

# **Project Dynamics with Applications to Change Management and Earned Value Tracking**

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## Abstract

*In this paper, we present a novel project management model that incorporates several features yet to be actively addressed in the literature and focuses on earned value management. The model utilizes the basic structures employed in building project dynamics models. The effects of time-varying project team size, of varying productivity, of training and communication overload, and of change management are incorporated into our model. With the help of our model and a hypothetical software technology project, we demonstrate how a system dynamics model can contribute beyond basic project tools like MS Project, in generating the earned value management indicators required by project managers under different scenarios and starting assumptions. Results indicate the later within the projects that the changes arrive, the longer is the delay in completing the projects. Also, the later the changes arrive, the more expensive they are to fix. These phenomena are propagated through the earned value measures to see the actual effects upon schedule and cost performance indices.*

## 1.0 Introduction

Traditional methods of project management and analysis were based around the idea of decomposing the project into its individual parts in a structured way. For example,

PERT charts were used to manage time and the Work Breakdown Structure was used to manage scope. Although both of these models were very informative, they did not focus much on the relationships between the parts of a system. They fail to provide useful guidance to project managers in certain areas for the simple reason that they represent a static view of the project taken before the start of the project or at some point in time during the project execution. Customers often change the requirements of a project causing a rippling effect of delays and cost overruns. As projects grow complex, and "project failure" is appallingly a major trend in the several areas of economic activity, traditional approaches to project management have proven ineffective to cope with the complexity, and hence new, more sophisticated techniques are needed to improve performance. Managing modern complex, integrated projects requires the use of models that have the power to focus on the relationships between the different parts of a system. Therefore, a holistic approach is required. System Dynamics views the project in its wholeness.

“Project management is, at once, one of the most important and most poorly understood areas of management. Delays and cost overruns are the rule rather than the exception in construction, defense, power generation, aerospace, product development, software, and other areas”(Sterman, 1992). This assertion clearly underscores the importance of need for greater research in the area of project management.

Project management has long since been a topic of interest for system dynamics researchers. Significant contributions have been made to the study of project management using a system dynamic approach by Cooper (1980), Richardson and Pugh (1981),

Morecroft and Abdel-Hamid (1983), Abdel-Hamid (1984), Ford and Sterman (1997), Lyneis et al., (2001), and more recently by Park and Pena-More (2003). However, certain features of technology projects that are not explicitly addressed in the research to date provide motivation for extensions to existing research.

In this paper, we shall utilize system dynamics to capture project dynamics vis-à-vis a tracking methodology known as earned value management. The interest in this paper is to re-visit some former project dynamics models and to incorporate within them features that are missing, such as the actual earned value tracking mechanism and the human stress levels that can accrue as the project nears scheduled completion. The project type assumed here is of the technology type, where there is lots of communication and interaction overhead. This is in contrast to conventional construction projects where the communication overhead is minimal and there are many trained human resources. The effects of a time-varying project team size in which new members must be trained before they can be added and such addition necessarily lowers the productivity level of the aggregate are incorporated into existing project model structures. In addition, the effects of change management are included in which changes to the existing build result in substantial rework. Therefore, within the existing structure, these additional considerations are included—training and interaction (communication) overhead, change orders along with explicit modeling of earned value factors such as schedule performance index and cost performance index.

The client also plays a huge role in project dynamics. An enormous amount of projects run over-budget and over-schedule, and this is due to a multitude of reasons but

one of the dominant ones is the client. When clients (customers) change their requirements and budgets, they send a rippling effect throughout the project that inevitably makes the project late and over budget. This is especially true when the change is late breaking. These changes can build up and expand the scope of the project so dramatically that it will never reach completion within the scheduled time; no matter how much more money the client is willing to spend. Clients also may impose schedule restrictions and introduce delays in many different ways. System Dynamics helps the manager to deal with these changes and complete the project on time.

The use of System Dynamics models within Project Management (PM) appears to be focused on three major objectives: (1) estimating, (2) risk analysis, and (3) progress monitoring and diagnosis. Some models estimate the duration of the project, cost of the project, the resources used on a project. This is essential in determining the value of the project. Risk analysis models allow for the possible affects of various policies to be assessed. Here is where a modeler inputs a series of possibilities to see how it would affect the overall project. With models that consider progress monitoring and diagnosis, the project manager is able to see if the project is on schedule and under budget, how certain client requests will affect the development, and so on. The proposed model falls largely within the last two categories of system dynamics models for PM.

Alexandre Rodrigues and Terry Williams, of the University of Strathclyde, Glasgow, Scotland, have developed a project management integrated model (PMIM, 1996). PMIM provides a general framework for the use of System Dynamics models in an integrated fashion with traditional procedures in supporting ongoing project planning and

control. PMIM uses System Dynamics models at both the strategic and the operational management levels, aimed at providing continuous support to the planning and monitoring functions. Within the planning function, the models are used to estimate the project outcome and to help identify better planning alternatives, ensuring that the plan is based on realistic assumptions.

Whether the Client will ask for changes, introduce delays, or impose schedule restrictions, situations occur in which effective negotiation is crucial for the project outcome. Traditional tools and techniques have proven inadequate to provide quick and reliable information to the manager. In order for a project manager to effectively and efficiently manage the project, they must use a combination of the traditional models, mental models and System Dynamics models. If they are used in unison, they can be very effective tools in guaranteeing the projects' success. "The application of System Dynamics to Project Management covers a wide range of uses, in particular creating team learning and training environments, providing a tool for advanced planning and control of on-going projects, and post mortem analysis to support legal dispute resolution" (Rodrigues and Williams, 1996).

The remainder of this paper is organized as follows. Section 2 discusses the choice of software and explains the general outline of the hypothetical project being modeled, with the details of the Vensim model developed using a PLE version (Vensim 2005). Additionally, section 2 also discusses the Earned value management concepts, and the manner of adopting them in the current model. The results from the simulation of base case and three other alternate scenarios are presented with comments in section 3, followed

by discussion of inferences that may be drawn from these results. Finally section 4 lists the contributions, limitations of our model and possible future improvements.

## **2.0 Modeling Methodology**

We choose to develop our model using Vensim PLE application software (Ventana 2005). Since basics of a typical project management model are well known in the system dynamics community, we go straight to the discussion of the project being modeled. (The detailed Stock-and-Flow-Diagram-SFD views representing the project dynamics are depicted in figures 1, 2, and 3).

### The project

The project stereotype we are dealing with here is a seemingly simple software technology project. However, the seemingly simple project needs to be planned and executed with caution in the view of the often-quoted Brook's law, "adding resources to a late project makes it even later." Brook's statement was made with specific reference to software projects (Sterman, 1992). If the project was to be characterized into the two categories identified by Boehm (1981) and referred by Morecroft and Abdel-Hamid (1983), then it would be a hi-bred of 'organic mode' and 'embedded mode' with a greater lean towards embedded mode. In a typical embedded mode software development project, the constraints on the project are rather tight and demands on innovative data processing architectures and algorithms are high (Morecroft and Abdel-Hamid 1983, pp13).

Referring to the SFD in Appendix-A, we can quickly spot the main segments as, 'project work,' and 'project staff.' Workload requirements affect the staff assignments to the project, and the project team size influences the workflow rate, subject to the

productivity factor. Schedule pressure factor affects the rejection rate and staff turnover normal. Staff turnover normal affects the staff turnover rate, which in turn affects the staff requirements.

In its present form, the model consists of three basic components, a project-staff-and-wages component that includes a staff pool from which project staff are extracted and returned, a work sector, and a changed-requirements-and-earned-value component. The work sector includes four stocks: project-work-to-be-done, project-work-in-progress, work-completed and rework-identified. Additionally, the model includes the information infrastructure necessary to compute the basic variables that comprise earned value analysis, including earned value, planned value, schedule variance, cost variance, as well as schedule and cost performance indices.

#### Base case scenario

In a base case scenario, the project starts at time 0 (months) with an 'initial-contracted-load' (expressed in person\*month). Staff are assigned to the project based on a staffing requirement arrived at by dividing the initial-project-load (person\*month) by the 'scheduled-completion-time.' (Denoted in months) The initial-contracted-load is the starting value for the stock 'project-work-to-be-done.' Work performed by the project staff, moves from the stock project-work-to-be-done to the stock 'project-work-in-progress.' However, the work flow is affected by a productivity factor that is derived from a table look-up based on the number of staff currently on the project. The project-work-in-progress is subjected to an inspection. Inspection process is assumed to be built into the workflow and performed by the staff performing the project work; as such explicit staff

assignment is not made for inspection process. Whereupon, the work failing to meet the required standards moves to ‘rework-identified’ and the work that passes the inspection moves to ‘project-work-completed’. Rework-identified gets priority over project-work-to-be-done for the simple reason that typical technology projects build up in cumulative fashion. The structure for the work sector appears below in Figure 1.

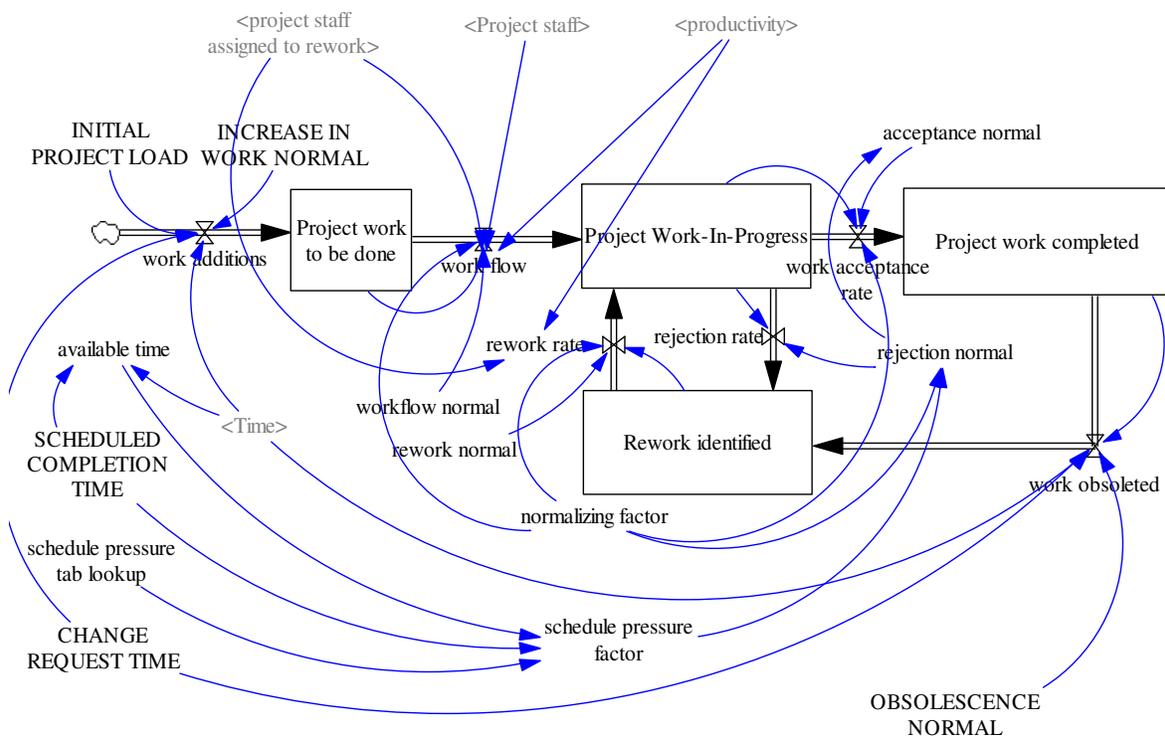


Figure 1. The Work Sector for the Project Dynamics Model

The “logic” of the staff-and-wages sector follows. As previously mentioned, staff are assigned to the project based on a staffing requirement arrived at by dividing the initial-project-load by the ‘scheduled-completion-time.’ An appropriate fraction of project staff is assigned to attend rework, and the remaining staff tackles the project-work-to-be-done. As the project advances, at each time interval, the requirements of project staff are assessed,

and if additional staff is required based on scheduled completion, such additions are allowed. (Conversely, towards the end when there is surplus of staff on project they are moved back to the available pool). It is assumed that this particular enterprise has some available staff awaiting assignment to different projects. As the project advances, the available time declines, this causes an increase in ‘schedule-pressure’. An increase in schedule-pressure increases, rejection-rate and staff-turnover-rate. These changes have negative impacts on the project completion time. The structure for the staff-and-wages sector(s) appears in Figure 2 below.

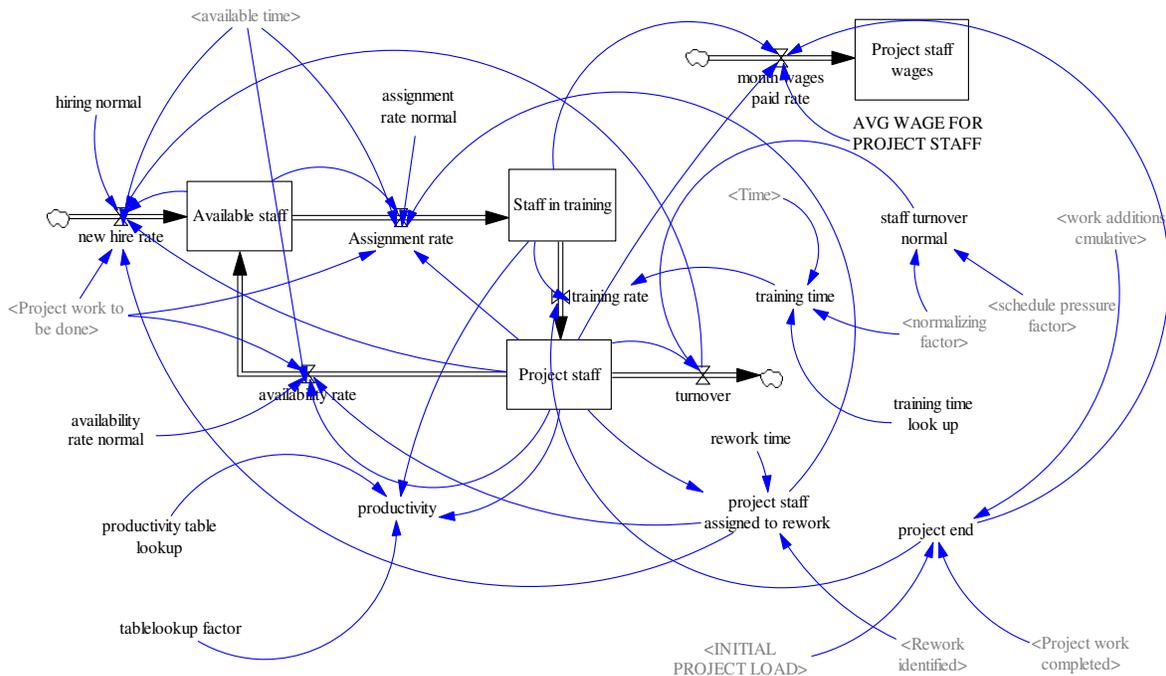


Figure 2. Structure of the Staff-and-Wages Component of the Project Dynamics Model

Finally, the project dynamics model includes all the necessary infrastructure for accommodation of changes and change management as well as supporting structure for

Earned Value Management. The structure of this third component appears in Figure 3 below.

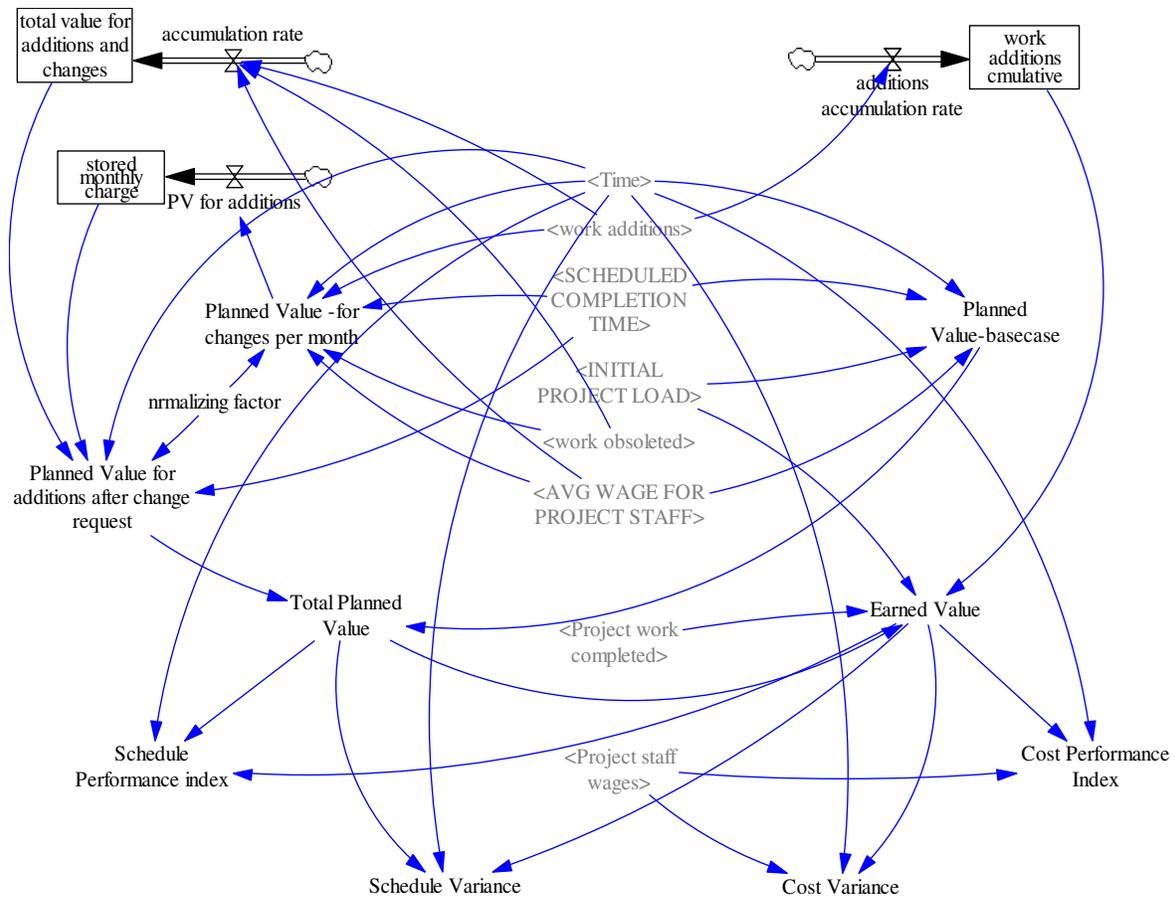


Figure 3: Change Management and Earned Value Management Structure

### Alternate scenarios

The one major difference, between the base case and each of the alternate cases is that a change request is incorporated in the alternate scenarios. In fact, whether the changes are requested by the client, or caused by some hidden factors in project work, they are typically stochastic in nature. One never knows when these changes arise. However, what is well known in project management circles is that, ‘changes are a rule rather than an exception.’ Therefore, there appears to be a certain deterministic tendency to their

unfailing occurrence. The alternate cases are modeled to reflect this situation of change requests arriving at different points of time in project execution. For simplicity's sake, the changes are assumed to arrive at end of first quarter, at end of second quarter and at the end of third quarter in case 2, case 3, and case 4 respectively.

#### What is new in the current model?

In the work sector (component) of the model, there is explicit provision for "Rework identified" rather than just returning this work to "Project work to be done." This allows for this work to be handled differently from "project work to be done" so that this work can be expedited, etc.

The model includes a productivity multiplier that declines as team size increases. In a typical large technology project, there is a lot of interaction overhead. We have created a productivity table look-up using data provided by Louis Fried (1995) in his book, "Managing Information Technology in Turbulent Times." The author provided productive time estimates for groups ranging from 10-100 employees. These tables have been extended for smaller groups based on Fried's comments in the same chapter in respect to smaller groups, "...therefore, it may be estimated that 55 percent of each employee's time can be considered productive in a group of up to 10 employees" (Fried 1995, pp 130). At each iteration interval, project staff requirements are adjusted to meet the scheduled completion. This adjustment is made by dividing the work yet to be done by available time without considering the productivity factor, as a normal project manager would do based on his mental models. When available time is  $<1$ , an If-then-else construct retains available time=1 for the purpose of this equation.

All new staff joining the project midway needs training like the orientation to the current stage of the project with an appreciation of work done up to date to be effective and the training time depends upon the time-point when the new staff is to join existing project staff. Typically, in the initial stages at time point 1, no additional training is required since the initial project team is selected on the basis of their suitability to execute the project as well as the fact that the initial team defines the outline and manner of project execution. However, if new staff is to join six months into the project, they need about 2 months training before they are effective. The following table look-up delivers the logic required for this model by returning training time requirements as a function of time. Note that no one requires more than five months training, and training time is zero, initially.

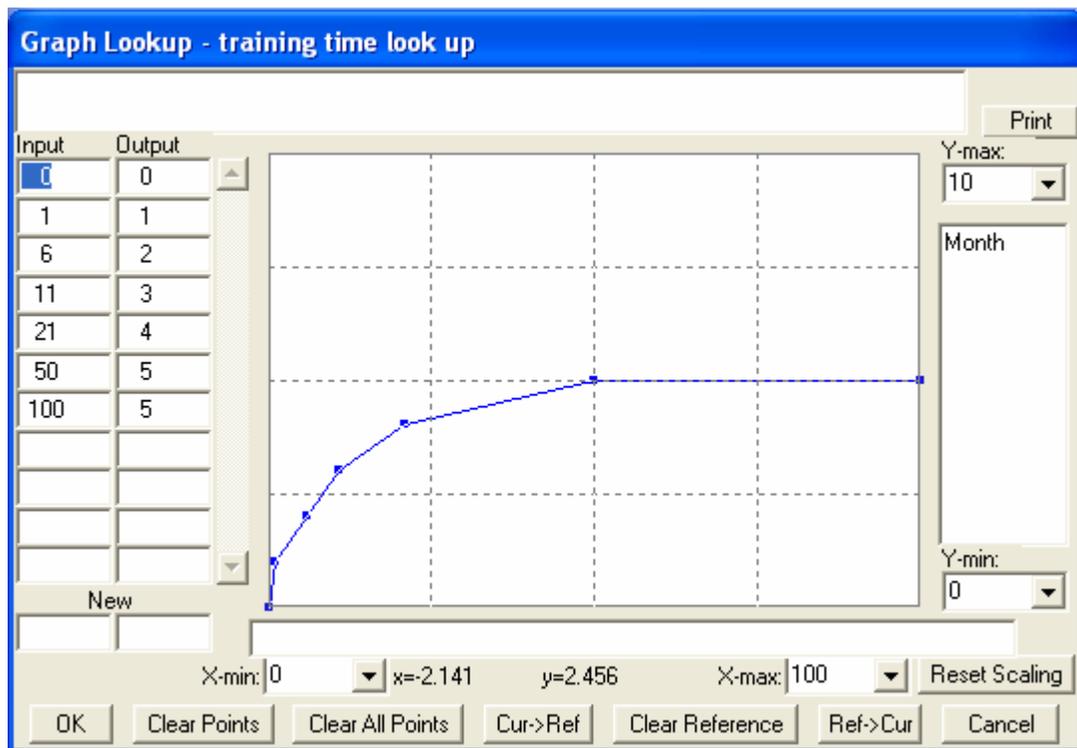


Figure: 4 Training time requirement

From the 'staff in training' stock, a fraction of trained staff is moved to the project staff stock based on training time value.

#### What is new in the model: Earned Value Management (EVM) Indicators

Earned value management is a project performance measurement technique that integrates scope, time, and cost data (Schwalbe 2004, pp 242). The basics of earned value management are simple and easy to understand. Projects have budgets, scope, and schedules. It is important to know how the project is progressing in terms of a) staying within the budget, b) percentage of completed work at each regular time interval and c) staying on course towards a scheduled completion. A few simple cost variables are used to compute the EVM indicators. The following descriptions of various cost computations are adopted and / are summarized from Schwalbe (2004).

Planned Value (PV), formerly called Budgeted Cost of Work Scheduled (BCWS), is that portion of the approved total cost estimate planned to be spent on an activity during a given period.

Actual Cost (AC), formerly called the Actual Cost of Work performed (ACWP), is the direct and indirect cost incurred in accomplishing the work on an activity during a given period.

Earned Value (EV), formerly called the Budgeted Cost of Work Performed (BCWP), is an estimate of the value of physical work actually completed.

Cost Variance (CV) is, by definition, the earned value minus the actual cost. If cost variance is negative, it means that the actual work performed cost more than the value earned thus far.

Schedule Variance (SV) is, by definition, the earned value minus the planned value. Schedule variance calculates the difference between the current value earned and the value that was scheduled to be earned at this point in time.

Cost Performance Index (CPI) is the ratio of earned value to actual cost and can be used to compute the projected cost of completing the project. An index equal to '1' (or 100%) denotes that earned value and actual costs are equal, or costs are exactly as planned. If the index is lower than 1 (or 100%), it indicates that, then the project is over budget.

Schedule Performance Index (SPI) is the ratio of earned value to planned value and can be used to estimate the projected time to complete the project. This index is interpreted similar to the cost performance index, with the difference that SPI measures the time and schedule aspects instead of the costs.

The following table (Schwalbe 2004) lists the formulas for EVM indicators.

<u>Term (Indicator)</u>	<u>Formula</u>
Earned Value	$EV = PV \text{ to date } * \text{ percent completed}$
Cost Variance	$CV = EV - AC$
Schedule Variance	$SV = EV - PV$
Cost Performance Index	$CPI = EV / AC$
Schedule Performance Index	$SPI = EV / PV$
Estimate at Completion	$EAC = BAC / CPI$
Estimated Time to Completion	Original time estimate/SPI

### Adopting EVM indicators

Software developers' wages form the bulk of the software technology project cost. Controlling and monitoring the wage bill in a software project needs greater priority than controlling other direct and indirect costs. In the proposed model under this study, we have attempted to provide the EVM measures with reference to the 'project staff wages.' It is our contention that project managers have to keep a close watch on the wage bills more than any other costs in a project of this type and hence, the model will be helpful in assisting managers in this goal. The Vensim model view labeled "Earned Value Tracking" incorporates all the significant EVM indicators mentioned in Table 1 (see Figure3).

### **3.0 Simulation Run Results and Discussion**

The SFD needs the units, equations, and starting values for the stocks and rates to make simulation runs. We have already identified some of the required values in our description of the project under section 2. Given below is a complete list of all major assumptions and data values used in the model.

#### Assumptions and Data Values

- Work to be done: 100 man-months (person\*month)
- Initially staff available: 20 (persons)
- Scheduled completion time: 25 months
- Initial project staff assigned will be 4 (persons).
- Interaction effect is provided by way of table look up (Fried 1995)
- Base case –simulation is for project with no change requests
- Case1,2,3 are for projects with change requests(only one) at time point 7<sup>th</sup>,13<sup>th</sup>, and 19<sup>th</sup> month
- Each change entails in 20% increase in work load.
- Each change also obsoletes 40% of work completed to date.
- Staff requirements are adjusted on monthly basis.
- New staff joining the project need training--training time is a time dependent value ranging from 1 to 5 months
- Rejection normal is initially set at 5%
- Acceptance normal is complement of rejection normal, hence 95% at start.
- Rework identified gets priority over project work to be done.

- All rework identified is assumed to be reworked within one month
- Project staff are allocated to rework first and the remaining are assigned to project work to be done.
- Entire (combined) project staff is taken as the basis for productivity table look up
- Available time is computed as ‘schedule time-elapsed time,’ subject to a minimum of ‘one moth’ at all times.
- Reduction in available time, increases schedule pressure ranging from 1 to 2 and this schedule pressure affects the rejection rate as well as staff turnover
- Average wage per staff per month is \$5,000.
- Available staff at all times needs to be maintained at 10% of the project staff.
- If-then-else logic is employed in many equations to prevent negative draining of stocks as well as to prevent recurring fractional computations

With the above assumptions and some constructs implicit for a Vensim model, the base case and three alternative policy runs are made and the results appear below.

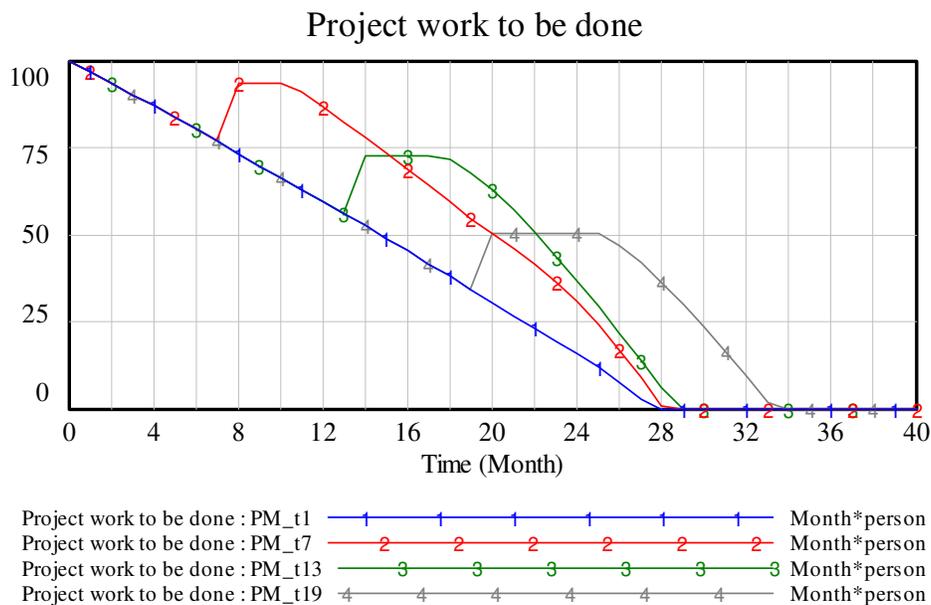


Fig 5- Behavior-Over-Time (BOT) graph- project work to be done

In Figure 5, the project is virtually complete when the “Project work to be done” is zero. The curve labeled “1” has no changed requirements and finished in 28 months. The

curve labeled “2” has changed requirements that occur at the end of the first quarter only. The project is still able to be completed in 28 months. The curve labeled “3” has changed requirements that occur at the end of the second quarter only. The result is a month’s delay in the entire project. The curve labeled “4” has the same changed requirements observed in connection with curves 2 and 3, except these changes are now occurring at the end of the third quarter. Clearly late-breaking changes result in substantial delay in the completion of the project—roughly six months. This is so because, the later the change arrives, the greater is the volume of completed work rendered obsolete that needs to be reworked. Further as will be discussed in the Future Improvements section (refer #3) of the paper, current model assumes available time to be always no less than 1 month. Thus, an increase in the workload arising from changed requirements at the end of 1<sup>st</sup> and 2<sup>nd</sup> quarters does not appear to have serious impact on the completion time, though it increases the wage bill.

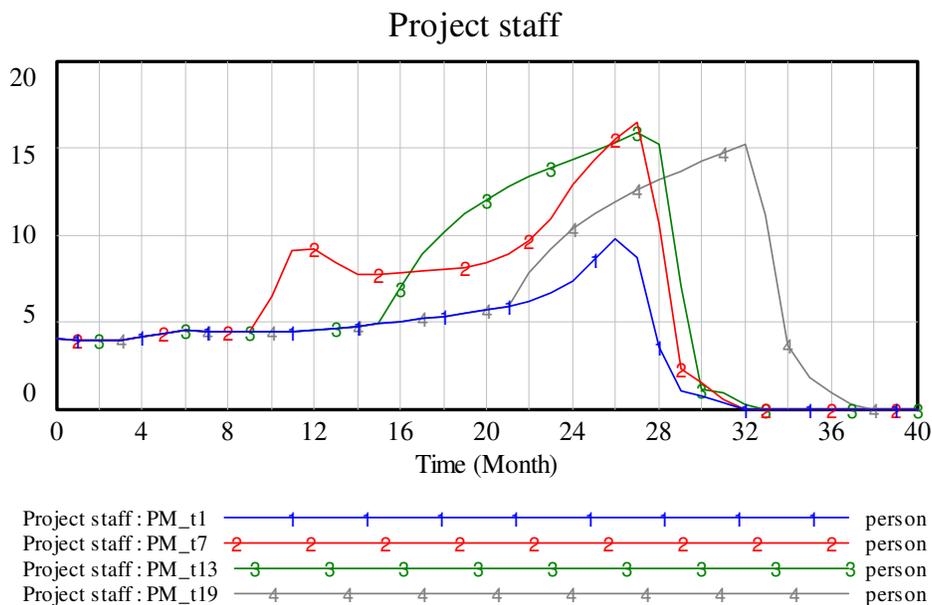


Figure 6-BOT graph - project staff

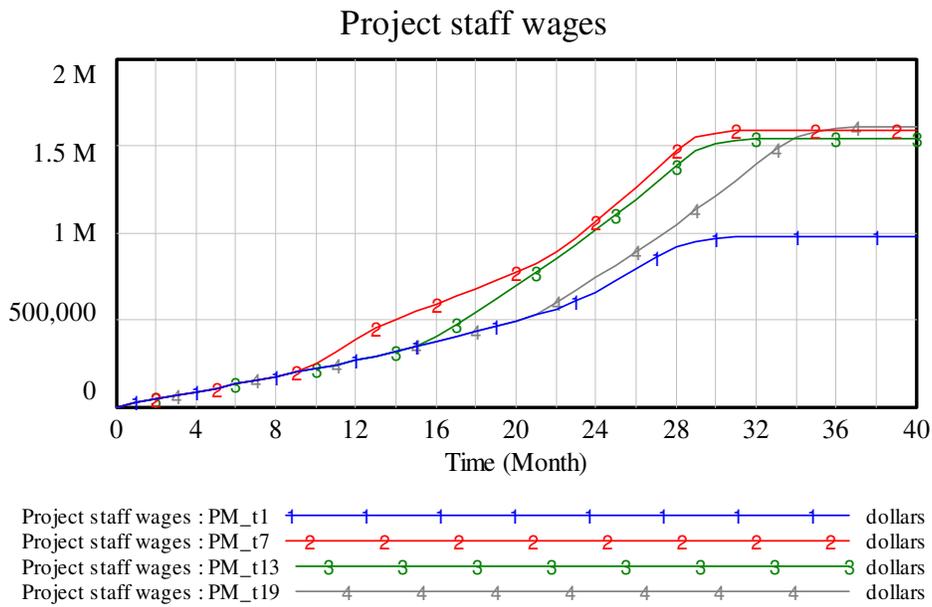


Figure 7-BOT graph - Project staff wages

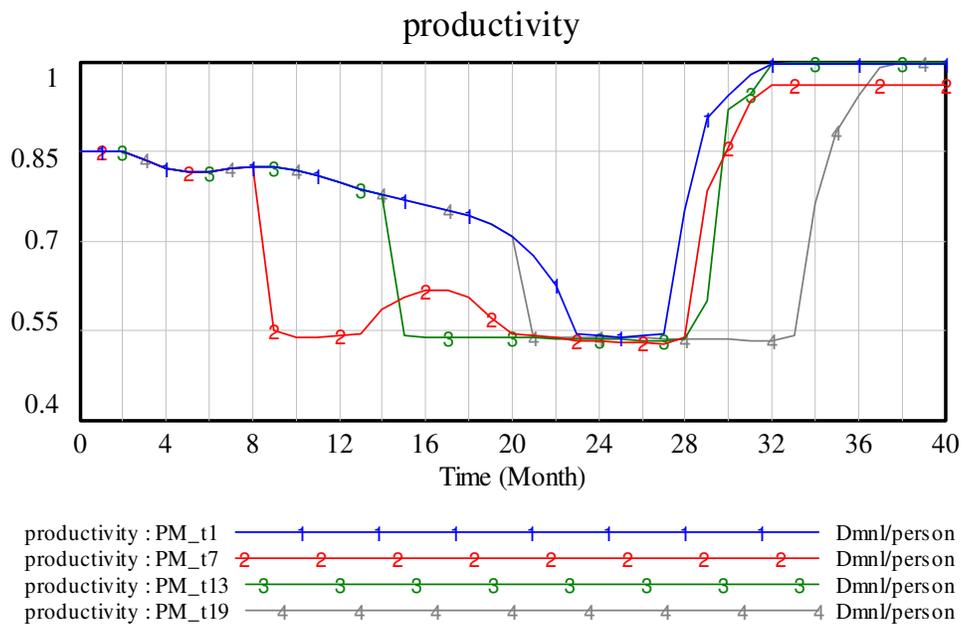


Figure 8-BOT graph - productivity

### Total Planned Value

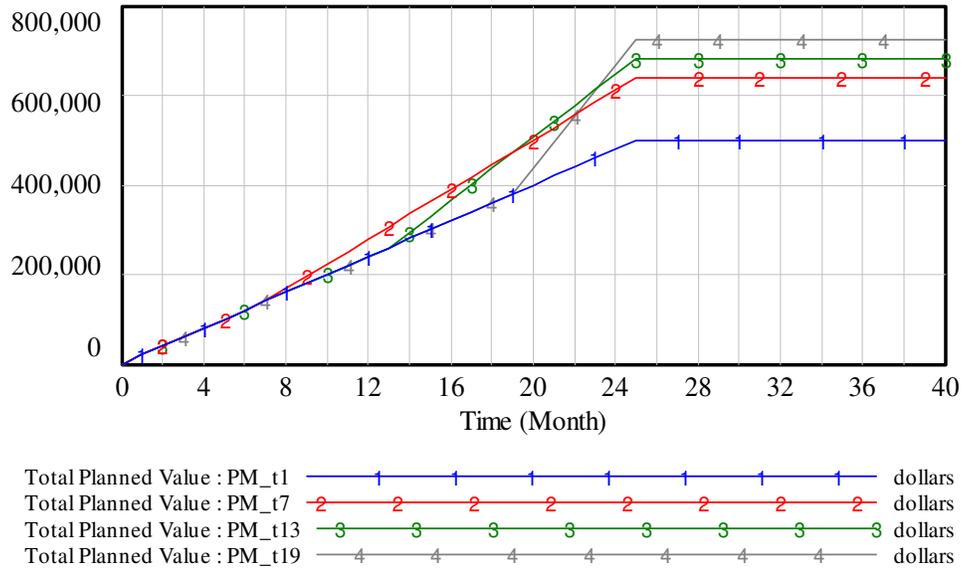


Figure 9-BOT graph - Total Planned Value

### Earned Value

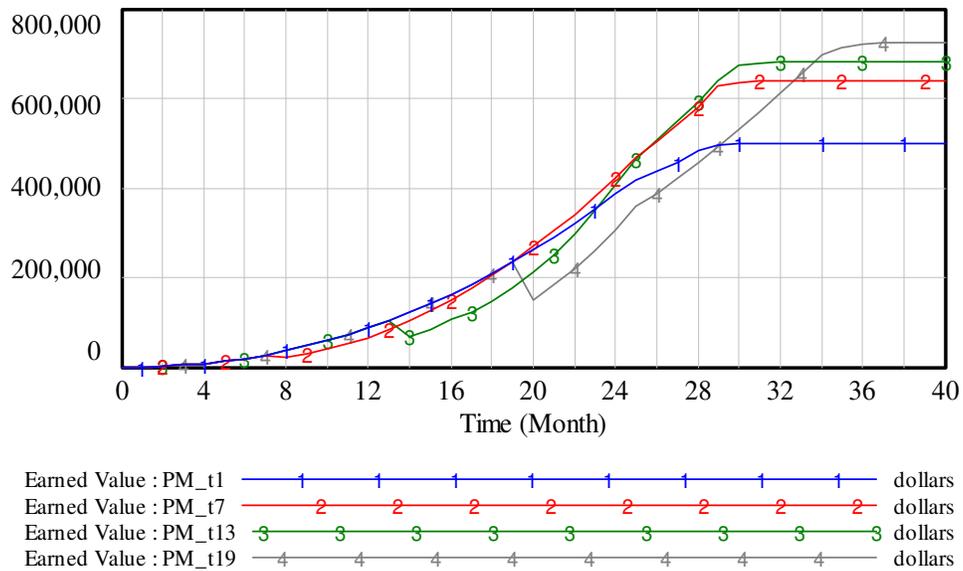


Figure 10-BOT graph - Earned Value

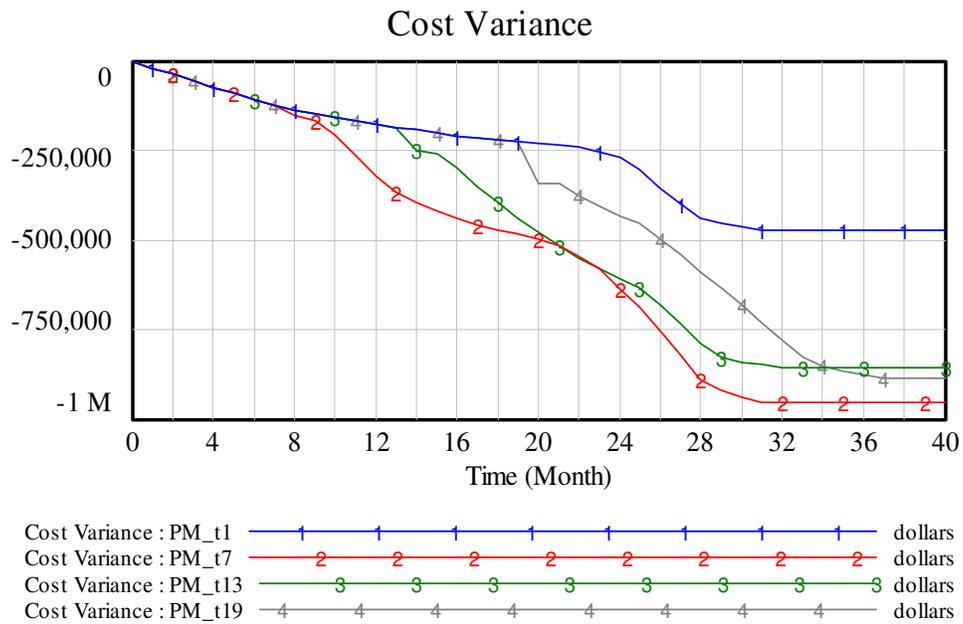


Figure 11-BOT graph - Cost Variance

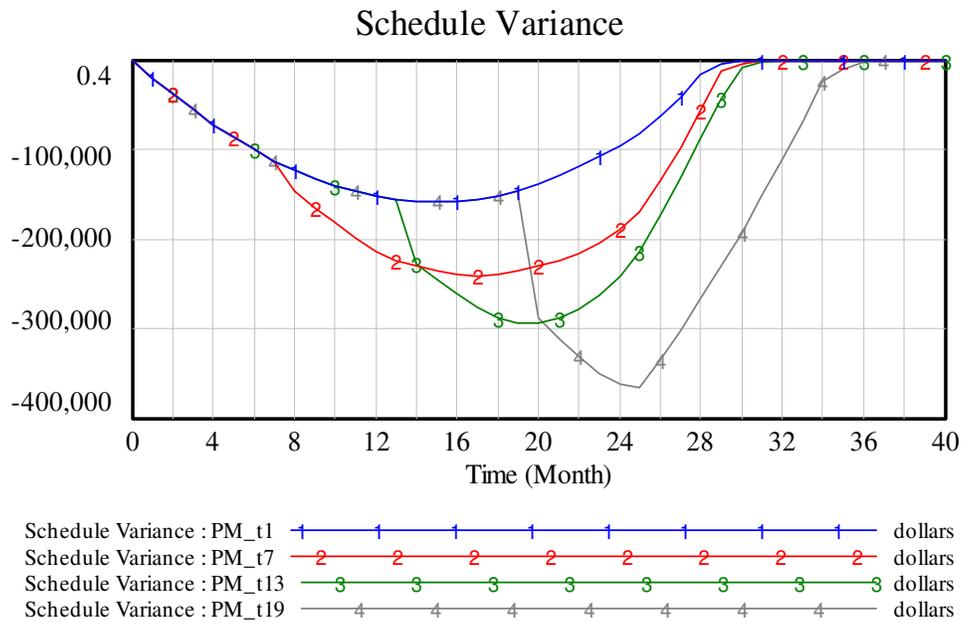


Figure 12-BOT graph - Schedule Variance

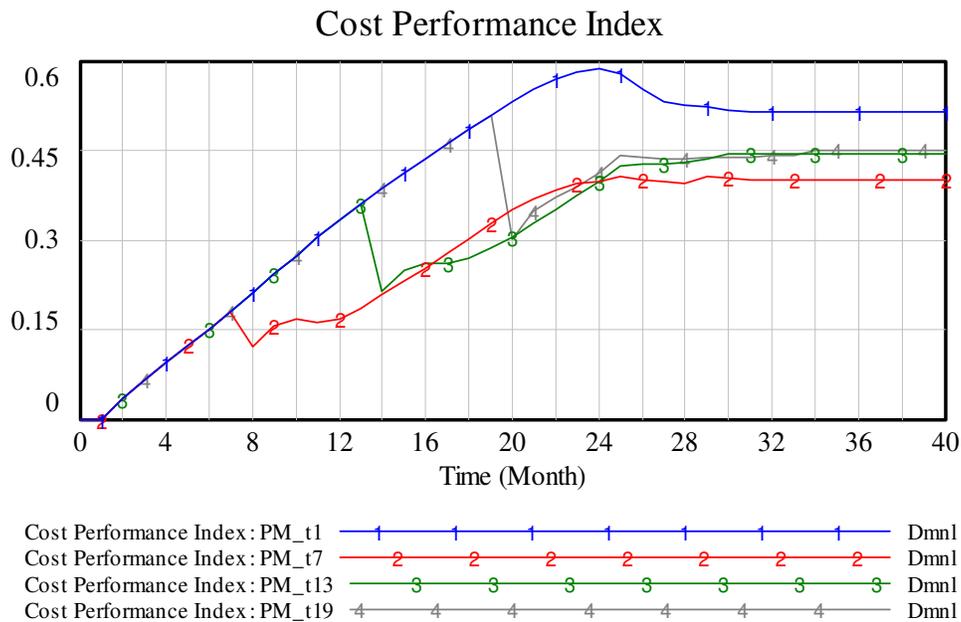


Figure 13-BOT graph - Cost Performance Index

All figures 6 through 13 depict the effects of the same four scenarios discussed in figure 5. Specifically,

- Curve 1- has no changes- is the base case
- Curve 2-Change requests arrive at the end of 1<sup>st</sup> quarter
- Curve 3-Change requests arrive at the end of 2<sup>nd</sup> quarter
- Curve 4-Change requests arrive at the end of 3<sup>rd</sup> quarter

shows the sudden surges in project staff engaged in the project work in order to clear the surges in rework, as well as to catch up with mounting workloads towards the completion of the project. All three change requests lead to more than proportionate increases in the costs compared with budgeted costs, as may be seen from Figure 7. This is because of the productivity losses occurring with increases in staff size.

Figure 8 shows falling productivity levels corresponding to increasing team sizes. The fall would have been more dramatic if we were simulating projects that required teams

of 40 or more members, based on the productivity table look-up adapted from Fried (1995) as reproduced below in Figure 14.

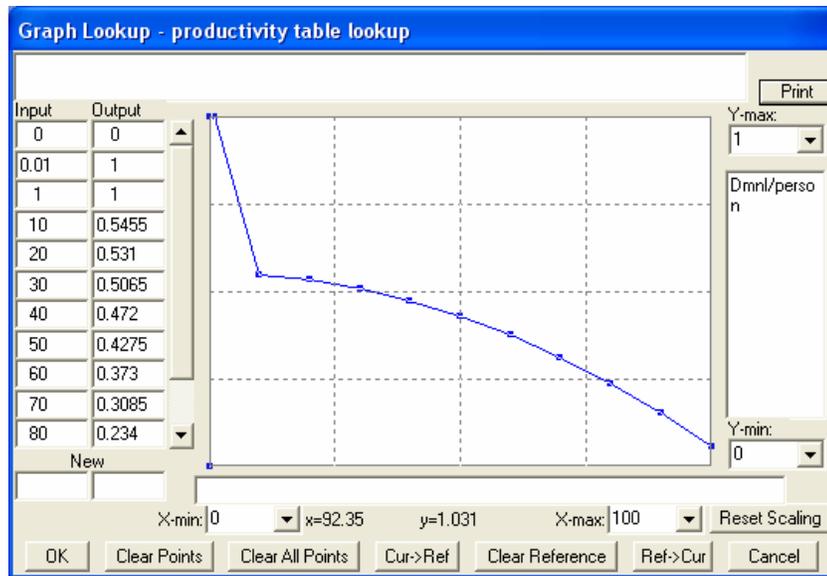


Figure 14: Productivity Multiplier-based on team size

As may be seen, the productivity does not vary much from team size 10 to 20, as much as it would between team sizes 30 to 40 and higher. (Here, each vertical bar represents 25 additional employees.)

Figure 9 and Figure 10 show how the ‘planned value’ (PV) and ‘Earned value’ (EV) fluctuate under the different scenarios. Cost variance and schedule variance in Figure 11 and Figure 12 bring forth the effect of change requests by quantifying the same in dollar amounts. The cost performance index displayed in Figure 13 provides a means to compare the various project scenarios because the index here is dimensionless and a standardized indicator.

### Inferences from the simulation results

Some straightforward inferences may be made from the plain reading of the graphs as follows.

1. With or without change requests, project executions will be delayed and project costs exceed the budgeted costs, for the simple reason of team size effect on the productivity of the project staff. So productivity effects need to be factored in, while assessing the project staffing requirements as well as cost budgets.

2. Without a proper intervention to complete the projects within the scheduled time, all project executions will exceed the scheduled time for the reasons of team size effect on productivity as well as the inherent rejection rate (error rate) in the project work.

3. As was seen in the base case, typical increases in project costs with no interference could be as high as 40%.

4. Change requests coming in the first half of the project execution are easier to handle in terms of staying on schedule than the change requests received in the later half of the project. In all cases, more than proportionate increases in costs is unavoidable.

5. EVM indicators captured show that cost variance and cost performance index are most favorable in the base case than in any alternate scenario.

6. It may easily be shown that, by defining a larger scheduled completion time and reducing the initial team size suitably, cost variance and the cost performance index indicators can be improved, and total costs (project staff wages) will be reduced.

7. Similarly, by suitable changes, we can show that reducing the volume of interaction among team members and increasing the productivity of project staff can provide substantial cost savings and improve the financial bottom line of the enterprise.

Simulations with small variations can provide some very useful insights into the project dynamics and the effect thereof on project costs and EVM indicators.

#### **4.0 Contributions, Limitations and future improvements**

There are many useful contributions emerging from the model as follows.

1. The model incorporates the effect of team size and interaction effect on the productivity of project team, to help project managers to take suitable decisions.

2. The model demonstrates the capture of EVM indicators and shows how these vary over time.

3. By varying the parameters (model constants) like, 'INITIAL PROJECT LOAD,' 'INCREASE IN WORK NORMAL,' 'CHANGE REQUEST TIME,' etc. (all coded in upper case letters in the model), and by suitably adjusting the initial project staff, several different project scenarios can be simulated.

4. The model provides decision support to project managers in assessing the effect of customer change requests in an objective manner and to make suitable price quotes.

5. As was stated in the introduction section, a model like the current one can also provide help in resolving cost disputes arising out of change request.

6. The model can very easily be adopted to other types of projects by making suitable changes in the structure to reflect the peculiar/unique situations present under

those projects. Namely, delays in construction projects due to climatic changes, could be accommodated, as could the effects of crashing and shortening the duration of tasks as suggested by Goldratt (1997).

#### Limitations of the model

As is the case with any simulation model, no model can be validated perfectly. “All models are wrong, so no models are valid or verifiable in the sense of establishing their truth. The question facing the client and modelers is never whether a model is true but whether it is useful” (Sterman 2000). So also, the real values of the parameters are bound to differ with the values used in the model to gain an understanding of the dynamics present. The true usefulness of the model lies in providing a better understanding of the dynamics and guidance in the place of the mental models that would be used otherwise. Some explicit limitations of the model are,

1. All parameter values used in the model, like the workload, rejection rate, and acceptance rate are assumed for a typical technology project. Estimates that are more accurate need be used for studying the effects with reference to a real enterprise based on empirical data of the specific enterprise.

2. The model assumes a steady rejection rate (affected only by the schedule pressure) but rejections pattern and identification of rework pattern may be different and distinct in certain project settings.

3. Staff interaction effect and the productivity table look up that is modeled herein is assumed to take care of the effect of time lost in training the new members joining the team midway. No other explicit time loss is modeled.

4. Staff working overtime is not explicitly modeled; instead more staff are assigned to the project as the schedule demands.

5. Fractions in staff numbers are allowed on the assumption that the enterprise will be able to allocated the idle time to other useful productive tasks (other than the project).

### Future Improvements

Many variations to the current model are possible to improve the usefulness and effectiveness of the model as a decision support tool.

1. Effects of multiple change requests can be studied by providing for multiple change requests arriving at stochastically selected time points.

2. Change request coming in may be assumed to have varying degrees of effect in terms of increasing the work load and obsolescing the work completed to date.

3. Currently, the model assumes that available time is never less than 1 month. However, by modeling the available time to explicitly reflect reality, we can devise a model that would show all alternatives reaching completion of the project at schedule time. It is to be assumed in those cases that cost is not a serious constraint.

4. Currently, the model doesn't assume any upper limit on staff. If there are constraints on the project staff, we may specify an upper limit on the project staff that may be employed in a project to see the effects on schedule and costs.

5. By extending the structure of the model, costs other than the staff wages may also be tracked to provide more comprehensive EVM indicators. Those costs would include indirect costs, which in turn, would enable the effects of crashing on both direct and indirect costs to be more realistically represented.

## References

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