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# PROJECT PLANNING AND PREDICTIVE EARNED VALUE ANALYSIS VIA SIMULATION

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## ABSTRACT

A simulation-based Earned Value Management methodology is introduced for modeling and analyzing project networks with stochastic activity times and activity costs. The methodology uses simulation to establish a project plan and estimate the planned value over the life of the project. During project execution, these reference measures can be used to determine if the project is on track to completion. The simulation tool can be used to evaluate potential alternatives and predict their impact on the project.

## 1 INTRODUCTION

Earned Value Management (EVM) is a useful technique that has been extensively used by project managers to monitor project performance, with respect to scope, cost and schedule, throughout the implementation of a project. In addition, EVM serves as a forecasting mechanism that indicates expected project results. As such, EVM allows project managers to adjust project strategy and make trade-offs based on the project objective, as well as adapt to the project environment (Anbari, 2003).

In this paper, we present a simulation-based EVM methodology for modeling and analyzing project networks with stochastic activity times and activity costs. The methodology uses simulation to establish a project plan and estimate the planned value over the life of the project. Once the planned value is established, simulation is used to predict the earned value performance measures for the project. After the project begins, the project manager can use these reference measures to determine if the project is on track to completion or if adjustments need to be made. If changes need to be made to the project plan, the project manager can use the simulation tool to predict how potential alternatives may impact the remainder of the project.

In addition, this work is particularly focused on the case where a project contains several milestones. Often, projects have milestones that need to be met as the project develops. In those cases, future project funding may depend on meeting these milestones. Therefore, a project manager must weigh the time-cost tradeoffs of the costs associated with meeting the project milestones while taking into consideration the overall project costs and timeline.

## 2 RELATED WORK

Current archival literature related to project management and simulation-based methods has focused primarily on the time-cost tradeoff problem based on project completion time and overall project costs. Some of this work has included simulation-based crashing methods (Bissiri and Dunbar 1999; Gutjahr, Strauss, and Wagner 2000; Haga and Marold 2004; Haga and Marold 2005; Kuhl and Tolentino-Pena 2008). Although these methods are appropriate for managing to project completion, they do not directly

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address intermediate project goals (milestones) and progress toward the project completion. In this work, we combine simulation with earned value management to address these issues.

## 3 BACKGROUND

In this section, the terms used in Earned Value Management will be briefly discussed given that they constitute the framework of the presented simulation. The simplified version of EVM provided by Anbari (2003) will be used as a foundation for this research.

### 3.1 Earned Value Main Components

The following concepts and their values need to be identified in the planning phase of the project.

- Planned Start (PS): time at which each activity is planned to start.
- Planned Duration (PD): amount of time over which each activity is planned to be completely executed.
- Planned Completion (PC): time at which each activity is expected to complete.
- Planned Value (PV): budget that is projected to be spent up to a given period of the project. It is sometimes referred to as budgeted cost of work scheduled (BCWS).
- Budget at Completion (BAC): total budget available for the execution of the project or, in other words, the sum over the planned values of all activities.
- Schedule at Completion (SAC): total expected project duration that results from the traditional Critical Path Method (CPM).

With the purpose of identifying if the project is performing as expected by comparing the baseline plan with actual expenditures, the following values need to be computed and tracked:

- Actual Start (AS): time at which the activity actually began to be performed.
- Actual Duration (AD): amount of time over which each activity was actually completed.
- Actual Finish (AF): time at which each activity was truly completed.
- Earned Value (EV): represents, in terms of cost, the amount of work accomplished at a specific period of the project. It is also known by budgeted cost of work performed (BCWP). It is calculated by multiplying the total project or activity planned value by the percentage of work that has been accomplished.
- Actual Cost (AC): actual amount spent up to a given point in time. It is also known as actual cost of work scheduled.

Figure 1 provides a visual representation of the actual expenditures versus the planned values. In this example, the project is behind schedule (given that the Earned Value is less than the Planned Value) and over budget (considering that the Actual Cost is greater than the Planned Value).

### 3.2 Earned Value Performance Measures

The performance indicators used in the Earned Value methodology provide the PM a notion of how the project is performing in terms of duration and costs. Performance indicators give the PM's an early warning signal that lets them know that corrective actions need to be implemented. Among these indicators are (see Table 1 for calculations):

- Schedule Performance Index (SPI): compares the Earned Value and the Planned Value at a given period of a project.

- Cost Performance Index (CPI): compares the Earned Value and the Actual Cost at a specific period of a project.
- Schedule Variance (SV): contrasts the Earned Value and the cost of work that was scheduled to be performed to date (Planned Value).
- Cost Variance (CV): contrasts the amount of money budgeted for the work that has been performed up to date (Earned Value) and the actual cost of executing that work (Actual Cost).
- Time Variance (TV): defines the amount of time the project is ahead or behind by translating the Scheduled Variance (SV) to time units.

Figure 2(a) visually shows CV, SV and TV for the same project used to generate Figure 1.

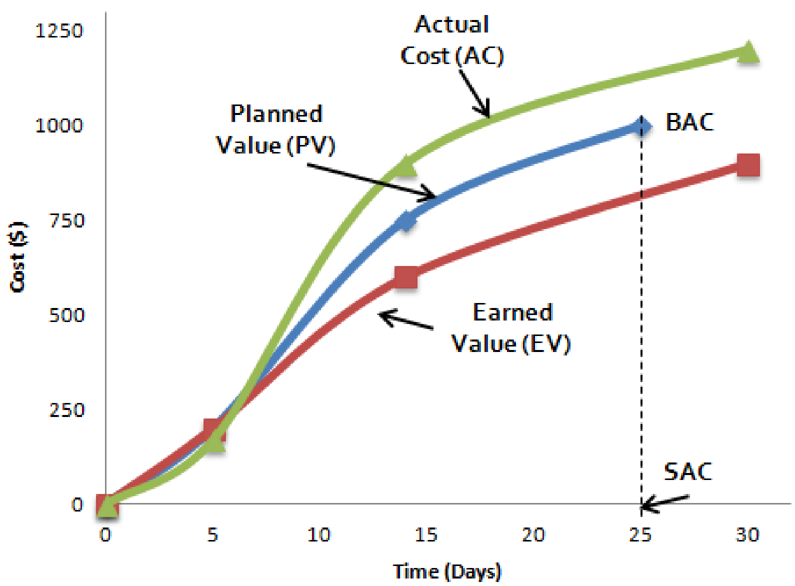



Figure 1: Earned Value main components.

Table 1: Summary of earned value performance measure calculations.

| Performance Measure | Notation | Formula |
|---|---|---|
| Earned Value | EV | PV * %Work Complete |
| Schedule Performance Index | SPI | EV / PV |
| Cost Performance Index | CPI | EV / AC |
| Schedule Variance | SV | EV - PV |
| Cost Variance | CV | EV - AC |
| Time Variance | TV | SV / [BAC / SAC] |
| Estimated at Completion | EAC | EAC / CPI |
| Estimated to Complete | ETC | EAC - AC |
| Variation at Completion | VAC | BAC - EAC |
| Time Estimate at Completion | TEAC | SAC / SPI |
| Time Variance at Completion | TVAC | SAC - TEAC |

### 3.3 Earned Value Forecasting Indicators

Forecasting indicators predict the project's time and cost at completion based on actual performance achieved up to a specific time of the project. These indicators are (see Table 1 for calculations):

- Estimated at Completion (EAC): which is also referred to as Cost Estimated at Completion (CEAC) indicates the cost at which the project will be completed based on the current performance of the project.
- Estimated to Complete (ETC): estimates the cost needed to complete the project from the evaluated instance forward.
- Variation at Completion (VAC): indicates the variation between the original budget at completion and the new predicted cost to complete the project.
- Time Estimate at Completion (TEAC): forecasts the time at which the project will be completed given the unintentional changes produced to the initial plan.
- Time Variance at Completion (TVAC): indicates the amount of time the project was completed ahead or behind schedule.

Figure 2(b) illustrates the calculation of the ETC, EAC, and VAC forecasting indicators.

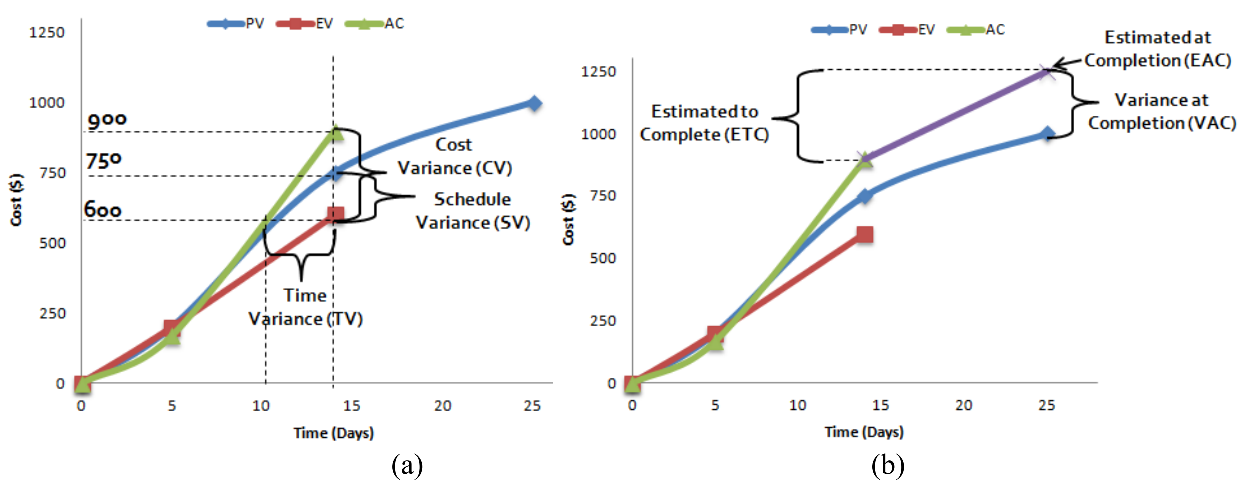



Figure 2: (a) Earned Value variances; and (b) Earned Value forecasting indicators.

## 4 EARNED VALUE SIMULATION METHOD

The earned value simulation methodology enables the project manager to utilize the simulation to establish a base-line plan for the project (planned value), and predict earned value during implementation of the project. To aid in developing the project plan and planned value over time, the simulation can be used to compare alternative project plans before the project begins.

Once a project plan is defined and the project has started, the proposed earned value simulation approach allows graphing the average values for EV and AC over the remaining course of a project. Activities with uncertain times and costs provide expected values for predicted earned value and actual cost when generating several instances of the project. By considering a tolerance band of ±10% of the planned value, the proposed approach helps identify easily when EV and AC deviate from the plan and when the reevaluations of the project plan can take place.

### 4.1 Assumptions

The general assumptions considered in the simulation method include:

- Activity time and cost distributions for all alternative resources can be estimated.
- Activity times are independent.
- Precedence relationships due to technical constraints are defined before the project starts and will not change throughout its execution.
- Activities cannot be split. It is assumed that once activities have been placed in schedule, they will be worked on continuously until finished.
- A single resource/resource set is needed to execute an activity.
- The remaining time and cost for in progress activities can be accurately estimated.

### 4.2 Earned Value Simulation Model

The simulation model uses input parameters to simulate instances of a project network. The model consists of two submodels. Submodel I determines the planned value (PV) at the planned completion (PC) times of the activities. Then, Submodel II calculates the planned value (PV), earned value (EV) and actual cost (AC) at the actual finish (AF) times of the activities. The two submodels will be described in detail in the following sections.

The simulation model was developed in Arena Simulation Software. The model was built to be flexible for modeling project networks without having to add new modules into the model. Input parameters defined as expressions and variables define the characteristics of the project and allow the model to simulate a specified project network. Once the model runs, the results are written into a preformatted Excel document.

The main components of the simulation model, which include the input parameters, simulation model, and output parameters, will be described in detail in the following sections.

#### 4.2.1 Input Parameters

The input parameters feed the simulation model with information regarding the characteristics of the project network under evaluation. The parameters that serve as input to the simulation model are the following:

$n$ = number of activities in the project
$PD_i$ = planned duration of activity $i = 1, \ldots, n$
$PV_i$ = planned value of activity $i = 1, \ldots, n$
$ADD_i$ = actual duration distribution of activity $i = 1, \ldots, n$
$ACD_i$ = actual cost distribution of activity $i = 1, \ldots, n$
$S_i$ = successors of activity $i = 1, \ldots, n$
$NS_i$ = number of successors of activity $i = 1, \ldots, n$
$NP_i$ = number of predecessors of activity $i = 1, \ldots, n$
$SS$ = start node successors
$NSS$ = number of start node successors
$EP$ = end node predecessors
$R_i$ = resource assigned to activity $i = 1, \ldots, n$

### 4.2.2 Simulation Submodel I – Determining Planned Value at Planned Completion of Activities

Submodel I determines the planned values at the planned completion times of the activities. The process for this submodel is summarized in Figure 3. In order to calculate the planned value, the following variables are used to keep track of activity start and completion times:

$st_i$ = is 1 if activity $i$ started, 0 otherwise $\forall\ i = 1,\ldots,n$

$PS_i$ = planned start of activity $i = 1,\ldots,n$

$PC_i$ = planned completion of activity $i = 1,\ldots,n$

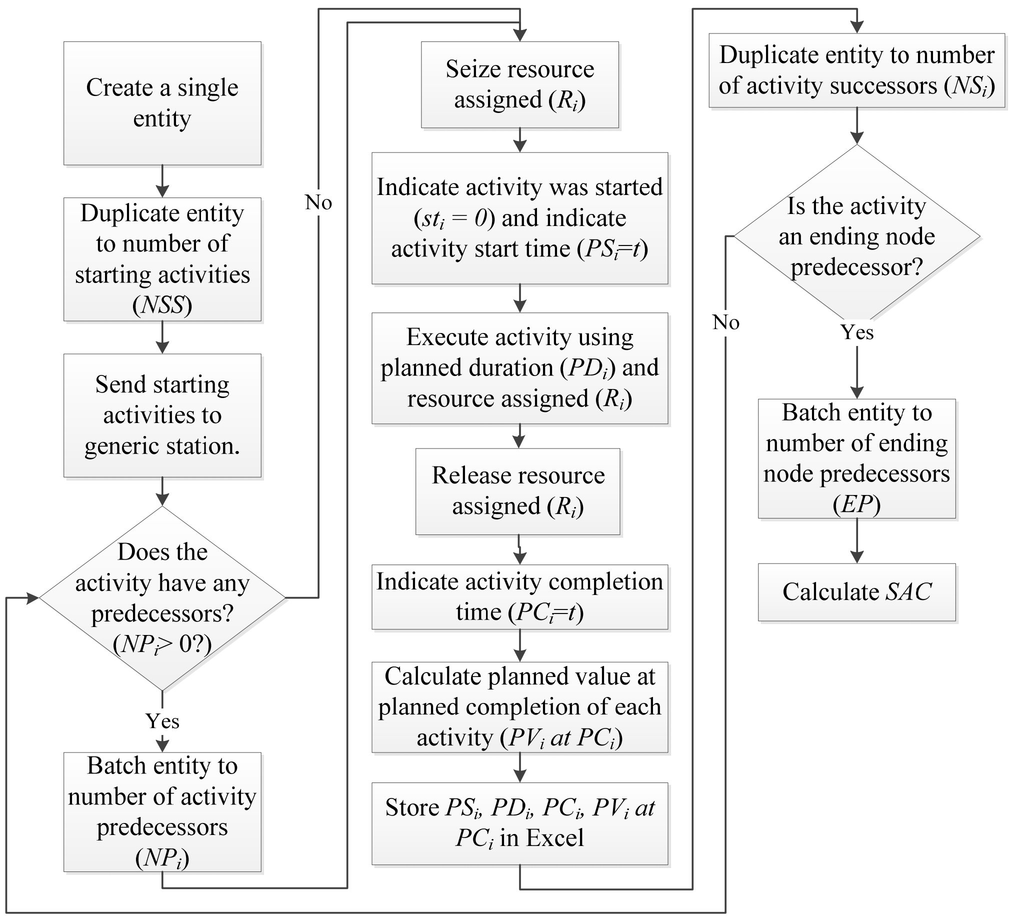



Figure 3. Submodel I algorithm.

At the start of the simulation, a single entity that represents an activity is created. This entity is duplicated into the number of activities that succeed the start node. These starting activities are sent to their corresponding stations from among a generic station set. Since the station number is equivalent to the activity number, the model can easily determine the destination of each activity. Once in the generic station, the activities are batched together if they have a common successor. If they do not need to be batched, they proceed to the next step. The activity seizes the assigned resource required for execution. Upon completion, the PV at PC is calculated by using (1). The formula essentially calculates the percentage of the task completed by time $t$ and multiplies it by the planned value of the task to obtain the planned value of the activity that should be completed by time $t$:

$$PVatPC_i = \sum_{i=1}^{m}\left(st_i \times \left(\frac{min(t - PS_i\ ,\ PD_i)}{PD_i}\right) \times PV_i\right) \tag{1}$$

After the calculation, the values of planned start, planned duration, planned completion and planned value at planned completion are stored in a preformatted Excel file. The entity is duplicated to the number of activity successors and the cycle is repeated. Once all activities have been completed, the ending activities are batched together and the schedule at completion time is generated. When Submodel I concludes, the single entity travels to a transfer node where $st_i$ is reset. The entity is then sent to Submodel II.

### 4.2.3 Simulation Submodel II – Determining PV, EV and AC at Actual Finish of Activities

Submodel II (Figure 4) determines the planned value, earned value and actual cost at the actual finish times of the activities.

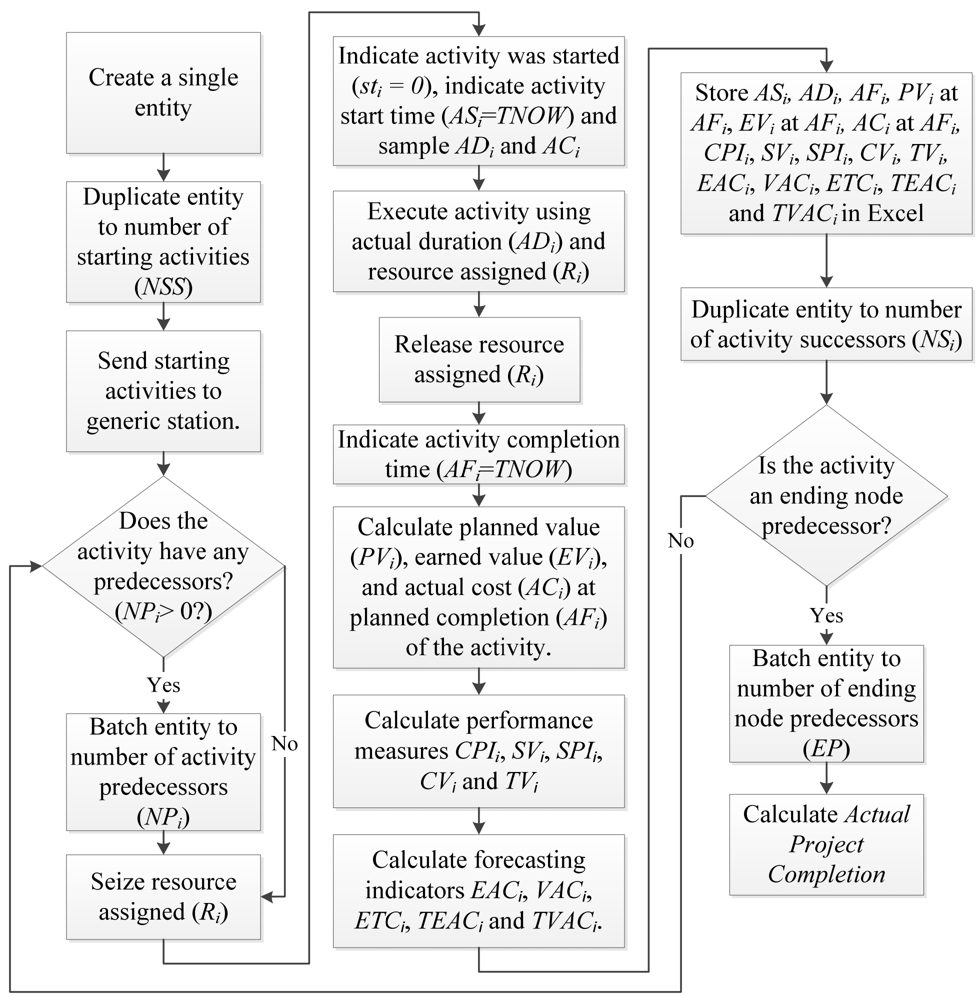



Figure 4. Submodel II algorithm.

Based on these values, the relevant earned value predictive performance measures are calculated. In order to calculate these, the following variables are used to keep track of activity start and completion times:

$st_i$ = is 1 if activity $i$ started, 0 otherwise $\forall\ i = 1,\dots,n$

$AS_i$ = actual start of activity $i = 1,\dots,n$

$AF_i$ = actual finish of activity $i = 1,\dots,n$

The PV, AC and EV at AF are calculated by using equations (2-4):

$$PV_i\ at\ AF_i = \sum_{i=1}^{m}\left(st_i \times \left(\frac{\min(t - PS_i\ ,\ \ PD_i)}{PD_i}\right) \times PV_i\right) \tag{2}$$

$$AC_i\ at\ AF_i = \sum_{i=1}^{m}\left(st_i\ \times \left(\frac{min(t - AS_i\ ,\ \ AD_i)}{AD_i}\right) \times AC_i\right) \tag{3}$$

$$EV_i\ at\ AF_i = \sum_{i=1}^{m}\left(st_i\ \times \left(\frac{min(t - AS_i\ ,\ \ AD_i)}{AD_i}\right) \times PV_i\right) \tag{4}$$

#### 4.2.4 Output Performance Measures

Once the simulation runs, a preformatted Excel document is populated with earned value parameters for several periods of the project. The document provides the information per replication as well as average values. The earned value parameters provided include:

Actual Start (AS): time at which the activity actually began to be performed.
Actual Duration (AD): amount of time over which each activity was actually completed.
Actual Finish (AF): time at which each activity was truly completed.
Planned Value (PV): budget projected to be spent by at the actual finish (AF) of each activity.
Earned Value (EV): represents, in terms of cost, the amount of work accomplished at the actual finish (AF) of each activity.
Actual Cost (AC): actual amount spent up to at the actual finish (AF) time of each activity.
Performance Measures: SPI, CPI, SV, CV, and TV.
Forecasting indicators: EAC, ETC, VAC, TEAC, and TVAC.

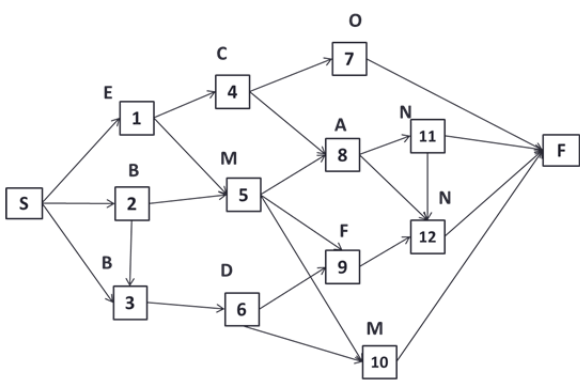
The mean, variance and tolerance interval on the earned value parameters are also calculated in the Excel document. The following example illustrate the types of graphs and information generated from the simulation model.

## 5 EXAMPLE APPLICATION OF THE EARNED VALUE SIMULATION METHODOLOGY

To illustrate the earned value simulation methodology, the project network shown in Figure 5 is used. The stochastic activity durations, resources required, and stochastic activity costs are also displayed in Figure 5. The result of running Submodel I, is the planned value for the project plotted over time along with the 10% contingency band displayed in Figure 7. In addition to a completion time, we will assume that the project has a milestone (determined by the project contract) at time 25.

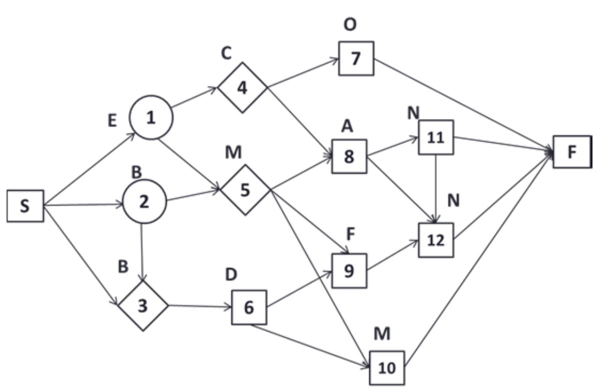
Given the project plan, the project can start and be tracked by the project manager over time to determine if the project remains on schedule. For the next phase of this example, we consider that the project is currently in progress and the first 13 days of the project have been completed. At time 13, the status of the project activities are as shown in Figure 6. Activities that have been completed by time 13 are represented by circular nodes, diamond shaped nodes symbolize in progress activities, and activities represented by squared nodes have not been started. In Figure 7, the first vertical line indicates the current time (day 13). We can observe that the earned value of the project has deviated beyond the 10% contingency band indicating that action may be needed by the project manager.

Given actual durations and costs for completed and in progress activities (Figure 6) and the distributions for those activities that have not been started, the stochastic times and costs from Figure 5, we can utilize simulation submodel II to predict the values of future earned value performance measures if the project manager continues with the current plan. By running 1000 replications of the project, the average earned value and actual cost at several points of the project where determined. Figure 7 shows graphically the results of the method. The vertical line at day 13 makes a distinction between what is currently known (left side) and the average calculated values of EV and AC (right side). The second vertical line (dotted) indicates the upcoming project milestone. Figure 7 shows that, given how the project has developed, the milestone will not be met in time or cost. At the milestone, the results show that the project will be behind schedule and over budget. Hence, a reevaluation of the initial resource configuration might be considered at this point in order to meet the milestone at time 25 and at the end of the project.




| Activity | Resource | Duration | Cost |
|---|---|---|---|
| 1 | E | TRIA(7,10,13) | TRIA(100,125,150) |
| 2 | B | EXPO(5) | TRIA(150,155,160) |
| 3 | B | TRIA(13,15,17) | EXPO(200) |
| 4 | C | UNIF(7,17) | UNIF(175,205) |
| 5 | M | TRIA(11,15,19) | TRIA(140,150,160) |
| 6 | D | UNIF(3,7) | UNIF(100,170) |
| 7 | O | UNIF(8,12) | UNIF(300,330) |
| 8 | A | TRIA(17,20,23) | EXPO(100) |
| 9 | F | TRIA(18,23,28) | EXPO(140) |
| 10 | M | TRIA(14,17,20) | EXPO(200) |
| 11 | N | TRIA(8,10,12) | UNIF(100,130) |
| 12 | N | TRIA(12,15,18) | EXPO(100) |

Figure 5. Project network example – Resources, stochastic activity durations and costs.




| Activity | Actual Duration | Actual Cost |
|---|---|---|
| 1 | 7 | 125 |
| 2 | 5 | 155 |
| 3 | 13 | 250 |
| 4 | 12 | 190 |
| 5 | 15 | 155 |

Figure 6. Project network example – Actual values for completed and in progress activities.

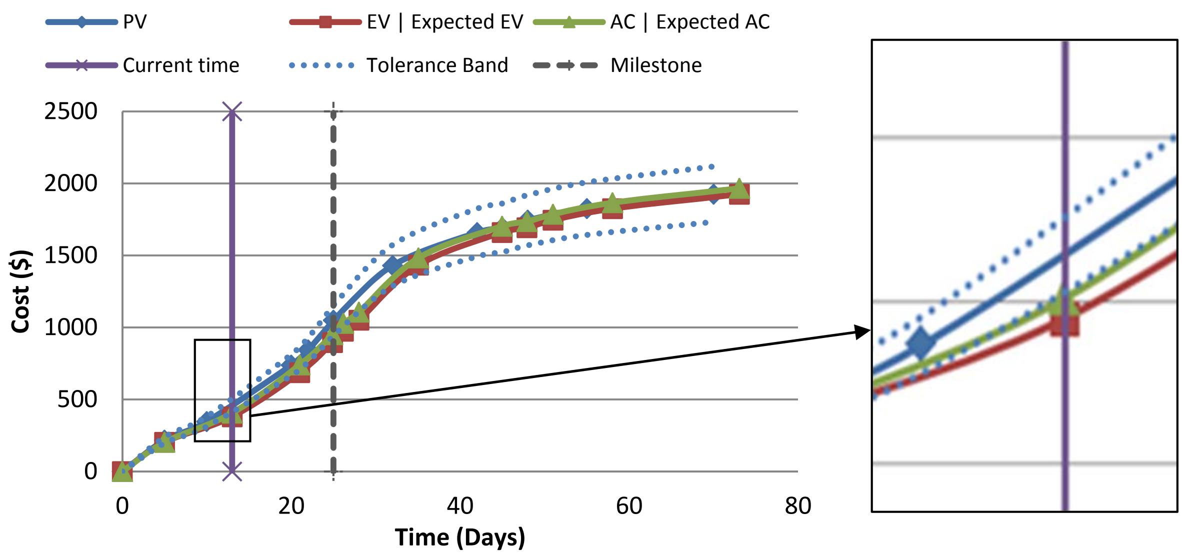



Figure 7. Earned value measures at day 13, and predicted performance measures.

## 6 CONCLUSIONS AND FUTURE WORK

Earned value management (EVM) is a method used to measure project progress at a given point during the project. EVM not only provides information regarding the current project status through schedule and cost variances, but also forecasts the project completion time and cost. The methodology presented in this paper demonstrates how simulation can be used to predict earned value performance measure for projects with stochastic activity durations and cost distributions.

This work presented in this paper demonstrates the simulation methodology for earned value prediction, and "what-if" analysis. These methods will serve as a basis for continued research into simulation-optimization decision support tools for evaluating alternative actions that the project manager may want to evaluate either before the start of the project in developing a project plan or during the implementation of the project when the project manager wants or needs to get the project back on schedule. In particular, we plan to pursue a simulation-based optimization methodology that will evaluate alternatives based on a function of costs associated with meeting project milestones as well as the overall completion costs of the project.

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