A Deliverable-Oriented EVM System Suited to a Large-Scale Project

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ABSTRACT

The Large Hadron Collider (LHC) is under construction at CERN, the European Laboratory for Particle Physics, near Geneva, Switzerland. In 2003, a new earned value management (EVM) system was introduced to improve transparency in LHC project reporting, to allow a clearer distinction between cost differences to the baseline due to overruns versus resulting delays, and to provide the project management team with a more reactive project management information system for better decision-making. EVM has become a *de facto* standard for the follow-up of cost and schedule and several commercial packages are offered for implementing an EVM system. But because none of these packages fulfilled CERN's requirements, its executive management decided to proceed with an inhouse development. In this paper, an overview of what CERN considers to be good requirements for an EVM system suited to large-scale projects is provided: the deliverable-oriented, collaborative and lean management dimensions are enforced. In conclusion, we discuss some of our positive and negative experiences so those who would like to develop or implement similar enterprise-wide project control systems can be more aware of common pitfalls.

Keywords: large-scale project management; deliverable-oriented project management; earned value management; performance monitoring

Vol. 37, No. 1, 67-80, ISSN 8756-9728/03

Introduction

One of the challenges of project management is that it aims at providing management methodologies and insights for a wide diversity of endeavors, ranging from small projects involving a few people part-time, over a short time (days or a few weeks), to large-scale projects involving sometimes several thousands of people, billions of dollars or euros, spanning over many years or even decades. It becomes obvious that it is up to each project manager or project management team to implement the right management methodologies suited to the characteristics of their projects, targeting overall management efficiency and effectiveness.

Among the specificities of large-scale projects, the following could be cited:

- The number of contributors to the project
- The number of activities to perform, and their relative complexity
- The number of intermediate deliverables to release all along the project execution
- The number of activities that are outsourced to external contractors through result-oriented contracts, or carried out by project partners through result-oriented partnership agreements
- The project duration that can span over a decade that makes long-lead activities quite inaccessible at the early stage of the project.

The challenge of managers and project management teams of large-scale projects, then, lies in their ability to handle huge amounts of information efficiently; more specifically, to sufficiently understand all the activities to perform during the overall project's lifespan and to miss none of them, and furthermore, to get timely and precise statuses of activities so effective coordination and decision-making are possible.

Project management is not new and many large-scale projects have succeeded, so one could think that all the means are available. Certainly, many textbooks and articles relate or report on efficient project management methodologies fully compatible with the challenges of large-scale projects. It is wise to continue investigating new approaches for addressing this endless quest for optimal efficiency.

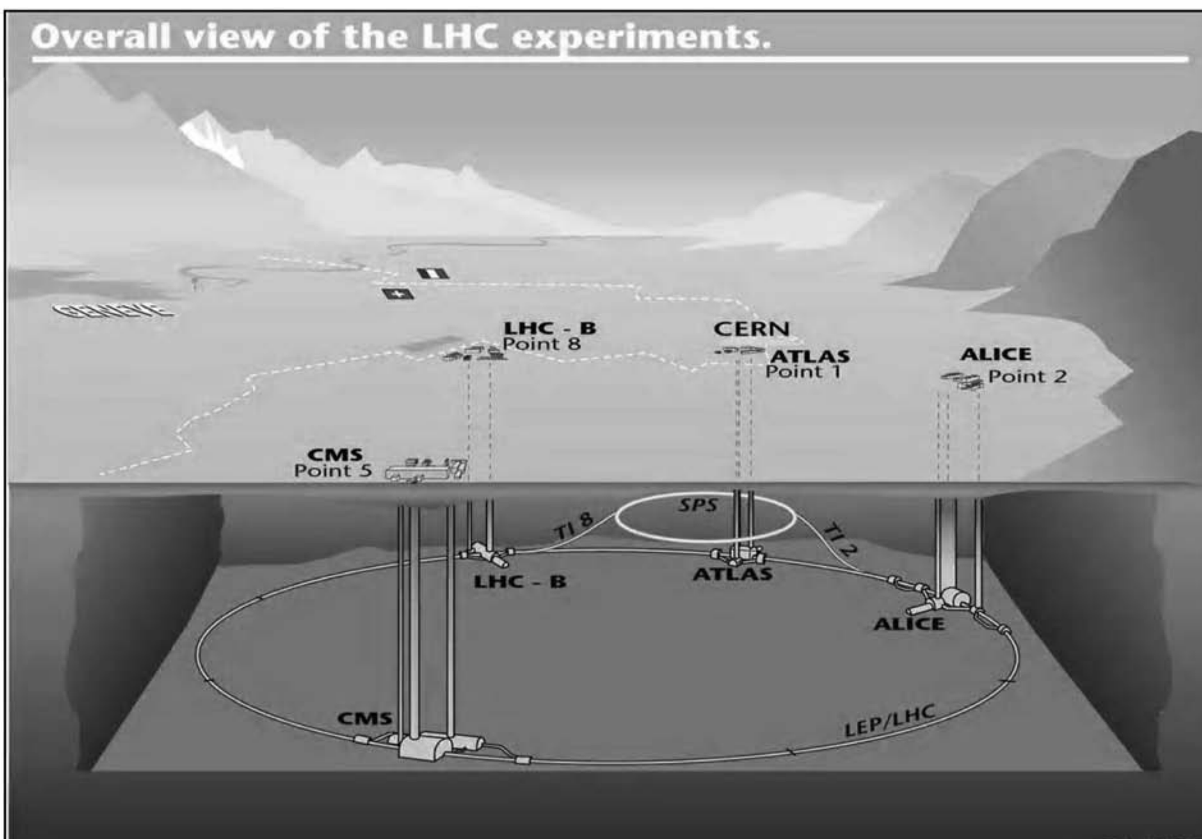
Being efficient in project management could consist of describing all the activities to perform in very deep detail. This is possible and many large-scale projects proceed this way. But setting up a project management system for handling such a level of detail has also a cost that certainly affects the effectiveness of the project management. Being effective may consist of handling fewer details and consequently more complex *management items*. If there is less detail to handle, then the project management team can be downsized with cost saving at the end. CERN has experienced this with its ongoing large-scale project, the Large Hadron Collider (LHC) that is being constructed near Geneva, Switzerland (see Exhibit 1). But to work, this lean project management approach requires quite an involvement from all the project's key contributors. This article aims at presenting the project management system CERN has developed for the LHC project, and to discuss outcomes and improvements.

This paper is organized as follows. The rationale of a deliverable-oriented earned value management (EVM) system is given in the next section. The activity model is then presented, and the fourth section exhibits how this activity model copes with the requirements of an EVM system, focusing on how technical, commercial, and economical uncertainties are handled. Finally, the last section presents an alternative EVM approach. The LHC project that serves as a support for this new approach to large-scale projects is not presented in detail. Presenting this project in this paper would have been too long and detrimental for the understanding of the proposed approach. Readers who need more insight on that specific implementation are invited to refer to Bonnal and De Jonghe (2003).

Rationale for a Deliverable-Oriented Project Management Approach

Efficient Project Planning

Before discussing the benefits of a deliverable-oriented project management approach, let us say some words on the



Budget	4.20 GCHF
Materiel	3.25 GCHF
Personnel	~700 FTEs
Start Date	December 1995
Finish Date	Summer 2007
Circumference	~27 km
Collisions	7.0+7.0 TeV
Magnetic Field	8.7 T
Operating Temperature	1.85 K

Exhibit 1: The LHC project (machine)

rationale for a systematic planning approach. It is commonly agreed that an efficient project management system can only be supported by an efficient work breakdown structure (WBS). To satisfy the requirements of all types of project management systems, it is necessary that the project's WBS be consistent. This means that the WBS must be set up in such a way that an exhaustive list of activities can be guaranteed. Furthermore, the WBS must be well balanced. This means that all systems that make the final deliverable shall be broken down to a similar level of definition.

Ideally, a methodology should be used to derive a consistent WBS such that it becomes a repeatable process: different project management teams should arrive at a very similar WBS. A systematic project planning approach, such as the ones proposed by Bachy and Hameri (1997) or Vallet (2003), is then recommended.

In the context of a large-scale project, the advantage of proceeding this way is triple:

- Because of the rather long duration of large-scale projects, it happens frequently that the project team, including the project management team, is partially renewed over the project makespan. If a systematic way has been used to plan and schedule the project, it is easier for newcomers to take over plans and schedules, rather then refurbishing the existing plans and schedules left by their predecessors to have them arranged in a way that corresponds to personal habits.
- Because of the size and the complexity of large-scale projects, all the key contributors of the project need to be involved in the planning and scheduling exercise. For a project such as the LHC, key contributors represent about 300 engineers and physicists. If a systematic approach for planning is provided, then the sub-WBSs that are to be prepared by each of the key contributors may be more straightforwardly merged, and the resulting project's WBS will be quickly coherent and consistent with much less effort. If the project management team is not able to provide a framework for sub-WBS preparation, then some contributors will provide the project with sub-WBSs too detailed while others will provide insufficiently detailed sub-WBSs. This may jeopardize the execution of the project: an important effort of reporting is to be asked from some contributors, while an insufficient level of reporting will be asked from others.
- Finally, some projects are not performing as expected because some activities were forgotten in its planning phase, or considered twice by two different project contributors. Professional project management practitioners know that integrating unplanned and unscheduled activities always has consequences on the overall performance of a project. The project management reserve aims at dealing with these unexpected events (see ANSI/EIA-#748-A-1998 *Standard* [2002] or PMI's *Practice Standard for Earned Value Management* [Project Management Institute, 2004] for instance). WBS can mitigate this risk efficiently using a systematic approach to build a project.

Involvement of all Project Key Contributors and the "90% Syndrome"

A lean project management team supposes that part of the project progress reporting duty is transferred to the direct contributors to the project (large-scale projects may involve hundreds or even thousands of contributors). It has always been difficult for project planners, controllers, and surveyors to collect the actual status of activities, delays, and cost expenditures. With the advent of sophisticated project management information systems that use the Internet extensively, this collecting task has definitively been made easier. But involving all key contributors in a project reporting process that may include physical achievements remaining to complete, and time and cost expenditures require a reporting framework that is much more structured than what is usually promoted in project management textbooks or by the suppliers of project management information systems.

While collecting project expenditures is usually not too difficult, obtaining physical progress statuses of ongoing activities is a duty that is much more challenging. All project management practitioners have been confronted, at least once, with the "90% Syndrome." The manifestation of this syndrome occurs when the project management team relies on physical progress information provided by the *activity holders* without cross checks of the achievements. As mentioned by Ford and Sterman (2003), in the absence of a clear metrics for reporting physical progress, activity holders have the tendency to provide figures that are linearly proportional to the temporal progress of the activity. Often when the 90% duration allocation is reached, the "90% physical progress figure" is kept and the last 10% takes much longer than expected.

Process-Oriented vs. Deliverable-Oriented Project Management

In addressing this, Ford and Sterman (2003) proposed an interesting framework that uses notions of system dynamics. We have preferred a more pragmatic way that shares to some extent with Andersen (1996) or Howard (1998), which argue toward deliverable-oriented project management approaches. These authors make the case that traditional project management practices tend to focus too much on activities, considering that if individual activities are doing well, then the whole project is doing well. But any experienced project manager knows that this principle is never true. It happens that some activities consume resources without producing a valuable deliverable for the project. In a deliverable-oriented project management system, the deliverables are the *management items* to keep in sight. They are the intermediate results to gather all along the project execution; the gates to go through for switching from a predecessor activity to a successor activity. They are the framework to guarantee the completion of the project on time, on budget, and at the expected level of quality or performance. In such a project management context, the activities are just the means to generate the various deliverables.

Deliverable vs. Product. Some textbooks (e.g., Vallet, 2003) or articles (e.g., Bachy & Hameri, 1997) promote the product breakdown structure (PBS) as a prerequisite to the WBS.

We would like to highlight that products and deliverables are not necessarily equivalent concepts. A product is a constituent of the project's end-product and is time-independent, while a deliverable is time-dependent; it corresponds to a set of statuses a product must go through before being integrated in the end-product. There are also deliverables that are not directly associated to constituents of the project's end-product, such as tooling, or general project management or engineering documents. Let us use an example to illustrate this. Consider an undulator that is generally a constituent of a particle accelerator; the undulator as such is a product of the project PBS. The following are deliverables of this product:

- "Undulator conceptual design file released"
- "Undulator detail design review held and passed"
- "Contract for undulator manufacture and assembly awarded and signed"
- "Undulator delivered and provisionally accepted"
- "Undulator installed; pre-commissioning done and passed."

The reader can easily see the difference in the way products and deliverables are labeled. Doing so is not sufficient to ensure a real coherency in deliverable labeling. It is generally up to the project management team or to the corporate project management office (PMO), if it exists, to provide conventions for a coherent deliverable labeling.

If deliverables are associated with all the activities of the project and activity physical progress is gathered on the achievement of these deliverables, appraised by non-ambiguous statuses (such as yes/no, true/false or quantities), then the physical progress monitoring of the project becomes much easier to perform and the project reports will certainly be closer to the true reality.

In conclusion, if a project manager wants to increase the effectiveness of the management processes, he or she must switch from a process-oriented approach to a deliverable oriented one. By doing so, the "90% Syndrome" is eliminated and progress monitoring is more objective and requires less audits. Project management information systems can be used as a means for collecting statuses. The management lag needed to consolidate individual reports is decreased because of the quality of the information collected through an electronic medium. To work, this project management system must be based on a WBS that is coherently constructed. A new project activity planning, scheduling, and monitoring model is needed and described in the next sections.

A New Typology of Project Activities

In the traditional project management paradigm, the production of deliverables is implicit. In the deliverable-oriented project system (DOPS) presented in this paper, it is clearly explicit. In addition to the classical characteristics of an activity—it consumes time, it usually consumes resources, it has a start date and a finish date, it is assignable—and a DOPS activity has zero, one or several deliverables. Figure 1a presents a simplified entity-relation diagram of activities as generally handled in traditional project management systems; Figure 1b gives an equivalent diagram, but for DOPS activities. Because DOPS activities are more informative than the usual elementary activities, they are henceforth called work units. In the DOPS model, there are four types of work units: standard work units, single-deliverable work units, multi-deliverable work units and level-of-efforts work units. Rationales, definitions, and real-world examples for each of these four types of work units are given hereafter. But before having an in-depth look at these work units, we will define more precisely what a DOPS deliverable is.

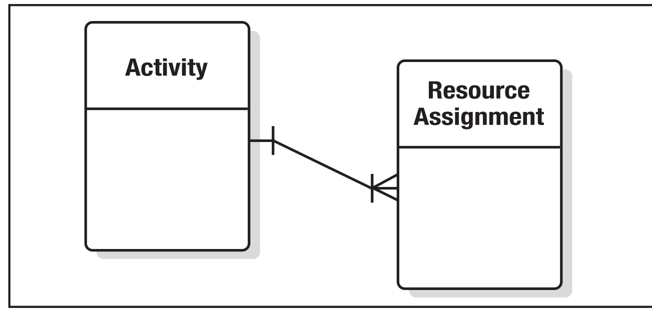


Figure 1a: Simplified entity-relation diagram of a traditional project management system

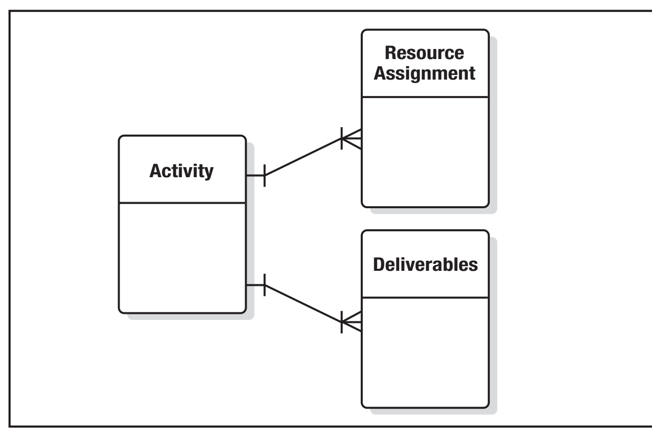


Figure 1b: Simplified entity-relation diagram of a deliverable-oriented project management system

DOPS Deliverables

The deliverable definition given in this subsection is particularly suited to large-scale projects of construction, technological, industrial, or scientific natures. A DOPS deliverable is uniquely defined by a *code* that attaches it to a unique work unit, by a *label* that is worded according to some conventions for avoiding ambiguities, and by a *metric* that can be one of two types:

- Boolean—Yes/no or true/false, meaning that the deliverable status will be true as soon as it is achieved and false otherwise
- Numeric—A quantity and its unit that is used for collecting the physical progress of the deliverable. To allow maximum flexibility, many units may be offered. Table 1 gives some examples of units that can be used for collecting progress in the framework of a particle accelerator project.

It is obvious that at the project start *date*, all the deliverables are either set to false or zero.

A DOPS deliverable is also defined by a date at which it is expected to be delivered. The dates of the deliverables result in an activity network calculation.

Finally a *weight* is used for balancing the effect of a deliverable within a work unit, and a *mode of accrual* defines if the deliverable value is accrued at achievement (step function), or linearly accrued from the previous deliverable to its planned achievement date. The practical purposes of the weight and mode of accrual are discussed and exemplified in the next subsections.

Standard Work Unit (Std-WU)

The standard work unit (Std-WU) is the first type of work unit. A Std-WU is very similar to an elementary activity of a traditional project activity network that is represented by a bar on a Gantt chart. Typically, a Std-WU has two deliverables: the first one that corresponds to the work unit planned start date; a second one that corresponds to the work unit planned finish date.

The first deliverable has usually a true/false metrics. It is labeled so it becomes true as soon as the work unit has started. "Basic design studies of the cooling plant started" or "installation of feedboxes started" are typical labels for such deliverables. It has also a zero weight. The fact of achieving the deliverable does not accrue value for the corresponding work unit, or for the project. This first deliverable has two basic purposes: to allow precedence scheduling of the work unit, since temporal information are only defined at deliverable level; and to get informed of the work unit actual start date, when it has started.

The second deliverable is associated to the work unit completion. To avoid manifestation of the "90% Syndrome," it is important to label it without ambiguity and to associate a well-matched metric to it. Labels such as "basic design studies of the cooling plant completed" or "feedboxes installed" may be misleading and should be avoided. Labels such as "basic design studies of the cooling plant reviewed and approved" or "feedboxes installed and quality control documents issued and approved" convey less ambiguity, and activity outcomes that are approved by project contributors definitely have a higher value for the project. The metrics of these second deliverables can be of true/false type: their status become true as soon as the corresponding documents are approved. It may also happen that an end deliverable corresponds to the delivery of several components or documents; in that case a linear accrual shall be preferred. If the work unit consists of pulling cables, a metric that measures the length of cables pulled is certainly more appropriate. Figure 2 shows a Std-WU with a stepped planned value (PV) accrual while Figure 3 represents a Std-WU with a linear PV accrual.

Single-Deliverable Unit (1De-WU)

Modern large-scale projects are characterized by the fact that many activities are outsourced. When contractors are bound by a result-oriented contract for performing a subset of the project's scope of work, they are committed toward delivery dates. Expected start dates can be communicated for information, but experience shows that it is very difficult to rely on this information. As a consequence, it has often little value to take these start dates into account in the project management information system. Therefore, the corresponding work units must rely on a single deliverable: the one at which the delivery is expected; the PV accrual is stepped as featured in Figure 4.

Here is an example to illustrate this for a set of outsourced and off-shored activities. Consider that to complete a particle accelerator project four beam stoppers of a certain type are required. After the design and specifications are completed, a call for tender is published and a result-oriented contract is then awarded at date *D0*. The contract negoti-

Unit	Description	Unit	Description
%	Percentage	M3	Cubic Meter
1/2 CELL	Half-Cell	MM	Millimeter
BAR	Bar	SECTOR	Sector
BATCH	Batch	SET	Set
COIL	Coil	SHEET	Sheet
KG	Kilogram	SPOOL	Spool
KM	Kilometer	TON	Ton
M	Meter	U	Unit
M2	Square Meter	UL	Unit Length

Table 1: Examples of units that can be used for collection progress

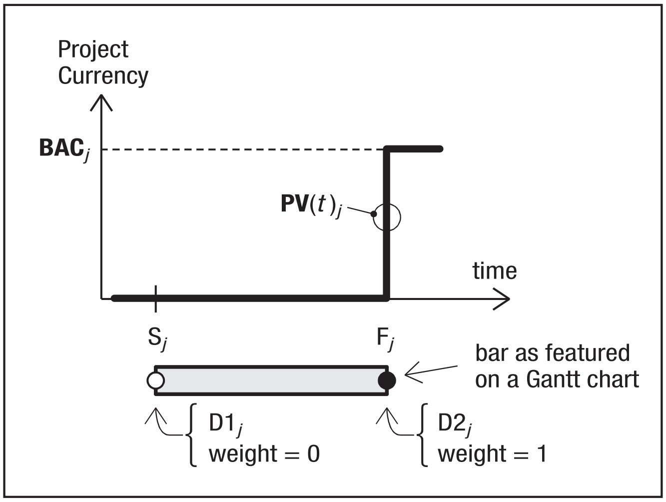


Figure 2: PV(t)$_j$ of a standard work unit *j* with a stepped PV accrual

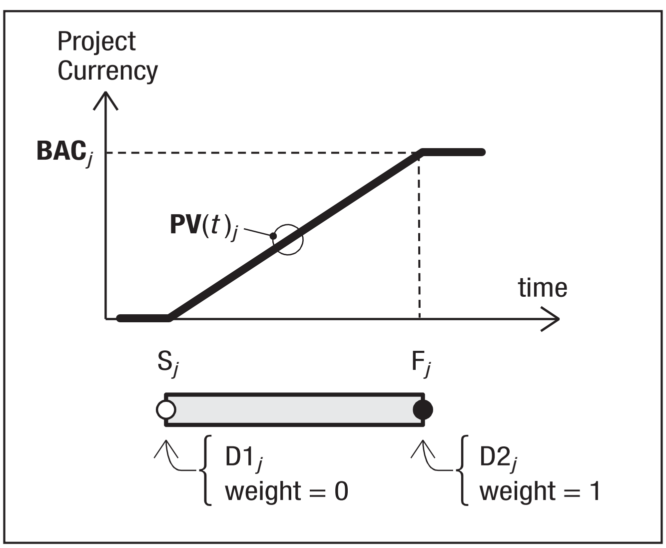


Figure 3: PV(t)$_j$ of a standard work unit *j* with a linear PV accrual

ated price is P. It is agreed with the supplier that a manufacturing file is expected at a date D1=D0+X, and 10% of the contract price is to be paid after that delivery. A first batch of two beam stoppers is expected at date D2=D1+Y, and a second batch of another two at D3=D2+Z. A 45% payment is associated with each of these two deliveries. These outsourced activities are taken into account in the project management information system as depicted in Figure 5. One single-deliverable work unit (1De-WU) has been created for each of the three delivery packages. A single deliverable statement is associated with each work unit. The PV accrual for this subproject is stepped: the project PV is accrued when something is delivered.

Multi-Deliverable Unit (MDe-WU)

Large-scale projects will not be made solely of "simple work units" associated to one or two deliverables. Typically, activities that are carried out at the earlier stages of the project's life cycle (engineering and design activities), or at the end of

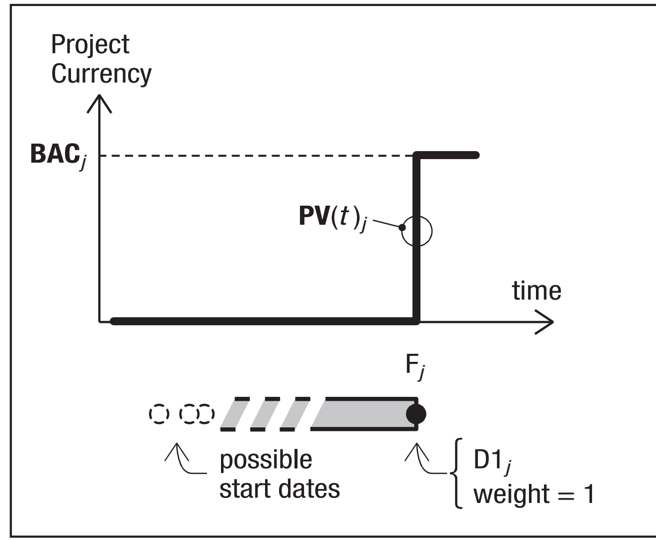


Figure 4: PV(t)$_j$ of a single-deliverable work unit *j*

the project makespan (integration and commissioning activities), are of a more complex nature. The so-called "vee" project life-cycle model proposes a visual framework for appraising this (see Figure 6).

Typically, complex activities require several deliverables in order to provide a fair physical progress reporting. These activities are considered complex because they do not fully respond to the definition of an elementary activity. For instance, design activities aim at producing a design file that is made of several design documents and drawings, each document or drawing issued for approval or approved can be seen as the design work unit's deliverable. Even if these documents and drawings should be prepared in sequence, there are a lot of iterations and decision points in a design process. The promoters of the design structure matrix (e.g., Browning, 1999; Eppinger, 1997; Steward, 1981) have performed in-depth investigations on this issue, and provide explanations on encountered failures while using CPM or PDM project scheduling on design activities. A further argument toward aggregating design activities is that in the planning and scheduling phase of a project, it is quite difficult to estimate accurately the resources needed for producing each of the design documents and drawings because the quantity and type of them is subject to evolution during the design activity, and because some of them will be released straightforwardly while others may require several iterations. Providing global workloads for design activities leads to more accurate estimates. The same reasoning applies to commissioning activities.

Multi-deliverable work-units aim at providing an appropriate framework for planning activities of complex nature. Figures 7 and 8 give examples of MDe-WUs. The first example corresponds to an engineering work unit with linear accruals; the second example features a commissioning work unit with stepped accruals. The lower parts of both figures show how the PV is accrued over the work unit makespans.

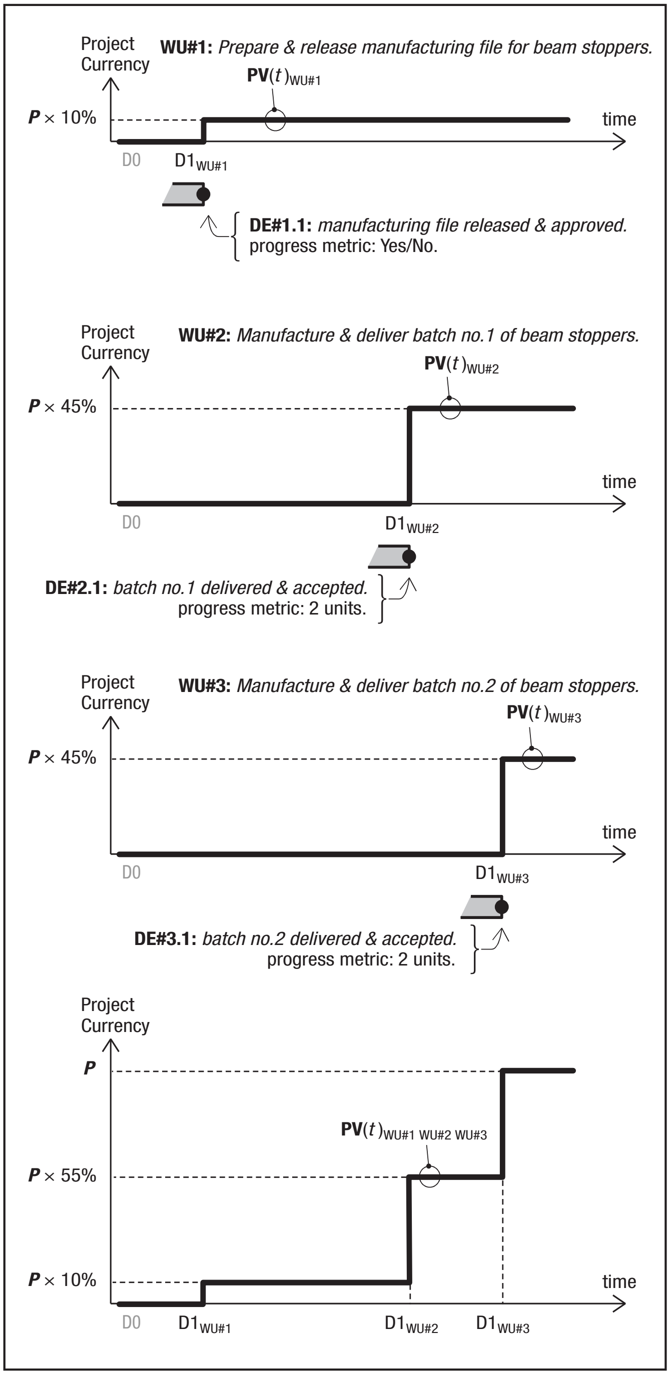


Figure 5: Summing up of planned value of single-deliverable work units

Level-of-Effort Work Unit (LoE-WU)

As mentioned in the ANSI/EIA-#748-A-1998 Standard (2002) or in the *Practice Standard for Earned Value Management* (2004), there are some project activities that do not produce tangible outcomes, so objective physical progress metrics can be set up. Examples typically include the project management duty. Planning the deliverables associated with the work of a project manager is almost impossible. To avoid creating artificial deliverables, professional practices admit that some project activities/work units are of level-of-effort type: as Std-WUs, level-of-effort work units (LoE-WU) have start and finish dates, and therefore two deliverables, one for each date. The first deliverable features the start date of the LoE-WU and has a true/false metrics; the second one has a finish date and has percentage metrics. Physical progress for this second deliverable is then simply proportional to the time elapsed. For instance, when a LoE-WU has reached half of its allocated duration, the

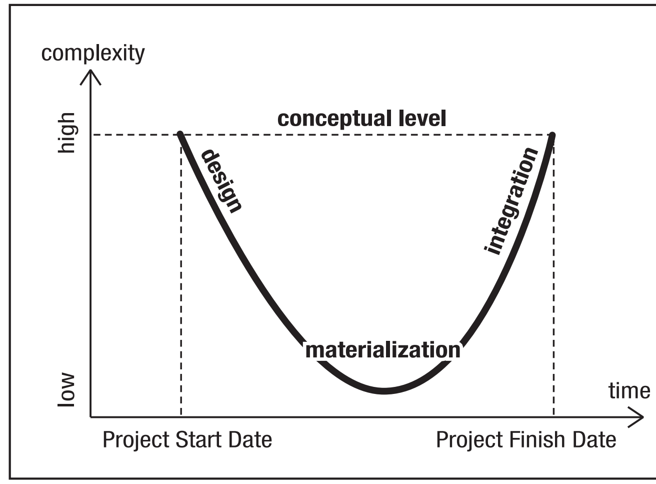


Figure 6: "Vee" project life cycle

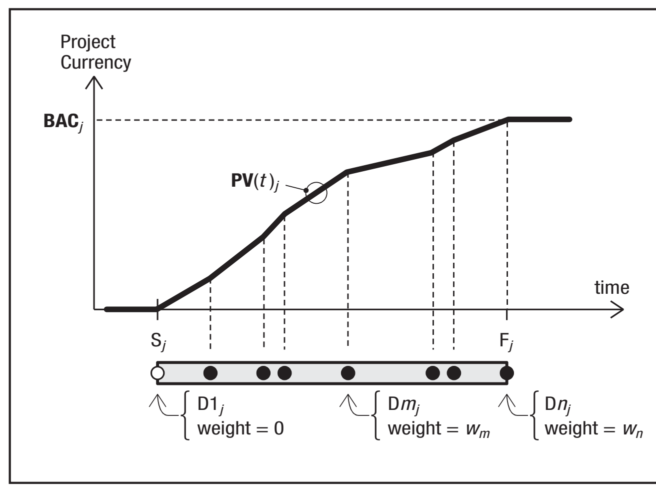


Figure 7: $PV(t)_j$ of a multi-deliverable work unit *j* with a linear PV accrual

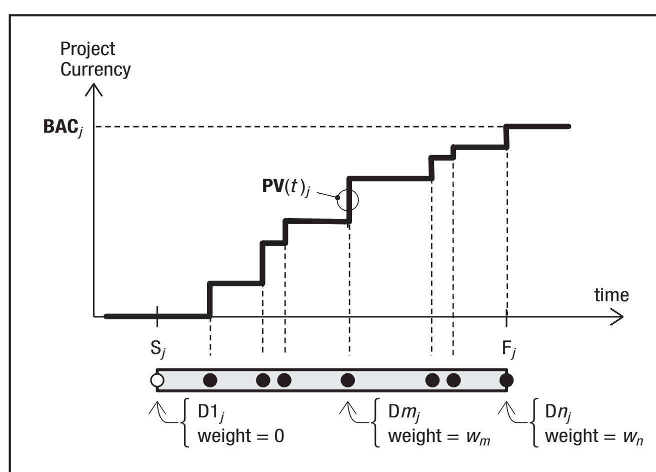


Figure 8: $PV(t)_j$ of a multi-deliverable work unit *j* with a stepped PV accrual

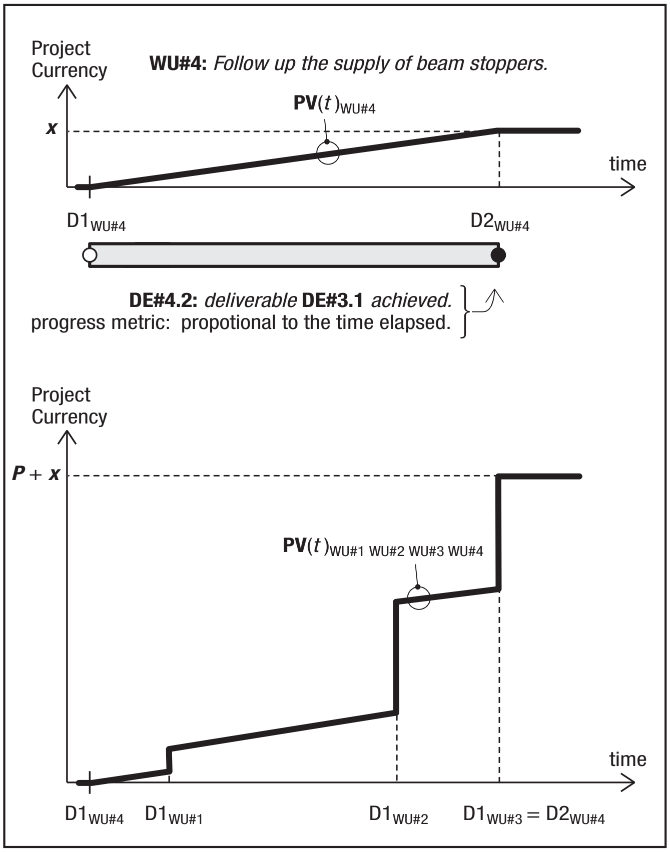


Figure 9: Beam stopper acquisition planned value curve

physical progress on the second deliverable will be set at 50%. As clearly specified in the standards mentioned above, the amount of LoE-WUs shall be kept to the lowest practical level. For large-scale projects, this "practical level" can be set at about 1%—in amount or in budget—of the work units of a coherent project portfolio of work units. To avoid distortion in the schedule and cost variances, it is important to ensure that to the planned and earned values for LoE-WU are regularly distributed (for the LHC project, this is done on a bi-monthly basis).

The use of LoE-WUs shall not be limited to the project management activities. Contract follow-up activities may fall in this category of work units.

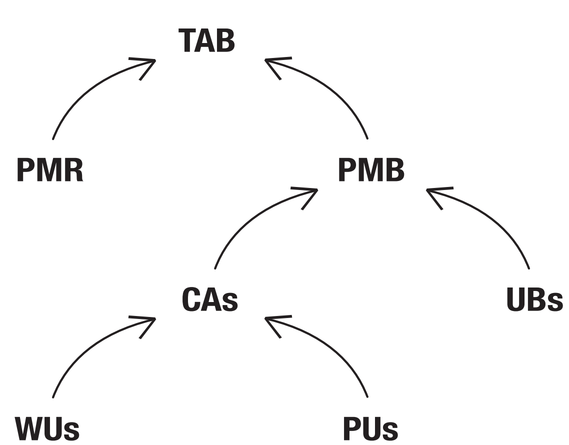
Figure 9 gives an example of a LoE-WU. It is associated with the undulator acquisition work units used to exemplify a LoE-WU.

Integration in an EVM System

The EVM methodology has become a *de facto* standard for the following-up of cost and schedule. It is commonly defined as a means for relating resource planning and usage to schedules and to technical performance requirements (Abba, 1997). The strength of this project management methodology is that it brings together project cost and schedule controls, providing project managers with a more accurate assessment of the project status. EVM was born in the 1960s under the auspices of the U.S. Department of Defense. At that time it was known as the cost/schedule control system criteria (C/SCSC). Readers are invited to refer to Fleming and Koppelman (2000) or to PMI's *Practice Standard for Earned Value Management* (2004) for further insights on the development of the EVM methodology. Because EVM basics can be found in many textbooks, this issue is not addressed in the present paper.

Constructing the Planned Value Curve

The PV is a time-phased projection of the budgeted expenditures that are expected to be done at a given moment over the project makespan. Before the project starts, PV is equal to zero. When it is completed, PV is equal to the budget at completion (BAC) (i.e., the base-lined expenditures). It is important to state that the BAC should be lower than the total allocated budget. Many projects are speculative endeavors and some reserve must be kept to deal with unforeseen events. In the EVM jargon, this is called the project management reserve (PMR). Figure 10 gives a hierarchy of the various EVM figures and how they



Unit	Description
TAB	Total Allocated Budget
PMR	Project Management Reserve
PMB	Performance Measurement Baseline
CAs	Control Accounts (i.e. Systems)
UBs	Undistributed Budgets
WUs	Work Units: near-term activities
PUs	Planned Units: far-term activities

Figure 10: Hierarchy and aggregate of various EVM figures

aggregate all together. This breakdown is rather complicated, and to make it easier to understand for all project contributors, it appears wise to us to combine work packages, planned packages, and undistributed budgets in a single *management item*: the work unit as described in the previous section. Planned packages and undistributed budgets are just flagged work units (WUs) that are checked to be sufficiently far in the future. It is up to the project management information system to alert the *holders* of these work units when they cross the near-term threshold to have them either detailed or delayed (this is sometimes called "rolling wave" planning and scheduling).

The project PV curve is obtained by aggregating all the PV curves associated to all the WUs of the project. As presented in the previous section, the deliverable weights are used for consolidating several deliverables at WU level, and then resource budgets (*resource BAC* in the EVM jargon) are used for balancing all WUs' PV curves at project level. The resulting PV curve is sometimes called the S-curve of the project because of its shape. The PV curve is set up at the early stage of the project.

In the case of a long-lead project, it is mandatory to provide means to re-baseline from time to time to let project's stakeholders appraise the performance of the project not only from the initial baseline, but also from intermediate baselines. A project performance management system must be objective and fair. Among the unforeseen events that may affect the project, some, such as technical failure, are the responsibility of the project team; … others, such as currency exchange rates, inflation, bid prices, and contractors' bankruptcy are not fully under the project team control. Consequently, the project team cannot be fully charged for the occurrence of theses unexpected events. Typically, the PMR aims at covering these risks. To avoid misunderstanding, it is necessary to provide clear rules of the game for transferring budgets from the PMR to the project PV. This is discussed in the next section.

Calculating the Earned Value

In a DOPS environment, collecting progress reports from WU holders is quite straightforward. The calculation of the earned value of the $EV_{project}(t)$ is then:

$$EV_{project}(t) = \sum_{j \in W} \left(\left(\sum_{k \in R_j} BAC_{jk} \right) \times \left(\frac{\sum_{\ell \in D_j} \omega_{j\ell} \times \frac{AQD_{j\ell}(t)}{TQD_{j\ell}}}{\sum_{\ell \in D_j} \omega_{j\ell}} \right) \right)$$

where:
W is the set of all the work units that make the project;
R_j is the set of all the resources assigned to the j^{th} work unit;
BAC_{jk} is the budget at completion of the k^{th} resource assigned to the j^{th} work unit;
D_j is the set of all the deliverables of the j^{th} work unit;
$\omega_{j\ell}$ is the weight of the ℓ^{th} deliverable of the j^{th} work unit;
$AQD_{j\ell}$ is the actual quantity of the ℓ^{th} deliverable from the j^{th} work unit delivered;
$TQD_{j\ell}$ is the total quantity of the ℓ^{th} deliverable from the j^{th} work unit to deliver.
t is the date at which project progress information has been collected.
If the ℓ^{th} deliverable is of true/false type, the ratio $\frac{AQD_{j\ell}(t)}{AQD_{j\ell}}$ is equal to 0 if the deliverable has not been achieved at date, t and 1 if it has.

It is important to note that the weight $\omega_{j\ell}$ reflects the importance of the entire ℓ^{th} deliverable *line*. As an example let us take a design work unit with two deliverables:

Weight ω	Description	*TQD*
1	Design specification released and approved	1 document
3	Detailed component drawing released and approved	6 drawings

The weights reflect the importance of each deliverable line (i.e., in that example the second line earns three times more value than the first). Let us assume that at date t the design specification is released and approved while only three drawings are released and approved; the physical progress of the work unit is then:

$$\frac{100\% \text{ x } 1 + 50\% \text{ x } 3}{1 + 3} = \frac{1 + 1.5}{4} = \frac{2.5}{4} = 62.5\%$$

and EV(t) = BAC x 62.5%.

An alternative interpretation for the weighing factor may be considered. Let us take the following example:

Weight ω	Description	*TQD*
2	Design specification released and approved	1 document
1	Detailed component drawing released and approved	6 drawings

In this case, we express that the "design specification" is twice as important as a "detailed component drawing" (of which there are six). Considering this, the physical progress of the work unit can be calculated as follows:

$$\frac{1 \text{ document x } 2 + 3 \text{ drawings x } 1}{1 \text{ document x } 2 + 6 \text{ drawings x } 1} = \frac{2 + 3}{2 + 6} = \frac{5}{8} = 62.5\%$$

that is the same result. This yields an alternative formula for $EV_{project}(t)$:

$$EV_{project}(t) = \sum_{j \in W} \left(\left(\sum_{k \in R_j} BAC_{jk} \right) \times \left(\frac{\sum_{\ell \in D_j} \omega_{j\ell} \times AQD_{j\ell}(t)}{\sum_{\ell \in D_j} \omega_{j\ell} \times TQD_{j\ell}} \right) \right)$$

For the LHC, project engineers felt more comfortable with the first interpretation of the weights.

Collecting Actual Costs

Projects' actual costs can finally be consolidated in a single monetary figure, expressed in the project currency that is often the usual currency of the organization that mainly supports the project. But from a cost collection point of view, there are two types of actual costs: the costs associated with expenditures, and the time spent by all the project contributors that can be converted in monetary figures by means of the appropriate rates.

Collecting at project level the actual costs associated to expenditures is usually straightforward. If the project management information system is correctly interfaced to the corporate accounting system—that should be the case in the framework of a large-scale project—the actual costs can be derived from the ledger. Standard practices such as the one previously mentioned or professional practices such as the ones proposed in textbooks (e.g., Fleming & Koppelman, 2000; Webb, 2003) suggest that actual costs are collected at the control account level, probably for that very reason. From a project management point of view, collecting actual costs at work-unit level would offer optimal drill-down analysis in case of interesting cost variances.

Some corporate management systems or enterprise resource planning systems do embed a module for collecting the time spent by the employees of the organization on various activities. For large-scale projects, contributors may be employees from many organizations, and for that very reason, it may be useful to have a "time sheeting" system dedicated to the projects. Several off-the-shelf project management packages that work in an Internet environment embed such a module. The project contributors are then asked to report the time they have spent on a weekly or an every second-week basis.

Cost-Variance Bias

The cost variance (CV) may be biased due to the different time of recording of the earned value (EV) versus the actual costs into the system. For the LHC project, we take the actual expenditures into account as soon as the agreement for payment has been given by the project engineer, so we do not wait for the actual payment to happen. In most cases, the progress reporting in the project management system has already been performed before that, and this results in a slightly positive CV bias. This bias is equal to the burn rate of the project times the average delay between the recording of the EV and the AC. Because we do not know the AC for each work unit, it is not obvious to determine this delay so it can only be done for those work units that can be linked directly to a well-defined expenditure (it gets more complicated with partial payments). We found that only about 15% of the expenditures could unambiguously be linked to single payments. In order to confirm the estimated delay, we have tried to determine the optimal α and Δt such that $EV(t) = \alpha \times AC(t + \Delta t)$. In this simple heuristic model, α is equivalent to the real cost performance index and Δt would be the delay with which AC follows EV. The result of both attempts yielded a delay that varied over time between 16 and 21 working days, with which the CV can be "corrected."

Dealing with Project Uncertainties

Uncertainties vs. Imprecision

Most projects are speculative endeavors, and an effective project management system must arrange some room to manage uncertainties. In addition, a large-scale project spans over a long period of time. Long-term activities are also subjected to the outcomes of short-term activities. Hence, planning and scheduling with too many details for long-term activities can be counterproductive. To cope with this requirement, the ANSI/EIA-#748-A-1998 Standard (2002) makes a distinction between work packages that are scheduled on the short term, and planned packages that correspond to long-term activities.

The aim is not to deal with uncertainty, but with imprecision: long-term activities are known to be necessary for the project, but because their outcomes are not sufficiently known at the early stage of the project, it is ineffective to spend time defining them in great detail. A planned package is, then, a raw work unit that has resources assigned on control account code, but for which no specific progress metrics has been looked at. Because this type of work units is scheduled over the long term, it does not affect EV reporting. There are also project deliverables that are known to be necessary to complete the project, so that they need resources, but that cannot yet be assigned to a specific holder. Because control accounts are often deeply interrelated with the organization breakdown structure of the project, it may be difficult to assign resources to a specific code. This is the purpose of the undistributed budgets of the ANSI/EIA-#748-A-1998 *Standard* (2002). Undistributed budgets can then be featured in the project management information system as raw work units, for which resources that do not map to specific budget codes are assigned.

Technical vs. Commercial vs. Economic Risks

Projects have to deal with uncertainty. In the framework of a large-scale project, they can typically be of three types: technical, commercial, or economical. These risks can be defined as follows:

- The technical risks are all the problems that can be encountered all along the project makespan related to the final deliverable itself or to the intermediate deliverables. Some insufficiently precise or coordinated

specifications will undoubtedly lead to deliverables that do not achieve expected levels of quality, and to rework, with consequences on the project schedule and cost. The PMR is aimed at covering these risks.
- Commercial risks are the risks associated with the relationship the project team has with external contractors. These risks occur as soon as a contract is awarded: the contract price may be higher or lower than the budget devoted for the corresponding activities and deliverables. Then, during the execution of the contract, the contractor may go bankrupt, may not deliver on time or may even not complete the contract for reasons that are external to the project. The project teams may be partially responsible for this risk, but not always, nor entirely. So the project owner—and the various stakeholders—may be solicited to contribute to cover this risk.
- It is evident that a 2% inflation rate has an important effect on a 10-year project. There are different ways of proceeding for dealing with this issue in the framework of a large-scale project (see Bonnal & De Jonghe, 2005a), but whatever the approach, it is usually not realistic to hold the project team responsible for covering the economic risk. One reason is that project management professionals are not experts in economics, and they cannot predict accurately inflation indices over several years or tendencies on foreign exchange rates!

An EVM system suited to a large-scale project must deal with this, to be effective. A simple way of doing so consists of affirming that the PMR aims at covering technical risks, and to increase, or decrease, the level of the PMR to absorb the effect of commercial or economic risks, and to guarantee that the estimate at completion (EAC) is below the total allocated budget (TAB).

Certainly, an EVM system can be designed to satisfy such requirements. But when a project is expected to last over a decade, relying on initial estimates and an initial baseline for performance monitoring is probably not extremely efficient. It may be wise to "re-baseline" the project regularly for many reasons, among which to be efficient, work units holders must commit themselves on a portfolio of work units that is made of activities on which one can rely. Speculative projects with a schedule that is not regularly reviewed cannot be efficiently managed: project contributors quickly find out that the information featured on initial project documents has become obsolete, and prefer to use their own informal network for relying on information that is not official but certainly more reliable. By tolerating such habits, the project managers may loose control over the project. To avoid this, it is judicious to allow project contributors to refurbish their work units so the bad effects of this are mitigated. However, clear "rules of the game" must be defined for adding, deleting, modifying, or breaking down work units.

Setting up and Refurbishing the Work Unit Portfolio

To stick to the arguments previously given, it is needed to provide a framework for refurbishing the portfolio of work units of a project, so it accurately describes the activities to be performed.

Rule 1. At the early stage of the project, all key contributors must participate in the work unit definition exercise, including assigning resources, identifying deliverables, and scheduling them in an activity network. The effort is focused on short-term work units. Long-term work units can be defined more roughly. From this, PV curves can be drawn for the entire project, by resource, by system, by control accounts, and so forth.

Rule 2. A planned work unit can be altered unilaterally by its holder (i.e., modified or broken down), if it is not ongoing, as far as this has no consequence on the resource balance and if the proposed rescheduling has no effect on the dates of deliverables belonging to work units that belong to different holders.

Rule 3. A set of planned work units can be altered by their holders, if all the holders agree on the consequences, if the work units are not ongoing, if the refurbishing has no consequence on the overall resource balance, and if the proposed rescheduling has no effect on the dates of deliverables belonging to work units for which the holders have not been involved in the refurbishing process.

Rule 4. Addition, deletion or modification of planned work units with consequences on the resource balance (i.e., the project's budget at completion, or on the project's master schedule) are subject to approbation from the project management core team. This may happen when additional funding is needed in response to technical, commercial, or economic risks for instance. In such cases, a prior change approval by the project manager is needed. The project is then rebaselined: new PV curves are calculated. The EV statuses are unchanged because the EV calculation is based on completed or ongoing work units.

Rule 5. Modifications of ongoing work units should be exceptional. When they are really needed, they should be of two types:
- Those without consequence on the EV calculation that in term of change control fall in one of the previously mentioned categories
- Those with consequences on EV calculation, for which change is subject to prior approval from the project management.

The strength of an efficient EVM system embedded in a project management information system is its ability to deal with these rules without burdening either the project's key contributors or the project management core team. Work unit holders shall have the possibility to freely refurbish their data unless these changes affect the overall project. To be efficient, the project management core team needs to be involved in changes that have consequences on the project; for the other changes, they just need to be informed.

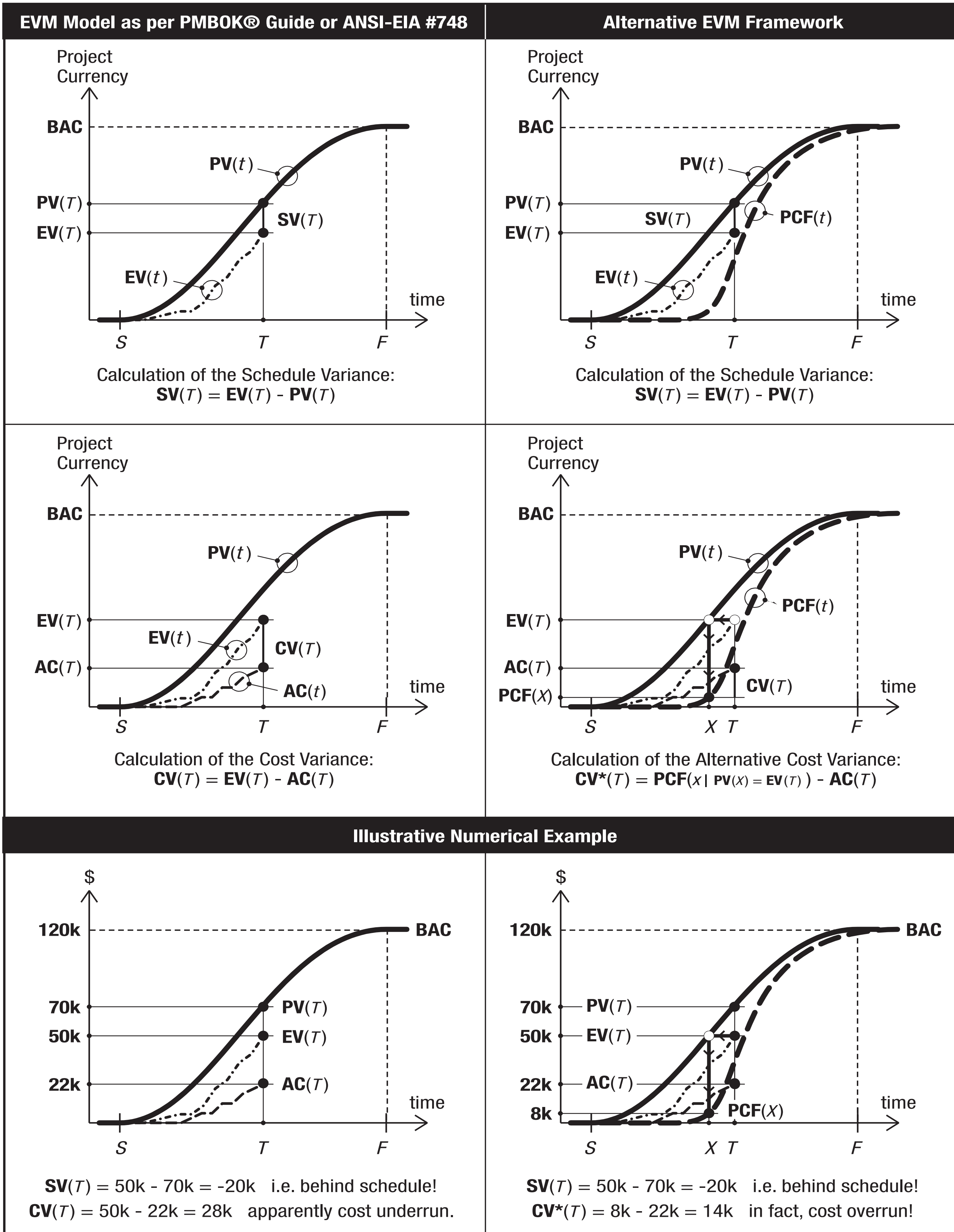


Exhibit 2: Elements for an alternative EVM framework

Conclusion and Improvement to the DOPS/EVM Model

CERN, the European Laboratory for Particle Physics, has carried out a specific development for implementing a deliverable-oriented EVM system. CERN's requirements toward such a system were those previously discussed:

- An EVM system that is deliverable-oriented, to stay away from project management pitfalls as the ones mentioned by Howard (1998). This implies that the EVM system is closely interfaced with the engineering data management system of the project.
- An EVM system that works in a collaborative environment, with all key contributors (about 300 work unit holders for the LHC project) involved in planning, scheduling and progress monitoring, and reporting activities.
- An EVM system that handles efficiently the management of technical risks, commercial risks, and economic risks.

For efficiency reasons, CERN had an additional requirement for its EVM system: to have it interfaced with other organization-wide corporate management systems, such as the accounting system for transferring actual costs, the contract management system for matching deliverables with contracts' payment schedules, and the human resource management system for resource sharing at corporate level.

Like many other scientific projects, the LHC project benefits from so-called in-kind contributions. CERN has signed agreements with other research institutes worldwide that will be incorporated in the project. But CERN will never be invoiced for these supplies; their values will never transit through its corporate accounting system, nor (for some of them) its asset management system. As a consequence, since actual costs cannot be recorded for these items, we assume them to be equal to their EV: $AC_{\text{in-kind contributions}} = EV_{\text{in-kind contributions}}$.

Three years ago, CERN surveyed several commercial packages, but none of them satisfied all these requirements. So an in-house development was decided. CERN now has two-year experience using this system. It has been adopted by all the LHC project contributors, submitting an average of 2,500 progress reports per month. It has really enhanced cost awareness at all levels of the project. Project analysis tools are also giving full satisfaction to the LHC project stakeholders. Finally, the LHC project office has been substantially downsized. With this experience in hands, two aspects would need to be further improved. They were not implemented because they are not featured in the ANSI/EIA-#748-A-1998 Standard (2002) that drove this implementation. This EVM system would have been more efficient if it had embedded a project/production scheduling engine, and if a clear distinction were made between planned values and planned cash flows.

Project/Production Scheduling Engine

A large-scale project is always a mixture of project activities (one-of-a-kind activities) and of operational (repetitive) activities. For instance, the LHC project will be made of about 1,240 dipole cryo-magnets. Manufacturing a dipole cryo-magnet can be seen as a project, but from a scheduling point of view, manufacturing 1,240 units is definitively not a project scheduling problem, but a production scheduling problem. For evident project control reasons, it is necessary to embed the production control system in a large-scale project scheduling engine. The line-of-balance method allow some insights to do this, but the integration of project scheduling functionalities with limited production scheduling functionality is not yet sufficiently explored to implement a project/production scheduling engine in an EVM system (see Bonnal & De Jonghe, 2005b) for a first attempt.

Planned Value vs. Planned Cash Flows

At the heart of the EVM methodology is the use of the EV status as a central figure to obtain the Schedule and cost variances respectively from the planned value and actual cost figures. But because the value is not earned as the cost is spent, there is a bias in the interpretation of the cost variance, unless cost and value accruals—different by nature—are globally balanced. On large-scale projects, this is rarely the case because many activities are outsourced and the invoicing is done when the work is performed (i.e., when the value is earned). A correlation formula such as the one introduced here before ($EV(t) = \alpha \times AC(t + \Delta t)$) can be an ad-hoc solution. But to tackle the problem at the root, a proposal could consist of enhancing the EVM methodology with a clearer distinction between the Planned Value to which the EV is compared to, and the planned cash flows to which the actual costs are compared to. It will result from this a slightly different project control model; Exhibit 2 gives the wide lines of this alternative EVM framework.

Acknowledgment

The authors would like to express their sincere thanks to all those who have contributed in the development and implementation of the LHC project earned value management system.

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