. For example, for the *a-b-c* project, the chance of the project's going beyond 30 time units would be about (7 + 4 + 5 + 2)/100 = 0.18 or 18%. The accuracy of this estimate can be improved by running the simulation for a larger sample size.

5. An application to a realistic project

In order to illustrate the teaching PERT by Excel® we consider the following. A project consists of nine tasks related to each other for their technological dependency as shown in Figure 4. Each task involves uncertain duration, captured by the "Triangular" distribution, which involves three parameters—*to* (optimistic completion time), *tm* (the most likely completion time), and *tp* (the pessimistic estimation of completion time). For each task, its *to*, *tm* and *tp* values were used to estimate the mean and the standard deviation values of the task duration (a random variable). An equivalent "normal" distribution was then substituted for the original triangular distribution—to permit use of a built-in Excel® function (NORMINV(prob, mean, sd)) to produce the random task times. Care kept the random times within (*to*, *tp*).

The procedure for using Excel® to perform PERT may be described stepwise as follows:
- Construct all paths from start to finish, *exhaustively—possible for small networks*.
- Incorporate uncertainty in each task duration by first triangular distribution to find average and SD (standard deviation), then using normal approximation to ease sampling.
- Conduct Monte Carlo—for the desired sample size, say 100 trials.
- Analyze simulation data by studying the histogram of completion times produced.
- Project the chance of overrun from the histogram, or more conveniently from the cumulative "S" curve or completion times.

The formulas for converting the uncertainty data available as the triangular distribution parameters *to*, *tm* and *tp* into the mean and standard deviation of the equivalent normal distribution used were   Mean = (*to* + 4*tm* + *tp*)/6 and SD = (*tp* – *to*)/6. The crux of the present procedure is setting up the Excel® worksheet on

which Monte Carlo replications are done. The processing of the output data is straightforward. The final result is a a histogram, and then estimating the probabilities corresponding to the different completion times Figure 5). This project would seem to have about 15% chance of going beyond 17 weeks, the target completion time.
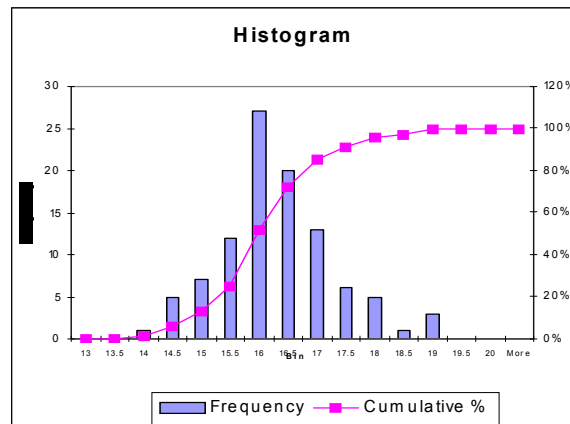

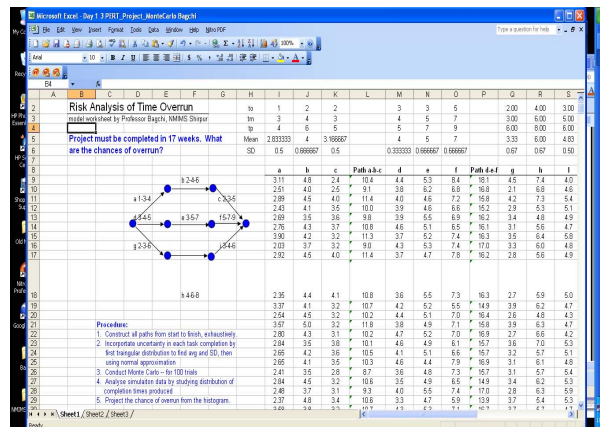Fig. 5: Histogram and S Curve for Simulated Project Completion Times

Fig. 6: Screenshot of a PERT Analysis worksheet built using Excel®

In doing the above, the instructor used only the straightforward features of Excel®. Of course it is possible to implement some of the steps such as replicating the simulation a certain number of times, determining the distribution and quantifying the risk of exceeding a pre-specified time limit, but these are embellishments easily achievable. A worksheet printout showing this sample problem appears in Figure 6. The original Excel® sheet usable for pedagogical purposes may be obtained from the author. What we have noticed in class exercises that used this approach is that students here are able to appreciate the different nuances of randomness in task times and the interaction of the network structure with the overrun risk much easier than when done using commercial project management tools used in a black box manner.

6. Conclusions

- This paper has demonstrated the efficacy of a simple and popular spreadsheet facility, namely, Excel® as a pedagogical tool to help teach a key aspect of project management—learning and conducting PERT.
- Five different MBA classes experimented with at NMIMS (Shirpur), SP Jain Institute of Management (Mumbai), NITIE (Mumbai), IIT Kanpur, and IEM/VGSOM (IIT Kharagpur) indicated that the students would require only an introductory UG course in probability and statistics [3] and nothing more advanced to use an Excel®-based technique to conduct risk analysis for time and cost overruns.

- However, a working knowledge of Excel® would be essential. The good thing is that the information that an exercise using the PERT framework on Excel® produces is technically equivalent to what commercial tools can produce. Cost overrun risks may be similarly analyzed.
- Additionally, since the analyst personally builds the models, he/she becomes intimately involved in the nitty-gritty of the project and with factors that could impact the tasks to make their durations uncertain.

This last aspect, it is also expected, would be useful in raising the appreciation of quantitative risk analysis of projects in the minds of students of construction, R&D, new product development, PM practitioners and other enterprises. The screenshot of a typical illustrative PERT spreadsheet used in an MBA project management class appears in Figure 6.

7. Acknowledgements

8. References

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