PROJECT MANAGEMENT UNDER RISK CONTROL: A MONTE CARLO SIMULATION APPROACH[1]

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ABSTRACT

With the advent of computer technology and ever-increasing power of processing chips, it has become possible to create business and engineering models that simulate reality and aid in making accurate predictions of vital parameters of real systems being simulated. One of the methods for simulating real world systems is Monte Carlo simulation. Its ability to take into account randomness by exploring seemingly infinite replications of different scenarios and then summarizing the results for deriving informed decisions is what makes Monte Carlo simulation attractive to scientists, engineers, and industry practitioners. This paper focuses on the use of the technique in tackling risk associated with Project Management networks, undetected by traditional software tools and methods. As such, this paper is an extension of authors' previous work [2] on this important area of research.

INTRODUCTION

The *Program Evaluation and Review Technique* (PERT) is a model for project management invented by The U.S. Department of Defense's *US Navy Special Projects Office* in 1958 as part of the *Polaris* mobile submarine launched ballistic missile project. This project was a direct response to the Sputnik challenge. The method has since been used as method of choice for managing critical business enterprise and large scale engineering projects. Even today many government agencies contractually require the use of the technique. PERT determines how much time and consequently budget, a project needs before it is completed. Each individual activity of the project is assigned a best, worst, and most probable completion time estimate and budget. These estimates are used to determine the expected value of completion time. The average times are used to figure the critical paths and estimates of some measures of variability of completion times for the entire project. However, recent more in-depth statistical analysis of the technique reveals serious problems and undiscovered flaws in the method. Modern computer software tools such as *MS Project* is not capable of dealing with such flaws. The PERT based Project Management methods and related software tools generally do not take an adequate account of risk. Monte Carlo Simulation provides an improved methodology to quantify schedule risk. This paper aims in investigating the use of this methodology and its shortcomings for better understanding, designing, and managing a project such that the detrimental effects of these risks are minimized. Incidentally, analysts at Remington Rand and DuPont developed CPM in 1957. It differs from PERT in the details of how time and cost are handled.

Project Management: What is a project? A collection of events or activities, related to each other over time, whose purpose is to achieve a specific goal. The Apollo project is a good example. President Kennedy launched the Apollo program in his 1961 message to Congress, establishing a national goal: "before this decade is out, of landing a man on the moon and returning him safely to the earth."

[1] This is an abbreviated version of the paper. The full paper is available from the authors upon request.

Hundreds of thousands of activities and tens of thousands of events were involved. PERT techniques enabled project managers to identify the few hundred activities that were "critical" to keeping the project on track and monitor these critical activities continuously. In January 2004, President Bush announced the Vision for Space Exploration for NASA. This vision directs NASA “to develop and execute a program aimed at returning humans to the moon, sending explorers on to Mars, and facilitating future exploration activities to ‘destinations beyond’.” Managing risk and computing accurate estimates of time and budget in projects of this magnitude requires more sophisticated analysis than relying solely on some commercial software package, such as *MS Project*. Recent research in using Monte Carlo Simulation in studying networks of activities of Project Management has been quite promising. We will investigate this issue and suggest methods to more accurately compute estimates of risk factors and time and budget figures using specialized optimization algorithms [3] and computer simulation via EXTEND simulation software package [2].

Simulation Approach: Simulation is one of the most widely used tools for analyzing complex processes and systems. Its use in business and engineering systems management has increased dramatically in recent years, in part because of the increased power of personal computers and workstations, on which the vast majority of simulations are carried out. As a powerful research method, simulation enables researchers to look at an artificial world move forward into the future, giving the user the unprecedented opportunity to intervene and attempt to make improvements to performance. As such it is a laboratory, safe from the risks of the real environment, for testing out hypotheses and making predictions. Computer models are used to learn about a real life situation that cannot be altered directly, either because the system does not yet exist or it is too difficult to change just for experimental purposes. Simulation models can help explain a system as complex of the Internet or a large scale engineering project such as NASA’s mission to Mars, ORION PROJECT. The purpose of simulation modeling is to help the decision maker solve a business problem with more insight into to random phenomenon that is often cannot be captured, modeled, or treated by deterministic methods.

Specifically, in managing large projects, Project Management techniques such as the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) do not account or estimate risks involved. It is therefore important to investigate why simulation should be used on any large or complex engineering project where traditional management science analysis and techniques, including CPM and PERT, fail to account for factors such as path convergence and thus tend to underestimate project duration, cost, budget, and other critical parameters. It is easier to demonstrate, with a simulation, how tasks not on the critical path may end up on the critical path due to unforeseen deviations from the plan and derail a project. Also, with simulation one can illustrate the negative impact of parallel paths converging at critical points, another critical point which may only be uncovered through the use of Monte Carlo simulation.

First we focus on the use simulation to relax some of the restrictive assumptions of PERT [4] to generate more reliable, though not necessarily definitive, probability distributions for the completion time and budget for an entire project. Large-scale engineering projects are usually original, one-of-a-kind projects. At its current state, PERT is not fully capable of handling all the features of such projects. PERT is designed to handle only the so-called “PERT-distribution” for random activity durations with the three estimates for activity durations. However, in many projects there is a need for other probability distributions, as well as “activities with selection probabilities.” PERT assumes that there exists “a single dominant critical path” in the project network, which most likely not true in most very-large scale engineering projects. Also, PERT assumes that random variables representing the task times on the critical path are "independently and identically distributed", when making its conclusions as to the completion probabilities of the project, which most likely not true in most very-large scale engineering projects. This work emphasizes these issues and proposes some suggestions.

ACTIVITY- TIME PROBABILITY DISTRIBUTION

To be perceived successful, a project must meet two important criteria that are traditionally associated with success, namely, completed on time and completed within budget. One of the critical factors of all operations in managing large scale projects is the risk of failing to complete activities on time and hence the entire projects, and consequently dealing with cost overruns and other possible contractual penalties. The pert method introduces uncertainty into the project network by treating each activity's completion time as a random variable, say, x with density f (x). In particular, a Beta probability distribution for the activity time random variable is often assumed.

A random variable *X* has the probability beta distribution, if its density function is given by

$$f(x) = \frac{1}{B(\alpha,\beta)} x^{\alpha-1}(1-x)^{\beta-1}, 0 < x < 1.$$

Where, the Beta function is given by

$$B(\alpha,\beta) = \int_0^1 x^{\alpha-1}(1-x)^{\beta-1}dx = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)}.$$

and the two parameters α and β are called shape parameters and thus by letting the values of α and β change over specified intervals, one may produce a family of distributions. The triangular distribution, uniform distribution, and a few others that are incorporated in cpm networks, are closely approximated by particular values parameters of beta distribution. In practice however, simple triangular distribution is used instead of Beta due to the complexity of derivations in the follow up analysis under the Beta distribution [4]. In particular, in the pert system, for practical simplicity of the follow up analysis, such as crashing considerations, expected value and standard deviation of beta distribution is used instead. In the sequel, we will exploit other properties of beta distribution that may result in more reliable estimates of the activity completion times.

UNDERLYING ASSUMPTIONS REVISITED

The formal beta distribution given above is a continuous distribution that has the following distinct properties: (1) it has finite limits, (2) it can be asymmetrical, and finally (3) beta distribution is flexible [1]. These properties are further exploited in variance reduction analysis of the project's completion time. Additionally, common assumptions used to derive estimates of the parameters to describe the beta distribution and to compute mean and variance of project completion times in the underlying PERT representation must be revisited. PERT approximations of project duration and the underlying probability statements derived from such approximations are shown to be quite misleading at times. The most widely recognized source of bias is near critical paths that emerge as critical in a realization of the project. By avoiding PERT formulas, however, simulation can overcome the bias in the PERT and in particular in standard deviation of completion times. As it turns out, this can be achieved by making careful choices of the parameters of beta distribution resulting in a wider variety of shapes to model activity completion times in a network simulation.

CONCLUDING REMARKS

Simulation should be used on any large or complex Engineering project since traditional Management Science methods such as the CPM and PERT do not adequately account for path convergence phenomena and hence tend to underestimate project duration. Using Monte Carlo Simulation, we can illustrate the negative impact of parallel paths converging at critical points and demonstrate how non critical tasks may end up on the critical path due to deviations from the plan and thus derail a project.

REFERENCES

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