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Editor's note: Second Editions are papers that were previously published, either in the distant past or in a language other than English, which have continued relevance today and deserve additional visibility. The paper below was originally presented at the ***PMI'99 Annual Seminars/Symposium – PMI's 30th Annual Symposium on Project Management*** *in Philadelphia, Pennsylvania, USA* in October, 1999*. This paper is included here with the permission of the author, who is copyright holder.*

Earned Value Management (EVM) Techniques for Engineering and Prototype Production Activities

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Introduction

Earned Value Management (EVM) techniques are presently extensively used in the Aerospace field, as an essential tool of cost and schedule management. The Earned Value concept is related to the performance measurement of the project, in order to evaluate *what we got* (i.e. the earned value) with respect to *what we spent* and *what we planned to spend*.

The paper provides an overview of EVM techniques applied in our company, based on usage of Work Breakdown Structure (WBS), Organizational Breakdown Structure (OBS), and Responsibility Assignment Matrix. The Cost Accounts (CA) are used as basic units of reporting. The Work Packages (WP) and the associated Measurable Milestones (MM) are used as basic units of control.

The paper will present the guidelines of standard procedures for EV reporting applied within our company. It will focus in particular on EVM applications in the field of engineering activities and prototype production, both typical of the space industry. At the end, future company directions in the field of EVM will be illustrated.

Earned Value in our company

Earned Value Management has been introduced in our company since 1989, applied only to some major satellite programs (Italsat, Artemis). A more systematic application of EVM techniques has started in 1993, by the introduction of the *Variance Analysis Report*, described below. EV techniques are currently used for all major space programs (with a budget greater than approximately 20M US$). EVM implementation is in fact quite expensive. Typically total cost of Project Planning and Control support account for approximately 5% of direct labor. EVM use is thus recommended only when the effective benefits are larger than the implementation costs.

EVM methodology and procedures are presently under verification for compliance with the European Cooperation for Space Standardization (ECSS) Standards and best practices .

The ECSS (Werner 1997) is an initiative established in the autumn 1993 to develop a single coherent set of user-friendly standards for use in all European space activities The cooperation is comprised of the European Space Agency, various national (including the Italian) Space Agencies and EUROSPACE representing European Industry (including our company).

The ECSS is designed to increase the efficiency of the European space industry and to strengthen its international competitiveness. The documentation is basically organized into three main branches: Management, Product Assurance and Engineering. A specific volume of ECSS Management standards is dedicated to Cost & Schedule Management (ECSS Secretariat, 1996).

EVM General Concepts and Definitions

Earned Value Terminology

It seems recommendable to summarize first of all the EV terminology used throughout the paper because several authors use different ones. For example someone (Brandon 1998, Dye 1997) use an opposite sign convention for Schedule and Cost Variances to account for general management expectation that positive variations correspond to cost overruns and negative ones correspond to cost underruns, others (e.g. Taylor 1998) do not agree to this approach. Someone additionally provide a different definition of the Cost and Schedule Performance Indexes (Dye 1997), while others do not agree to this approach (Barr 1996).

We agree with some of the points raised by Dye (Dye 1998). In particular:

- we agree on his suggestions for what concern the calculation of Cost Variance and Schedule Variance because it seems more correct from a mathematical point of view (in particular when working with percentage value of variances)
- we prefer the usual definition of performance indexes (being less than 1 when actual performance is worse than planned, both for schedule and cost).

Anyway, in order to avoid confusion with respect to the main topic of this paper, the terminology we are going to use is the same recommended by Project Management Institute (PMI Standard Committee 1996) and more widely used by project management community (Kerzner 1998 and Sparrow 1998). What does actually matter in fact is to respect consistency throughout the project and to ensure that the project team properly share the used convention.

We start with the basic definitions of:

BCWS = Budgeted Cost for Work Scheduled (baseline)
BCWP = Budgeted Cost for Work Performed (earned value)
ACWP = Actual Cost for Work Performed (actual cost)

By using these three definitions, EVM allows us to answer the following basic management question: "*What we got* (earned value) *for the money we spent* (actual cost), *compared with what we planned* (baseline)*?*"

The curve of the BCWS throughout the lifecycle of the project is called Cost Baseline (often referred as S-Curve). Its behavior reflect the time distribution of budget made at the beginning of the project.

The ACWP is provided by the Cost Control Department each months and is usually expressed in currency units. The most difficult evaluation is that concerned with the BCWP (earned value). EVM techniques are particularly focused on its estimation.

Exhibit 1 provides a typical representation of the three EVM curves.

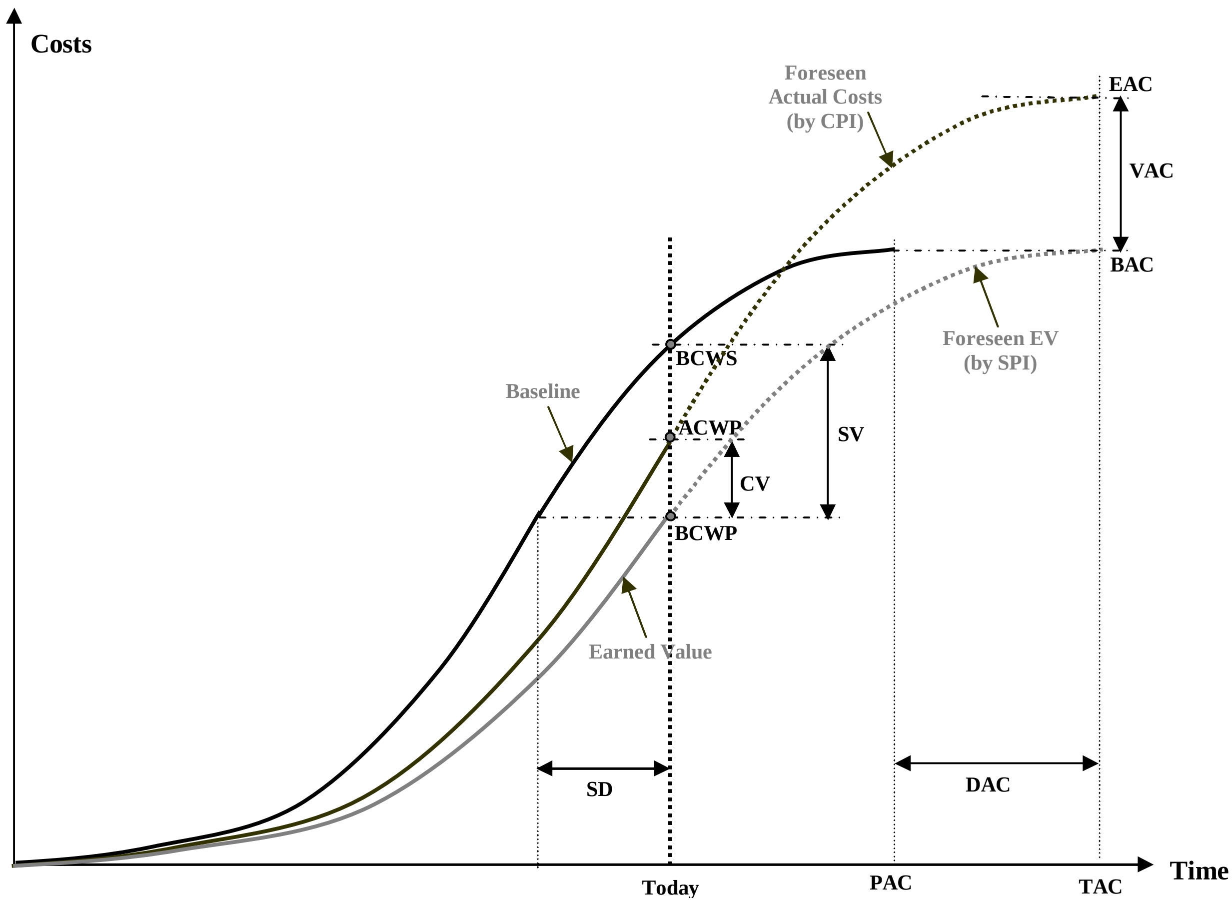

Exhibit 1 – Earned Value Trend Curves

In order to evaluate the performances of a project (or of a work element) in terms of cost and schedule, the following definition are introduced:

Cost Variance CV = BCWP – ACWP

Schedule Variance	SV = BCWP - BCWS
Cost Performance Index	CPI = BCWP / ACWP
Schedule Performance Index	SPI = BCWP / BCWS

Cost Management Metrics

We introduce now the following additional definitions:

BAC = Budget At Completion
ETC = Estimate To Complete
EAC = Estimate At Completion
VAC = Variance At Completion
BCWR = Budgeted Cost for Work Remaining (i.e. the complement of the BCWP to reach the original BAC) the last of which is defined as: BCWR = BAC - BCWP

Two relations of general validity are:

EAC = ACWP + ETC
VAC = BAC - EAC

Anyway different situations will lead to different estimations of ETC and consequently EAC and VAC.

First of all we should remember that project activities may be classified, according to their accounting characteristics, in three groups (Kerzner 1998, Chapter 15):

- *Measurable Efforts* (ME): discrete increments of work with a predefined schedule for accomplishment, whose completion produce tangible results
- *Level Of Effort* (LOE): work that does not lend itself to subdivision into discrete schedule increments of work, such as project planning and control, product assurance, and configuration management support.
- *Apportioned Effort* (AE): work that does not lend itself to subdivision into discrete schedule increments of work but that can be accounted in proportion to some Measurable Efforts activity (e.g. inspection activity on mass production). This is rarely used, even if some people try to use it for supervision, that is not a valid application.

For simplicity we consider initially only Measurable Efforts type of activities without activity at Level Of Effort.

a) If the underrun/overrun is due to a general and constant trend of project performances that will continue until completion:

$$\text{ETC} = \frac{\text{BAC - BCWP}}{\text{CPI}} = \frac{\text{BCWR}}{\text{CPI}}$$

$$\text{EAC} = \frac{\text{BAC}}{\text{CPI}} = \text{BAC} \cdot \left(\frac{\text{ACWP}}{\text{BCWP}}\right)$$

where the CPI is the cumulative performance index since the start of the project.

b) If the project is presently (i.e. in the last *n*-months) experiencing a trend of cost performances that has changed with respect to the past and is expected to last until completion of the project (Sparrow 1998):

$$ETC = \frac{BAC - BCWP}{CPI_n} = \frac{BCWR}{CPI_n}$$

$$EAC = ACWP + \frac{BCWR}{CPI_n}$$

The CPI_n in the previous formula may be calculated in two ways, and is based on the project performance over the last *n*-months. In particular:

1. as the ratio of BCWP over the last *n*-months and the ACWP over the last *n*-months, i.e.:

$$CPI_n = \frac{BCWP_n}{ACWP_n}$$

2. or as the average of the latest *n* monthly-CPI (which are the CPI based on BCWP and ACWP for that month).

The first of the two methods has demonstrated an overall validity throughout the lifecycle of the project when used with $n = 3$.

c) If the underrun/overrun is due to an isolated event rather than a performance trend, it could be expected than the remaining activities could be performed with nominal performance (i.e. with future CPI=1 and ETC = BCWR). Then:

$$ETC = BAC - BCWP = BCWR$$

$$EAC = ACWP + BAC - BCWP = ACWP + BCWR$$

This formula may be useful also for as a Best Case EAC evaluation of the former cases a) and b) .

Now we consider also the Level Of Effort (LOE) activities that will represent a certain percentage (%LOE) of the overall task content. The percentage of Measurable Efforts type of activities will be: %ME = (1 - %LOE). Then:

d) If the underrun/overrun is due to a trend of project performances that will continue until completion:

$$ETC = \frac{BAC - BCWP}{CPI \cdot (1 - \%LOE) + SPI \cdot (\%LOE)}$$

$$EAC = \frac{BAC}{CPI \cdot (1 - \%LOE) + SPI \cdot (\%LOE)} = BAC \cdot \left(\frac{ACWP}{BCWP}\right)$$

Some authors (Green 1998) have proposed the introduction of a further performance index:
CR = Critical Ration = CPI · SPI
to be used as the denominator of the EAC formula to forecast the maximum funds likely required to complete the project, i.e.:

$$EAC = \frac{BAC}{CPI \cdot SPI} = \frac{BAC}{CR}$$

The resultant EAC shall be, in our opinion, actually considered as the higher extreme (Worst Case) of final expenditure more than a realistic estimation of the EAC, because it is intrinsically pessimistic (effect of schedule performance is accounted twice on Measurable Efforts activities, and effect of cost performance is probably overestimated on Level Of Effort activities).

e) If the underrun/overrun is due to an isolated event rather than a performance trend, the same formulas of case c) may be used.

We shall note that the above formulas have demonstrated to be more or less reliable with respect to the current stage of the project (starting, in the middle, or ending), but usually all of them become more reliable after 15 to 20 percent of the overall schedule. This is due to the fact that performance indexes suffer greater variations in the initial stage of the project (Kerzner 1998).

Time Management Metrics

In a similar way we can calculate the:

TAC = Time At Completion
DAC = Delay At Completion

starting from the present Schedule Delay (SD) and the Plan At Completion (PAC) by means of (Brandon 1998):

$$TAC = \frac{PAC}{SPI}$$

$$DAC = PAC - TAC$$

Usually in a large organization better tools for schedule management exist (PERT and Critical Path Method Network, Monte Carlo Analysis, etc.), that can provide better estimation for final schedule performances. Anyway the DAC estimation based on EV techniques could be used as a good term of comparison.

Work Definition and Responsibility Assignment

Application of EV concepts in our organization is performed using work breakdown techniques. Prior to start a project, a *Work Breakdown Structure* (WBS) shall be defined.

The WBS is an organized tree of several project elements, called *Cost Accounts* or *Control Accounts* (CA), that organize and define the total scope of the project with each descending level representing an increasingly detailed definition. The Cost Account represents the lowest level at which program performances are reported to program manager and functional responsible. Analysis of EV parameters at CA level is of paramount importance in order to avoid cancellation effects between different CAs in a WBS branch. For each Cost Account a CA Manager shall be identified, providing a correlation (Responsibility Assignment Matrix) between the WBS and the Organization Breakdown Structure (OBS), which represents a hierarchical breakdown of the organizational units that will provide resources to the project (Howard 1998).

Each CA can be divided in several Work Packages (WP). The Work Packages is comprised of a detailed description of all the inputs necessary to perform the WP content, of the activities to be performed, and of the outputs or end items produced by means of these activities. In addition activities specifically excluded by the WP may be added for clearness. Budget allocation is performed within the CA for each WP in terms of manpower (hours), materials, travels, subcontracts and all other cost categories.

In order to allow an accurate determination of earned value (i.e. BCWP) associated to the specific WP throughout the lifecycle of the project, a certain number of Measurable Milestones (MM) shall be established for each tasks considered at Measurable Effort (ME). Standard formats in use in our company allow for a maximum of 17 WPs for each CA, and a maximum of 12 MMs for each WP.

Measurable Milestones shall not be confused with Program/Contract Milestones (i.e. those defined in the Milestone Payment Plan), even if the two are sometimes correlated.

A proper choice of the dimension of the Work Packages and of related Measurable Milestones is of paramount importance in order to ensure a suitable discretization of the BCWP curve (avoiding the presence of large steps in the curve). Special attention has to be given to the time allocation of the WPs: a certain number of shorter WPs properly distributed along the project different phases is preferable with respect to longer WPs overlapped among them (see Exhibit 2).

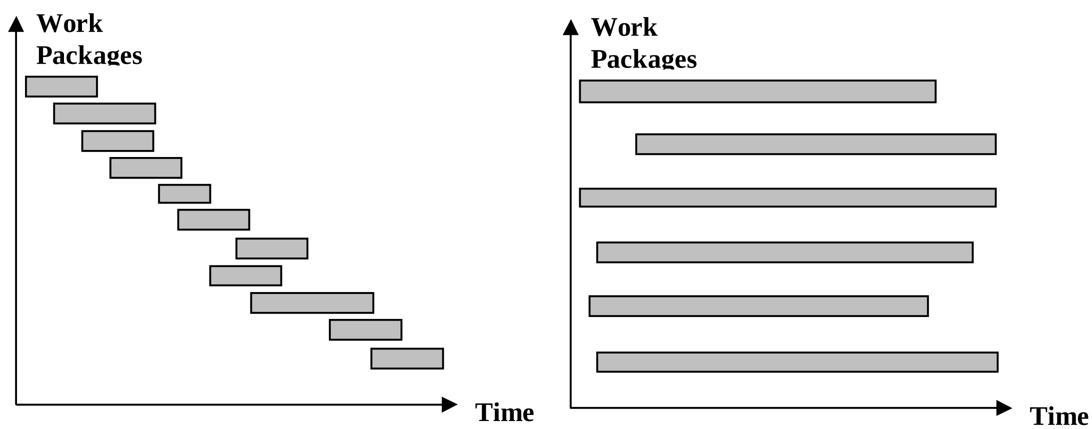

Exhibit 2 – Work Package Timing

Also the frequency of the MMs shall be carefully evaluated. In particular at least one MM for each evaluation/reporting period (typically one month) shall be foreseen.
An interesting overview of the proper choice of WP dimensioning are provided by Raz and Globerson (Raz 1998).

The next section will focus on guidelines to be followed for proper determination of Measurable Milestones for engineering and prototype production activities, both typical of the space industry.

EVM for Engineering and Prototype Production Activities

For this kind of activities identification of suitable deliverables (usually limited to the technical documentation issued at some specific milestone), and a correct evaluation of the completion percentage is very difficult. Such activities are in fact significantly affected by the "*90 percent complete syndrome*", i.e. the considerable overestimation of the task accomplishment degree at the initial stage of the work.

In order to overcome this problem particular attention shall be given to the definition of the Work Package contents and of the Measurable Milestones (MM).

Typical MM of engineering and prototype production activities are:

- Documentation preparation and releases
  Typically the majority of the documentation is completed and formally issued just toward the end of the engineering phase. If we consider just the completion of the documents as MM, the effort of the early phase of the engineering activity could not be tracked properly. Thus an objective criteria shall be developed in order to estimate the completion percentage of documentation in a realistic way.
  Core sections of the documents to be produced shall be identified and their relative weight, with respect to the document completion, shall be established. In this way we can assign a MM to each core section, with a due date and a certain budget of working hours. This requires the preparation of the document respecting a standard approach for each type of document.
  Another important aspect to be taken into account is that some documents are usually released several times during a project phase. In this case the 50% of the MM value is recognized (as earned value) at the first issue, while the remaining 50% is recognized only at the very last issue.
- Alternative design selection
  If a trade-off between different technical solutions is foreseen at the beginning of the engineering phase, the alternative selection may be taken as a measure of the engineering effort.
- Supplier selection
  If a trade-off between different suppliers for subsystem/equipment/component is foreseen during the engineering phase, the supplier selection completion may be quoted as a MM.
- Design reviews preparation
  In order to verify the maturity of the project, design reviews are performed throughout the engineering phase of a project. Effort required to prepare, to held and to close out the review may be quoted as different MMs.
- Prototyping of equipment
  Typically engineering activities are supported by the production of engineering prototype models of the unit, to perform a preliminary verification of the functionality of the design. The related activities may be divided in MM by considering the completion of the different sections or boards of the engineering prototype model.

Another significant problem is related to the fact that most of the errors occurred during the engineering phase and prototype production are discovered only at later stages, and in particular during testing. In this respect the quality and completeness of the end items of engineering and prototyping phase (documentation and prototype) become an essential parameter to be taken into account in order to avoid future disruptive effects on the project performances. This quality verification shall be used as a final MM of each major WP.

The Performance Evaluation

The performance evaluation is performed periodically for all the active programs of the company. Two levels of performance reporting is foreseen:

- for each program using CAs as basic unit of reporting, by means of a *Variance Analysis Report* (VAR)
- for each Operative Unit of the company using programs as basic unit of reporting, by means of a *Tableau de Board*

The purpose of the VAR is to give a complete and synthetic overview on the program status, on a monthly basis. It includes several information regarding schedule (end item delivery dates status, critical path), cost (contractual change status, EV parameters) and technical performance (synthetic description of technical problems, critical areas and corrective actions identified, etc.). For what concern EV methodology, the contents of the VAR can be realized according to the following steps:

- *Physical Progress* is based on the identification of the real accomplishment of the tasks. The data are organized in a table with a MM in each row. For each MM the following data are reported: its description, due dates (baseline and current), BCWS, ACWP, BCWP and the SPI. Then data are summarized at CA level.
- *Trend Analysis* is performed by comparing in one diagram the trend of the BCWS, ACWP and BCWP curves for the overall project. SPI and CPI trends are evaluated as well.
- *Estimation at completion* (EAC) is determined by the CA responsible using a special form called CERF (Cost Estimation Review Form) by means of the formulas previously described.

The Project Control section of the company Tableau de Board, is comprised of the following elements:

- *Schedule Efficiency Analysis* is performed calculating two distinct SPI for that period, in the following way:
  $SPI_N = (MM_{NR} / MM_{NB})$
  i.e. the ratio of the number of MMs reached in the period (MM_{NR}) and the number of MMs foreseen in the period
  $SPI_Q = (MM_{QR} / MM_{QB})$
  i.e. the EV amount of MMs reached in the period (MM_{QR}) and the baseline value of the same MMs (MM_{QB})
- *Cost Efficiency Analysis* is performed calculating the CPI for that period using the ratio of the EV amount of MMs reached in the period (MM_{QR}) and the actual costs of the period ($ACWP_P$):
  $CPI_Q = (MM_{QR} / ACWP_P)$

Conclusions and Future Trends

Our company has gained a significant experience in the application of Earned Value Management since 1989. EV is currently applied on all the major space projects in which the company is involved and it is considered as a fundamental tool in support of project management inside the company.

The commercial market demand for *better, faster and cheaper* programs, imposes a radical change in the awareness of the overall organization with respect to schedule and cost control. In this environment, EVM applications are no more limited to tracking costs and predict resources required to reach project accomplishment. It is also used to assist management in decision making processes, in order to evaluate impacts and results of alternative choices, and in support of risk management techniques (identification of early symptoms in terms of program cost overrun, identification of critical activities).

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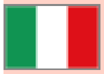

Sergio GEROSA is an Aeronautical Engineer working since more than fifteen years in Thales Alenia Space, the largest European aerospace industry. Head of Commercial Telecommunication Programs (in Italy) between 2002 and 2006, he has then been appointed as Director Product Competitiveness. He has a large experience in the implementation of state of the art project management techniques, in particular of EVM and Risk Management methodologies. He is a member of Project Management Institute (PMI) since 1998, and Associate Member of the Board of the PMI Rome Italy Chapter. He is member of the Editorial Board of the International Journal of Engineering Management & Economics (Inderscience Publishers). Sergio teaches Project Management in three Masters of Science organized by Italian Universities (University of Rome “La Sapienza” and University of Rome “Tor Vergata”), as well as at the Thales University for the Passport to Program Management and Introduction to Contract Management courses. He is author of the several papers on project management ("The Project of a Lifetime ", IPMA World Congress 2008; "The Tower of Babel: When Communicating Becomes a Nightmare ", PMI EMEA 2008; "A Design to Cost Methodology to Manage Complex Product Development in the Space Industry", PMI EMEA 2007; "Using Knowledge Elicitation Techniques in the Risk Assessment of Space Projects", PMI EMEA 2006; "Project Financing and Risk Management: a new challenge for program management in the space industry of the third millennium", PMI Europe 2001 and published as Cover Story on “Project & Profits”; "Earned Value Management: How to avoid the 90% complete syndrome" IPMA 2002; "Methods and applications of Risk Management in space programs" & "Earned Value Management techniques for engineering and prototype production activities", PMI 1999 Annual Symposium). Sergio can be contacted at Sergio.Gerosa@thalesaleniaspace.com.

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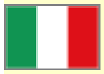

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