The Case for Comprehensive Models and Methodologies for Project Planning, Tracking and Managing

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***Abstract*- Task estimation, task execution and task tracking continue to engage the attention of project management professionals and project management researchers alike, with an eye on achieving the most sought after twin-goals of completing the project on time and within budget. We analyze EVA tracking, a well-regarded technique for project execution and identify some shortcomings. Likewise, we analyze PERT-based probabilistic approach to estimation and tracking, a widely accepted methodology, in conjunction with critical path concepts with the objective of highlighting likely implications and making a case for comprehensive methodologies for project planning, tracking, and managing.**

***Keywords*- Project Management; EVA; PERT; CPM; CCPM; Change Management; Simulation Modeling**

I INTRODUCTION

Project Managers want to complete projects on time and within budget and with full functionality. In their pursuit of these goals, project managers use models and tools that they consider to best fit their project environment and context. Unfortunately, the majority of the models and tools in use are static in nature and/or do not seem to view the project from a holistic and dynamic perspective. We examine two of the most popular techniques viz. Project Evaluation and Review Technique (PERT) and Earned Value Analysis (EVA) closely to develop useful insights for possible improvements.

Goldratt asserted that, when called to estimate task times as part of a project planning effort, seasoned estimators tended to build safety into their estimates [1]. Consequently, typical probabilistic estimates of task times under PERT methodology tend to end up higher than the realistic estimates of task times. This will be particularly true in the context where such probabilistic estimates are provided by the employees responsible for executing the relevant project tasks. In most cases this tendency of including safety in task estimates results in an overstatement of the mean time for sure, and often time is coupled with an understatement of the variance for each activity time as well[2]. Not surprisingly, [3] reiterated that estimation is the weakest link in project management. Consequently, the tracking of the project is affected by these padded task estimations resulting in avoidable schedule and cost variations.

We contend that EVA method is flawed because it does not take paths, much less the critical path, into account. PERT is deficient in that it provides probability estimates of project completion computed before the project begins but doesn't provide revisions and corrections as the project proceeds for known variations that occur in project execution from time to time. In other words, PERT is a predictive tool that predicts the probability of completing a project on time and within budget at the beginning of the project. EVA is a diagnostic tool that can track the project progress during its execution to provide signals about the likely time and budget for completion of the project. Neither of these tools can provide the much needed critical decision support to project managers for change management during the execution of the project to steer it back on to track and to dynamically correct its course of progress.

The rest of the paper is organized as follows. First we begin with a relevant literature review. Then we present two contrived and simple projects to get a "feel" for the limitations of conventional EVA and PERT alluded to above. These examples will also highlight how EVA can produce an indication of being behind-schedule, when in fact the critical path may actually be ahead-of-schedule, making the entire project ahead-of-schedule and vice versa. Next, some approaches to fix the problems with conventional EVA are suggested. Then we discuss possible use of simulation models capable of capturing the dynamic aspects of project to provide better opportunities for not only to track the project progress but also to suggest ways and means to bring the project back on course for completion in time and/ or within budget. We conclude with summarizing the contributions and conclusions of the paper.

II LITERATURE REVIEW

Much has been written about the usefulness and applicability of EVA to project management. For example, [4] provided detailed notes on ways to improve the performance of earned value analysis in the context of construction project management. Based on data taken from twelve projects that exceeded their budgets [5] compared various EVA models for their accuracy. Further, [5] also observed that in order for these models to predict the final cost with credible level of accuracy, a project needs to be fairly advanced, say about 60% complete.

Baseline schedule has been considered an important tool for project management for resource allocation, project tracking and other project related activities [6]. While [7] studied optimal resource allocation models of the resource-constrained, project scheduling problems, [8] researched search space restrictions on project scheduling problems.

Project Management Institute’s Body Of Knowledge (PMBOK) makes extensive references to EVM and EV [9]. PERT/Cost is a technique that has seen some uses although it doesn’t facilitate forecasting total project cost or duration [10] [2, p.380], and [11] provides rationale and justification for holistic approaches to PERT/CPM.

Earned Value Project Management Method and its Extensions by Anbari is an excellent compendium [12]. Project managers and stakeholders will find the discussion of Planned Value Rate (PV Rate) and Time Variance (TV) interesting. The behavior over time plots of SPI, CPI, CR, EAC and VAC are significant indicators of project progress and trend over time. This paper demonstrates how, all of these metrics appear to be time functions. Anbari has also authored an excellent text on quantitative methods for management of projects [13] and has been a significant contributor to the project management literature.

Goldratt published a book *Critical Chain* [1] in which he introduced a new perspective on project management termed as Critical Chain Project Management (CCPM) which is based on theory of constraints and statistical fluctuations. Since then, CCPM, has been well researched and written about [14], [15], [16], [17], [18], [19] [20]. CCPM is essentially an approach for getting projects finished fast and at substantially less cost. The main focus is on completion within time, with cost control being an incidental objective rather than being an objective of main focus.

Leach discusses the basics of critical chain project management (CCPM) in [14]. This article describes actual projects that benefited significantly by putting to practice the CCPM methodology. Further, [14] opines that CCPM is a much easier tool than EVA for project management purposes. However, a major limitation of CCPM is that it doesn’t concern itself with cost control at all. Nevertheless, [14] is highly recommended for project managers because it highlights and reminds us of the frailties and failings of project management. Interestingly, [21] employs simulation to study time and cost tradeoffs in a project setting endorsing the fact that time and cost are intertwined and neither can be controlled or tracked in isolation of the other. In [22] authors compare commercial project management software calculation results with their own developed software and demonstrate how they are able to incorporate a new variable SV(t), Schedule Variances respect to Time while matching or exceeding the performance of commercial software in tracking other conventional metrics. In [23] two new metrics viz, Schedule Control Index (SCoI) and Cost Control Index (CCoI) are proposed that combine Earned Value Management and Project Risk Management. These indexes allow project managers to analyze whether project over-runs are within expected variability or whether there are structural and systemic changes over the project life cycle. Article [24] describes a completely new project performance evaluation system that utilizes DEA (data envelop analysis) in a case study context. Results were encouraging as the corporate sponsor found the measures useful for projects but also for individual professional evaluation, thus enabling the same system to assist with individual reward and merit. However, the study was a deterministic approach. Authors in [25] present an innovative computation method based on EVM, ES, and Statistical prediction and testing methods. They demonstrate with their empirical EVM data from twelve projects over 497 months that most reliable prediction of upper and lower bounds of cost and schedule duration can be obtained after 60% of the project is completed using a 90% confidence interval.

We found a modest amount of research related to:

- the use of probabilistic PERT to estimate probabilities of finishing a project within a budget;
- critical path sensitive probabilistic network tracking and management;
- revising the cost and time durations of project from a knowledge of progress of a project;
- approaches to address behavioral issues in task estimation in project planning context;
- development of models and methodologies that are more comprehensive and holistic in their perspective to tackle the project planning, execution, tracking, and correcting aspects of managing projects.

In this paper, we attempt to provide possible approaches to address these issues.

III PERT MODEL WITH EVA AND SOME IMPROVEMENTS

Simple PERT models help us understand the concerns we have with EVA/EVM tracking. As is the case with most production operations, projects also suffer from common cause variation in time durations for activity performance. PERT (Program Evaluation & Review Technique) is known for accommodating such variations, fluctuations and the dependent events in projects. It’s only natural that any variation in time durations must reflect in the dependent cost variations. We seek to address the cost variation aspect by suggesting a simple-to-use set of formulas. Let’s consider a couple of PERT examples towards this end.

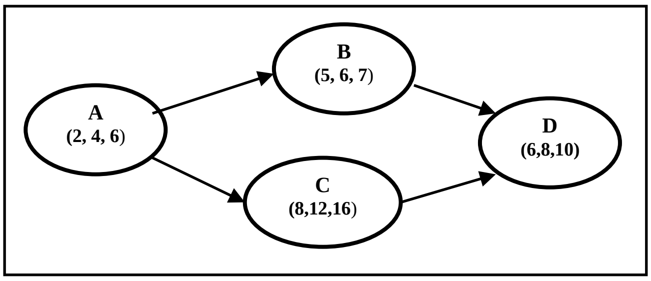

Figure 1 A Probabilistic, Four-Step, PERT Network(activity durations are numbers in parenthesis)

Figure 1 above, depicts a typical PERT model with four activities and their probabilistic time durations, expressed as Beta distributions. As is well known in PERT notation, the three numbers in parentheses in each box denote the optimistic estimate **a**, the most likely estimate **m**, and the pessimistic estimate **b**. The numbers (**a**, **m**, and **b**) are rather contrived for purposes of the ensuing discussion. Using the standard PERT formulas to calculate the mean, standard deviation and variance of each task given below, the corresponding values for the activities of above network are shown in TableI below.

Mean of task i = $\mathbf{x_i} = (\mathbf{a_i} + 4\mathbf{m_i} + \mathbf{b_i})/6$. (1)

Standard deviation of task i = $\sigma_i = (\mathbf{b_i}-\mathbf{a_i})/6$. (2)

Variance of task i = σ_i^2. (3)

TABLE I TABLE OF MEAN, STANDARD DEVIATION AND VARIANCE FOR EACH TASK IN FIGURE 1

Task	a_i	m_i	b_i	Mean	Std. Deviation	Variance
A	2	4	6	4	0.667	0.444
B	5	6	7	6	0.333	0.111
C	8	12	16	12	1.333	1.778
D	6	8	10	8	0.667	0.444

Assume that the project started ten (10) business days ago, Activity A was completed in 4 days as scheduled and that Activities B and C were commenced promptly thereafter. Tables IIA, IIB, and III exhibit the basic earned value calculations for the probabilistic PERT network exhibited in Figure 1.

TABLE II-A BASIC EVA CALCULATIONS FOR NETWORK EXHIBITED IN FIGURE 1 (INPUTS ARE SHOWN IN BOLD)

Task	Days	Cost/day	Budget	%COM-plete	ACWP
A	4	**$ 4,000**	$16,000	**100%**	**$20,000**
B	6	**$ 5,000**	$30,000	**60%**	**$30,000**
C	12	**$6,000**	$72,000	**60%**	**$40,000**
D	8	**$7,000**	$56,000	**0%**	**$ -**
Total			$174,000		**$90,000**

TABLE II-B BASIC EVA CALCULATIONS FOR NETWORK EXHIBITED IN FIGURE 1(INPUTS ARE SHOWN IN BOLD)

Task	BCWS	BCWP	CV	SV
A	$16,000	$ 16,000	$ (4,000)	$ -
B	$ 30,000	$ 18,000	$ (12,000)	$(12,000)
C	$ 36,000	$ 43,200	$ 3,200	$ 7,200
D	$ -	$ -	$ -	$ -
Total	$ 82,000	$ 77,200	$(12,800)	$(4,800)

TABLE III MORE EVA CALCULATIONS FOR NETWORK EXHIBITED IN FIGURE 1

Task	CI	SI	Days Ahead	Days Slack	Cost/day	Excess Cost
A	0.8	1	0.00	0	$ 4,000	$ -
B	0.6	0.6	(2.40)	6	$ 5,000	$ (12,000)
C	1.08	1.2	1.20	0	$ 6,000	$ 7,200
D	NA	NA		0	$ 7,000	
Total	0.86	0.94				$ (4,800)

In Table II A, column '% COMplete' denotes the percentage of the task that is assessed to be complete, presumably, by the project manager or by the assigned project player using his "best" estimate of the work completed. Budget is just the sum of all the individual task budgets, or $174,000. From Table III above, we can calculate the EAC (Estimate at Completion) using the constant-cost-efficiency rate formula: EAC = BAC / CI. It should be evident that EAC = $174,000/.86 = $202,325. Likewise from Table 3 above, we can calculate the ETAC (Estimated Time at Completion) based on the TAC (Time at Completion). Time at Completion is just the sum of the task means for all tasks on the critical path. The tasks on the critical path are A, C and D with a combined duration of 24. Since ETAC = TAC/SI, it should be evident that ETAC = 24/.94 = 25.53. Days ahead (in Table III) is computed based on the formula (BCWP-BCWS) / (Cost/day) which yields, (43,200-36,000)/6000 = 1.2 days for Activity C. As for the Days Slack (in Table III above), we simply use the standard conventions applied to the non-critical activities on a network diagram. It should be noted that both the Schedule Variance (SV) and the Cost Variance (CV) for the project are negative by about $4,800 to $12,800; similarly, the Schedule Index (SI) and Cost Index (CI) are both less than one. A negative Schedule Variance (or a Schedule Index less than one) suggests that the project is behind schedule. Likewise, a negative Cost Variance (or a Cost Index less than one) suggests that the project is over budget. So at this stage of execution, this project appears, based on conventional EVA considerations, to be over budget and behind schedule.

However, as may be noted from the network diagram, A-C-D task sequence is the critical path (CP) for this project. Task C is ahead of schedule by 1.2 days and Task D has yet to be started since only ten days have transpired and task A and C combined are 16 days in duration. If this rate of progress is maintained, the project will finish about 2.4 days early roughly (assuming same speed for the rest of task C and no delays in task D). Notice, in Table III, the lateness of the non-critical Task B (at this point in time by 2.4 days) does not interfere with Task C finishing overall 2.4 days ahead. For the case of B, 2.4 of the six days of slack are used up, leaving several days of slack.

Given the probabilistic time of activities with corresponding variance in task durations in Figure 2, it is possible to calculate a prior probability of completing the project in 30,27,24, 21, or 18 days as shown in table IV. Typically, the standard normal variate z is computed using the formula z = (projected duration – duration of critical path) / Square root of variance of critical path

TABLE IV PROBABILITY OF COMPLETING THE PROJECT ON OR BEFORE A CERTAIN DUE DATE

Projected Project Duration	Project Duration per Critical Path	SD of Critical Path = SQRT(Sum of Variances of A, C, D)	Corresponding z Value	Cumulative Probability
18.00	24.00	1.63	(3.67)	0.0001
21.00	24.00	1.63	(1.84)	0.0331
24.00	24.00	1.63	0.00	0.5000
27.00	24.00	1.63	1.84	0.9669
30.00	24.00	1.63	3.67	0.9999

Just as we are able to calculate probabilities of completing the project (a milestone or task) by a particular date, we can calculate the probability of completing the project within a budget using PERT estimates, although the authors are unaware of other researchers attempting such estimations. Prior to execution of the project, the following calculations could be performed, for example. The formulas we use for calculation of total project costs are (assuming all costs are expressed in costs per day and are deterministic):

$$\text{Mean Cost of Project} = \sum_{i=1}^{n} \text{Mean duration of Task}_i * \text{Cost per Day for Task}_i \quad (4)$$

$$\text{Cost Deviation of Task}_i = \{(\mathbf{b_i} - \mathbf{a_i}) * \text{Cost per Day for Task}_i / 6\} \quad (5)$$

$$\text{Cost Deviation of Project} = \sum_{i=1}^{n} \text{Cost Deviation of Task}_i = \sigma \quad (6)$$

assuming there are *n* tasks. Given that cost variation in performing any of the tasks could impact the overall cost of the project, we include cost deviation of all tasks to compute the Cost Deviation of Project and not limit it to just cost deviation of tasks on the critical path.

Further, if we consider project costs as having both 'fixed cost' and 'variable cost' components, then we could consider following changes to the above equations,

$$\text{Mean Cost of Project} = \sum_{i=1}^{n} \text{Mean duration of Task}_i * \text{Cost per Day for Task}_i + \sum_{i=1}^{n} \text{Fixed cost component of Task}_i \quad (4A)$$

It's not hard to visualize that the fixed cost component could well be one-time costs, setup costs, material costs, and other such costs not dependent on the duration of activities. If no variations are expected in the fixed costs, Eqs.5 and 6 need no modifications. For simplicity's sake, we shall assume that costs per day subsume both direct and indirect costs per day. Also, we shall assume all fixed cost components are zero.

We can then calculate a standard normal random variate as follows:

Z = (Projected Cost of Project - Mean Cost of Project)/σ(7)

Using a Standard Normal Table, a probability of completing a project within a projected dollar amount can then be determined. For the PERT problem exhibited in Figure 1 above, the following probabilities in Table V can be calculated. We can do this in MS Excel as well with the function, = NORM.S. DIST (z, cumulative =yes/no) by choosing cumulative =yes to denote that we are interested in finding the cumulative probability associated with the corresponding z score. What we already know is that, for projected costs below the average of $174,000, the probability is less than .5. For projected costs above the Mean Project Cost of $174,000, the probability is above .5. Now from the Table V below, we know that there is nearly an 83% chance that the cost will be $190,000 or less. Conversely, the probability that the project will cost more than $190,000 is 17% or less.

TABLE V PROBABILITY CALCULATION OF PROJECT COST, BASED ON PERT ESTIMATES

Projected Project Cost	Mean Project Cost	Project Cost Deviation	z value	Cumulative Probability
$ 170,000	$ 174,000	-$4000.00	(0.24)	0.40699
$ 180,000	$ 174,000	$6,000.00	0.35	0.637934
$ 190,000	$ 174,000	$16,000.00	0.94	0.826693
$ 200,000	$ 174,000	$26,000.00	1.53	0.936919
$ 210,000	$ 174,000	$36,000.00	2.12	0.982898

As is well known, delays in non-critical tasks do not increase the total project duration (as long as they do not exceed the slack associated with that task). However, such delays do, nevertheless, increase the cost of the project. From Table III, last column, it may be noted that the project is $4,800 over budget, from a scheduling perspective. Notice that this is precisely the amount by which the cumulative SV (Schedule Variance) column in Table IIB predicts that the project is behind schedule at this stage of project execution (10 business days into execution). Notice that schedule variance is measured here in dollar amount.

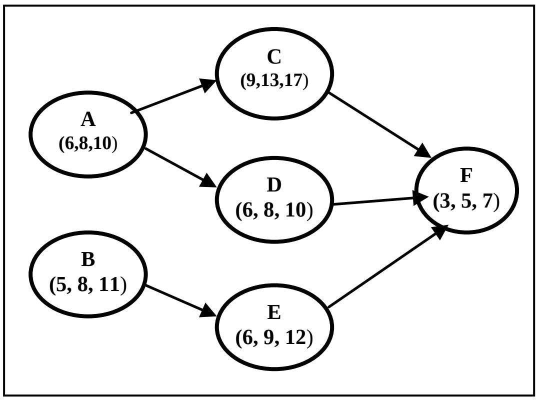

Figure 2 A probabilistic, six-step, activity-on-node network (activity durations are numbers in parenthesis)

Consider next, a six-task problem that is 12 days old with Activities A and B completed within scheduled time of 8 days and C, D and E having commenced promptly thereafter. Figure 2 above depicts a six-activity PERT network with probabilistic time durations, expressed as Beta distributions. As explained earlier, the three numbers shown in the parenthesis by task name above are the optimistic estimate **a**, the most likely estimate **m**, and the pessimistic estimate **b**. Following the PERT model formulas, one can compute the mean, standard deviation and variance of each task in Table VI:

TABLE VI TABLE OF MEAN, STANDARD DEVIATION AND VARIANCE FOR EACH TASK IN FIGURE 2

Task	a_i	m_i	b_i	Mean	Std. Deviation	Variance
A	6	8	10	8	0.667	0.444
B	5	8	11	8	1.000	1.000
C	9	13	17	13	1.333	1.778
D	6	8	10	8	0.667	0.444
E	6	9	12	9	1.000	1.000
F	3	5	7	5	0.667	0.444
Total						5.11

Given that the project started twelve business days ago and Tasks A & B have been completed as per schedule, Tables VII,VIIIA and VIIIB exhibit the basic earned value inputs and calculations for the probabilistic PERT network exhibited in Figure 2.

TABLE VII BASIC INPUTS FOR EVA CALCULATIONS OF NETWORK EXHIBITED IN FIGURE 2(INPUTS ARE SHOWN IN BOLD)

Task	Days	Cost/day	Budget	%COMplete	ACWP
A	8	**$ 1,200**	$ 9,600	**100%**	**$ 9,000**
B	8	**$ 1,000**	$ 8,000	**100%**	**$ 8,000**
C	13	**$ 2,000**	$ 26,000	**8%**	**$ 2,000**
D	8	**$ 1,600**	$ 12,800	**90%**	**$ 5,000**
E	9	**$ 1,400**	$ 12,600	**75%**	**$ 6,000**
F	5	**$ 1,200**	$ 6,000	**0%**	**$ -**
Total			$ 75,000		$ 30,000

TABLE VIII-A EVA CALCULATIONS FOR NETWORK EXHIBITED IN FIGURE 2

Task	Budget	COMP	ACWP	BCWS
A	$ 9,600	100%	$ 9,000	$ 9,600
B	$ 8,000	100%	$ 8,000	$ 8,000
C	$ 26,000	8%	$ 2,000	$ 8,000
D	$ 12,800	90%	$ 5,000	$ 6,400
E	$ 12,600	75%	$ 6,000	$ 5,600
F	$ 6,000	0%	$ -	$ -
Total	$ 75,000		$ 30,000	$ 37,600

TABLE VIII-B EVA CALCULATIONS FOR NETWORK EXHIBITED IN FIGURE 2

Task	BCWP	CV	SV	CI	SI
A	$ 9,600	$ 600	$ -	1.0667	1
B	$ 8,000	$ -	$ -	1	1
C	$ 2,080	$ 80	$(5,920)	1.04	0.26
D	$11,520	$ 6,520	$ 5,120	2.304	1.8
E	$ 9,450	$ 3,450	$ 3,850	1.575	1.6875
F	$ -	$ -	$ -	NA	NA
Total	$40,650	$ 10,650	$ 3,050	1.355	1.081117

Since the project is 12 days old, the BCWS for A, of 8 days duration at $1200/day cost, is $9600; the BCWP is also $9600 because it is 100% complete. The BCWS for C, however, is $8000 (because it started four days ago with a cost per day of $2000), while the BCWS for F is 0, as it is not yet scheduled to start.

For this project, the BAC = $75,000, while the TAC = 26 (the length of the critical path, A-C-F). From these numbers, EAC = BAC/CI= $75,000/1.35 = $55,555, while the ETAC = TAC/SI= 26/1.08 = 24.07. Thus, at this stage of its execution, this probabilistic project model appears to be both under budget and ahead of schedule.

However, a closer look at the critical path (A-C-F), reveals that Task C is well behind schedule. In fact Task C is nearly 3 days behind (divide the schedule variance by the cost per day for Task C to get 2.96). It will, consequently cause the entire project to be delayed by 3 days. Rather than finishing in 24.07 days (about 2 days early) as the EVA would suggest, the project is headed for a finish no sooner than 29 days, based on the critical path consideration. Moreover, the cost will definitely be greater than $55,555 because the project will be delayed in its completion.

To summarize, in addition to computing aggregate BCWP's, ACWP's and BCWS's to determine aggregate CV, SV, SI, CI, the analyst must consider these measures with reference to the critical path perspective. In particular, the CV, SV, SI and CI numbers of the critical path must be examined closely. The project appears, based on conventional EVA considerations, to be under budget and ahead of schedule with a positive cost variance of $13,880 and a positive schedule variance of $4,280. Project stakeholders may very well conclude that the project is ahead of schedule and under budget. But, in reality and based on what's happening on the critical path, this project will most likely miss its deadline of 26 days and will likely be over budget as well. One might argue that the project manager could divert resources from Tasks D and E to apply them to C. This would be possible only if the project manager was aware that critical Task C is behind schedule while D and E are ahead; but with conventional EVA as his tracking methodology, he wouldn't be. The project manager would have known this, had he also been using Gantt charts to track the project and path progress.

Because of the probabilistic nature of the network in Figure 2, it is possible to calculate a probability of completing the network in 24, 26 or even 28 days. As has been explained earlier, the standard normal variate z is computed using the formula z = (projected duration – duration of critical path) / Square root of variance of the critical path.

Using a Standard Normal Table, a probability of completing a project within a projected dollar amount can then be determined. For the PERT problem exhibited in Figure 2 above, the following probabilities in Table IX can be calculated. However, these are *a priori* probabilities appropriate for the project before execution begins. Now after twelve days of project execution, a closer look at the critical path and the extent of slack on the other non-critical paths leads us to estimate that a completion time of 26 days is not likely and is obviously less probable than .5, and may perhaps be closer to .1.

TABLE IX PROBABILITY OF COMPLETING THE PROJECT ON OR BEFORE A DUE DATE

Projected Project Duration	**Project Duration per Critical Path**	**SDof Critical Path = SQRT(Sum of Variances of A, C, F)**	**Correspo-nding z Value**	**Cumulative Probability**
22.00	26.00	1.63	(2.45)	0.0072
24.00	26.00	1.63	(1.22)	0.1103
26.00	26.00	1.63	0.00	0.5000
28.00	26.00	1.63	1.22	0.8897
30.00	26.00	1.63	2.45	0.9928

Once again using Formulas 4 through 7, we determine that the project cost deviation **σ** is \$7733. Knowing **σ**, we can calculate the Z-values in Table X. Using a Standard Normal Table, a probability of completing a project within a projected dollar amount can then be determined. For the PERT problem exhibited in Figure 2 above, the following probabilities can be calculated. What we learn from this list is that, for projected costs below the average of \$75,000, the probability is less than .5. For projected costs above the Mean Project Cost of \$75,000, the probability is above .5. There is a 90% chance that the cost will be less than \$85,000, for example. We would like to note that we haven't come across other researchers attempting to ascertain probability of completing a project within dollar amount as above.

TABLE X PROBABILITY CALCULATION OF PROJECT COST, BASED ON PERT ASSUMPTIONS

Projected Project Cost <=	**Mean Project Cost**	**Project Cost Deviation**	**z Value**	**Cumulative Probability**
\$ 55,000	\$ 75,000	-\$20,000	(2.59)	0.0048519
\$ 65,000	\$ 75,000	-\$10,000	(1.29)	0.0979876
\$ 75,000	\$ 75,000	\$0	0.00	0.5
\$ 85,000	\$ 75,000	\$10,000	1.29	0.9020124
\$ 95,000	\$ 75,000	\$20,000	2.59	0.9951481

Since all of the information in Table X can be ascertained before commencement of project, we can think of this information as *a priori* probability information. However, now that the project is into its 13th day and we have new data about the project progress, what we need is an *aposteriori* (or updated) probability estimate that takes into account this new data. As may be observed, critical path is delayed by 2.96 days due to delay in Task C even though tasks on the critical path prior to Task C finished on time.

In statistical terms, the conditional probability we are seeking is P (project will be completed in 26 or less days/given Task C is 2 or more days behind at execution day 13). So whatever fair chance (say 0.50) of completing the project on time we had at the start of the project is now impaired to the extent that Activity C which is on the critical path is delayed by nearly three days. So the probability of overall completion of the project in 26 days is definitely much lower than what it was at the start of the project. Consequently, the project could be described as being in "at risk" status. It's not hard to visualize that the calculation of conditional probabilities would be greatly facilitated if there was a historical database of similar projects executed in the past. Likewise, the historical database could facilitate estimating the probabilities of completing a project within budget, in the light of new data of budget variances up to a point in progress.

IV DISCUSSION AND RECOMMENDATIONS

A. Addressing Task Estimation Issues

Given that task estimates may be notoriously padded with safety, and that usually safety gets wasted through student syndrome, multitasking, and the accumulation of late finishes, removing unwarranted safety from the estimate is a major issue in project planning. While educating project players in CCPM methodology [14, 19] and requiring them to provide estimates that are only 50% probable looks to be a simple and straight forward fix to this issue, there is still no guarantee that the project members will comply with this requirement. So CCPM suffers from this issue of task estimations. Further as already noted, CCPM is not concerned about project costs, rather it's focused on completing the project on time. CCPM also can't accurately determine how much safety, if any is included in any task/part of the project.

Burns and Janamanchi provided an effective solution to the behavioral issue of task estimation by use of a questionnaire to elicit task estimates and extracting the realistic estimates based on the responses to those questions in [26]. Burns and Janamanchi also include an excellent discussion of improved CCPM methodology in [26].

B. Major Limitations of Traditional Methods

As has been discussed, EVM suffers from the drawback that it does not take into account the critical path (CP) for its calculations. Consequently, EVM is susceptible to provide wrong signals to the project managers for project tracking. EVA calculations can be performed all through the progress of the project and thereby they can be updated constantly but they still remain unresponsive to the progress on the CP. In other words, the analytical diagnostic capability of EVA is impaired due to its non-responsiveness to activity progress (or the lack of it) on the CP.

PERT is CP sensitive and provides project cost and duration probability estimates but fails to factor in the known facts for later updates as the project progresses. Thereby PERT serves more as a predictive tool rather than as an 'in-process' diagnostic tool and much less as a decision support mechanism. In other words, the predictive capability of PERT is static rather than dynamic in nature and fails to respond to deviations in project execution process.

C. What Tools Are Needed?

As has been noted, a good deal of recent project management research has been focused on improving and refining the existing methodologies to forecast completion of projects within certain cost and time boundaries and comparing the relative strengths and weaknesses of alternate methods or software [22], [23], [24], [25], [27], [28]. Not much research effort is directed towards developing models that can provide decision support to put derailed projects back on track. In general, extant research appears to assume that project managers know what corrective action is required once they are able to track CV, SV, EV and /or ES. However, given the complex feedback loops present in typical project structure that have a tendency to product overshoot and oscillation in salient metrics involved, project managers need reliable decision support for implementing corrective action should the project progress deviate from expected path either in cost or schedule perspective.

Project managers need models and methodologies, tools and techniques that are more comprehensive and holistic in their perspective to tackle the project planning, execution and tracking aspects of managing projects. Tools that are akin to the integrated development environment whereby one can plan, implement, track and correct the project execution. Until the arrival of such tools, project managers would be well advised to use traditional tools in conjunction with each other to ensure a more comprehensive view of the project and monitor the progress accordingly.

In essence, models and methodologies that are not only "predictive" and "diagnostic" but are also "corrective" and "therapeutic" in nature are required. For obvious reasons, such tools would facilitate not only proactive planning but also reactive corrections at all stages of the project execution on a dynamic in-process manner.

Consider for example: simulation models that can incorporate the EVA concepts will be able to address some of these limitations. Asimulation model that can track EVA metrics can be simulated with different time estimates of the projects to assess likely costs under different scenarios. Further, these simulation models can be utilized to simulate the progress of the projects to assess the likely completion times and costs of the projects.

Further, simulation models permit incorporation of several "what if" scenarios to assess the likely impact on the project progress.

For example: one can test:

- what if there is 35% rework identified;
- what if the project review and revisions add 20% additional work;
- what if there is 10% drop in productivity;
- what if there is a 5% staff attrition;
- what if there is shortage/delay in inputs?

The above stated capabilities of simulation models permit a proactive planning before the project begins. During the execution of project, running further simulations with current status of project progress at various points permits managers to make reactive corrections while not losing sight of the overall objective function.

For example: a project manager who finds his project to be running behind by a day or two needs decision support in terms of corrective action, such as:

a) add more workers at additional cost;

b) allow existing workers to work overtime;

c) focus on improving productivity giving incentives;

d) let the project run at the current pace because there is a time buffer at the end of project schedule –while ensuring zero attrition rate.

In essence, project manager should be able to analyze the outcomes of these options in an objective manner and chose the most appropriate option.

It's interesting to note that [29] presented a System Dynamics model that was developed for tracking a software technology project execution and demonstrated how to incorporate the EVA metrics in the project to assess the effect of changes to project work on project costs and duration. The behavior over time charts generated clearly show how a project is trending over time. However, this study was limited to a hypothetical software project rather than to real project.

Similarly, [30] developed and test implemented a Project Management Integration Model (PMIM) that seeks to integrate System Dynamics models with the traditional project management framework to provide better decision support for project managers. The primary focus of PMIM has been to assist project managers to better manage software projects.

With simulation models it is also possible to run the project model under varying starting assumptions and input values to identify leverage points that will yield most beneficial results with least effort. Simulation models are also amenable to "optimization" runs that identify tradeoffs between cost and time and other project objectives. For example a constrained optimization model could assist in decision support under a variety of constraints of project variables such as machine hour constraints, labor hour constraints, weather related disruptions, delays in receipt of inputs and so on.

V SUMMARY, CONTRIBUTIONS AND CONCLUSION

In this paper, by means of a couple of small contrived PERT/EVA models, we have demonstrated some shortcomings of traditional project management tools in terms of their inability to correctly guide the project managers in project execution. We have also demonstrated how these traditional tools tend to be rather 'static' in nature. Such models do not dynamically monitor the progress of the project to provide real-time project management support.

We have also demonstrated how, if everything works as expected, to use PERT to calculate probabilities of on-time and within-budget completion within projects and to utilize concepts from probability theory to improve project tracking and management. We suggest that whenever the probability of critical path completion within time is less than 0.5, the project would be regarded as "at risk".

To improve the project tracking, we demonstrated how the calculation of days ahead/behind taken in relation to days slack can be performed to aid in this endeavor. Then we showed the need for constantly updating the project metrics while the project is in-process to ensure a better tracking and control, in particular, with the help of current status of project execution. We also demonstrated the use of probabilistic PERT to calculate probabilities of finishing a project within a given budget.

Finally we argued that new models and methodologies that are holistic and comprehensive in their perspective are needed for better planning, tracking and management of projects. Until the arrival of such tools, we suggest that, project managers would be well advised to use traditional tools in conjunction with each other to ensure a more comprehensive view of the project and monitor the progress accordingly.

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APPENDIX 1

Notation and Definitions used in this paper

AC -- Actual Cost
ACWP -- Actual Cost of Work Performed, also known as Actual Cost (refer to PMBOK pp-123)
BAC -- Budget at Completion (original planned cost of the project)
BCWP -- Budgeted Cost of Work Performed, also known as Earned Value (refer to PMBOK pp-123)
BCWS -- Budgeted Cost of Work Scheduled, also known as Planned Value (refer to PMBOK pp-123)
CI -- Cost Index, also known as cost performance index, CPI
CP -- Critical Path
CPI -- Cost Performance Index, also known as cost index, CI
CR -- Critical Ratio (=SPI * CPI)
CV -- Cost Variance = BCWP – ACWP = EV - AC
EAC -- Estimate at Completion (forecasted final cost of the project)
ETAC -- Estimated Time at Completion (forecasted completion time of the project)
EV -- Earned Value, also known as Budget Cost of Work Performed (BCWP)
EVA -- Earned Value Analysis
EVM -- Earned Value Management
ES -- Earned Schedule
PERT -- Project Evaluation and Review Technique
PV -- Planned Value, also known as Budgeted Cost of Work Scheduled (BCWS)
PV Rate -- Planned Value Rate (= BAC / SAC)
SAC -- Schedule at Completion
SI -- Schedule Index, also known as Schedule Performance Index, SPI
SV -- Schedule Variance = BCWP – BCWS = EV - PV
SV(t) -- Schedule Variances respect to Time
SPI -- Schedule Performance Index, also known as schedule Index, SI
TV -- Time Variance (= SV / PV Rate
TAC -- Time at Completion (original planned completion time of the project)
VAC -- Variance at Completion (= EAC – BAC)

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