# Progress Monitoring of the Construction of Prefabricated Bridge with the Methods of Earned Value Analysis (EVA) and Earned Schedule Analysis (ES)

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## Abstract
The methods for monitoring and evaluating the progress of the projects resulted from the need to find ways to monitor and estimate the total cost and the total duration of the project according to the actual progress of activities and not to the original design. These methods can predict the final cost and the total duration, calculating indices using the estimated and actual cost of activities. Two well known methods for monitoring and evaluating the progress of the projects are the Earned Value Analysis (EVA) and the Earned Schedule Analysis (ES). The Earned Value Analysis, which is the oldest method, is successful in estimating the final cost and generally fails in estimating the total duration. The Earned Schedule Analysis, which is more recent, improves significantly the Earned Value Analysis in estimating the total duration. The two methodologies are complementary. In this paper the two methods are summarized and are implemented to monitor the construction progress of the C6 bridge of the Egnatia Motorway. The bridge is located in the section 4.1.2 Panagia-Grevena of Egnatia Motorway. The C6 bridge is constructed with the method of prefabricated beams and is a twin split carriageway bridge. The total length of each branch is 157,4m.

## Keywords
Progress monitoring of the construction, Prefabricated bridge, Earned value analysis (EVA), Earned schedule analysis (ES)

## 1. Introduction

The method of Earned value was developed in 1967 as an evolution of the method PERT / CPM and CSCS criteria (Cost Schedule Control Systems) by the US Department of Defense, as an attempt to reconcile the cost with the time of performed work.
The method helps to answer the following questions:
a) Is the project on schedule, ahead of schedule, or behind schedule?
b) Is the project within the planned budget, over the planned budget, or under the planned budget?
c) Are there any cost and schedule variances and which ones?
d) What is the estimate for the cost of the project at completion?
e) Is the project ahead or behind in relation to the scheduled completion date?

The Earned Value Analysis (EVA) is based on a comparison of the actual cost of work performed with

the budgeted cost of work performed and the budgeted cost of work scheduled. The term earned value comes from the fact that each deliverable of the project has a budgeted cost, the value of which is obtained from the project once the deliverable is complete (Burke R., 2002). The difficulty in understanding the Earned Value Analysis lies in the fact that it measures the performance of schedule in cost units instead of time units. Another drawback of the EVA is that at the end of a project that is behind schedule, references at time that is close to the actual (delayed) completion date, give us evidence that the project is completed on time.

The Earned Schedule Analysis (ES), which was proposed in 2003 by Walter Lipke (Handshuh R., 2006), is a method that stems from the EVA and is an extension, solving simultaneously the aforementioned paradox. Unlike EVA indices, which are based on cost, the ES uses indices based on time and provides reports and assessment for the schedule of the project, similar to those given for the cost by EVA.

## 2. Earned Value Analysis (EVA)

For the implementation of the method three steps are required:

- Identify project deliverables.
- Develop a schedule for the completion of deliverables.
- Assign a cost (value) for each deliverable.

The method is based on three variables:

- Budgeted Cost of Work Scheduled (BCWS) or Planned Value (PV), defined as the value to be earned as a function of project work accomplishments up to a given point of time.
- Budgeted Cost of Work Performed (BCWP) or Earned Value (EV), defined as the amount budgeted for performing the work that was accomplished by a given point of time.
- Actual Cost of Work Performed (ACWP) or Actual Cost (AC), defined as the cost spent and recorded for the completion of work performed up to a given point of time.

The formulas coming out of the method, with which we evaluate the progress of the project until a certain time and make predictions about its future evolution, can be grouped into three categories:

1) Variances:
   - Schedule Variance: SV=BCWP–BCWS
   - Cost Variance: CV=BCWP–ACWP
   - Variance At Completion: VAC=BAC–EAC
2) Indices:
   - Schedule Performance Index: SPI=BCWP/BCWS
   - Cost Performance Index: CPI=BCWP/ACWP
   - To Complete Performance Index: TCPI=(BAC-BCWP)/(BAC-ACWP)
3) Forecasts:
   - Time Estimate At Completion: TEAC=PD/SPI,
     where PD is the Planned Duration.
   - Estimate At Completion: EAC=BAC/CPI
   - Estimate To Complete: ETC =(BAC–BCWP)/CPI

Figure 1 explains the variables of the method (Burke R., 2002).

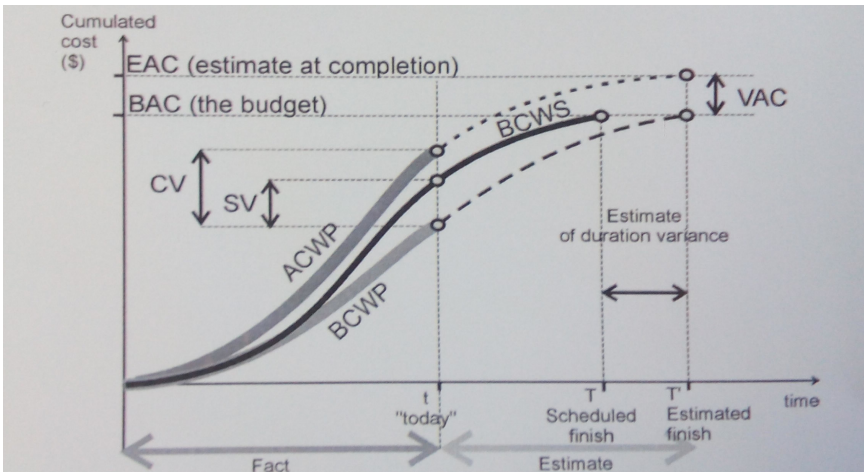


**Figure 1: Variables of Earned Value Analysis**

## 3. Earned Schedule Analysis (ES)

Unlike EVA indices which are based on cost, the ES method uses indices based on time and provides reports and evolution assessment for the schedule of the project, similar to those given for the cost of the EVA method.

The method works as follows: we create BCWP (EV) and BCWS (PV) curves and we find the real schedule variance based on time SV (t), which results from the projection of the curve EV on the curve PV, namely when the two variables are equal.

The points of time when BCWS (PV) and BCWP (EV) are equal are the following:

- For earned value (BCWP or EV) that point of time is called Actual Time (AT).
- For planned value (BCWS or PV) that point of time is called Earned Schedule (ES).

The Schedule Variance based on time, SV(t), is calculated by the following formula:

$SV(t)=ES–AT$

- If $SV(t) > 0$, the project is ahead of schedule.
- If $SV(t) = 0$, the project is on schedule.
- If $SV(t) < 0$, the project is behind schedule.

The Schedule Performance Index based on time, SPI(t), which gives a more accurate picture of the progress of the project, especially in its later stages, and gives a more accurate estimate of the duration of the project, is calculated by the following formula:

$SPI(t)=ES/AT$

- If $SPI(t) > 1$, the project is ahead of schedule.
- If $SPI(t) = 1$, the project is on schedule.
- If $SPI(t) < 1$, the project is behind schedule.

The total duration of the project is calculated by the following formula:

$TEAC(t)=PD/SPI(t)$,

where PD is the planned duration.

Figure 2 explains the variables of the method (Handshuh R., 2006).

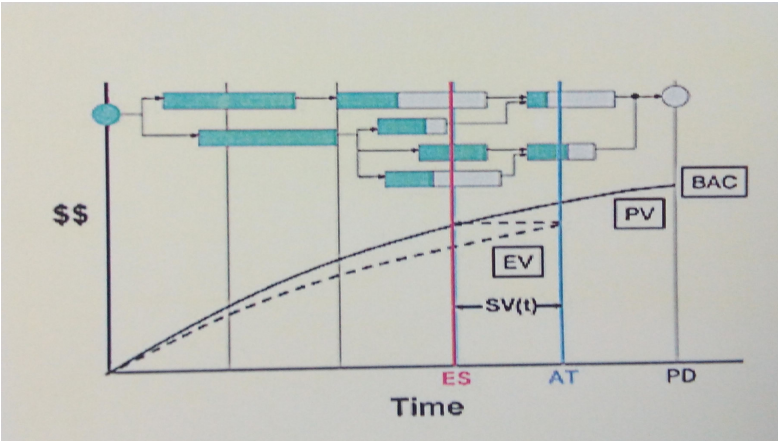


**Figure 2: Variables of Earned Schedule Analysis**

## 4. The Construction of Bridge C6

### 4.1 Prefabricated bridges

The prefabricated bridges, that appeared mainly after the War, have a large proportion of the conventional bridge engineering. This is due to the fact that they give solution for bridges with superstructures at a height of over 10 metres above ground, since this height is regarded as a boundary for cast-in-situ bridges. In addition, these bridges are characterized by relatively low initial construction cost, reduced construction time and minimum traffic disruption, in case of maintenance of traffic below the bridge during the construction. Nevertheless, the disadvantage of prefabricated bridges regarding their durability is known. There are two primary factors related to the decreased durability:
(a) The great volume of elastomeric bearings that is required, especially for earthquake resistant bridges of this kind. And it is known that these devices must be replaced many times in the life-cycle of the bridges.
(b) The presence of end joints, that require many replacements, similarly to the bearings.

### 4.2 Schedule of the construction

According to the original schedule the project should be completed in 102 weeks, but eventually it was completed in 116 weeks, mainly due to some problems relating to the carriage mechanism of the beams.

For the control of the bridge construction schedule, the project management software Microsoft Office Project 2007 was used. In this case, the construction materials (concrete, loose reinforcement, prestressing steel) with their corresponding unit cost were introduced as resources (Tzaveas Th., 2006).

### 4.3 Monitoring the progress of the bridge construction

The progress of the project will be checked at various dates that coincide with the beginning or the end of important activities for the evolution of the entire project. 7 control dates were chosen for the project. The control dates and the corresponding work completion rates are given in Table 1. Construction works started on 10/10/2006. For each control date, the date, the completion percentage of the activities were introduced and the date was set as Baseline. Then the variables of the Earned Value Analysis were calculated for each control date.

**Table 1: Control dates for the progress of the project**

| No | Date | Weeks after the start of the project | Comments | Completion percentage of the project activities |
|---|---|---|---|---|
| 1 | 08/03/2007 | 21 | Completion of pilecaps A1R, A2R, A2L, M3R, M3L | 15% |
| 2 | 28/05/2007 | 33 | Completion of pilecaps M1R, M1L | 30% |
| 3 | 06/08/2007 | 43 | Completion of abutments A2L, A2R | 45% |
| 4 | 24/10/2007 | 54 | Completion of piers M2R, M3R | 60% |
| 5 | 13/02/2008 | 70 | Completion of all piers | 80% |
| 6 | 23/05/2008 | 85 | Completion of superstructures | 84% |
| 7 | 01/12/2008 | 112 | Finishings | 97% |

## 5. Results

### 5.1 Results of Earned Value Analysis

The results of the Earned Value Analysis are given in Table 2 and Figure 3 depicts the diagrams ACWP, BCWS, BCWP. The project shows zero cost variance and negative schedule variance throughout the construction period. The cost performance index is equal to one and the schedule performance index is less than one throughout the construction period. We can say about the project that it is within planned budget and behind schedule.

In the $112^{th}$ week and while the project completion is delayed by 10 weeks, the schedule variance that gives the method is SV = 0, while the schedule performance index SPI = 1. This leads to the paradox of the Earned Value Analysis that while we know that the project will be completed late, the references of the method still show that the project is completed on time.

**Table 2: Results of Earned Value Analysis**

| No | Weeks after the start of the project | Completion percentage of the project activities | ACWP | BCWS | BCWP | CV | SV | CPI | SPI | TEAC |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 21 | 15% | 89.468 | 115.433 | 89.468 | 0 | -25.965 | 1 | 0,78 | 132 |
| 2 | 33 | 30% | 270.831 | 358.260 | 270.831 | 0 | -87.429 | 1 | 0,76 | 135 |
| 3 | 43 | 45% | 776.621 | 935.990 | 776.621 | 0 | -159.369 | 1 | 0,83 | 123 |
| 4 | 54 | 60% | 1.063.853 | 1.432.959 | 1.063.853 | 0 | -369.106 | 1 | 0,74 | 137 |
| 5 | 70 | 80% | 2.048.117 | 2.626.927 | 2.048.117 | 0 | -578.810 | 1 | 0,78 | 131 |
| 6 | 85 | 84% | 2.285.361 | 2.626.927 | 2.285.361 | 0 | -341.566 | 1 | 0,87 | 117 |
| 7 | 112 | 97% | 2.626.927 | 2.626.927 | 2.626.927 | 0 | 0 | 1 | 1 | 102 |

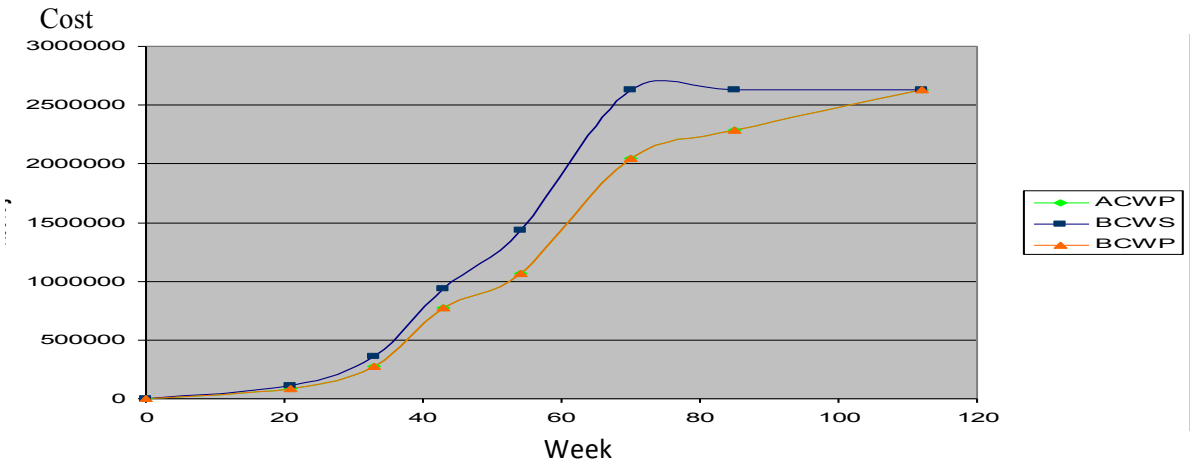


**Figure 3: ACWP, BCWS, BCWP diagrams**

### 5.2 Results of Earned Schedule Analysis

Figure 4 depicts the diagrams BCWS, BCWP, from which we get graphically the values of ES method. The results of ES method are given in Table 3.

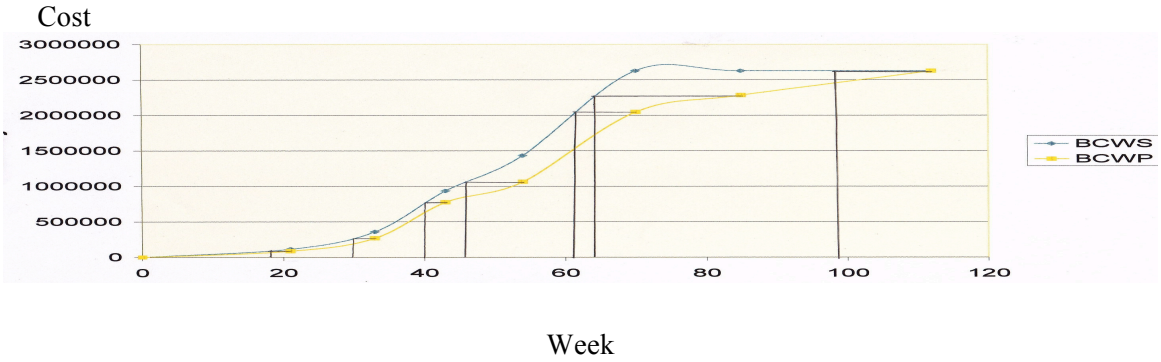


**Figure 4: BCWS, BCWP diagrams**

**Table 3: Results of Earned Schedule Analysis**

| No | Weeks after the start of the project | Completion percentage of the project activities | ES | AT | SV(t) | SPI(t) | TEAC(t) |
|---|---|---|---|---|---|---|---|
| 1 | 21 | 15% | 18 | 21 | -3 | 0,86 | 119 |
| 2 | 33 | 30% | 30 | 33 | -3 | 0,91 | 112 |
| 3 | 43 | 45% | 40 | 43 | -3 | 0,93 | 110 |
| 4 | 54 | 60% | 50 | 54 | -4 | 0,93 | 110 |
| 5 | 70 | 80% | 61 | 70 | -9 | 0,87 | 117 |
| 6 | 85 | 84% | 65 | 85 | -20 | 0,77 | 132 |
| 7 | 112 | 97% | 99 | 112 | -13 | 0,88 | 116 |

### 5.3 Comparison of the results of the two methods

Figure 5 depicts the values of the schedule performance index and figure 6 depicts the values of the estimated duration for the two methods. The value of the schedule performance index remains for the Earned Schedule Analysis less than one also at the end of the project, as opposed to the Earned Value Analysis where the value of the schedule performance index at the end of the project is equal to one, and in this way the ES method shows throughout the construction period that the project is behind schedule.
The ES method gives a reliable estimate of the duration of the project, especially in the last stages of the project, in contrast to the EVA method. This is proved by the fact that ES gives in the 112$^{th}$ week estimated duration 116 weeks, which was the actual duration of the project, while EVA gives in the 112th week estimated duration of 102 weeks, which was the initial estimated duration of the project.

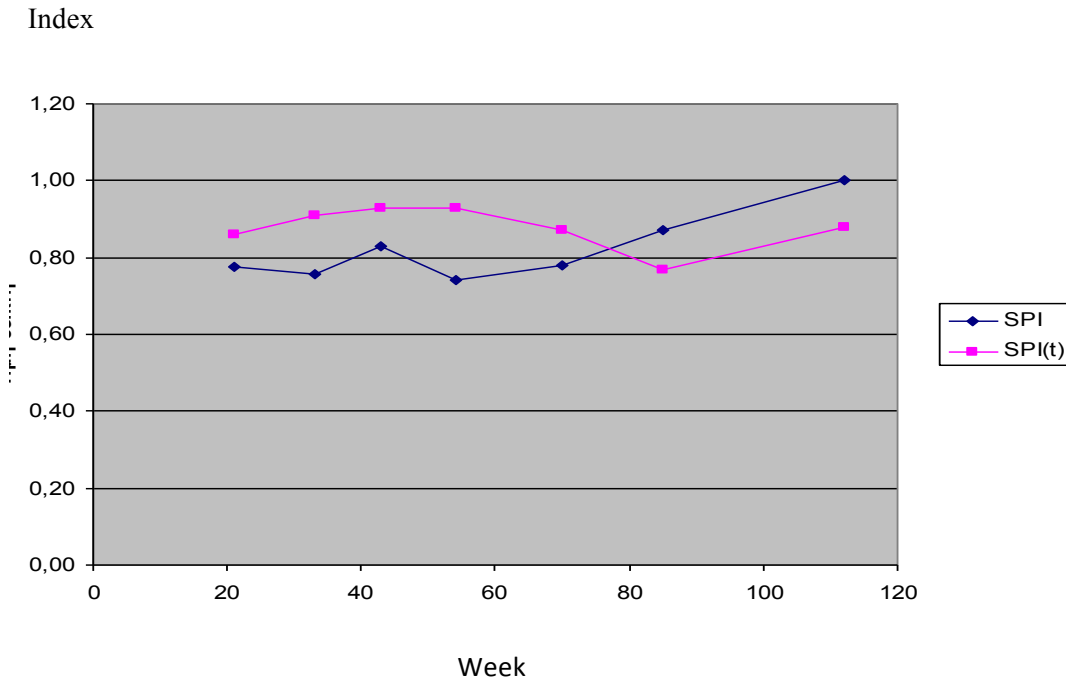


**Figure 5: Diagrams of Schedule performance index for the two methods**

Estimated duration

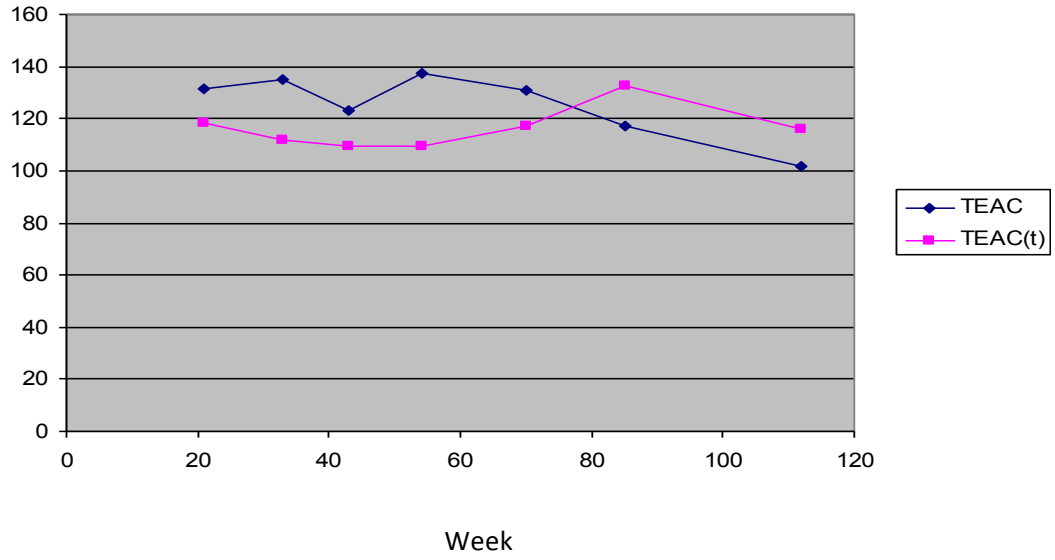


**Figure 6: Diagrams of estimated duration for the two methods**

## 6. Concluding Remarks

The methods for monitoring and evaluating the progress of the projects resulted from the need to find ways to monitor and estimate the total cost and the total duration of the project according to the actual progress of activities and not to the original design. Two well known methods for monitoring and evaluating the progress of the projects is the Earned Value Analysis (EVA) and the Earned Schedule Analysis (ES).

The comparison of the results of these two methods confirms that the ES method gives more reliable estimates for the duration of the project, particularly in its latter stages, and proves that both methods should be used in monitoring and evaluating the progress of a construction project.

## 7. References

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