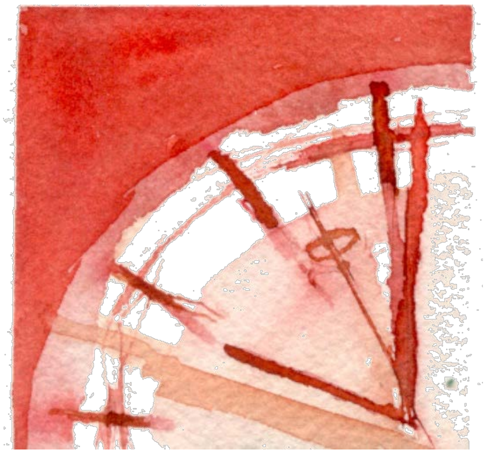
PROJECT CONTROL

LECTURE MATERIALS



Authors:

Nerea Toledo Gandarias

Jose Ramon Otegi Olaso

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GLOSARY

ANSI: American National Standards Institute

AC: Actual Costs

AT: Actual Time

BAC: Budget at Completion

CEO: Chief Executive Officer

CPI: Cost Performance Indicator

CV: Cost Variance

DoD: Department of Defense

EAC: Estimated Cost at Completion

ES: Earned Schedule

EV: Earned Value

EVMS: Earned Value Management System

ICB1: IPMA Competence Baseline 1

ICB4: IPMA Competence Baseline 4

ISO: International Standards Organization

IPMA: International Project Management Association

LRE: Last Revised Estimation

PF: Performance Factor

PM: Project Management

PMI: Project Management Institute

SPI: Schedule Performance Index

SC: Schedule Variance

TCPI: To-Complete Performance Index

WBS: Work Breakdown Structure

THEME 1. INTRODUCTION

1.1. Definition of Project

Projects exist since humanity is transforming raw material into a utility. The Pyramids of Egypt or the Great Wall in China can be considered projects. Moreover, common things in life, like starting a business or buying a house also fulfil the characteristics of a project. Therefore, a project may have several points of view and consequently, different definitions can be found. Looking up in the Oxford dictionary, the following definitions can be found:

Noun

1. *An individual or collaborative enterprise that is carefully planned to achieve a particular aim.*
   1.1. A piece of research work undertaken by a school or college student.
   1.2. A proposed or planned undertaking.
2. *(North American) A government-subsidized housing development with relatively low rents.*

Verb

1. *Estimate or forecast (something) on the basis of present trends.*
   *1.1. (often as adjective projected***)** *Plan (a scheme or undertaking)*
2. *[no object] Extend outwards beyond something else; protrude.*
3. *Throw or cause to move forward or outward.*
   3.1. Cause (light, shadow, or an image) to fall on a surface.
   3.2. Cause (a sound) to be heard at a distance.
   3.3. Imagine (oneself, a situation, etc.) as having moved to a different place or time.
4. *Present or promote (a particular view or image)*
   4.1. Present (someone or something) in a particular way.
   4.2. Display (an emotion or quality) in one's behaviour.
   4.3. **(***project something on to) Attribute or transfer an emotion or desire to (another person), especially unconsciously*
5. *(Geometry) Draw straight lines through (a given figure) to produce a corresponding figure on a surface or a line.*
6. *Make a projection of (the earth, sky, etc.) on a plane surface.*

Because of the variety of definitions related to the concept of project, a specific definition for engineering projects is required. Nevertheless, in the project management area of knowledge, different approaches have also been identified. Next, some definitions of a Project are introduced.

"The combination of human and non human resources joint in a temporal organization to achieve a specific purpose." (David I. Cleland y Willian R. King. 1975)

"An iterative decision making activity that produces the transformation of resources, preferably in an optimum manner, into systems an devices that respond to human needs." (T.T. Woodson, 1966)

"A set of tasks that have a specific goal and need to be completed following certain specifications."

"A time and cost constrained operation to realise a set of defined deliverables (the scope to fulfil the project's objectives) up to quality standards and requirements."

"A temporary endeavour undertaken to create a unique product, service, or result." (PMBoKv5)

As it can be observed, although the definitions are slightly different, there are some concepts that are repeated in all of them: resources, time and specifications or requirements. In other words, a project is a sequence of tasks and has a specific objective and which has to be accomplished under certain specifications, has a starting and an ending date, has limited funding and that consumes resources. Consequently, commonly the iron triangle shown in figure 1 is used to define a project:

Figure 1: The traditional iron triangle

What the iron triangle or the triple constraint represents is that the project should always stay within a budget; when the project schedule runs late, you've usually blown your budget too; the scope corresponds to the work you and your team have to do for the project; and that any time cost, scope or time change, it will affect to quality too. Hence, the control of those parameters should be the primary goal of a project manager. In fact, the success of the project was measured in terms of scope, cost and time. However, it should be pointed out that the definition of success in a project has been broadened. Imagine that you are the CEO of a company and you're asked about what is the definition of success in your project. The expected answer is that the only definition for your company is meeting the target profit margin in the contract, but the client will have a different definition for sure. Consequently, the definition of success in a project has to consider different points of view, that is, multiple definitions of project success exist. Therefore, the vertexes of the triple constraint turn into competing constraints as can be observed in figure 2.

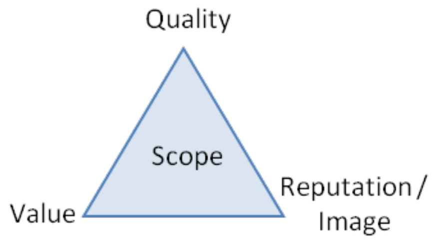

Figure 2: The extended iron triangle

In order to ensure that the project is progressing successfully, parameters to measure properly the constraints have to be defined. These parameters are the key performance indicators (KPI) that will serve to evaluate the state of the project. As defined by W. Eckerson, *"a KPI is a metric measuring how well the organization or an individual performs an operational, tactical or strategic activity that is critical for the current and future success of the organization."* H. Kerzner defined a KPI as *"an early warning sign that if an unfavorable condition exist and is not addressed, results could be poor."*

In order to measure KPIs and evaluate the progress of the project, a control system has to be implemented.

1.2. Definition of Project Management

As projects become more and more complex, achieving time, cost and scope objectives was becoming more and more challenging. Therefore, methodologies and tools were defined to address them. The term *Project Management* emerged in late 60s in the Department of Defense of the USA and it has evolved since then. In fact, nowadays a Project Manager is a professional that needs to master many competences in order to perform successfully. Besides technical competences, a Project Manager needs to know general knowledge areas like economy and finance, law, leadership, social competences and negotiation, etc. as can be regarded in figure 3.

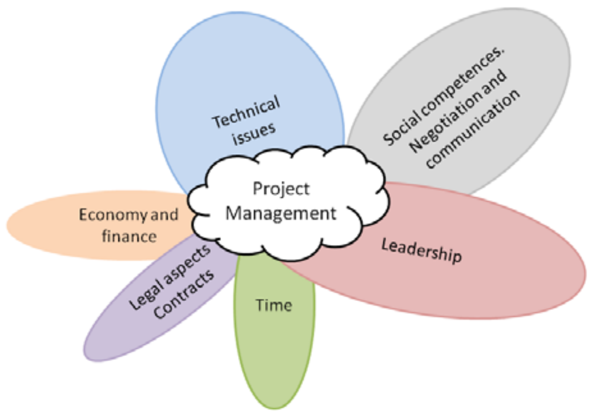

Figure 3: General knowledge areas covered by Project Management

In the figure 4 the chronological evolution of Project Management major milestones can be seen.

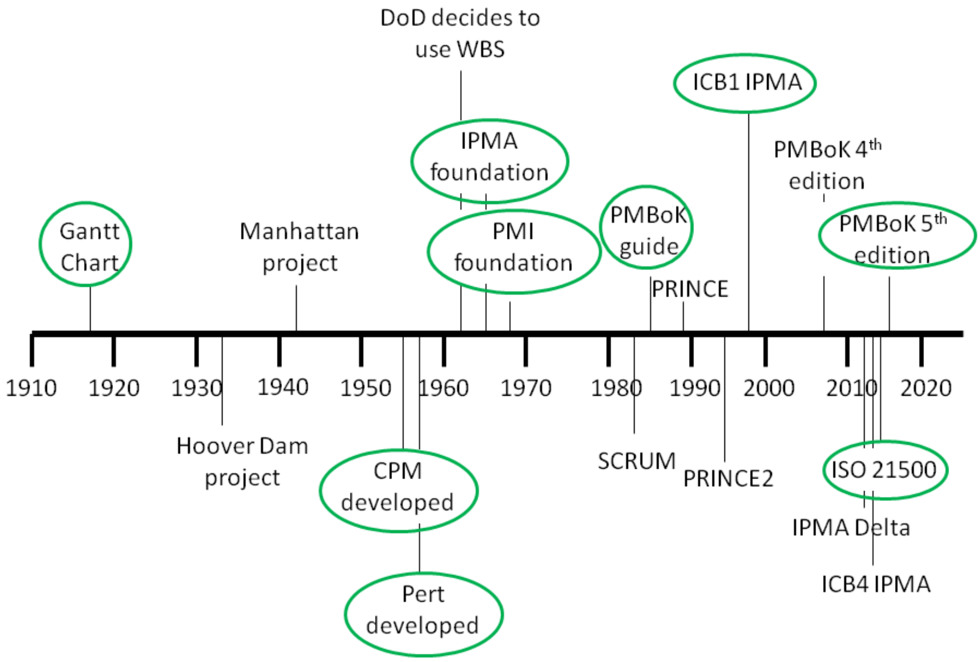

Figure 4: Evolution of Project Management and related associations

The Gantt diagram, defined in 1917, was the first tool to manage and control the schedule of the project. Afterwards, when projects proliferated in the DoD (Department of Defense) of USA and the Project Management emerged as a discipline, the CPM (Critical Path Method) and Pert methods where developed to manage the scheduling. In 1967, the IPMA (International Project Management Association) was legally registered in Zurich (Switzerland) and a couple of years later, in 1967, the PMI (Project Management Institute) was founded by 5 people in Pennsylvania (USA). The PMI published the first edition of Project Management book of knowledge in 1987. Apart from the standardization institutes ad associations that are in charge of publishing standards and guidelines, governments from different countries where developing in-house methodologies like PRINCE and in 2012 the guidance on Project Management, ISO 21500, was released.

THEME 2. PROJECT CONTROL

2.1. Fundamentals of Control

It is widely known that without a good planning it is very difficult to carry out a project successfully. In other words, failing to plan is planning to fail. However, a good planning does not guarantee that the project will succeed because reality is unpredictable, and commonly, plans suffer unexpected variations. Obviously, the better the planning is completed, the lower is the probability to deviate from the original plan.

Deviations with respect to the initial plan that occur during the execution of the project are unavoidable, and they may have many reasons, for example:

- The appearance of a new project in the company that implies resource sharing and changes in the priorities of the existing projects.
- The absence of resources that have been previously planned, e. g. the draughtsman is sick leave, or the providers of certain components has bankrupted.
- Priority changes in the ongoing tasks due to for instance, scope changes or technical problems.
- Failures in the initial estimations. This happens especially in the last phases of the project, because they will take place late in time, which makes not being precise.
- A volatile and fragile international social and economic situation.
- Natural causes like wind, rain, snow, etc.

The fact that deviations are unavoidable does not mean that they should be accepted and nothing should be done to overcome them. If we want to have a successful project, we should control its development during its execution to detect deviations in time, to take corrective actions to solve or mitigate the problems caused.

Control procedures compare the real progress with the planned program, not only during the project execution phase but also in the initiation and closing phase, as it can be seen in Figure 5. Hence, project control should be applied in the rest of the process groups of a project: initiating, planning, executing and closing. It should be mentioned that the intensity of the works related to the monitoring and control of the project varies from process group to process group, while major efforts are conducted in the executing process group.

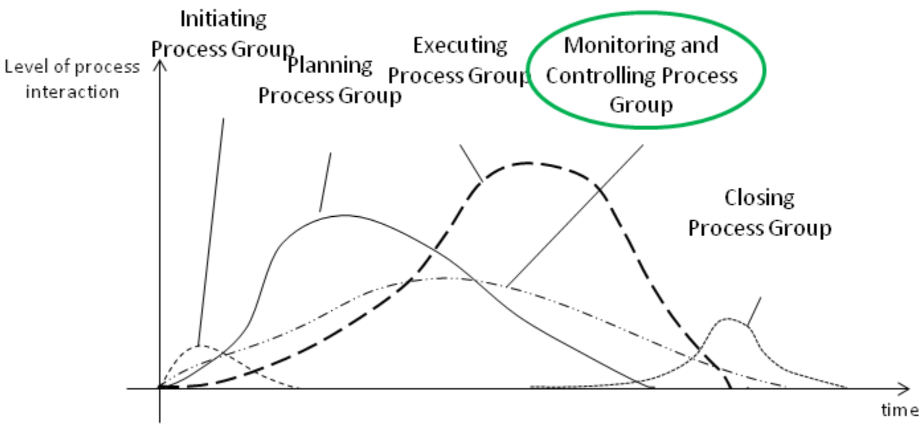

Figure 5: Interaction of the different process groups in the phases of a project

The control of the Project should be an integrated process, that is, it should have a global and integrated view of the progress of the project with respect to schedule, cost, quality, scope or risks.

Considering the aforementioned ideas, it should be underlined that planning and control procedures are complementary. A project is planned in order to control it (among other things), and it does not make sense to plan something that cannot be controlled. Because of this, when a task is being planned, how it will be controlled is also defined. In many cases, a too detailed plan is developed having no tools to afterwards control the execution of the project in that level, which is seen as a pointless effort.

The process of control can be represented as a sequence of the activities shown in Figure 6.

Figure 6: The process of control

As can be observed in figure 6, the control process consists of four different activities or tasks:

- *Monitoring:* In this task the status of the progress of the project is gathered. This is the most critical and probably the most difficult activity of the control procedures because adequate procedures to obtain objective information of the status of the project are needed.
- *Analysis:* In this phase, the monitored values are compared with the values planned previously and whether a deviation exists is analysed.
- *Corrective Actions:* Once the deviation between real and planned values is computed, corrective actions are taken to mitigate the effects of them in the project.
- *Re-planning:* When corrective actions are taken, it is necessary to re-define new reference values which will be used in the subsequent control processes.

Next, an example of the control process will be described in detail in order to understand the activities to be carried out in each task. If we consider a construction project of an industrial unit, we check the status of the project and observe that in the control day 8 pillars are placed (*monitoring*). Comparing to the expected number of pillars constructed, we observe that there is a delay of 4 days in the construction of pillars (*analysis*) because it has been raining the whole week. In order to accelerate the construction of the pillars and make up the delay, the project manager may decide to hire workers (*corrective action*), and finish the task in 3 weeks (*re-planning*) instead of in 5.

The process of control, is a cyclic process that it is repeated periodically along the duration of the project. The periodicity of the control depends on the nature and characteristics of the project. For instance, civil engineering projects are expected to be controlled in a monthly basis while software development projects (which are short and with high dynamicity) should be controlled weekly. It should be pointed out that the decision on the periodicity of the control is a decision of the project manager and could also vary during the project.

Any project manager should have in mind the following considerations when overtaking the control of any project:

- *Work is controlled, not the workers.* The control system should not be seen as a spy on system from of the companies' managers to the workers. In fact, the control system should be considered as a tool that allows workers to perform more efficiently. This way, the data provided by the workers will be more reliable.

- *The control system should be based on the motivation and self-control.* The worker in charge of completing a certain task is the person more capable of controlling its progress. The use of external controllers, could lead workers to refuse the control system and feel like being constantly oversight.

- *Control should be based on the completed work.* Each task of the project should have a means to evaluate the attainment of the goals previously specified.

- *Procedures of work monitoring should be part of the project work.* The worker should be able to know at anytime the progress of the task he/she is in charge of. Progress verification and evaluation procedures should be defined and agreed prior carrying out the task.

As pointed out previously, project control should be an integrated process that evaluates the overall status of the project in terms of schedule, cost, quality, scope and risks. In fact, standards and guidelines like PMBoK, ICB4 or ISO21500 define the control of the project as an integrated system that evaluates the progress of the project. Since in practice, it is difficult to implement an integrated control system, the main aspects that define a project are controlled individually. Nevertheless, a method that considers cost and schedule control in an integrated manner also exists: the Earned Value Management System (EVMS). This method is described in detail in Theme 3.

Next, the definition of project control by the aforementioned international organizations will be described in more detail.

2.2. Scope Control

The scope of the project establishes all the needed work included in the project in order to complete it successfully. More specifically, the scope of a project has a twofold goal: determine the work to be done in the project; determine the specifications and characteristics of the final product (result of the project).

Although the scope is established in the beginning of the project together with its goals and objectives, during the execution modifications that change the initially established scope can occur. These modifications can be due to different causes, e.g. the client, the contractor, the administration, the social and economical situation of the environment, etc. As expected, changes in the scope affect in the cost and schedule of the project.

The key element to control the scope is the WBS (Work Breakdown Structure), since it is a graphical representation of the work to be accomplished in the project. In addition, in the WBS the deliverables and the work packages of the project are also defined. As explained in section 2.1. unexpected situations that deviate the initial plan of the project occur. Since these deviations are unavoidable, a system for controlling scope changes is required. Moreover, these scope control systems should be integrated with other control systems because any change in the scope affect to the schedule, cost and quality of the project.

The scope control system should include the documentation, the monitoring systems and the required acceptance level to authorize the changes. The system should include procedures for the following actions:

- Present a change request. Who and how is someone prepared to present a change request.
- Accept the change request. Who and how is someone prepared to accept the change request.
- Update correspondent documents that are affected by the change (e.g. Gantt chart, budget, etc.).
- Disseminate the information of the changes to all the involved entities.

Regarding the procedures for the scope change control, the specifications of the sub-products and the work being developed are controlled. Commonly, this control is done using checklists. Next, an example of a checklist is shown in table 1:

Metric	Description	Priority (low - medium – high)	Evaluation date	Real Value	Estimated Value

Table 1: An example of a checklist

2.3. Schedule Control

The schedule and timing of the project is one of the most critical variables that need to be controlled. It is important to point out that deviation in the schedule affect to the cost of the project and to the entire coordination of the project. With respect to the cost changes, it should be noted that if the project is delayed, the incomes of the project (e.g. payments from the client and exploitation of the results) as well as the due date for paying the interest of the loan for funding the project will also be delayed.

The schedule control is usually made using Gantt charts. Specifically, the planned Gantt chart (planned scheduling) and the real Gantt chart (real scheduling and estimations) are compared. There are several software tools such as MS Project, Gantt Project, etc. that are used to carry out this task. In each control date, apart from having the real schedule, the time estimation of the remaining works is also required. As long as the project progresses, the analyst and/or the Project Manager has more information of the project and, thus, better task duration estimations could be done.

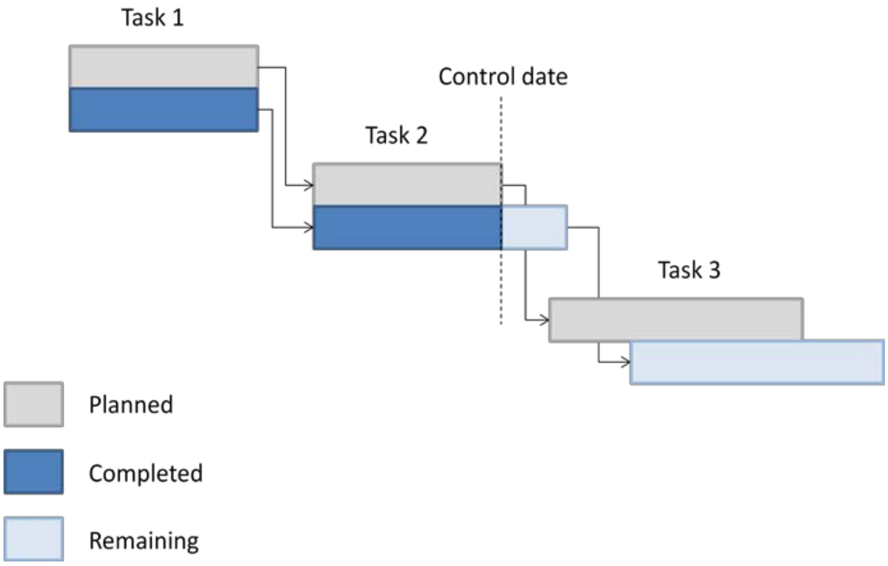

Figure 7: Schedule control using Gantt chart

As can be seen in figure 7 for the control date, Task 1 has been completed as planned, while Task 2 should have been finished but it is not. In fact, at the control date it has been estimated that more days are needed to finish the remaining work of Task 2. This delay, finishing Task 2, affects to the beginning of Task 3, so the person in charge of it has to be informed.

As mentioned before, software tools can be used to control the progress in terms of schedule of the project. Figure 8 shows the percentage of completed work and the comparison of both Gantt charts, the planned one and the real one.

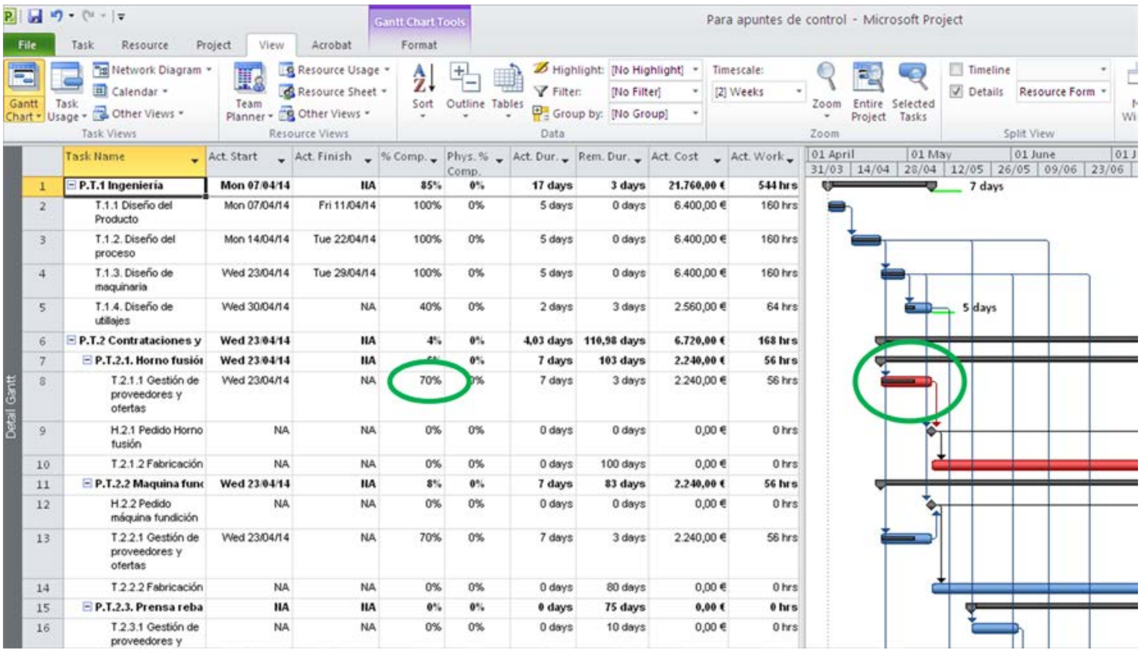

Figure 8: Planned and progress Gantt charts [caption done using MS Project software]

Apart from using Gantt charts to control the schedule of the project, images or graphical representations showing the evolution of the project can be used. This graphical method is commonly used in construction projects.

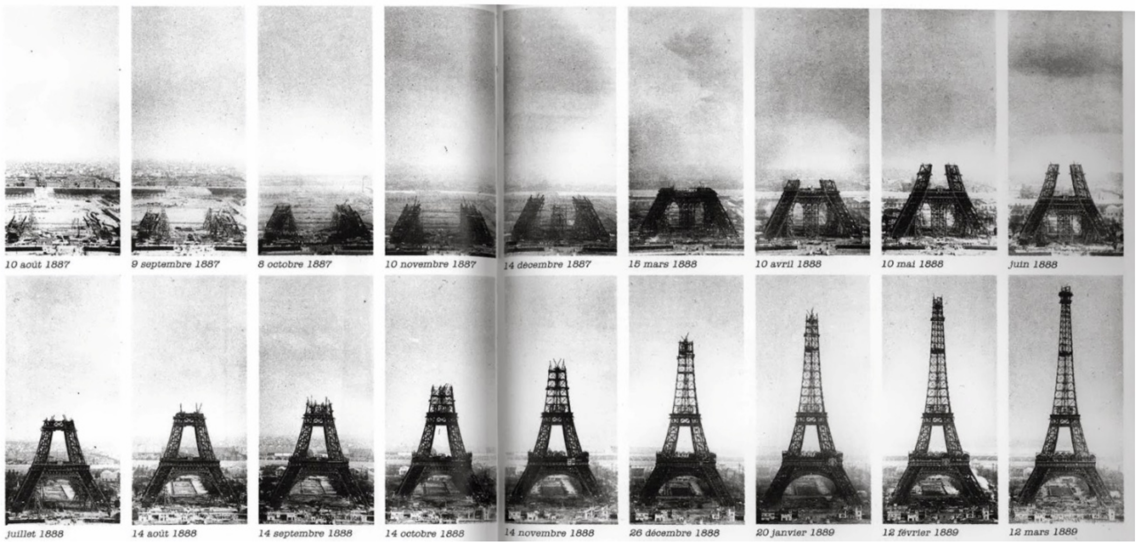

Figure 9: Schedule control of the Eiffel Tower building using graphical representation [Source: http://publicdomainarchive.com/public-domain-images-eiffel-tower-construction-1800s-2/

The photos show the evolution of the project in specific control dates, and whether the planned milestones are completed is checked.

2.4. Cost Control

Cost Control is another critical process in Project Management because not exceeding the budget is one of the objectives of the client. This control, as the scope control, is strictly linked to the quality control because before facing a payment to a provider or a subcontractor the scope and quality control of the deliverable (subproduct of the project) need to be checked.

The tool that is used to control the cost of a project is the cost baseline. By definition, the cost baseline is the cumulative budget distributed in time. Next, an example for computing the cost baseline is shown.

Consider a project with 5 tasks (A-E) that it is planned to begin in January and finish in June. In the table the distribution of the cost of each task is shown.

Task	BAC (Budget at Completion)	January	February	March	April	May	June
A	100 €	100 €					
B	400 €		200 €	200 €			
C	1200 €		400 €	400 €	400 €		
D	600 €				300 €	300 €	
E	200 €						200 €

Table 2: Project cost planning

With this information, the cost baseline is built as can be seen in figure 10:

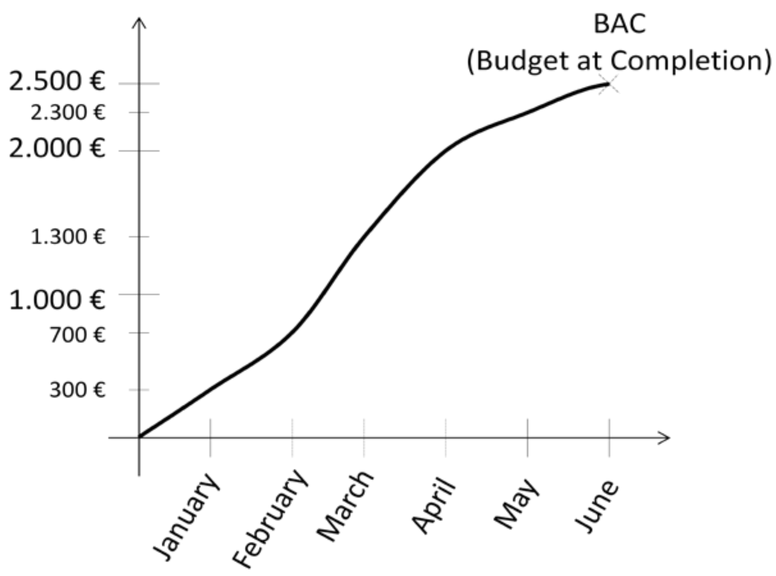

Figure 10: Cost baseline

Cost control includes the following procedures:

- Influence over the factors that can cause changes in the cost baseline.
- Update the changes in the cost baseline.
- Prevent from introducing non adequate changes in the cost baseline.
- Monitor the evolution of the costs and compare it with the cost baseline.
- Act to be within the cost overrun limit

Cost control can be carried out in different ways, but commonly a comparison table with the planned budget for each task, the committed budget (already hired) and the expenses incurred (already spent) is used. Notice that the committed budget means that there is already a contract signed but the payments have not been executed.

Another way of conducting cost control is by using graphical representation of the cumulative amount of money invested in the project. The graphical representation should have a limit with the minimum cost and another one with the maximum cost. It is worth pointing out that being under budget could also be a problem because this fact commonly means that the scope and/or the quality are not being fulfilled. Cost overrun is difficult to compensate without involving scope or quality changes, because the cost of the tasks is usually independent.

When carrying out cost control, a paradox comes out. Consider a project that is being controlled. At the control date 3 tasks should have been completed but only 2 and a half have been accomplished. Regarding the costs, the budget planned for the control date was 30.000€ and expenses incurred are 25.000€. How is the project performing in terms of time? ¿How is the project performing in terms of cost?

In terms of time, the project is behind the schedule, that is, it is delayed. Regarding the cost, we are not able to evaluate whether the project is under the budget or not because we cannot estimate how much would the half of the third task cost. This means that for analysing the performance of the project, the cost control is not enough and that an integrated cost and schedule control is required. This integrated control is done using the Earned Value Management System.

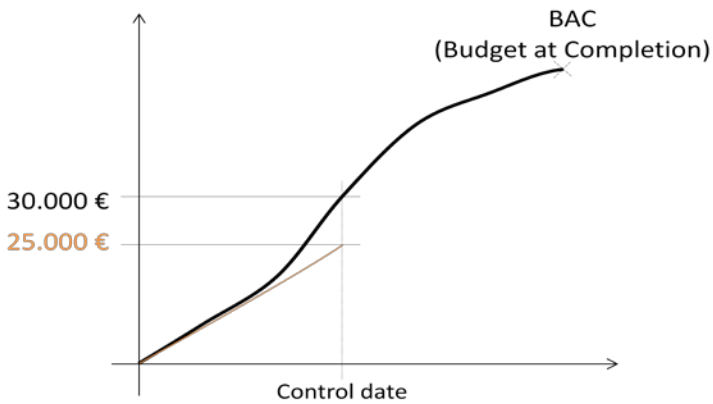

Figure 11: Figure illustrating the need of integrated control

THEME 3. EARNED VALUE MANAGEMENT SYSTEM (EVMS)

3.1. Fundamentals

In the 60s, the DoD of the USA, set as mandatory the use of an integrated schedule and cost control system to every contractor. The problem was the enormous delay and cost overrun. Because of this, the DoD defined the *Cost/Schedule Control System Criteria (C/SCSC).* However, many project managers didn't use this control system because it was seen as a financial control tool and hence that could be delegated to analytical specialists.

In 1967, EVM was introduced by the U.S. federal government as an integral part of the Cost/Schedule Control System Criteria to understand the financial aspects of programs and to be used in large acquisition programs in an attempt to establish a consistent methodology based on best practices.

In order to use the Earned Value Management system widely, the American National Standards Institute (ANSI)/Electronic Industries Alliance (EIA) published guidelines for EVMS in 1998: ANSI/EIA-748-98. In 1999, the standard was adopted in for the DoD adquisition. In the same way, the Project Management Institute (PMI) provided the basic terminology and formulas of the method. In addition, the PMI also published a specific *Practice Standard*.

In the next table, the main milestones of the integrated control systems are shown.

Year	Event
1967	Cost/Schedule Control System Criteria (C/SCSC) introduced by U.S. Department of Defense (DoD)
1972	First C/SCSC Joint Implementation Guide issued to ensure consistency among military departments
1991	DoD Instruction 5000.2—Defense Acquisition Management Policies and Procedures issued reaffirming use of EVM
1996	DODR 5000.2-R—Mandatory Procedures for Major Defense Acquisition Programs and Major Automated Information System Acquisition Programs issued. Draft industry guidelines accepted by Under Secretary of Defense and C/SCSC revised from 35 to 32 criteria
1998	American National Standards Institute/Electronic Industries Alliance published industry guidelines for EVM Systems (EVMS; ANSI/EIA-748-98)
1999	Under Secretary of Defense adopts ANSI/EIA-748-98 for DoD acquisition
2000	Simplified EVM Terminology published by Project Management Institute
2005	Practice Standard for Earned Value Management published by the Project Management Institute (revised; second edition published in 2011)

Table 3: Major milestones in the history of EVMS

The latest version of the PMBoK, the PMBoKv5, defines the Earned Value Management (EVM) as *"a methodology that combines scope, schedule, and resource measurements to assess project performance and progress, which helps the project management team assess and measure project performance and progress".*

It is worth pointing out that the EVM is a procedure used as an early warning sign of the status of the project, not for cost overrun and delay prevention. It should be noted that the prevention can only be achieved through a proper management. In this sense, the EVM is considered a tool for health-check and forecast.

By definition, the earned value of a task is the work performed at the control date expressed in terms of the budget. Thus, the earned value of the project is the summation of all the works performed to date. Consequently, the method for evaluating the progress of the work in economical terms needs to be defined in advance. It should be noted that there are some works that are not directly related to the work to be completed in a tasks (this is common with non productive departments), which are commonly prorated. The key element that aids in the definition of the measurement method of the progress of an activity is the WBS (Work Breakdown Structure) since all the work required to complete the project is determined in it. That is, the methods for measuring the progress of the tasks of the project have to be defined in the planning phase of the project.

The cost baseline of the project is computed as the intersection of the WBS and the OBS (Organization Breakdown Structure), since in the OBS defines the organization breakdown structure in terms of resources. Figure 12 shows how the baseline is computed.

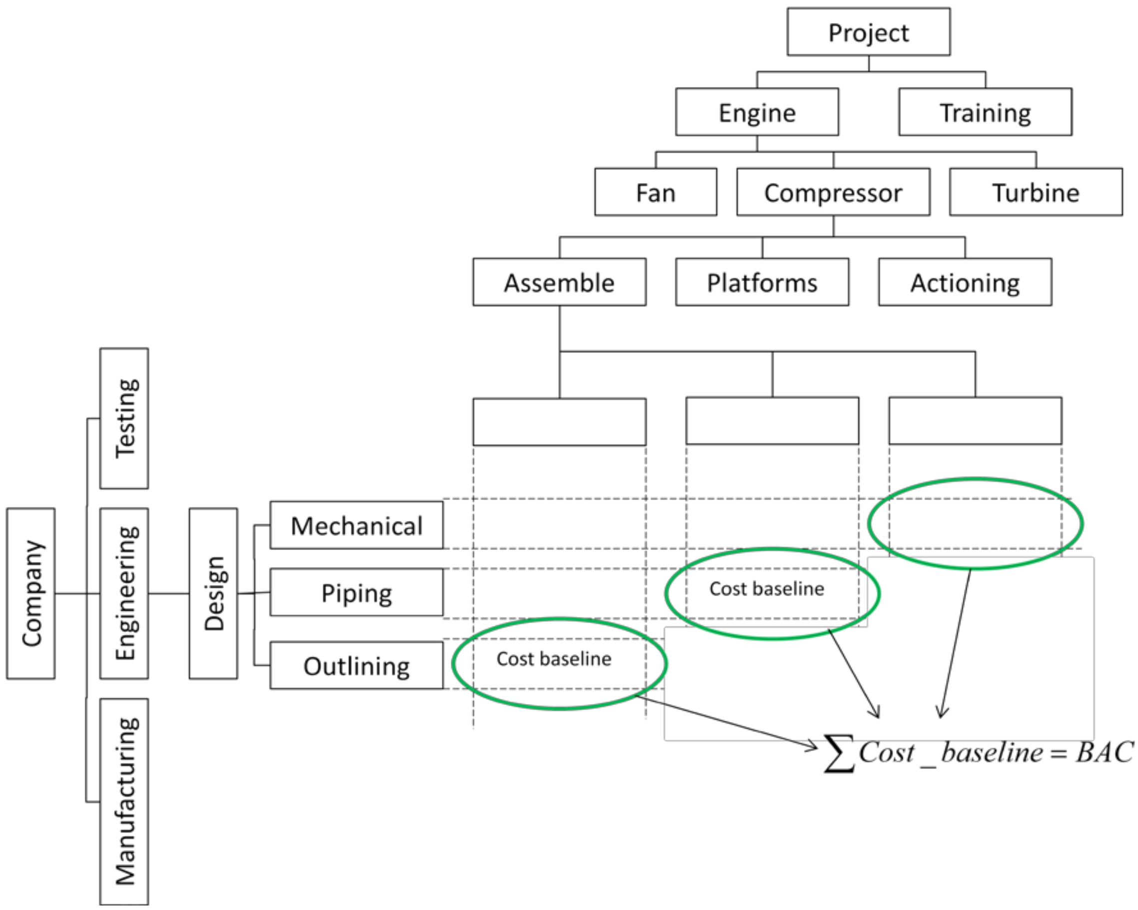

Figure 12: Computation of the baseline as the intersection of the WBS and the OBS

More specifically, the intersection of the WBS and the OBS should contain the following information: (1) scope of the task; (2) duration; (3) associated cost; (4) person in charge; (5) method for measuring the progress.

Regarding the method for measuring the progress of a task, different methods can be used. In other words, how the cost of the task is distributed in time has to be defined in order to be the earned value computed. Next, the most utilized methods are described:

- *Uniform distribution:* The cost of the task is distributed uniformly along the duration of it. In this method, the progress is measured in a subjective manner by the person in charge of the task or by the controller.

- *Valued milestones:* For long tasks, milestones are established in between, which have a percentage of the total cost of the task associated. In this method, whether the milestone is completed or not is checked. If it is completed, the correspondent cost percentage is assigned to the progress of the work. Commonly, the combination of the *uniform distribution* and *valued milestones* methods is used.

- *Completed units:* When similar activities are completed in a long duration task, the total cost of the activity is split into the number of units to be completed in the task in order to know the cost per unit. When evaluating the progress of this task, the number of completed units is checked and their cost per unit is applied.

- *25/75, 50/50, etc.:* This cost distribution is applied in short tasks. The planner assigns an initial cost to the task and a final cost. When the progress is evaluated in this type of tasks, whether the task has begun or not is checked. If the task has started, the first cost percentage is assigned to the task and the rest of the cost is assigned when the task is finished.

The EVM is based on three parameters: **EV (Earned Value),** which responds to the question of how much work has been completed in reality; **PV (Planned Value),** which responds to the question of how many work has been planned; and **AC (Actual Costs),** which responds to the question of how much does it cost to complete the actual work**.** Commonly, in the EVMS analysis the cumulative values of the parameters are used. Next, the definitions of the parameters as specified in the PMBoK (version 5) are detailed:

- **EV:** The Earned Value is the measure of work performed expressed in terms of the budget authorized for that work. It is the budget associated with the authorized work that has been completed. The EV is often used to calculate the percent complete of a project, that is, the progress of the project.

- **PV:** The Planned Value is the authorized budget assigned to scheduled work. That is, the planned value defines the physical work that should have been accomplished. Commonly, the total of the PV at a point in time is referred to as the performance measurement baseline. In addition, the total planned value for the project is also known as budget at completion (BAC).

- **AC:** The Actual Cost is the realized cost incurred for the work performed on an activity during a specific time period. In other words, it is the total cost incurred in accomplishing the work that the EV measured.

It should be underlined that the formulae described in this theme regarding the EVMS method is the same as the one defined in the paper entitled *"Earned value project management method and extensions",* published by F.T. Anbari in IEEE Engineering Management Review (Volume 32, issue 3, 2004), and subsequently adopted by the PMI in its PMBoK guideline.

3.2. Deviation indicators

Once the main parameters are computed (EV, PV and AC) the deviation in terms of cost and schedule can be calculated, which are: **CV** (Cost Variation) and **SV** (Schedule Variation). The following formulas are used to compute them:

$$CV = EV - AC$$

$$SV = EV - PV$$

The CV represents the deviation in cost of the project at the control date. That is, the CV is the difference between the budget and the real cost of the work performed to the control date.

The SV represents the variation in the schedule of the project at the control date. That is, the SV is the difference between the planned and the accomplished work, both of them measured in planned budget.

It should be pointed out that although SV compares works (planned and accomplished) it is measured in monetary units, which is considered a limitation of the method.

Graphically, the three key parameters (EV, PV and AC) and the CV and SV are show in figure 13.

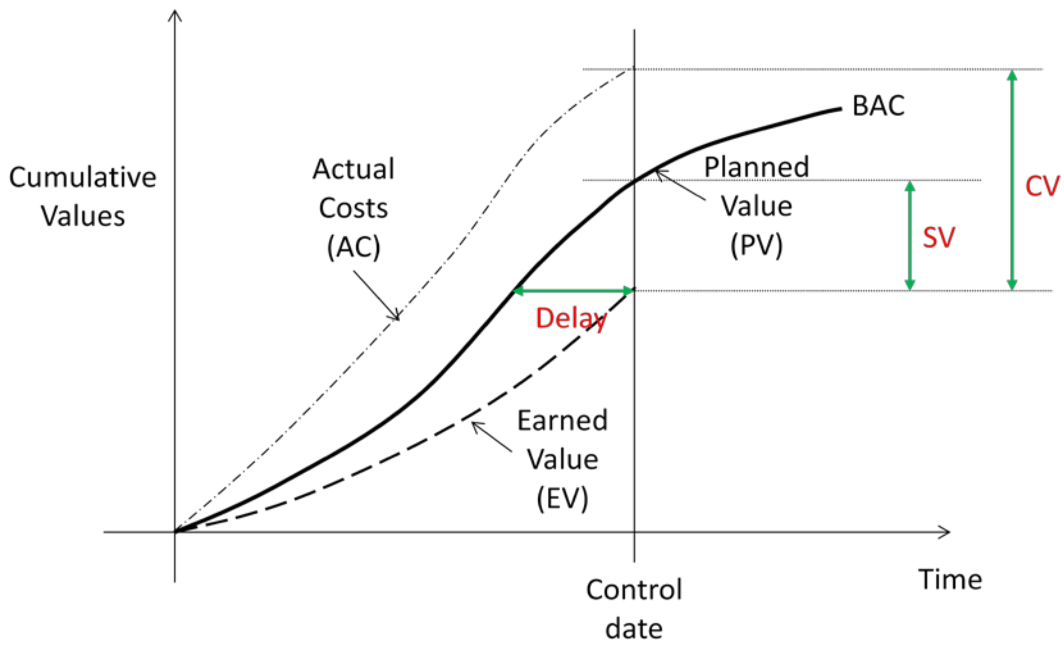

Figure 13: Graphical representation of the EVMS

The figure shows that the curves, commonly known as the *S*-curves, for the EV, AC and PV that represent the cumulative values for the mentioned parameters. The curve that it is known before the project begins is the PV curve because it represents the cumulative budget for the work planned. The rest of the curves are drawn as the control is carried out.

In an ideal situation, the three curves are equal, which means that the estimations and the project performance coincide. However, it is common to have cost overrun and delays in the project due to situations that take place during the execution of the project.

In the control date, the difference between EV and PV provide the SV, and the difference between EV and AC the CV. It is worth mentioning that the end value of the PV curve represents the budget of the project: BAC (Budget at Completion).

Since the SV is computed in monetary units, the delay in time is also represented in the figure. It's defined as the difference in time between the date that was planned for the completed work (projection of EV value in the PV curve) and the control date.

Next, an example is given to better describe the calculation of the key parameters and the deviation indicators.

Let's assume that we have a project with 2 tasks, A and B, and this information:

- Task A: Duration 4 days; budget 50 €
- Task B: Duration 6 days: budget 200 €
- Uniform cost distribution
- Task dependence: Task B begins when Task A is finished

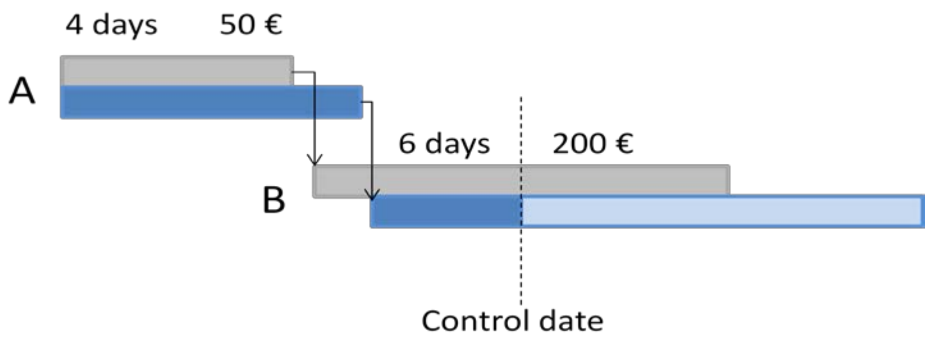

Figure 14: Example for computation of EV, AC, PV and CV, SV

At the control day, the Project Manager has the following information:

Task	Planned work	Completed work	Remaining work	Planned budget	Real Cost
A	4 days (100%)	5 days	0 days	50€	55€
B	3 days (50%)	2 days	6 days	100€	90€

Table 4: Project report

As can be seen in the table, task A was planned to be completed in four days, but five days where needed to complete it. The initial budget was of 50€ but the real cost has been 55€. Regarding task B, the plan was to complete half of it in three days, but the team was worked on it two days and that six more days are needed to complete it. The initial budget for the half of the work was 100€ but the real cost has been 90€. Based on the results at the control date, the main EVMS parameters are computed:

Tarea	PV (Planned value)	EV (Earned value)	AC (Actual cost)	SV = EV - PV (Schedule variation)	CV = EV - AC (Cost variation)
A	50€	50€	55€	0	-5€
B	100€	50€	90€	-50€	-40€
Project	150€	100€	145€	-50€	-45€

Table 5: Project status calculation using EVMS

It is worth noticing that since Task A is finished, the PV and the EV are equal. This is because the EV is defined as the work completed expressed in terms of planned budget. So, when a task is finished the planned work and the completed work are the same, hence, all the value has been earned.

For Task B, we can consider that the 25% of the work is completed because 2 work days have been done out of 8. As its cost is 200€, the EV is 50€ (25% of the budget).

In overall terms, the project is delayed and has cost overrun. As can be observed, although task A has been delayed, SV = 0. This is because the EVMS shows the state of the project at the control date, not taking into account what happened to the project till that date. That is, the EVMS provides the *health* of the project at the control date. In this example, as task B does not start until task A finishes, the delay in completing task A is assumed by task B. Another important thing to point out is that although task A has been delayed, the schedule variation parameters does not show this delay. This fact is because the EVMS measures the delay in monetary units.

3.3. Performance indicators

One of the major benefits of the EMVS is that at any time of the execution of the project it is possible to estimate how it will end in terms of cost and schedule. In fact, studies demonstrate that obtained estimations when the 15 – 20% of the project is completed show a trend that is maintained until the end of the project. Next, the performance indicators are described:

- **CPI (Cost Performance Indicator).** The CPI is the performance in terms of cost of the work completed until the control date and it is computed as:

  $$CPI = \frac{EV}{AC}$$

  If CPI < 1, for each monetary unit invested in the project a work of less value was completed, while if CPI > 1 means that less monetary units have been invested for the work completed. In other words, more money than the planned in the budget has been spent for the completed work when CPI < 1 and the other way round when CPI > 1. In an ideal situation the value of CPI = 1 and CPI < 1 is considered an unfavourable situation.

- **SPI (Schedule Performance Indicator).** The SPI is the performance in terms of schedule of the work completed until the control date and it is computed as:

  $$SPI = \frac{EV}{PV}$$

If SPI < 1, means that it has completed less work than the work planned, and thus it is an unfavourable situation, while SPI > 1 means that it has performed more work than the planned, so the project is performing faster than the schedule. It is worth pointing out that when the project is finished, all the planned works have been completed, i.e. EV = PV, and consequently SPI = 1. That is, although the project could have finished with delay, the SPI parameter does not represent this delay.

Although all the indexes are important, and thus, it is necessary to control them, the CPI is more critical and important than the SPI. This is because when the CPI begins to have a value less than the unit (CPI < 1), i.e. an unfavourable trend, it is very difficult to compensate it not changing the scope and the quality of the project. That is, if the project is overrunning cost, it is very difficult to compensate this cost overrun because the cost of the activities is independent. The only way to compensate the cost overrun and remain within budget is to change the scope of the project to a more affordable one.

On the other hand, a SPI < 1, i.e. the delay of the project, is easier to compensate, but this issue commonly means using more resources and thus, investing more funds. In addition, the SPI is more important in the initial phases of the project, because in the end of the project SPI = 1. Figure 15 shows the progress of the CPI and SPI performance indexes in time.

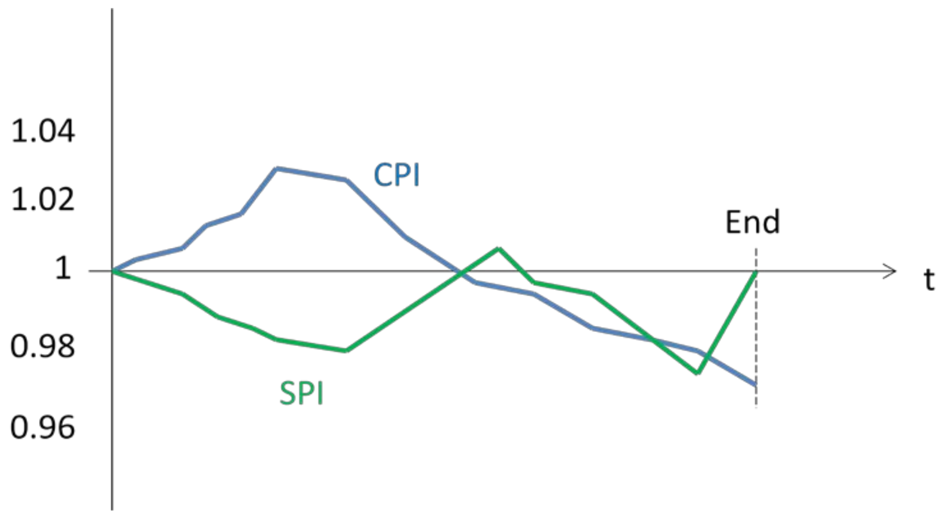

Figure 15: Progress of the CPI and SPI indexes

As can be seen in the figure, in the beginning of the project, the CPI outperforms the SPI. This means that for each monetary unit that it is being invested in the project a work of less value has been completed. Since the SPI < 1, this means that the project is delayed. Consequently, the situation of CPI > 1 and a SPI < 1 represents that less work than the planned is being carried out in the project and that this is the reason of investing less money than the planned and performing “good” in terms of cost.

Further on, it can be seen that the situation changes. That is, the CPI is going down progressively and the SPI changes its trend to eventually decrease as well. This situation represents that the project is being delayed and that it has cost overrun.

It should be pointed out that the SPI in a certain point changes again its trend, goes up and reaches the SPI=1 value. As explained before, the SPI=1 means that all the planned works have been completed (EV=PV), i.e. that the project is finished. The inflection point of the SPI curve can be interpreted at the time where the PV remains constant, while the EV increases its value, i.e., the theoretical finishing time of the project.

3.4. Prediction calculations

Once the performance data of the project at the control date is known, it is possible to predict how will end the project in terms of cost and schedule. In order to compute those estimations, the performance indexes are used. In the same way, it is possible to graphically compute the cost and schedule estimations at project completion. First of all, the estimated end date of the project should be calculated by extrapolating the EV curve. The projection in the x axis of the intersection point between the extrapolated EV curve and the budget cost (contract target cost) is the estimated end of the project. Notice that until now, the schedule variation has been computed in monetary units, while graphically, it can be computed using time units. In the same way, the estimated cost at project completion is the intersection between the estimated date of end and the extrapolation of the AC curve. Figure 16 shows the described estimations.

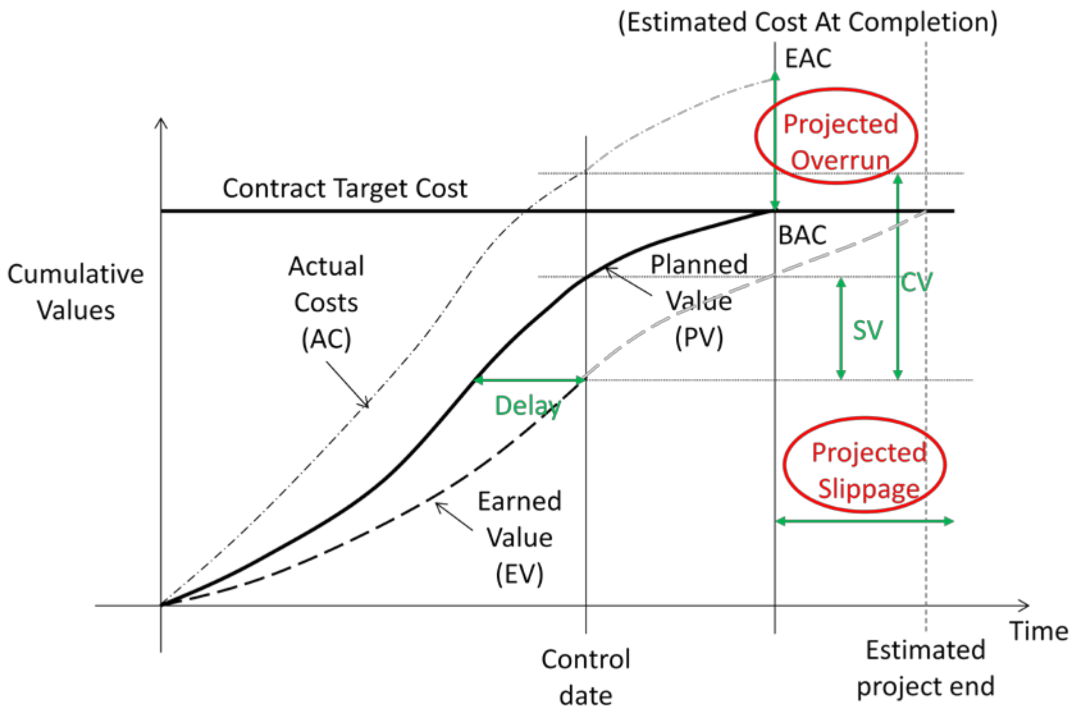

Figure 16: Prediction calculations using EVMS

Figure 16 describes graphically the estimated project cost at its completion, value that could be calculated it as follows:

$$EAC = \frac{BAC}{CPI}$$

where EAC stands for *Estimation At Completion*. That is, the budget that was planned for the project but considering also the cost performance index. This estimation is the simplest one because it considers that only the CPI will affect the final cost of the project and does not take into account the schedule performance. Because of this, the most adequate formula to compute the EAC is the following:

$$EAC = AC + \frac{BAC - EV}{PF}$$

where *PF* stands for *Performance Factor* and represents the expected performance considered by the analyst. The first addend of the formula represents the committed costs of the project until the control date. The second addend is the cost related to the remaining work *(BAC – EV)* taking into account the expected performance.

Regarding the Performance Factor, the most used PFs are:

PF = CPI
PF = CPI x SPI
PF = 0.2SPI + 0.8CPI

If the analyst is using *PF = CPI,* it means that the estimation of the EAC is optimistic, because it assumes that the project will maintain the performance of the CPI. On the other hand, *PF = CPI x SPI,* corresponds to a pessimistic scenario. Reality is commonly an in between value. It should be noted that in all of the aforementioned cases, the expected performance is considered to be constant but in reality, the learning curve or a worst performance because of project complexity should be taken into account.

Apart from the performance index that used to control the performance of the project until the control date, it is also possible to compute with which cost performance should carry out the project in order to complete it within a specific target cost. This target cost could be the planned budget (BAC) or a final cost estimated by the contractor, i.e. *Last Revised Estimation (LRE)*. This performance is known as the *To-Complete Performance Index (TCPI)* and it is calculated as follows:

$$TCPI = \frac{BAC - EV}{Target\ cost - AC}$$

A TCPI > 1 means that for each monetary unit invested, a work of a higher value than a unit should be performed, that is, the performance in terms of cost should be increased to finish the project within the target cost.

When the TCPI is computed using the LRE as the target cost, the index highlights whether the contractor could achieve the project within the cost it determines. This is done comparing the CPI and the TCPI. Notice that the CPI represents the performance of the project until the control date (past) and the TCPI estimates the performance that should have the project from the control date to its end (future). Therefore, if CPI = 0.51 and the TCPI using the LRE is 1.05, ¿are the contractors final cost estimations realistic?

We would say that the contractors predictions (LRE, *Last Revised Estimation*) are not realistic because for 100€ being invested in the project, only 51€ have become work. Consequently, it is difficult to believe that from the control date and on, 105€ will become work from the 100€ invested.

THEME 4. ENHANCEMENTS TO EVMS

4.1. Limitations and need of modifications

As underlined before, the EVMS measures the schedule performance of the project in monetary units, which results in masking the delay of the project. In other words, the EVMS is not a reliable tool for controlling the scheduling of the project, especially when it is finishing.

This shortcoming of the EVMS is because the EV and the PV (work completed and work planned) are both measured using monetary units, and when a project finishes EV = PV, that is, all the planned work is completed. Consequently, when a project finishes SV = 0 and SPI = 1, regardless the delay.

4.2. Earned Schedule Management System

In other to have a more reliable schedule control indicators, the Earned Schedule method was been defined by Lipke in 2003. It should be underlined that the formulae described in this is the same as the one defined by Lipke in 2003 in its paper entitled *"Schedule is different".*

The *Earned Schedule (ES)* is defined as the time in which the work completed was planned to be done. Based on its definition, the ES is obtained projecting the EV value at the control date in the PV curve.

In the same way as the EVMS, the Earned Schedule method defines the calculation of the Deviation, the Performance indexes and the Prediction.

Regarding the deviation indicator, it should be pointed out that it is computed in a time basis. In order to distinguish between the schedule variation of both methods (EVMS and ES), *SV (t)* is used for the ES and it is computed as:

$$SV\ (t) = \ ES - AT$$

where ES stands for the Earned Schedule, AT stands for Actual Time (the duration from the start to the project to now) and SV (t) is the schedule variation.

If SV (t) < 0, this means that the project is delayed SV (t) months. Consequently, when the project finishes, the result of the schedule variation will provide the precise information of the delay (or advance) of the project.

For computing the Schedule Performance Index, the following formula, which is analogue to the EVMS is used:

$$SPI\ (t) = \frac{ES}{AT}$$

Figure 17 describes the process for calculating the ES graphically. As mentioned, the ES is defined as the time in which the work completed until the control date was planned to be done. Consequently, the first step is to project the EV value in the PV curve. Once this point is known, its correspondent time (x axis) will be the ES.

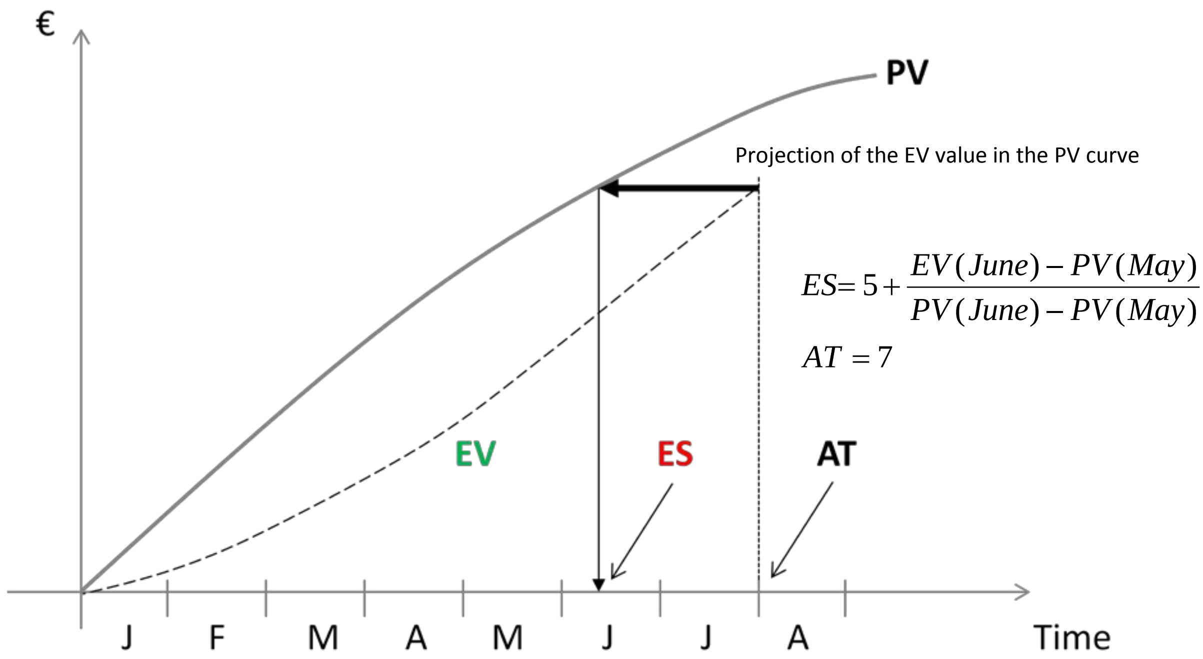

Figure 17: Graphical representation of the ES

The second addend of the ES is computed using the Thales theorem for triangle similarities and interpolating:

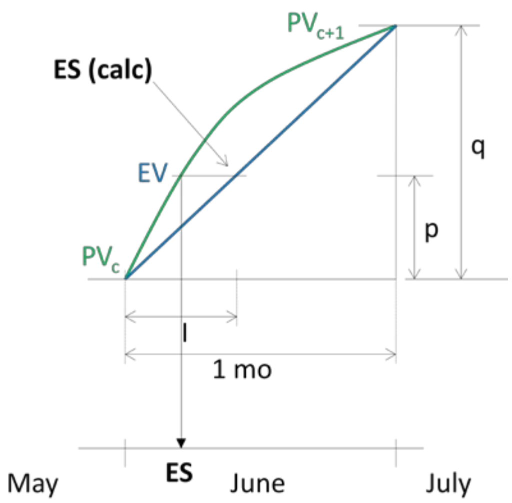

Figure 18: Graphical representation of the ES computation

$$\frac{I}{1mo} = \frac{p}{q}$$

$$I = \left(\frac{p}{q}\right) \times 1mo$$

$$p = EV - PV_C$$

$$q = PV_{C+1} - PV_C$$

$$I = \frac{EV - PV_C}{PV_{C+1} - PV_C} \times 1mo$$

Once the SPI (t) is known, it is possible to estimate when the project will end in an analogue form to the EVMS. In this case, the estimation is named *Estimate Duration At Completion EAC (t)*:

$$EAC\ (t) = AT + \frac{PD - ES}{PF}$$

where PD stands for Predicted Duration of the project and PF is the performance factor considered by the analyst.

The first addend of the formula is the actual time, i.e. the time consumed in the project, and the second addend is the remaining time for the remaining work considering a specific performance. If it assumed that the project could follow the schedule *PF = 1* is considered while if it is expected to maintain the performance *PF = SPI (t)* will be used.

In the same way as the EVMS, it is possible to estimate the theoretical performance of the project to finish it within a target deadline. This parameter is known as the *To-Complete Performance Index (TCPI (t))*. The target deadline can be the planned duration (PD) or the duration provided by the contractor. The formula to compute the TCPI (t):

$$TCPI\ (t) = \frac{PD - ES}{target\ deadline - AT}$$

In order to better describe the calculation of the ES and the rest of the parameters introduced an example is provided. Consider a project with that is planned to be finished in 10 months and the following information at the control date (month 8):

PV (July) = 1.805 $ PV (August) = 2.135 $

EV (July) = 1.610 $ EV (August) = 1.900 $

First of all, the PV and the EV curves are drawn. Then, the projection of the EV value in the PV curve is done and the ES is computed using the triangle similarity theorem and extrapolating.

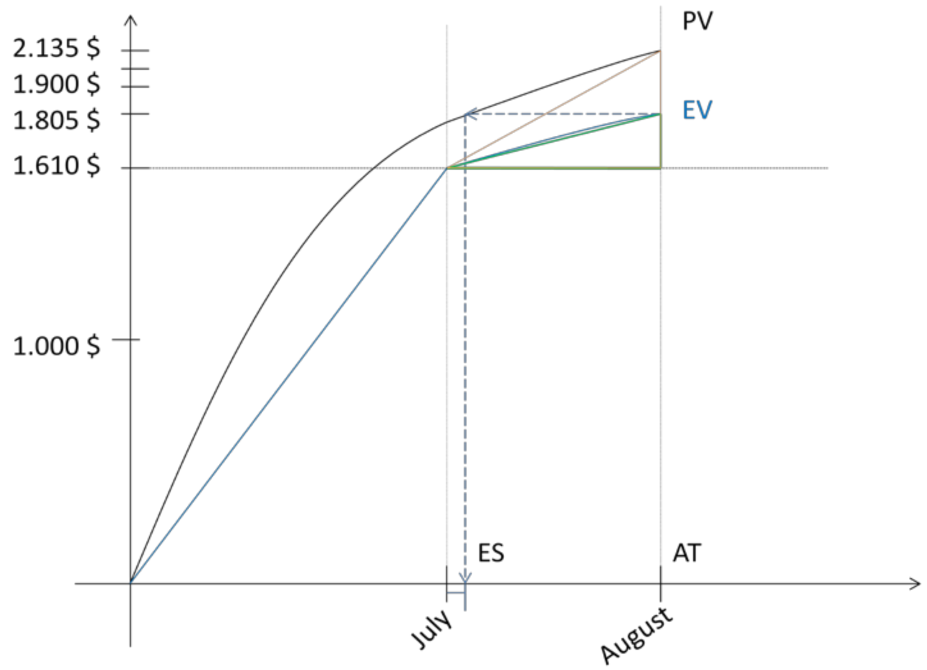

Figure 19: Graphical representation of the project data

The ES is computed as (assuming that the project began in January):

$$ES = 7 + \frac{EV\ (August) - PV(July)}{PV(August) - \ PV(July)} = 7 + \frac{1900 - 1805}{2135 - 1805} = 7.288$$

This means that the work that has been completed until the control date (actual time, month 8), was planned to be done by the month 7.288. Consequently, the project is delayed. In order to compute the delay in terms of time, we calculate the schedule variation:

$$SV\ (t) = \ ES - AT = 7.288 - 8 = 0.712$$

That is, the project is delayed 0.712 months. The Schedule Performance Indicator is as follows:

$$SPI(t) = \frac{ES}{AT} = \frac{7.288}{8} = 0.911$$

Once the SPI (t) is known, the estimated end of the project can be computed.

$$EAC\ (t)_{PF=1} = \ AT + \frac{PD - ES}{PF} = 8 + \frac{10 - 7.288}{1} = 10.712\ months$$

$$EAC\ (t)_{PF=SPI(t)} = AT + \frac{PD - ES}{PF} = 8 + \frac{10 - 7.288}{0.911} = 10.977\ months$$

In the first estimation (PF = 1) the project is expected to end 0.712 months later than the planned deadline, but for doing so, the project should follow the schedule programmed. In the second estimation (PF = SPI (t)) the project is expected to end 0.911 months later than the planned deadline, but for doing so, the project should follow the SPI (t) performance.